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J. Quittek
R. Winter
T. Dietz
NEC Europe Ltd.

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Definition of Managed Objects for Battery Monitoring
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Abstract

This memo defines a portion of the Management Information Base (MIB) for use with network management protocols in the Internet community. In particular, it defines managed objects that provide information on the status of batteries in managed devices.

Status of this Memo

Copyright Notice

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1. Introduction

Today, more and more managed devices contain batteries that supply them with power when disconnected from electrical power distribution grids. Common examples are nomadic and mobile devices, such as notebook computers, netbooks, and smart phones. The status of batteries in such a device, particularly the charging status is typically controlled by automatic functions that act locally on the device and manually by users of the device.

In addition to this, there is a need to monitor battery status of these devices by network management systems. This document defines a portion of the Management Information Base (MIB) that provides means for monitoring batteries in or attached to managed devices. The Battery MIB module defined in Section 5 meets the requirements for monitoring the status of batteries specified in [I-D.ietf-eman-requirements].

The Battery MIB module serves for monitoring the battery status. It does not implement a Power Monitor as defined in the framework for energy management [I-D.ietf-eman-framework]. Amongst other things, the Battery MIB allows to monitor:

- the current charge of a battery,
- the age of a battery (charging cycles),
- the state of a battery (e.g. being re-charged),
- last usage of a battery,
- maximum energy provided by a battery (remaining and total capacity).

Further, means are provided for battery-powered devices to send notifications when the current battery charge has dropped below a certain threshold in order to inform the management system of needed replacement. The same applies to the age of a battery.

There is already instrumentation for monitoring battery status on many battery-driven devices, because this is already needed for local control of the battery by the device. This reduces the effort for implementing the managed objects defined in this document. For many devices only additional software will be needed but no additional hardware instrumentation for battery monitoring.

Since there are a lot of devices in use that contain more than one battery, means for battery monitoring defined in this document support addressing multiple batteries within a single device. Also, batteries today often come in packages that can include identification and might contain additional hardware and firmware. The former allows to trace a battery and allows continuous monitoring even if the battery is e.g. installed in another device. The firmware version is useful information as the battery behavior might be different for different firmware versions.

Not explicitly in scope of definitions in this document are very small backup batteries, such as for example, batteries used on PC motherboard to run the clock circuit and retain configuration memory while the system is turned off. Other means may be required for reporting on these batteries. However, the MIB module defined in Section 3 can be used for this purpose.

A traditional type of managed device containing batteries is an Uninterruptible Power Supply (UPS) system; these supply other devices with electrical energy when the main power supply fails. There is already a MIB module for managing UPS systems defined in RFC 1628 [RFC1628]. This module includes managed objects for monitoring the batteries contained in an UPS system. However, the information provided by these objects is limited and tailored the particular needs of UPS systems.

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

2. The Internet-Standard Management Framework

For a detailed overview of the documents that describe the current Internet-Standard Management Framework, please refer to section 7 of RFC 3410 [RFC3410].

Managed objects are accessed via a virtual information store, termed the Management Information Base or MIB. MIB objects are generally accessed through the Simple Network Management Protocol (SNMP). Objects in the MIB are defined using the mechanisms defined in the Structure of Management Information (SMI). This memo specifies MIB modules that are compliant to the SMIv2, which is described in STD 58, RFC 2578 [RFC2578], STD 58, RFC 2579 [RFC2579] and STD 58,RFC 2580 [RFC2580].

3. Structure of the Battery MIB Module

The Battery MIB module defined in this document defines objects for reporting information about batteries. All managed objects providing information of the status of a battery are contained in a single table called batteryTable. The batteryTable contains one conceptual row per battery.

If there is an implementation of the Entity MIB module [RFC4133] that identifies the batteries to be reported on by individual values for managed object entPhysicalIndex, then it is REQUIRED that these values are used as index values for the batteryTable.

The kind of entity in the entPhysicalTable of the Entity MIB module is indicated by the value of enumeration object entPhysicalClass. Since there is no value called 'battery' defined for this object, it is RECOMMENDED that for batteries the value of this object is chosen to be powerSupply(6).

The batteryTable contains three groups of objects. The first group (OIDs ending with 2-10) provides information on static properties of the battery. The second group of objects (OIDs ending with 11-18) provides information on the current battery state, if it is charging or discharging, how much it is charged, its remaining capacity, the number of experienced charging cycles, etc.

```
batteryTable(1)
+--batteryEntry(1) [batteryIndex]
   +-- --- Integer32       batteryIndex(1)
   +-- r-n SnmpAdminString batteryIdentifier(2)
   +-- r-n SnmpAdminString batteryFirmwareVersion(3)
   +-- r-n Enumeration     batteryType(4)
   +-- r-n Unsigned32      batteryTechnology(5)
   +-- r-n Unsigned32      batteryNominalVoltage(6)
   +-- r-n Unsigned32      batteryNumberOfCells(7)
   +-- r-n Unsigned32      batteryNominalCapacity(8)
   +-- r-n Unsigned32      batteryMaxChargingCurrent(9)
   +-- r-n Unsigned32      batteryTrickleChargingCurrent(10)
   +-- r-n Unsigned32      batteryActualCapacity(11)
   +-- r-n Unsigned32      batteryChargingCycleCount(12)
   +-- r-n DateAndTime     batteryLastChargingCycleTime(13)
   +-- r-n Enumeration     batteryChargingState(14)
   +-- r-n Unsigned32      batteryCurrentCharge(15)
   +-- r-n Unsigned32      batteryCurrentVoltage(16)
   +-- r-n Integer32       batteryCurrentCurrent(17)
   +-- r-n Integer32       batteryTemperature(18)
   +-- rwn Unsigned32      batteryLowAlarmCharge(19)
   +-- rwn Unsigned32      batteryLowAlarmVoltage(20)
   +-- rwn Unsigned32      batteryReplacementAlarmCapacity(21)
   +-- rwn Unsigned32      batteryReplacementAlarmCycles(22)
   +-- r-n Integer32       batteryHighAlarmTemperature(23)
```

The third group of objects in this table (OIDs ending with 19-23) indicates thresholds which can be used to raise an alarm if a property of the battery exceeds one of them. Raising an alarm may include sending a notification.

The Battery MIB defines three notifications. One indicating a low battery charging state, one indicating an aged battery that may need to be replaced and one indicating the battery temperature to have risen above a predefined value.

4. Battery Technologies and Properties

Static information in the batteryTable includes battery type and technology. The battery type distinguishes primary (not re-chargeable) batteries from secondary (re-chargeable) batteries and capacitors. The battery technology describes the actual technology of a battery, which typically is a chemical technology.

Since battery technologies are subject of intensive research and massively used technologies are often replaced by successor technologies within an few years, the list of battery technologies was not chosen as a fixed list. Instead, IANA has created a registry for battery technologies at http://www.iana.org/assignments/eman where numbers are assigned to battery technologies (TBD).

The table below shows battery technologies known today that are in commercial use with the numbers assigned to them by IANA. New entries can be added to the IANA registry if new technologies get developed or if missing technologies are identified. Note that there exists a huge number of battery types that are not listed in the IANA registry. Many of them are experimental or cannot be used in an economically useful way. New entries should be added to the IANA registry only if the respective technologies are in commercial use and relevant to standardized battery monitoring over the Internet.

battery technology	assigned number
unknown	1
other	2
Zinc-carbon	3
Zinc-chloride	4
Oxy nickel hydroxide	5
lithium-copper oxide	6
lithium-iron disulfide	7
lithium-manganese dioxide	8
Zinc-air	9
Silver-oxide	10
Alkaline	11
Lead acid	12
Nickel-cadmium	13
Nickel-metal hybride	14
Nickel-zinc	15
Lithium ion	16
Lithium polymer	17
Double layer capacitor	18

The lifetime of a battery can be approximated using the measure of charging cycles. A commonly used definition of a charging cycle is the amount of discharge equal to the nominal capacity of the battery [SBS]. This means that a single charging cycle may include several steps of partial charging and discharging until the amount of discharging has reached the nominal capacity of the battery. After that the next charging cycle immediately starts.

5. Definitions

```
BATTERY-MIB DEFINITIONS ::= BEGIN

IMPORTS
    MODULE-IDENTITY, OBJECT-TYPE, NOTIFICATION-TYPE,
    mib-2, Integer32, Unsigned32
        FROM SNMPv2-SMI                                  -- RFC2578
    SnmpAdminString
        FROM SNMP-FRAMEWORK-MIB                          -- RFC3411
    DateAndTime
        FROM SNMPv2-TC                                   -- RFC2579
    MODULE-COMPLIANCE, OBJECT-GROUP, NOTIFICATION-GROUP
        FROM SNMPv2-CONF;                                -- RFC2580
```

```
   batteryMIB MODULE-IDENTITY
       LAST-UPDATED "201106261200Z"         -- 26 june 2010
       ORGANIZATION "IETF EMAN Working Group"
       CONTACT-INFO
           "General Discussion: eman@ietf.org
           To Subscribe: http://www.ietf.org/mailman/listinfo/eman
           Archive: http://www.ietf.org/mail-archive/web/eman

           Editor:
             Juergen Quittek
             NEC Europe Ltd.
             NEC Laboratories Europe
             Kurfuersten-Anlage 36
             69115 Heidelberg
             Germany
             Tel: +49 6221 4342-115
             Email: quittek@neclab.eu"

       DESCRIPTION
           "This MIB module defines a set of objects for monitoring
           batteries of networked devices and of their components.

           Copyright (c) 2010 IETF Trust and the persons identified as
           authors of the code.  All rights reserved.

           Redistribution and use in source and binary forms, with or
           without modification, is permitted pursuant to, and subject
           to the license terms contained in, the Simplified BSD
           License set forth in Section 4.c of the IETF Trust's Legal
           Provisions Relating to IETF Documents
           (http://trustee.ietf.org/license-info).

           This version of this MIB module is part of RFC yyyy; see
           the RFC itself for full legal notices."
   -- replace yyyy with actual RFC number & remove this notice

   --  Revision history

       REVISION "201106261200Z"         -- 26 June 2010
       DESCRIPTION
           "Initial version, published as RFC yyyy."
   -- replace yyyy with actual RFC number & remove this notice

       ::= { mib-2 zzz }
   -- zzz to be assigned by IANA.

   --******************************************************************
   -- Top Level Structure of the MIB module
```

```
   --******************************************************************

   batteryNotifications OBJECT IDENTIFIER ::= { batteryMIB 0 }
   batteryObjects       OBJECT IDENTIFIER ::= { batteryMIB 1 }
   batteryConformance   OBJECT IDENTIFIER ::= { batteryMIB 2 }

   --==================================================================
   -- 1. Object Definitions
   --==================================================================

   --------------------------------------------------------------------
   -- 1.1. Battery Table
   --------------------------------------------------------------------
   batteryTable  OBJECT-TYPE
       SYNTAX      SEQUENCE OF BatteryEntry
       MAX-ACCESS  not-accessible
       STATUS      current
       DESCRIPTION
           "This table provides information on batteries.
           It contains one conceptual row per battery."
       ::= { batteryObjects 1 }

   batteryEntry OBJECT-TYPE
       SYNTAX      BatteryEntry
       MAX-ACCESS  not-accessible
       STATUS      current
       DESCRIPTION
           "An entry providing information on a battery."
       INDEX  { batteryIndex }
       ::= { batteryTable 1 }

   BatteryEntry ::=
       SEQUENCE {
          batteryIndex                     Integer32,
          batteryIdentifier                SnmpAdminString,
          batteryFirmwareVersion           SnmpAdminString,
          batteryType                      INTEGER,
          batteryTechnology                Unsigned32,
          batteryNominalVoltage            Unsigned32,
          batteryNumberOfCells             Unsigned32,
          batteryNominalCapacity           Unsigned32,
          batteryMaxChargingCurrent        Unsigned32,
          batteryTrickleChargingCurrent    Unsigned32,
          batteryActualCapacity            Unsigned32,
          batteryChargingCycleCount        Unsigned32,
          batteryLastChargingCycleTime     DateAndTime,
          batteryChargingState             INTEGER,
          batteryCurrentCharge             Unsigned32,
```

```
          batteryCurrentVoltage           Unsigned32,
          batteryCurrentCurrent           Integer32,
          batteryTemperature              Integer32,
          batteryLowAlarmCharge           Unsigned32,
          batteryLowAlarmVoltage          Unsigned32,
          batteryReplacementAlarmCapacity Unsigned32,
          batteryReplacementAlarmCycles   Unsigned32,
          batteryHighAlarmTemperature     Integer32
       }

   batteryIndex OBJECT-TYPE
       SYNTAX      Integer32 (1..2147483647)
       MAX-ACCESS  not-accessible
       STATUS      current
       DESCRIPTION
           "This object identifies a battery for which status is
           reported. Index values MUST be locally unique.

           If there is an instance of the entPhysicalTable (defined in
           the ENTITY-MIB module, see RFC 4133) with an individual
           entry for each battery, then it is REQUIRED that values of
           batteryIndex match the corresponding values of
           entPhysicalIndex for the batteries. Otherwise, index values
           may be chosen arbitrarily."
       ::= { batteryEntry 1 }

   batteryIdentifier OBJECT-TYPE
       SYNTAX      SnmpAdminString
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object contains an identifier for the battery.

           Many manufacturers deliver not pure batteries but battery
           packages including additional hardware and firmware.
           Typically, these modules include an identifier that can be
           retrieved by a device at which a battery has been installed.
           The identifier is useful when batteries are removed and
           re-installed at the same or other devices. Then the device
           or the network management system can trace batteries and
           achieve continuity of battery monitoring.

           If the battery identifier cannot be represented using the
           ISO/IEC IS 10646-1 character set, then a hexadecimal
           encoding of a binary representation of the battery
           identifier must be used.

           The value of this object must be an empty string if there
```

```
           is no battery identifier or if the battery idenitfier is
           unknown."
       ::= { batteryEntry 2 }

   batteryFirmwareVersion OBJECT-TYPE
       SYNTAX      SnmpAdminString
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object indicates the version number of the firmware
           that is included in a battery module.

           Many manufacturers deliver not pure batteries but battery
           packages including additional hardware and firmware.

           Since the bahavior of the battery may change with the
           firmware, it may be useful to retrieve the firmware version
           number.

           The value of this object must be an empty string if there
           is no firware or if the version number of the firware is
           unknown."
       ::= { batteryEntry 3 }

   batteryType OBJECT-TYPE
       SYNTAX      INTEGER {
                       unknown(1),
                       other(2),
                       primary(3),
                       rechargeable(4),
                       capacitor(5)
                   }
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object indicates the type of battery.
           It distinguishes between primary (not re-chargeable)
           batteries, secondary (rechargeable) batteries and capacitors
           which are not really batteries but often used in the same
           way as a battery.

           The value other(1) can be used if the battery type is known
           but none of the ones above.  Value unknown(2) is to be used
           if the type of battery cannot be determined."
       ::= { batteryEntry 4 }

   batteryTechnology OBJECT-TYPE
       SYNTAX      Unsigned32
```

```
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object indicates the technology used by the battery.
           Numbers identifying battery types are registered at IANA.
           A current list of assignments can be found at
           <http://www.iana.org/assignments/eman>.

           Value 0 (unknown) MUST be used if the type of battery
           cannot be determined.

           Value 1 (other) can be used if the battery type is known
           but not one of the types already registered at IANA."
       ::= { batteryEntry 5 }

   batteryNominalVoltage OBJECT-TYPE
       SYNTAX      Unsigned32
       UNITS       "millivolt"
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object provides the nominal voltage of the battery
           in units of millivolt (mV).

           Note that the nominal voltage is a constant value and
           typically different from the actual voltage of the battery.

           A value of 0 indicates that the nominal voltage is unknown."
       ::= { batteryEntry 6 }

   batteryNumberOfCells OBJECT-TYPE
       SYNTAX      Unsigned32
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object indicates the number of cells contained in the
           battery.

           A value of 0 indicates that the number of cells is unknown."
       ::= { batteryEntry 7 }

   batteryNominalCapacity OBJECT-TYPE
       SYNTAX      Unsigned32
       UNITS       "milliampere hours"
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object provides the nominal capacity of the battery
```

```
            in units of milliampere hours (mAh).

            Note that the nominal capacity is a constant value and
            typically different from the actual capacity of the battery.

            A value of 0 indicates that the nominal capacity is
            unknown."
        ::= { batteryEntry 8 }

    batteryMaxChargingCurrent OBJECT-TYPE
        SYNTAX      Unsigned32
        UNITS       "milliampere"
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "This object provides the maximal current to be used for
            charging the battery in units of milliampere (mA).

            Note that the maximal charging current may not lead to
            optimal charge of the battery and that some batteries can
            only be charged with the maximal current for a limited
            amount of time.

            A value of 0 indicates that the maximal charging current is
            unknown."
        ::= { batteryEntry 9 }

    batteryTrickleChargingCurrent OBJECT-TYPE
        SYNTAX      Unsigned32
        UNITS       "milliampere"
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "This object provides the recommended current to be used for
            trickle charging the battery in units of milliampere (mA).

            Typically, this is a value recommended by the manufacturer
            of the battery or by the manufacturer of the charging
            circuit.

            A value of 0 indicates that the recommended trickle charging
            current is unknown."
        ::= { batteryEntry 10 }

    batteryActualCapacity OBJECT-TYPE
        SYNTAX      Unsigned32
        UNITS       "milliampere hours"
        MAX-ACCESS  read-only
```

```
       STATUS      current
       DESCRIPTION
           "This object provides the actual capacity of the
           battery in units of milliampere hours (mAh).

           Note that the actual capacity needs to be measured and is
           typically an estimate based on observed discharging and
           charging cycles of the battery.

           A value of 'ffffffff'H indicates that the actual capacity
           cannot be determined."
       ::= { batteryEntry 11 }

   batteryChargingCycleCount OBJECT-TYPE
       SYNTAX      Unsigned32
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object indicates the number of completed charging
           cycles that that the battery underwent. In line with the
           Smart Battery Data Specification Revision 1.1, a charging
           cycle is defined as the process of discharging the battery
           by a total amount equal to the battery nominal capacity as
           given by object batteryNominalCapacity. A charging cycle
           may include several steps of charging and discharging the
           battery until the discharging amount given by
           batteryNominalCapacity has been reached. As soon as a
           charging cycle has been completed the next one starts
           immediately independent of the battery's current charge at
           the end of the cycle.

           For batteries of type primary(1) the value of this object is
           always 0.

           A value of 'ffffffff'H indicates that the number of charging
           cycles cannot be determined."
       ::= { batteryEntry 12 }

   batteryLastChargingCycleTime OBJECT-TYPE
       SYNTAX      DateAndTime
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "The date and time of the last charging cycle.  The value
           '0000000000000000'H is returned if the battery has not been
           charged yet or if the last charging time cannot be
           determined.
```

```
           For batteries of type primary(1) the value of this object is
           always '0000000000000000'H."
       ::= { batteryEntry 13 }

   batteryChargingState OBJECT-TYPE
       SYNTAX      INTEGER {
                       unknown(1),
                       charging(2),
                       maintainingCharge(3),
                       noCharging(4),
                       discharging(5)
                   }
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object indicates the current charging state of the
           battery.

           Value unknown(1) indicates that the charging state of the
           battery cannot be determined.

           Value charging(2) indicates that the battery is being
           charged in a way that the charge of the battery increases.

           Value maintainingCharge(3) indicates that the battery is
           being charged with a low current that compensates
           self-discharging. This includes trickle charging, float
           charging and other methods for maintaining the current
           charge of a battery.

           Value noCharging(4) indicates that the battery is not
           charged or discharged by electric current between the
           battery and electric circuits external to the battery.
           Note that the battery may still be subject to
           self-discharging.

           Value discharging(5) indicates that the battery is being
           discharged and that the charge of the battery decreases."
       ::= { batteryEntry 14 }

   batteryCurrentCharge OBJECT-TYPE
       SYNTAX      Unsigned32
       UNITS       "milliampere hours"
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object provides the current charge of the battery
           in units of milliampere hours (mAh).
```

```
           Note that the current charge needs to be measured and is
           typically an estimate based on observed discharging and
           charging cycles of the battery.

           A value of 'ffffffff'H indicates that the current charge
           cannot be determined."
       ::= { batteryEntry 15 }

   batteryCurrentVoltage OBJECT-TYPE
       SYNTAX      Unsigned32
       UNITS       "millivolt"
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object provides the current voltage of the battery
           in units of millivolt (mV).

           A value of 'ffffffff'H indicates that the current voltage
           cannot be determined."
       ::= { batteryEntry 16 }

   batteryCurrentCurrent OBJECT-TYPE
       SYNTAX      Integer32
       UNITS       "milliampere"
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object provides the current charging or discharging
           current of the battery in units of milliampere (mA).
           Charging current is represented by positive values,
           discharging current is represented by negative values.

           A value of '7fffffff'H indicates that the current current
           cannot be determined."
       ::= { batteryEntry 17 }

   batteryTemperature OBJECT-TYPE
       SYNTAX      Integer32
       UNITS       "degrees Celsius"
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "The ambient temperature at or near the battery.

           A value of '7fffffff'H indicates that the temperature
           cannot be determined."
       ::= { batteryEntry 18 }
```

```
   batteryLowAlarmCharge OBJECT-TYPE
       SYNTAX      Unsigned32
       UNITS       "milliampere hours"
       MAX-ACCESS  read-write
       STATUS      current
       DESCRIPTION
           "This object provides the lower threshold value for object
           batteryCurrentCharge.  If the value of object
           batteryCurrentCharge falls below this threshold,
           a low battery alarm will be raised.  The alarm procedure may
           include generating a batteryLowNotification.

           A value of 0 indicates that no alarm will be raised for any
           value of object batteryCurrentCharge."
       ::= { batteryEntry 19 }

   batteryLowAlarmVoltage OBJECT-TYPE
       SYNTAX      Unsigned32
       UNITS       "millivolt"
       MAX-ACCESS  read-write
       STATUS      current
       DESCRIPTION
           "This object provides the lower threshold value for object
           batteryCurrentVoltage.  If the value of object
           batteryCurrentVoltage falls below this threshold,
           a low battery alarm will be raised.  The alarm procedure may
           include generating a batteryLowNotification.

           A value of 0 indicates that no alarm will be raised for any
           value of object batteryCurrentVoltage."
       ::= { batteryEntry 20 }

   batteryReplacementAlarmCapacity OBJECT-TYPE
       SYNTAX      Unsigned32
       UNITS       "milliampere hours"
       MAX-ACCESS  read-write
       STATUS      current
       DESCRIPTION
           "This object provides the lower threshold value for object
           batteryActualCapacity.  If the value of object
           batteryActualCapacity falls below this threshold,
           a battery aging alarm will be raised.  The alarm procedure
           may include generating a batteryAgingNotification.

           A value of 0 indicates that no alarm will be raised for any
           value of object batteryActualCapacity."
       ::= { batteryEntry 21 }
```

```
   batteryReplacementAlarmCycles OBJECT-TYPE
       SYNTAX      Unsigned32
       UNITS       "milliampere hours"
       MAX-ACCESS  read-write
       STATUS      current
       DESCRIPTION
           "This object provides the upper threshold value for object
           batteryChargingCycleCount.  If the value of object
           batteryChargingCycleCount rises above this threshold,
           a battery aging alarm will be raised.  The alarm procedure
           may include generating a batteryAgingtNotification.

           A value of 0 indicates that no alarm will be raised for any
           value of object batteryChargingCycleCount."
       ::= { batteryEntry 22 }

   batteryHighAlarmTemperature OBJECT-TYPE
       SYNTAX      Integer32
       UNITS       "degrees Celsius"
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "This object provides the upper threshold value for object
           batteryTemperature.  If the value of object
           batteryTemperature rises above this threshold, a battery
           high temperature alarm will be raised.  The alarm procedure
           may include generating a batteryHighTemperatNotification.

           A value of '7fffffff'H indicates that no alarm will be
           raised for any value of object batteryCurrentCharge."
       ::= { batteryEntry 23 }


   --==================================================================
   -- 2. Notifications
   --==================================================================

   batteryLowNotification NOTIFICATION-TYPE
       OBJECTS     {
           batteryCurrentCharge,
           batteryCurrentVoltage
       }
       STATUS      current
       DESCRIPTION
           "This notification can be generated when the current charge
           (batteryCurrentCharge) or the current voltage
           (batteryCurrentVoltage) of the battery falls below a
           threshold defined by object batteryLowAlarmCharge or
```

```
           object batteryLowAlarmVoltage, respectively."
       ::= { batteryNotifications 1 }

   batteryAgingNotification NOTIFICATION-TYPE
       OBJECTS     {
           batteryActualCapacity,
           batteryChargingCycleCount
       }
       STATUS      current
       DESCRIPTION
           "This notification can be generated when the actual
           capacity (batteryActualCapacity) falls below a threshold
           defined by object batteryReplacementAlarmCapacity
           or when the charging cycle count of the battery
           (batteryChargingCycleCount) exceeds the threshold defined
           by object batteryReplacementAlarmCycles."
       ::= { batteryNotifications 2 }

   batteryHighTemperatNotification NOTIFICATION-TYPE
       OBJECTS     {
           batteryTemperature
       }
       STATUS      current
       DESCRIPTION
           "This notification can be generated when the actual
           temperature (batteryTemperature) rises above a threshold
           defined by object batteryHighAlarmTemperature."
       ::= { batteryNotifications 3 }


   --==================================================================
   -- 3. Conformance Information
   --==================================================================

   batteryCompliances OBJECT IDENTIFIER ::= { batteryConformance 1 }
   batteryGroups      OBJECT IDENTIFIER ::= { batteryConformance 2 }

   -------------------------------------------------------------------
   -- 3.1. Compliance Statements
   -------------------------------------------------------------------

   batteryCompliance MODULE-COMPLIANCE
       STATUS      current
       DESCRIPTION
           "The compliance statement for implementations of the
           POWER-STATE-MIB module.

           A compliant implementation MUST implement the objects
```

```
            defined in the mandatory groups batteryDescriptionGroup
            and batteryStatusGroup."
        MODULE  -- this module
        MANDATORY-GROUPS {
            batteryDescriptionGroup,
            batteryStatusGroup
        }
        GROUP   batteryAlarmThresholdsGroup
        DESCRIPTION
           "A compliant implementation does not have to implement
            the batteryAlarmThresholdsGroup."
        GROUP   batteryNotificationsGroup
        DESCRIPTION
           "A compliant implementation does not have to implement
            the batteryNotificationsGroup."
        ::= { batteryCompliances 1 }

    --------------------------------------------------------------------
    -- 3.2. MIB Grouping
    --------------------------------------------------------------------

    batteryDescriptionGroup OBJECT-GROUP
        OBJECTS {
           batteryIdentifier,
           batteryFirmwareVersion,
           batteryType,
           batteryTechnology,
           batteryNominalVoltage,
           batteryNumberOfCells,
           batteryNominalCapacity,
           batteryMaxChargingCurrent,
           batteryTrickleChargingCurrent
        }
        STATUS      current
        DESCRIPTION
           "A compliant implementation MUST implement the objects
           contained in this group."
        ::= { batteryGroups 1 }

    batteryStatusGroup OBJECT-GROUP
        OBJECTS {
           batteryActualCapacity,
           batteryChargingCycleCount,
           batteryLastChargingCycleTime,
           batteryChargingState,
           batteryCurrentCharge,
           batteryCurrentVoltage,
           batteryCurrentCurrent,
```

```
          batteryTemperature
       }
       STATUS      current
       DESCRIPTION
          "A compliant implementation MUST implement the objects
          contained in this group."
       ::= { batteryGroups 2 }

   batteryAlarmThresholdsGroup OBJECT-GROUP
       OBJECTS {
          batteryLowAlarmCharge,
          batteryLowAlarmVoltage,
          batteryReplacementAlarmCapacity,
          batteryReplacementAlarmCycles,
          batteryHighAlarmTemperature
       }
       STATUS      current
       DESCRIPTION
          "A compliant implementation does not have to implement the
          object contained in this group."
       ::= { batteryGroups 3 }

   batteryNotificationsGroup NOTIFICATION-GROUP
       NOTIFICATIONS {
          batteryLowNotification,
          batteryAgingNotification,
          batteryHighTemperatNotification
       }
       STATUS      current
       DESCRIPTION
           "A compliant implementation does not have to implement the
           notification contained in this group."
       ::= { batteryGroups 4 }
   END
```

6. Security Considerations

This sections needs to be updated after changing four managed objects from read-only to read-write.

There are no management objects defined in this MIB module that have a MAX-ACCESS clause of read-write and/or read-create. So, if this MIB module is implemented correctly, then there is no risk that an intruder can alter or create any management objects of this MIB module via direct SNMP SET operations.

Some of the readable objects in this MIB module (i.e., objects with a

MAX-ACCESS other than not-accessible) may be considered sensitive or vulnerable in some network environments. It is thus important to control even GET and/or NOTIFY access to these objects and possibly to even encrypt the values of these objects when sending them over the network via SNMP. These are the tables and objects and their sensitivity/vulnerability:

- This list is still to be done.

SNMP versions prior to SNMPv3 did not include adequate security. Even if the network itself is secure (for example by using IPsec), even then, there is no control as to who on the secure network is allowed to access and GET/SET (read/change/create/delete) the objects in this MIB module.

It is RECOMMENDED that implementers consider the security features as provided by the SNMPv3 framework (see [RFC3410], section 8), including full support for the SNMPv3 cryptographic mechanisms (for authentication and privacy).

Further, deployment of SNMP versions prior to SNMPv3 is NOT RECOMMENDED. Instead, it is RECOMMENDED to deploy SNMPv3 and to enable cryptographic security. It is then a customer/operator responsibility to ensure that the SNMP entity giving access to an instance of this MIB module is properly configured to give access to the objects only to those principals (users) that have legitimate rights to indeed GET or SET (change/create/delete) them.

7. IANA Considerations

7.1. SMI Object Identifier Registration

The Battery MIB module defined in this document uses the following IANA-assigned OBJECT IDENTIFIER value recorded in the SMI Numbers registry:

Descriptor	OBJECT IDENTIFIER value
batteryMIB	{ mib-2 xxx }

[NOTE for IANA: Please allocate an object identifier at http://www.iana.org/assignments/smi-numbers for object batteryMIB.]

7.2. Battery Technology Registration

Object batteryTechnology defined in Section 5 reports battery technologies. 18 values for battery technologies have initially been defined. They are listed in a table in Section 4.

For ensuring extensibility of this list, IANA has created a registry for battery technologies at http://www.iana.org/assignments/eman and filled it with the initial list given in Section 4.

New assignments of numbers for battery technologies will be administered by IANA through Expert Review ([RFC5226]). Experts must check for sufficient relevance of a battery technology to be added.

[NOTE for IANA: Please create a new registry under http://www.iana.org/assignments/eman for battery types. Please fill the registry with values from the table in Section 4]

8. Open Issues

8.1. Writable Notification thresholds

Do we want to have the thresholds for sending notifications (batteryLowAlarmPercentage, batteryLowAlarmVoltage, batteryReplacementAlarmCapacity, batteryReplacementAlarmCycles) to be read-write or read-only?

8.2. Re-arming batteryLowNotification

What needs to happen after sending a batteryLowNotification before another batteryLowNotification can be sent for the same battery?

8.3. Alignment with the Smart Battery Data Specification

How closely do we need to align with the Smart Battery Data Specification [SBS]?

9. Acknowledgements

We would like to thank Steven Chew for his input.

10. References

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Authors' Addresses

Juergen Quittek
NEC Europe Ltd.
NEC Laboratories Europe
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE

Phone: +49 6221 4342-115
Email: quittek@neclab.eu

Rolf Winter
NEC Europe Ltd.
NEC Laboratories Europe
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE

Phone: +49 6221 4342-121
Email: Rolf.Winter@neclab.eu

Thomas Dietz
NEC Europe Ltd.
NEC Laboratories Europe
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE

Phone: +49 6221 4342-128
Email: Thomas.Dietz@neclab.eu

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J. Parello
B. Claise
Cisco Systems, Inc.
October 31, 2011

Energy-aware Networks and Devices MIB
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Status of this Memo

Copyright Notice

Abstract

This document defines a subset of a Management Information Base (MIB) for energy management of devices. The module addresses device identification, context information, and the relationships between reporting devices, remote devices, and monitoring devices.

Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

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1. Introduction

The EMAN standards provides network administrators with a specification for Energy Management. This document defines a subset of a Management Information Base (MIB) for use with network management protocols for Energy monitoring of Electrical Equipments (for example network devices and devices attached to the network.)

This focus of this MIB module is on monitoring Energy Objects as defined in [EMAN-FMWK]. The module addresses Energy Object Identification, Energy Object Context, and Energy Object Relationships.

Devices and their sub-components are characterized by the power-related attributes of a physical entity present in the ENTITY MIB [RFC4133].

1.1. Energy Management Document Overview

This document specifies the Energy-Aware Networks and Devices MIB. This document is based on the Energy Management Framework [EMAN-FMWK] and meets the requirements specified in the Energy Management requirements [EMAN-REQ].

The Power and Energy Monitoring MIB [EMAN-MON-MIB] contains the Energy Objects for monitoring of Power States, along with the Power and Energy consumption of Electrical Objects. Power State monitoring includes: retrieving Power States, Power State properties, current Power State, Power State transitions, and Power State statistics. This MIB module provides the detailed properties of the Power, Energy, along with optional characteristics.

EDITOR’S NOTE: Replace characteristics with consensus term when defined. This is electrical qualities or characteristics.

The applicability statement document [EMAN-AS] provides the list of use cases, cross-reference between existing standards and the EMAN standard, and shows how the EMAN framework relates to other frameworks.

2. The Internet-Standard Management Framework

For a detailed overview of the documents that describe the current Internet-Standard Management Framework, please refer to section 7 of RFC 3410 [RFC3410].

Managed objects are accessed via a virtual information store, termed the Management Information Base or MIB. MIB objects are generally accessed through the Simple Network Management Protocol (SNMP). Objects in the MIB are defined using the mechanisms defined in the Structure of Management Information (SMI). This memo specifies MIB modules that are compliant with SMIv2, which is described in STD 58, RFC 2578 [RFC2578], STD 58, RFC 2579 [RFC2579] and STD 58, RFC 2580 [RFC2580].

3. Requirements and Use Cases

Requirements for power and energy monitoring for networking devices are specified in [EMAN-REQ]. The requirements in [EMAN-REQ] include communications network devices, such as switches, routers, and various connected endpoints and Electrical Equipments.

The use cases for this MIB are specified in the EMAN applicability statement document [EMAN-AS].

EDITOR’S NOTE: say a few words about the use cases when we will have a stable version of the EMAN applicability statement document.

Accordingly, the scope of the MIB module in this document is in accordance to the requirements specified in [EMAN-REQ] and the use cases in [EMAN-AS].

4. Terminology

The definitions of basic terms like Energy Management, Energy Monitoring, Power, Energy, Energy Object, Energy Object Parent, Energy Object Child, Energy Management Domain, Power State, Power State Set, Energy Object Relationships, Aggregation Relationship, Power Source Relationship, Proxy Relationship, Dependency Relationship, Nameplate Power can be found in the temporary draft[EMAN-TERMINOLOGY].

EDITOR’S NOTE: all terms will be copied over from the final version of the [EMAN-TERMINOLOGY] draft.

5. Architecture Concepts Applied to the MIB Module

This section describes the basic concepts specified in the Energy Management Architecture [EMAN-FMWK], with specific information related to the MIB module specified in this document

The following diagram shows the relationship of the identifying information.

```
          +---------------------------+
          |  EO Context Information   |
          | ------------------------- |
          |  eoRoleDescription        |
          |  eoKeywords               |
          |  eoImportance             |
          |  eoPowerCategory          |
          +---------------------------+
                 |
                 |
                 v
            +---------------------------------+
            |  EO Identification              |
            |_------------------------------- |
         |->| entPhysIndex (*)                |
         |  | entPhysicalName (*)             |
         |  | entPhysicalUris (*)  (EO UUID)  |
         |  | eoDomainName                    |
         |  | eoMgmtMacAddress                |
         |  | eoMgmtAddress                   |
         |  | eoMgmtAddressType               |
         |  | eoMgmtDNSName                   |
```

```
         |  +--------------------------------+
         |
         |
         |  +------------------------------+
         |--|   Links to other Identifiers |
         |  | ---------------------------- |
         |  |  eoEthPortIndex (**)         |
         |  |  eoEthPortGrpIndex (**)      |
         |  |  eoLldpPortNumber (***)      |
         |  |  eoAlternateKey              |
         |  +------------------------------+
         |
         |
         |  +-------------------------------------------+
         |--|   EO Child Relationships (optional)       |
         |  | ----------------------------------------- |
         |  |  eoMeteredBy (Parent(s) UUID list)        |
         |  |  eoPoweredBy (Parent(s) UUID list         |
         |  |  eoDependentOf (Parent(s) UUID list)      |
         |  |  eoAggregatedBy (Parent(s) UUID list      |
         |  |  eoProxyBy (Parent(s) UUID list)          |
         |  |  eoParentProxyAbilities (Parent abilities)|
         |  +-------------------------------------------+
         |
         |
         |  +-----------------------------------------+
         |--|   EO Parent Relationships (optional)    |
            | --------------------------------------- |
            |  eoChildrenList (Child(ren) UUID list)  |
            +-----------------------------------------+


         +-----------------------------------------+
         |         EO Identity Persistence         |
         | --------------------------------------- |
         |  eoTablePersistence (boolean)           |
         +-----------------------------------------+


     (*)    Compliance From the ENTITY MIB [RFC4133]
     (**)   Link with the Power over Ethernet MIB [RFC3621]
     (***)  Link with LLDP MIBs [LLDP-MIB] [LLDP-MED-MIB]
```

Figure 1: MIB Objects Grouping

As displayed in figure 1, there are six different logical groups of MIB objects in the ENERGY-AWARE-MIB module:

1) The Energy Object Identification. See Section 5.1 "Energy Object Identification"
2) The Context Information. See Section 5.2 "Energy Object Context"
3) The links to other MIB modules. See Section 5.3 "Links to other Identifiers"
4) The Energy Object Child Relationships specific information. See Section 5.4 "Child: Energy Objects Relationship."
5) The Energy Object Parent Relationships specific information. See Section 5.5 "Parent: Energy Objects Relationship."
6) The Energy Object Identity Persistence. See Section 5.6 "Energy Object Identity Persistence"

5.1 Energy Object Identification

Refer to the "Energy Object Information" section in [EMAN-FMWK] for background information about Energy Objects.

Every Energy Object MUST support the unique index, entPhysicalIndex, from the ENTITY MIB [RFC4133], which is used as index for the primary Energy Object information in the ENERGY-AWARE-MIB module eoTable table.

The ENERGY-AWARE-MIB MIB module, specified in this document requires the implementation of some managed objects in the ENTITY MIB [RFC4133].

Other ENTITY MIB managed objects MAY be implemented.

Every Energy Object MUST have a printable name. Energy Objects MUST implement the entPhysicalName object specified in the ENTITY-MIB, which must contain the Energy Object name.

By the [RFC4133] definition, the entPhysicalUris contains a white space separated list of Uniform Resource Identifier (s)(URIs). For the ENERGY-AWARE-MIB compliance, every Energy Object instance MUST implement the entPhysicalUris from the ENTITY MIB [RFC4133]. The entPhysicalUris MUST contain the Energy Object UUID, according to [RFC4122].

As displayed in [RFC4122], the following is an example of the string representation of a UUID as a URN: urn:uuid:f81d4fae-7dec-11d0-a765-00a0c91e6bf6.

Other ENTITY MIB managed objects, next to entPhysicalIndex, entPhysicalName, and entPhysicalUris, MAY be implemented.

When a Energy Object Parent acts as a Power Aggregator or a Power Proxy, the Energy Object Parent and its Energy Object Child/Children MUST be members of the same Energy Management Domain, specified by the eoDomainName MIB Object.

Each Energy Object MUST belong to a single Energy Management Domain or in other words, a Energy Object cannot belong to more than one Energy Management Domain. Refer to the "Energy Management Domain" section in [EMAN-FMWK] for background information. The eoDomainName, which is an element of the eoTable, is a read-write MIB object. The Energy Management Domain should map 1-1 with a metered or sub-metered portion of the site. The Energy Management Domain MUST be configured on the Energy Object Parent. The Energy Object Children MAY inherit their domain parameters from the Energy Object Parent or the Energy Management Domain MAY be configured directly in a Energy Object Child.

The eoMgmtMacAddress, eoMgmtAddress, eoMgmtAddressType, and eoMgmtDNSName MIB objects SHOULD be implemented for Energy Object Children, and MAY be implemented for Energy Object Parents.

5.2 Energy Object Context

Refer to the "Energy Object Context" section in [EMAN-FMWK] for background information.

A Energy Object can provide a eoImportance value in the range of 1..100 to help differentiate the use or relative value of the device. The importance range is from 1 (least important) to 100 (most important). The default importance value is 1.

A Energy Object can provide a set of eoKeywords. These keywords are a list of tags that can be used for grouping and summary reporting within or between Energy Management Domains.

Additionally, a Energy Object can provide a eoRoleDescription string that indicates the purpose the Energy Object serves in the network or for the site/business.

5.3 Links to Other Identifiers

While the entPhysicalIndex is the primary index for all MIB objects in the ENERGY-AWARE-MIB module, the Energy Management Systems (EnMS) must be able to make the link with the identifier(s) in other supported MIB modules.

The Energy Object eoethPortIndex and eoethPortGrpIndex MUST contain the values of pethPsePortIndex and pethPsePortGroupIndex from the Power over Ethernet MIB [RFC3621], if the Power over Ethernet MIB is supported by the Energy Object SNMP agent.

The Energy Object eoLldpPortNumber MUST contain the lldpLocPortNum from the LLDP MIB [LLDP-MIB], if the LLDP-MED MIB is supported on the Energy Object SNMP agent.

The intent behind the links to the other MIB module identifier(s) is to correlate the instances in the different MIB modules. This will allow the ENERGY-AWARE-MIB to reference other MIB modules in cases where the Power over Ethernet and the LLDP MIB modules are supported by the SNMP agent. Some use cases may not implement any of these two MIB modules for the Energy Objects. However, in situation where any of these two MIB modules is implemented, the EnMS must be able to correlate the instances in the different MIB modules.

The eoAlternateKey alternate key object specifies a manufacturer defined string that can be used to identify the Energy Object. Since EnMS may need to correlate objects across management systems, this alternate key is provided to facilitate such a link. This optional value is intended as a foreign key or alternate identifier for a manufacturer or EnMS to use to correlate the unique Energy Object Id in other systems or namespaces. If an alternate key is not available or is not applicable then NULL should be returned.

5.4 Child: Energy Object Relationships

Refer to the "Energy Object Parent and Child" section in [EMAN-FMWK] for background information.

In order to link the Energy Object Child and the Energy Object Parent, multiple objects are introduced in the MIB module. Depending on the Energy Object Relationship type, the following objects are appropriate:

```
Metering Relationship         ->   eoMeteredBy

Power Source Relationship     ->   eoPoweredBy

Dependency Relationship       ->   eoDependentOf

Aggregation Relationship      ->   eoAggregatedBy

 Proxy Relationship            ->   eoProxyBy,
                               ->   eoParentProxyAbilities
```

Each object contains the list of Energy Object Parent UUIDs for the specific Energy Object Relationship type. The UUIDs MUST comply to the RFC 4122 specifications. The object contains URIs and, therefore, the syntax of this object must conform to RFC 3986 [RFC3986], section 2. Multiple URIs may be present and are separated by white space characters. Leading and trailing white space characters are ignored.

For example, if an Energy Object Child is powered by two power sources, eoPoweredBy would contain the two power sources UUIDs, separated by a space: "urn:uuid:f81d4fae-7dec-11d0-a765-00a0c91e6bf6 urn:uuid:abcdec11-7abc-23e1-b876-00a0c91e6bf8".

The eoParentProxyAbilities object is specific to the Proxy Relationship. This object describes the capabilities of the Energy Object Parent for the Energy Object Child represented by the entPhysicalIndex. The possible capabilities are: report, configuration, and/or wakeonlan. This object only applies to an Energy Object Child.

If the Energy Object is not an Energy Object Child, or if the Energy Object doesn't have a Energy Object Relationship, the eoMeteredBy, eoPoweredBy, eoDependentOf, eoAggregatedBy, eoProxyBy, and eoParentProxyAbilities objects are not instantiated. A zero length octet string MAY also be returned in this case.

The Energy Object Child can indicate that it wants its Energy Object Parent to proxy capabilities such as, energy reporting, power state configurations, non physical wake capabilities (such as Wake-on-LAN)), or any combination of capabilities. These capabilities are indicated in the eoParentProxyAbilities object. In the case of Energy Object Parent, the eoParentProxyAbilities MUST be set to "none" (0).

Since the communication between the Energy Object Parent and Energy Object Child may not be via SNMP (as defined in EMAN-FMWK), a Energy Object Child can have additional MIB objects that can be used for easier identification by the EnMS. The optional objects eoMgmtMacAddress, eoMgmtAddressType eoMgmtDNSName can be used to help identify the relationship between the child and other NMS objects. These objects can be used as an alternate key to help link the Energy Object with other keyed information that may be stored within the EnMS(s).

The eoMeteredBy, eoPoweredBy, eoDependentOf, eoAggregatedBy, eoProxyBy, and eoParentProxyAbilities implementations are optional.

5.5 Parent: Energy Object Relationships

When the Energy Object is an Energy Object Parent, the eoChildrenList object represents the list of Energy Object Child(ren) UUIDs. This UUID list will help in the network discovery of Energy Objects, using the Energy Object Parent as entry points.

eoChildrenList has the same format as the eoMeteredBy, eoPoweredBy, eoDependentOf, eoAggregatedBy, and eoProxyBy. The UUIDs MUST comply to the RFC 4122 specifications. The UUIDs MUST comply to the RFC 4122 specifications. The eoChildrenList object contains URIs and, therefore, the syntax of this object must conform to RFC 3986 [RFC3986], section 2. Multiple URIs may be present and are separated by white space characters. Leading and trailing white space characters are ignored.

If the Energy Object is not an Energy Object Parent, the eoChildrenList objects is not instantiated. A zero length octet string MAY also be returned in this case.

The eoChildrenList implementation is optional.

5.6 Energy Object Identity Persistence

In some situations, the Energy Object identity information should be persistent even after a device reload. For example, in a static setup where a switch monitors a series of connected PoE phones, there is a clear benefit for the EnMS if the Energy Object Identification and all associated information persist, as it saves a network discovery. However, in other situations, such as a wireless access point monitoring the mobile user PCs, there is not much advantage to persist the Energy Object Information. Therefore, a specific MIB object, the eoTablePersistence, enables and disables the persistence globally for all Energy Objects information in the ENERGY-AWARE-MIB module.

6. Structure of the MIB

The primary MIB object in this MIB module is the energyAwareMIB Object. The eoTable table of energyAwareMIB Object describes an entity in the network that is a Energy Object according the [EMAN-FMWK].

```
+--  rwn TruthValue      eoTablePersistence(1)
+- eoTable(2)
   |
   +- eoEntry(1) [entPhysicalIndex]
   |  |
   |  +-- r-n PhysicalIndexOrZero          eoPhysicalEntity(1)
   |  +-- r-n PethPsePortIndexOrZero       eoEthPortIndex(2)
   |  +-- r-n PethPsePortGroupIndexOrZero  eoEthPortGrpIndex(3)
   |  +-- r-n LldpPortNumberOrZero         eoLldpPortNumber(4)
   |  +-- rwn SnmpAdminString              eoDomainName(5)
   |  +-- rwn SnmpAdminString              eoRoleDescription(6)
   |  +-- rwn MacAddress                   eoMgmtMacAddress(7)
   |  +-- r-n eoMgmtAddressType            eoMgmtAddressType(8)
   |  +-- r-n InetAddress                  eoMgmtAddress(9)
   |  +-- r-n SnmpAdminString              eoMgmtDNSName(10)
   |  +-- rwn SnmpAdminString              eoAlternateKey(11)
   |  +-- rwn EnergyObjectKeywordList      eoKeywords(12)
   |  +-- rwn Integer32                    eoImportance(13)
   |  +-- r-n INTEGER                      eoPowerCategory(14)
   |  +-- r-n OCTET STRING                 eoMeteredBy(15)
   |  +-- r-n OCTET STRING                 eoPoweredBy(16)
   |  +-- r-n OCTET STRING                 eoDependentOf(17)
   |  +-- r-n OCTET STRING                 eoAggregatedBy(18)
   |  +-- r-n OCTET STRING                 eoAggregatedBy(19)
   |  +-- r-n BITS                    eoParentProxyAbilities(20)
   |  +-- r-n OCTET STRING                 eoChildrenList(21)
```

7. MIB Definitions

```
-- ************************************************************
--
--
-- This MIB is used for describing the identity and the
-- context information of Energy Objects in network
--
--
-- ************************************************************

ENERGY-AWARE-MIB DEFINITIONS ::= BEGIN

IMPORTS
    MODULE-IDENTITY,
    OBJECT-TYPE,
    mib-2,
    Integer32
        FROM SNMPv2-SMI
    TEXTUAL-CONVENTION, MacAddress, TruthValue
        FROM SNMPv2-TC
    MODULE-COMPLIANCE,
    OBJECT-GROUP
        FROM SNMPv2-CONF
    SnmpAdminString
        FROM SNMP-FRAMEWORK-MIB
    InetAddressType, InetAddress
       FROM INET-ADDRESS-MIB
    PhysicalIndexOrZero
       FROM ENTITY-MIB;

energyAwareMIB MODULE-IDENTITY
    LAST-UPDATED    "201103050000Z"
    ORGANIZATION    "IETF EMAN Working Group"
    CONTACT-INFO
       "WG Charter:
        http://datatracker.ietf.org/wg/eman/charter/

       Mailing Lists:
        General Discussion: eman@ietf.org
        To Subscribe: https://www.ietf.org/mailman/listinfo/eman
        Archive: http://www.ietf.org/mail-archive/web/eman

       Editors:
          John Parello
```

```
             Cisco Systems, Inc.
             3550 Cisco Way
             San Jose, California 95134
             US
             Phone: +1 408 525 2339
             Email: jparello@cisco.com

             Benoit Claise
             Cisco Systems, Inc.
             De Kleetlaan 6a b1
             Degem 1831
             Belgium
             Phone:  +32 2 704 5622
             Email: bclaise@cisco.com"

      DESCRIPTION
         "This MIB is used for describing the identity and the
         context information of Energy Objects"
      REVISION
          "201103050000Z"
      DESCRIPTION
         "Initial version, published as RFC XXXX."


     ::= { mib-2 xxxxx }

   energyAwareMIBNotifs OBJECT IDENTIFIER
       ::= { energyAwareMIB 0 }

   energyAwareMIBObjects OBJECT IDENTIFIER
       ::= { energyAwareMIB 2 }

   energyAwareMIBConform  OBJECT IDENTIFIER
       ::= { energyAwareMIB 3 }


   -- Textual Conventions


   PethPsePortIndexOrZero ::= TEXTUAL-CONVENTION
   DISPLAY-HINT "d"
      STATUS            current
      DESCRIPTION
          "This textual convention is an extension of the
          pethPsePortIndex convention, which defines a greater than
```

```
          zero value used to identify a power Ethernet PSE port.
          This extension permits the additional value of zero.  The
          semantics of the value zero are object-specific and must,
          therefore, be defined as part of the description of any
          object that uses this syntax.  Examples of the usage of
          this extension are situations where none or all physical
          entities need to be referenced."
      SYNTAX Integer32 (0..2147483647)

   PethPsePortGroupIndexOrZero::= TEXTUAL-CONVENTION
   DISPLAY-HINT "d"
      STATUS            current
      DESCRIPTION
          "This textual convention is an extension of the
          pethPsePortGroupIndex convention, which defines a greater
          than zero value used to identify group containing the
          port to which a power Ethernet PSE is connected.  This
          extension permits the additional value of zero.  The
          semantics of the value zero are object-specific and must,
          therefore, be defined as part of the description of any
          object that uses this syntax.  Examples of the usage of
          this extension are situations where none or all physical
          entities need to be referenced."
      SYNTAX Integer32 (0..2147483647)

  LldpPortNumberOrZero ::= TEXTUAL-CONVENTION
       DISPLAY-HINT "d"
       STATUS     current
       DESCRIPTION
          "This textual convention is an extension of the
          LldpPortNumber convention specified in the LLDP MIB,
          which defines a greater than zero value used to uniquely
          identify each port contained in the chassis (that is
          known to the LLDP agent) by a port number.  This
          extension permits the additional value of zero. The
          semantics of the value zero are object-specific and must,
          therefore, be defined as part of the description of any
          object that uses this syntax.  Examples of the usage of
          this extension are situations where none or all physical
          entities need to be referenced."
     SYNTAX Integer32(0..4096)
```

```
  EnergyObjectKeywordList ::= TEXTUAL-CONVENTION
      STATUS          current
      DESCRIPTION
          "A list of keywords that can be used to group Energy
          Objects for reporting or searching. If multiple keywords
          are present, then this string will contain all the
          keywords separated by the ',' character. For example, if
          a Energy Object were to be tagged with the keyword values
          'hospitality' and 'guest', then the keyword list will be
          'hospitality,guest'."
      SYNTAX OCTET STRING (SIZE (0..255))

   -- Objects

   eoTablePersistence OBJECT-TYPE
       SYNTAX          TruthValue
       MAX-ACCESS      read-write
       STATUS          current
       DESCRIPTION
          "This object enables/disables persistence for
          all entries in the eoTable. A value of True enables the
          persistence, while a value of False disables the
          persistence."
       ::= { energyAwareMIBObjects 1 }


   eoTable OBJECT-TYPE
       SYNTAX          SEQUENCE OF EoEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "This table lists Energy Objects."
       ::= { energyAwareMIBObjects 2 }

   eoEntry OBJECT-TYPE
       SYNTAX          EoEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "An entry describes the attributes of a Energy Object.
          Whenever a new Energy Object is added or deleted a row in
          the eoTable is added or deleted."

       AUGMENTS        { entPhysicalIndex }
       ::= { eoTable 1 }
```

```
   EoEntry ::= SEQUENCE {
           eoPhysicalEntity            PhysicalIndexOrZero,
           eoEthPortIndex              PethPsePortIndexOrZero,
           eoEthPortGrpIndex           PethPsePortGroupIndexOrZero,
           eoLldpPortNumber            LldpPortNumberOrZero,
           eoDomainName                SnmpAdminString,
           eoRoleDescription           SnmpAdminString,
           eoMgmtMacAddress            MacAddress,
           eoMgmtAddressType           InetAddressType,
           eoMgmtAddress               InetAddress,
           eoMgmtDNSName               SnmpAdminString,
           eoAlternateKey              SnmpAdminString,
           eoKeywords                  EnergyObjectKeywordList,
           eoImportance                Integer32,
           eoPowerCategory             INTEGER,
           eoMeteredBy                 OCTET STRING,
           eoPoweredBy                 OCTET STRING,
           eoDependentOf               OCTET STRING,
           eoAggregatedBy              OCTET STRING,
           eoProxyBy                   OCTET STRING,
           eoParentProxyAbilities      BITS,
           eoChildrenList              OCTET STRING
   }

   eoPhysicalEntity OBJECT-TYPE
       SYNTAX          PhysicalIndexOrZero
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object contains the index of a physical entity in
          the ENTITY MIB [RFC4133].  This physical entity is the
          given observation point.  If such a physical entity
          cannot be specified or is not known then the object is
          zero."
       ::= { eoEntry 1 }

   eoEthPortIndex   OBJECT-TYPE
       SYNTAX       PethPsePortIndexOrZero
       MAX-ACCESS   read-only
       STATUS       current
       DESCRIPTION
          "This variable uniquely identifies the power Ethernet
          port to which the attached device is connected [RFC3621].
          If such a power Ethernet port cannot be specified or is
          not known then the object is zero."
       ::= { eoEntry 2 }

   eoEthPortGrpIndex   OBJECT-TYPE
```

```
       SYNTAX       PethPsePortGroupIndexOrZero
       MAX-ACCESS   read-only
       STATUS       current
       DESCRIPTION
          "This variable uniquely identifies the group containing
          the port to which a power Ethernet PSE is connected
          [RFC3621].  If such a group cannot be specified or is not
          known then the object is zero."
       ::= { eoEntry 3 }

   eoLldpPortNumber   OBJECT-TYPE
       SYNTAX       LldpPortNumberOrZero
       MAX-ACCESS   read-only
       STATUS       current
       DESCRIPTION
         "This variable uniquely identifies the port component
         (contained in the local chassis with the LLDP agent) as
         defined by the lldpLocPortNum in the [LLDP-MIB] and
         [LLDP-MED-MIB]. If such a port number cannot be specified
         or is not known then the object is zero."
       ::= { eoEntry 4 }

   eoDomainName OBJECT-TYPE
       SYNTAX          SnmpAdminString
       MAX-ACCESS      read-write
       STATUS          current
       DESCRIPTION
          "This object specifies the name of a Energy Management
          Domain for the Energy Object.  This object specifies a
          null string if no Energy Management Domain name is
          configured. The value of eoDomainName must remain
          constant at least from one re-initialization of the
          entity's network management system to the next re-
          initialization."
       ::= { eoEntry 5 }

   eoRoleDescription OBJECT-TYPE
       SYNTAX          SnmpAdminString
       MAX-ACCESS      read-write
       STATUS          current
       DESCRIPTION
          "This object specifies an administratively assigned name
          to indicate the purpose an Energy Object serves in the
          network.

          For example, we can have a phone deployed to a lobby with
          eoRoleDescription as 'Lobby phone'.
```

```
          This object specifies a null string if no role
          description is configured."
       ::= { eoEntry 6 }

   eoMgmtMacAddress OBJECT-TYPE
       SYNTAX          MacAddress
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object specifies a MAC address of the Energy
          Object. This object typically only applies to Energy
          Object Children. This object can be used as an alternate
          key to help link the Energy Object with other keyed
          information that may be stored within the EnMS(s). The
          eoMgmtMacAddress MIB object SHOULD be implemented for
          Energy Object Children, and MAY be implemented for Energy
          Object Parents."
       ::= { eoEntry 7 }

   eoMgmtAddressType OBJECT-TYPE
       SYNTAX          InetAddressType
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
         "This object specifies the eoMgmtAddress type, i.e. an
         IPv4 address or an IPv6 address. This object MUST be
         implemented when eoMgmtAddress is populated.  The
         eoMgmtAddressType MIB object SHOULD be implemented for
         Energy Object Children, and MAY be implemented for Energy
         Object Parents."
       ::= { eoEntry 8 }

   eoMgmtAddress OBJECT-TYPE
       SYNTAX          InetAddress
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
         "This object specifies the management address as an IPv4
         address or IPv6 address of Energy Object. The IP address
         type, i.e. IPv4 or IPv6, is determined by the
         eoMgmtAddressType value. This object can be used as an
         alternate key to help link the Energy Object with other
         keyed information that may be stored within the EnMS(s).
         The eoMgmtAddress MIB object SHOULD be implemented for
         Energy Object Children, and MAY be implemented for Energy
         Object Parents."
       ::= { eoEntry 9 }
```

```
   eoMgmtDNSName OBJECT-TYPE
       SYNTAX          SnmpAdminString
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object specifies the DNS name of the eoMgmtAddress.
          This object can be used as an alternate key to help link
          the Energy Object with other keyed information that may
          be stored within the EnMS(s).  The eoMgmtDNSName MIB
          objects SHOULD be implemented for Energy Object Children,
          and MAY be implemented for Energy Object Parents."

       ::= { eoEntry 10 }

   eoAlternateKey OBJECT-TYPE
       SYNTAX          SnmpAdminString
       MAX-ACCESS      read-write
       STATUS          current
       DESCRIPTION
          "This object specifies a manufacturer defined string that
          can be used to identify the Energy Object. Since Energy
          Management Systems (EnMS) and Network Management Systems
          (NMS) may need to correlate objects across management
          systems, this alternate key is provided to provide such a
          link. This optional value is intended as a foreign key or
          alternate identifier for a manufacturer or EnMS/NMS to
          use to correlate the unique Energy Object Id in other
          systems or namespaces. If an alternate key is not
          available or is not applicable then NULL should be
          returned."
       ::= { eoEntry 11 }

   eoKeywords OBJECT-TYPE
       SYNTAX          EnergyObjectKeywordList
       MAX-ACCESS      read-write
       STATUS          current
       DESCRIPTION
         "This object specifies a list of keywords that can be
         used to group Energy Objects for reporting or searching.
         This object specifies the null string if no keywords have
         been configured. If multiple keywords are present, then
         this string will contain all the keywords separated by
         the ',' character. For example, if a Energy Object were
         to be tagged with the keyword values 'hospitality' and
         'guest', then the keyword list will be
         'hospitality,guest'.
```

```
          If write access is implemented and a value is written
          into the instance, the agent must retain the supplied
          value in the eoKeywords instance associated with
          the same physical entity for as long as that entity
          remains instantiated.  This includes instantiations
          across all re-initializations/reboots of the network
          management system."
       ::= { eoEntry 12 }

   eoImportance OBJECT-TYPE
       SYNTAX          Integer32 (1..100)
       MAX-ACCESS      read-write
       STATUS          current
       DESCRIPTION
          "This object specifies a ranking of how important the
          Energy Object is (on a scale of 1 to 100) compared with
          other Energy Objects in the same Energy Management
          Domain. The ranking should provide a business or
          operational context for the Energy Object as compared to
          other similar Energy Objects. This ranking could be used
          as input for policy-based network management.


          Although network managers must establish their own
          ranking, the following is a broad recommendation:

          90 to 100 Emergency response
          80 to 90 Executive or business critical
          70 to 79 General or Average
          60 to  69 Staff or support
          40 to  59 Public or guest
          1  to 39 Decorative or hospitality"
       DEFVAL          { 1 }
       ::= { eoEntry 13 }

   eoPowerCategory OBJECT-TYPE
       SYNTAX          INTEGER {
                           consumer(0),
                           producer(1),
                           consumer-producer(2),
                           meter(3)
                       }
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object describes the Energy Object category, which
          indicates the expected behavior or physical property of
          the Energy Object, based on its design. A Energy Object
```

```
          can be a consumer(0), producer(1) or consumer-producer
          (2) or meter (3).

          There are devices with a dual mode - consuming energy and
          producing of energy and those are identified as consumer-
          producer.

          In some cases, a meter is required to measure the power
          consumption. In such a case, this meter Energy Object
          category is meter(3). "
       ::= { eoEntry 14 }

   eoMeteredBy OBJECT-TYPE
       SYNTAX      OCTET STRING
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
         "When this Energy Object is an Energy Object Child, this
         object represents the list of Energy Object Parent
         Universally Unique Identifiers (UUIDs) for the Metering
         Relationship.

         The UUIDs must comply to the RFC 4122 specifications.

         The object contains URIs and, therefore, the syntax of
         this object must conform to RFC 3986, section 2.

         Multiple URIs may be present and are separated by white
         space characters.  Leading and trailing white space
         characters are ignored.

         If this Energy Object is not an Energy Object Child, or
         if the Energy Object doesn’t have a Metering
         Relationship, the object is not instantiated.  A zero
         length octet string may also be returned in this case."
       REFERENCE
         "RFC 3986, Uniform Resource Identifiers (URI): Generic
         Syntax, section 2, August 1998.
         RFC 4122, Uniform Resource Identifier (UUID) URN
         Namespace, July 2005."
       ::= { eoEntry 15 }

   eoPoweredBy OBJECT-TYPE
       SYNTAX      OCTET STRING
```

```
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
         "When this Energy Object is an Energy Object Child, this
         object represents the list of Energy Object Parent
         Universally Unique Identifiers (UUIDs) for the Power
         Source Relationship.

         The UUIDs must comply to the RFC 4122 specifications.

         The object contains URIs and, therefore, the syntax of
         this object must conform to RFC 3986, section 2.

         Multiple URIs may be present and are separated by white
         space characters.  Leading and trailing white space
         characters are ignored.

         If this Energy Object is not an Energy Object Child, or
         if the Energy Object doesn't have a Power Source
         Relationship, the object is not instantiated.  A zero
         length octet string may also be returned in this case."
       REFERENCE
         "RFC 3986, Uniform Resource Identifiers (URI): Generic
         Syntax, section 2, August 1998.
         RFC 4122, Uniform Resource Identifier (UUID) URN
         Namespace, July 2005."
       ::= { eoEntry 16 }

   eoDependentOf OBJECT-TYPE
       SYNTAX      OCTET STRING
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
         "When this Energy Object is an Energy Object Child, this
         object represents the list of Energy Object Parent
         Universally Unique Identifiers (UUIDs) for the Dependency
         Relationship.

         The UUIDs must comply to the RFC 4122 specifications.

         The object contains URIs and, therefore, the syntax of
         this object must conform to RFC 3986, section 2.
```

```
          Multiple URIs may be present and are separated by white
          space characters.  Leading and trailing white space
          characters are ignored.

          If this Energy Object is not an Energy Object Child, or
          if the Energy Object doesn't have a Dependency
          Relationship, the object is not instantiated.  A zero
          length octet string may also be returned in this case."
        REFERENCE
          "RFC 3986, Uniform Resource Identifiers (URI): Generic
          Syntax, section 2, August 1998.
          RFC 4122, Uniform Resource Identifier (UUID) URN
          Namespace, July 2005."
        ::= { eoEntry 17 }

   eoAggregatedBy OBJECT-TYPE
        SYNTAX      OCTET STRING
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
          "When this Energy Object is an Energy Object Child, this
          object represents the list of Energy Object Parent
          Universally Unique Identifiers (UUIDs) for the
          Aggregation Relationship.

          The UUIDs must comply to the RFC 4122 specifications.

          The object contains URIs and, therefore, the syntax of
          this object must conform to RFC 3986, section 2.

          Multiple URIs may be present and are separated by white
          space characters.  Leading and trailing white space
          characters are ignored.

          If this Energy Object is not an Energy Object Child, or
          if the Energy Object doesn't have a Aggregation
          Relationship, the object is not instantiated.  A zero
          length octet string may also be returned in this case."
        REFERENCE
          "RFC 3986, Uniform Resource Identifiers (URI): Generic
          Syntax, section 2, August 1998.
```

```
         RFC 4122, Uniform Resource Identifier (UUID) URN
         Namespace, July 2005."
       ::= { eoEntry 18 }

   eoProxyBy OBJECT-TYPE
       SYNTAX      OCTET STRING
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
         "When this Energy Object is an Energy Object Child, this
         object represents the list of Energy Object Parent
         Universally Unique Identifiers (UUIDs) for the Proxy
         Relationship.

         The UUIDs must comply to the RFC 4122 specifications.

         The object contains URIs and, therefore, the syntax of
         this object must conform to RFC 3986, section 2.

         Multiple URIs may be present and are separated by white
         space characters.  Leading and trailing white space
         characters are ignored.

         If this Energy Object is not an Energy Object Child, or
         if the Energy Object doesn't have a Proxy Relationship,
         the object is not instantiated.  A zero length octet
         string may also be returned in this case."
       REFERENCE
         "RFC 3986, Uniform Resource Identifiers (URI): Generic
         Syntax, section 2, August 1998.
         RFC 4122, Uniform Resource Identifier (UUID) URN
         Namespace, July 2005."
       ::= { eoEntry 19 }

   eoParentProxyAbilities OBJECT-TYPE
       SYNTAX          BITS {
                           none(0),
                           report(1),
                           configuration(2),
                           wakeonlan(3)
                       }
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
```

```
          "This object describes the capabilities of the Energy
          Object Parent for the Energy Object Child represented by
          the entPhysicalIndex. This object only applies to a
          Energy Object Child.
          None (0) MUST be used when the Energy Object represented
          by the entPhysicalIndex is a Energy Object Parent, and no
          other bit can be set.
          Report(1) indicates that the Energy Object Parent reports
          the usage for the Energy Object Child represented by the
          entPhysicalIndex.
          Configuration(2) indicates that the Energy Object Parent
          can configure the Power Level for the Energy Object Child
          Child represented by the entPhysicalIndex.
          Wakeonlan(3) indicates that the Energy Object Parent can
          wake up the Energy Object Child, Child represented by the
          entPhysicalIndex, whatever the mechanism."
       ::= { eoEntry 20 }


   eoChildrenList  OBJECT-TYPE
       SYNTAX      OCTET STRING
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
         "When this Energy Object is an Energy Object Parent, this
         object represents the list of Energy Object Children
         Universally Unique Identifiers (UUIDs).

         The UUIDs must comply to the RFC 4122 specifications.

         The object contains URIs and, therefore, the syntax of
         this object must conform to RFC 3986, section 2.

         Multiple URIs may be present and are separated by white
         space characters.  Leading and trailing white space
         characters are ignored.

         If this Energy Object is not an Energy Object Parent, the
         object is not instantiated.  A zero length octet string
         may also be returned in this case."
       REFERENCE
         "RFC 3986, Uniform Resource Identifiers (URI): Generic
         Syntax, section 2, August 1998.
```

```
         RFC 4122, Uniform Resource Identifier (UUID) URN
         Namespace, July 2005."
       ::= { eoEntry 21 }


   -- Conformance

   energyAwareMIBCompliances  OBJECT IDENTIFIER
       ::= { energyAwareMIBObjects 3 }

   energyAwareMIBGroups  OBJECT IDENTIFIER
       ::= { energyAwareMIBObjects 4 }


   energyAwareMIBFullCompliance MODULE-COMPLIANCE
       STATUS          current
       DESCRIPTION
           "When this MIB is implemented with support for
           read-create, then such an implementation can
           claim full compliance. Such devices can then
           be both monitored and configured with this MIB."
       MODULE          -- this module
       MANDATORY-GROUPS {
                   energyAwareMIBTableGroup
                       }

       ::= { energyAwareMIBCompliances 1 }

   energyAwareMIBReadOnlyCompliance MODULE-COMPLIANCE
       STATUS          current
       DESCRIPTION
           "When this MIB is implemented without support for
           read-create (i.e. in read-only mode), then such an
           implementation can claim read-only compliance.  Such a
           device can then be monitored but cannot be configured
           with this MIB."
       MODULE          -- this module
       MANDATORY-GROUPS {
                    energyAwareMIBTableGroup
                       }

       OBJECT          eoTablePersistence
       MIN-ACCESS      read-only
       DESCRIPTION
           "Write access is not required."
```

```
        OBJECT          eoDomainName
        MIN-ACCESS      read-only
        DESCRIPTION
            "Write access is not required."

        OBJECT          eoRoleDescription
        MIN-ACCESS      read-only
        DESCRIPTION
            "Write access is not required."

        OBJECT          eoKeywords
        MIN-ACCESS      read-only
        DESCRIPTION
        "Write access is not required."

        OBJECT          eoImportance
        MIN-ACCESS      read-only
        DESCRIPTION
            "Write access is not required."

   ::= { energyAwareMIBCompliances 2 }

   -- Units of Conformance

   energyAwareMIBTableGroup OBJECT-GROUP
       OBJECTS          {
                            eoTablePersistence,
                            eoPhysicalEntity,
                            eoEthPortIndex,
                            eoEthPortGrpIndex,
                            eoLldpPortNumber,
                            eoDomainName,
                            eoRoleDescription,
                            eoMgmtMacAddress,
                            eoMgmtAddressType,
                            eoMgmtAddress,
                            eoMgmtDNSName,
                            eoAlternateKey,
                            eoKeywords,
                            eoImportance,
                            eoPowerCategory,
                            eoMeteredBy,
                            eoPoweredBy,
                            eoDependentOf,
                            eoAggregatedBy,
                            eoProxyBy,
                            eoParentProxyAbilities,
```

```
                           eoChildrenList
                       }
       STATUS          current
       DESCRIPTION
           "This group contains the collection of all the objects
           related to the EnergyObject."
       ::= { energyAwareMIBGroups 1 }


   END
```

8. Security Considerations

Some of the readable objects in these MIB modules (i.e., objects with a MAX-ACCESS other than not-accessible) may be considered sensitive or vulnerable in some network environments. It is thus important to control even GET and/or NOTIFY access to these objects and possibly to even encrypt the values of these objects when sending them over the network via SNMP.

There are a number of management objects defined in these MIB modules with a MAX-ACCESS clause of read-write and/or read-create. Such objects MAY be considered sensitive or vulnerable in some network environments. The support for SET operations in a non-secure environment without proper protection can have a negative effect on network operations. The following are the tables and objects and their sensitivity/vulnerability:

. Unauthorized changes to the eoDomainName, entPhysicalName, eoRoleDescription, eoKeywords, and/or eoImportance MAY disrupt power and energy collection, and therefore any predefined policies defined in the network.

SNMP versions prior to SNMPv3 did not include adequate security. Even if the network itself is secure (for example, by using IPsec), there is still no secure control over who on the secure network is allowed to access and GET/SET (read/change/create/delete) the objects in these MIB modules.

It is RECOMMENDED that implementers consider the security features as provided by the SNMPv3 framework (see [RFC3410], section 8), including full support for the SNMPv3 cryptographic mechanisms (for authentication and privacy).

Further, deployment of SNMP versions prior to SNMPv3 is NOT RECOMMENDED. Instead, it is RECOMMENDED to deploy SNMPv3 and to enable cryptographic security. It is then a customer/operator responsibility to ensure that the SNMP entity giving access to an instance of these MIB modules is properly configured to give access to the objects only to those principals (users) that have legitimate rights to GET or SET (change/create/delete) them.

9. IANA Considerations

The MIB module in this document uses the following IANA-assigned OBJECT IDENTIFIER values recorded in the SMI Numbers registry:

Descriptor	OBJECT IDENTIFIER value
energyAwareMIB	{ mib-2 xxx }

Additions to this MIB module are subject to Expert Review [RFC5226], i.e., review by one of a group of experts designated by an IETF Area Director. The group of experts MUST check the requested MIB objects for completeness and accuracy of the description. Requests for MIB objects that duplicate the functionality of existing objects SHOULD be declined. The smallest available OID SHOULD be assigned to a new MIB objects. The specification of new MIB objects SHOULD follow the structure specified in Section 6 and MUST be published using a well-established and persistent publication medium.

10. References

10.1. Normative References

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10.2. Informative References

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Authors' Addresses

Benoit Claise
Cisco Systems, Inc.
De Kleetlaan 6a b1
Diegem 1813
BE

Phone: +32 2 704 5622
Email: bclaise@cisco.com

John Parello
Cisco Systems, Inc.
3550 Cisco Way
San Jose, California 95134
US

Phone: +1 408 525 2339
Email: jparello@cisco.com

Network Working Group M. Chandramouli
Internet-Draft Cisco Systems, Inc.
Intended Status: Standards Track B. Schoening
Expires: April 31 2012 Independent Consultant
J. Quittek
T. Dietz
NEC Europe Ltd.
B. Claise
Cisco Systems, Inc.
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Power and Energy Monitoring MIB
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Status of this Memo

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Abstract

This document defines a subset of the Management Information Base (MIB) for power and energy monitoring of devices.

Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

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1. Introduction

This document defines a subset of the Management Information Base (MIB) for use in energy management of devices within or connected to communication networks. The MIB modules in this document are designed to provide a model for energy management, which includes monitoring for power state and energy consumption of networked elements. This MIB takes into account the Energy Management Framework [EMAN-FRAMEWORK], which in turn, is based on the Requirements for Energy Management[EMAN-REQ].

Energy management is applicable to devices in communication networks. Target devices for this specification include (but are not limited to): routers, switches, Power over Ethernet (PoE) endpoints, protocol gateways for building management systems, intelligent meters, home energy gateways, hosts and servers, sensor proxies, etc. Target devices and the use cases for Energy Management are discussed in Energy Management Applicability Statement [EMAN-AS].

Where applicable, device monitoring extends to the individual components of the device and to any attached dependent devices. For example: A device can contain components that are independent from a power-state point of view, such as line cards, processor cards, hard drives. A device can also have dependent attached devices, such as a switch with PoE endpoints or a power distribution unit with attached endpoints.

Devices and their sub-components may be characterized by the power-related attributes of a physical entity present in the ENTITY MIB, even though the ENTITY MIB compliance is not a requirement due to the variety and broad base of devices concerned with energy management.

2. The Internet-Standard Management Framework

For a detailed overview of the documents that describe the current Internet-Standard Management Framework, please refer to section 7 of RFC 3410 [RFC3410].

Managed objects are accessed via a virtual information store, termed the Management Information Base or MIB. MIB objects are generally accessed through the Simple Network Management Protocol (SNMP). Objects in the MIB are defined using the mechanisms defined in the Structure of Management Information (SMI). This memo specifies MIB modules that are compliant to SMIv2, which is described in STD 58, RFC 2578 [RFC2578], STD 58, RFC 2579 [RFC2579] and STD 58, RFC 2580 [RFC2580].

3. Use Cases

Requirements for power and energy monitoring for networking devices are specified in [EMAN-REQ]. The requirements in [EMAN-REQ] cover devices typically found in communications networks, such as switches, routers, and various connected endpoints. For a power monitoring architecture to be useful, it should also apply to facility meters, power distribution units, gateway proxies for commercial building control, home automation devices, and devices that interface with the utility and/or smart grid. Accordingly, the scope of the MIB modules in this document is broader than that specified in [EMAN-REQ]. Several use cases for Energy Management have been identified in the "Energy Management (EMAN) Applicability Statement" [EMAN-AS]. An illustrative example scenario is presented in Section 8.

4. Terminology

The definitions of basic terms such as Energy Object, Energy Object Parent, Energy Object Child, Energy Object Meter Domain, Power State can be found in the terminology draft draft-parello-eman-definitions.

Power State Set

A Power State Set is defined as a sequence of incremental energy saving modes of a device. The elements of this set can be viewed as an interface for the underlying device-implemented power settings of a device. Examples of Power State Sets include DTMF [DMTF], IEEE1621 [IEEE1621], ACPI [ACPI] and EMAN.

EDITOR NOTE: Use the latest definition from draft-parello-eman-definitions

Power State

A Power State is defined as a specific power setting for an Energy Object (e.g., shut, hibernate, sleep, high). Within the context of a Power State Set, the Power State of a device is one of the power saving modes in that Power State Set.

EDITOR NOTE: Use the latest definition from draft-parello-eman-definitions

5. Architecture Concepts Applied to the MIB Module

This section describes the concepts specified in the Energy Management Framework [EMAN-FRAMEWORK] that pertain to power usage, with specific information related to the MIB module specified in this document. This subsection maps to the section "Architecture High Level Concepts" in the Power Monitoring Architecture [EMAN-FRAMEWORK].

The Energy Monitoring MIB has 2 independent MIB modules. The first MIB module energyObjectMib is focused on measurement of power and energy. The second MIB module powerQualityMIB is focused on Power Quality measurements.

The energyObjectMib MIB module consists of four tables. The first table eoPowerTable is indexed by eoPowerIndex. The second table eoPowerStateTable indexed by eoPowerIndex,and eoPowerStateIndex. . The eoEnergyParametersTable and eoEnergyTable are indexed by eoPowerIndex.

```
 eoPowerTable(1)
  |
  +---eoPowerEntry(1) [eoPowerIndex]
  |   |
  |   +-- --- Integer32         eoPowerIndex(1)
  |   +---r-n Integer32         eoPower(2)
  |   +-- r-n Integer32         eoPowerNamePlate(3)
  |   +-- r-n UnitMultiplier    eoPowerUnitMultiplier(4)
  |   +-- r-n Integer32         eoPowerAccuracy(5)
  |   +-- r-n INTEGER           eoMeasurementCaliber(6)
  |   +-- r-n INTEGER           eoPowerCurrentType(7)
  |   +-- r-n INTEGER           eoPowerOrigin(8)
  |   +-- rwn Integer32         eoPowerAdminState(9)
  |   +-- r-n Integer32         eoPowerOperState(10)
  |   +-- r-n OwnerString       eoPowerStateEnterReason(11)
  |   |
  |   |
  +---eoPowerStateTable(2)
  |      +--eoPowerStateEntry(1)
  |      |     [eoPowerIndex,
  |      |      eoPowerStateIndex]
  |      |
  |      +-- --- IANAPowerStateSet  eoPowerStateIndex(1)
  |      +-- r-n Interger32         eoPowerStateMaxPower (2)
  |      +-- r-n UnitMultiplier
  |                eoPowerStatePowerUnitMultiplier (3)
  |      +-- r-n TimeTicks          eoPowerStateTotalTime(4)
  |      +-- r-n Counter64          eoPowerStateEnterCount(5)
  |

  +eoEnergyParametersTable(1)
  +---eoEnergyParametersEntry(1) [eoPowerIndex]
  |
  |   +-- r-n TimeInterval
  |               eoEnergyParametersIntervalLength (1)
  |   +-- r-n Integer32
  |               eoEnergyParametersIntervalNumber (2)
```

```
     |    +-- r-n Integer32
     |                eoEnergyParametersIntervalMode (3)
     |    +-- r-n TimeInterval
     |                eoEnergyParametersIntervalWindow (4)
     |    +-- r-n Integer32
     |                eoEnergyParametersSampleRate (5)
     |    +-- r-n RowStatus  eoEnergyParametersStatus (6)
     |
     +eoEnergyTable(1)
     +---eoEnergyEntry(1) [eoPowerIndex]
     |
     |    +-- r-n TimeInterval  eoEnergyIntervalStartTime (1)
     |    +-- r-n Integer32     eoEnergyIntervalEnergyConsumed (2)
     |    +-- r-n Integer32     eoEnergyIntervalEnergyProduced (3)
     |    +-- r-n Integer32     eoEnergyIntervalEnergyNet (4)
     |    +-- r-n UnitMultiplier
     |                 eoEnergyIntervalEnergyUnitMultiplier (5)
     |    +-- r-n Integer32     eoEnergyIntervalEnergyAccuracy(6)
     |    +-- r-n Integer32     eoEnergyIntervalMaxConsumed (7)
     |    +-- r-n Integer32     eoEnergyIntervalMaxProduced (8)
     |    +-- r-n TimeTicks
     |                    eoEnergyIntervalDiscontinuityTime(9)
     |    +-- r-n RowStatus     eoEnergyParametersStatus (10)
```

The powerQualityMIB consists of four tables. eoACPwrQualityTable is indexed by eoPowerIndex. eoACPwrQualityPhaseTable is indexed by eoPowerIndex and eoPhaseIndex. eoACPwrQualityWyePhaseTable and eoACPwrQualityDelPhaseTable are indexed by eoPowerIndex and eoPhaseIndex.

```
   eoPowerTable(1)
     |
     +---eoACPwrQualityEntry (1) [eoPowerIndex]
     |    |
     |    |
     |    +----- INTEGER      eoACPwrQualityConfiguration (1)
     |    +-- r-n Interger32  eoACPwrQualityAvgVoltage (2)
     |    +-- r-n Integer32   eoACPwrQualityAvgCurrent (3)
     |    +-- r-n Integer32   eoACPwrQualityFrequency  (4)
     |    +-- r-n UnitMultiplier
     |              eoACPwrQualityPowerUnitMultiplier (5)
     |    +-- r-n Integer32   eoACPwrQualityPowerAccuracy (6)
     |    +-- r-n Interger32  eoACPwrQualityTotalActivePower (7)
     |    +-- r-n Integer32
     |             eoACPwrQualityTotalReactivePower (8)
     |    +-- r-n Integer32   eoACPwrQualityTotalApparentPower (9)
     |    +-- r-n Integer32   eoACPwrQualityTotalPowerFactor(10)
```

```
     |   +-- r-n Integer32   eoACPwrQualityThdAmpheres (11)
     |
     +eoACPwrQualityPhaseTable (1)
     +---EoACPwrQualityPhaseEntry(1)[eoPowerIndex,
     |     |                         eoPhaseIndex]
     |     |
     |     +-- r-n Integer32  eoPhaseIndex  (1)
     |     +-- r-n Integer32
     |     |          eoACPwrQualityPhaseAvgCurrent (2)
     |     +-- r-n Integer32
     |     |          eoACPwrQualityPhaseActivePower (3)
     |     +-- r-n Integer32
     |     |          eoACPwrQualityPhaseReactivePower (4)
     |     +-- r-n Integer32
     |     |          eoACPwrQualityPhaseApparentPower (5)
     |     +-- r-n Integer32
     |     |          eoACPwrQualityPhasePowerFactor (6)
     |     +-- r-n Integer32
     |     |          eoACPwrQualityPhaseImpedance (7)
     |     |
     +eoACPwrQualityDelPhaseTable (1)
     +-- eoACPwrQualityDelPhaseEntry(1)
     |     |                           [eoPowerIndex,
     |     |                            eoPhaseIndex]
     |     +-- r-n Integer32
     |     |    eoACPwrQualityDelPhaseToNextPhaseVoltage (1)
     |     +-- r-n Integer32
     |     |    eoACPwrQualityDelThdPhaseToNextPhaseVoltage (2)
     |     +-- r-n Integer32  eoACPwrQualityDelThdCurrent (3)
     |     |
     +eoACPwrQualityWyePhaseTable (1)
     +-- eoACPwrQualityWyePhaseEntry (1)
     |     |                             [eoPowerIndex,
     |     |                              eoPhaseIndex]
     |     +-- r-n Integer32
     |     |    eoACPwrQualityWyePhaseToNeutralVoltage (1)
     |     +-- r-n Integer32
     |     |     eoACPwrQualityWyePhaseCurrent (2)
     |     +-- r-n Integer32
     |     |    eoACPwrQualityWyeThdPhaseToNeutralVoltage (3)
     |     .
```

A UML representation of the MIB objects in the two MIB modules are energyObjectMib and powerQualityMIB are presented.

```
   +--------------------------+
   |    Energy Object ID      |
   |                          |
   |  Energy-aware-MIB  (*)   |
   |                          | +----------------------------+
   |                          | |                            |
   | eoPowerIndex             | |_ EnergyObject Attributes   |
   |                          | |                            |
   +--------------------------+ | eoPowerNamePlate           |
             |                | | eoPowerMeasurementCaliber  |
             |                | | eoPowerOrigin              |
             |                | | eoPowerCurrentType         |
             |                | +----------------------------+
             |                |       |
             |                |       |
             v                |       v
   +------------------------------------------+
   |  EnergyObjec Measurement                 |
   |                                          |
   | eoPower                                  |
   | eoPowerUnitMultiplier                    |
   | eoPowerAccuracy                          |
   +------------------------------------------+
             ^                 |      ^
             |                 |      |
   +-------------------------+ |      |
   |    EnergyObject State   | |  +-------------------------+
   |                         | |  | EnergyObject   State    |
   | eoPowerAdminState       | |  |    Statistics           |
   | eoPowerOperState        | |  |                         |
   | eoPowerStateEnterReason | |  | eoPowerStateMaxPower    |
   +-------------------------+ |  | eoPowerStateTotalTime   |
                               |  | eoPowerStateEnterCount  |
                               |  +-------------------------+
                               |
                               |
                               |
                               |
```

Figure 1:UML diagram for powerMonitor MIB

(*)   Link with the ENERGY-AWARE-MIB

```
                          |
                          |
                          |
                          V
          +----------------------------------------+
          |    Energy Table                        |
          |                                        |
          |  eoEnergyIntervalStartTime             |
          |  eoEnergyIntervalEnergyConsumed        |
          |  eoEnergyIntervalEnergyProduced        |
          |  eoEnergyIntervalEnergyNet             |
          |  eoEnergyIntervalEnergyUnitMultiplier  |
          |  eoEnergyIntervalEnergyAccuracy        |
          |  eoEnergyIntervalMaxConsumed           |
          |  eoEnergyIntervalMaxProduced           |
          |  eoEnergyIntervalDiscontinuityTime     |
          +----------------------------------------+



           +---------------------------+
           |    EnergyObject ID        |
           |                           |
           |  Energy-aware-MIB  (*)    |
           |                           |
           | eoPowerIndex              |
           |                           |
           +---------------------------+
                      |
                      v
              +------------------------------------+
              |  Power Quality                     |
              |                                    |
              | eoACPwrQualityConfiguration        |
              | eoACPwrQualityAvgVoltage           |
              | eoACPwrQualityAvgCurrent
              | eoACPwrQualityFrequency            |
              | eoACPwrQualityPowerUnitMultiplier  |
              | eoACPwrQualityPowerAccuracy        |
              | eoACPwrQualityTotalActivePower     |
              | eoACPwrQualityTotalReactivePower   |
```

```
              | eoACPwrQualityTotalApparentPower    |
              | eoACPwrQualityTotalPowerFactor      |
              | eoACPwrQualityThdAmpheres           |
              +-------------------------------------+ ^
                               ^                   ^  |
                               |                   |  -------
                               |                   ----     |
                               |                       |    |
                               |                       |    |
             +-------------------------------------+   |    |
             |  Power Phase Quality                |   |    |
             |                                     |   |    |
             | eoPhaseIndex                        |   |    |
             | eoACPwrQualityPhaseAvgCurrent       |   |    |
             | eoACPwrQualityAvgCurrent            |   |    |
             | eoACPwrQualityFrequency             |   |    |
             | eoACPwrQualityPowerUnitMultiplier   |   |    |
             | eoACPwrQualityPowerAccuracy         |   |    |
             | eoACPwrQualityPhaseActivePower      |   |    |
             | eoACPwrQualityPhaseReactivePower    |   |    |
             | eoACPwrQualityPhaselApparentPower   |   |    |
             | eoACPwrQualityPhaseImpedance        |   |    |
             +-------------------------------------+   |    |
                                                       |    |
                                                       |    |
           +---------------------------------------------+  |
           |  Power Quality DEL Configuration            |  |
           |                                             |  |
           | eoACPwrQualityDelPhaseToNextPhaseVoltage    |  |
           | eoACPwrQualityDelThdPhaseToNextPhaseVoltage |  |
           | eoACPwrQualityDelThdCurrent                 |  |
           +---------------------------------------------+  |
                                                            |
                                                            |
               +---------------------------------------------+
               |  Power Quality WYE Configuration            |
               |                                             |
               | eoACPwrQualityWyePhaseToNeutralVoltage      |
               | eoACPwrQualityWyePhaseCurrent               |
               | eoACPwrQualityWyeThdPhaseToNeutralVoltage   |
               +---------------------------------------------+
```

Figure 2: UML diagram for the powerQualityMIB

5.1. Energy Object Information

Refer to the "Energy Object Information" section in [EMAN-FRAMEWORK] for background information. An energy aware device is considered as an instance of a Energy Object as defined in the [EMAN-FRAMEWORK].

The Energy Object identity information is specified in the MIB ENERGY-AWARE-MIB module [EMAN-AWARE-MIB] primary table, i.e. the eoTable. In this table, every Energy Object SHOULD have a printable name eoName, and MUST HAVE a unique Energy Object index eoIndex. The ENERGY-AWARE-MIB module returns the relationship (parent/child) between Energy Objects .

EDITOR’S NOTE: this last sentence will have to be updated with terms such as Aggregator, Proxy, etc... when the [EMAN-FRAMEWORK] will stabilize.

5.2. Power State

Refer to the "Power States" section in [EMAN-FRAMEWORK] for background information.

An Energy Object may have energy conservation modes called Power States. Between the ON and OFF states of a device, there can be several intermediate energy saving modes. Those energy saving modes are called as Power States.

Power States, which represent universal states of power management of an Energy Object, are specified by the eoPowerState MIB object. The actual Power State is specified by the eoPowerOperState MIB object, while the eoPowerAdminState MIB object specifies the Power State requested for the Energy Object. The difference between the values of eoPowerOperState and eoPowerAdminState can be attributed that the Energy Object is busy transitioning from eoPowerAdminState into the eoPowerOperState, at which point it will update the content of eoPowerOperState. In addition, the possible reason for change in Power State is reported in eoPowerStateEnterReason. Regarding eoPowerStateEnterReason, management stations and Energy Objects should support any format of the owner string dictated by the local policy of the organization. It is suggested that this name contain at least the reason for the transition change, and one or more of the following: IP address, management station name, network manager’s name, location, or phone number.

The MIB objects eoPowerOperState, eoPowerAdminState , and eoPowerStateEnterReason are contained in the eoPowerTable MIB table.

The eoPowerStateTable table enumerates the maximum power usage in watts, for every single supported Power State of each Power State Set supported by the Energy Object. In addition, PowerStateTable provides additional statistics: eoPowerStateEnterCount, the number of times an entity has visited a particular Power State, and eoPowerStateTotalTime, the total time spent in a particular Power State of an Energy Object.

5.2.1. Power State Set

There are several standards and implementations of Power State Sets. A Energy Object can support one or multiple Power State Set implementation(s) concurrently.

There are currently three Power State Sets advocated:

```
unknown(0)
IEEE1621(256) - [IEEE1621]
DMTF(512)     - [DMTF]
EMAN(1024)     - [EMAN-MONITORING-MIB]
```

The respective specific states related to each Power State Set are specified in the following sections. The guidelines for addition of new Power State Sets have been specified in the IANA Considerations Section.

5.2.2. IEEE1621 Power State Set

The IEEE1621 Power State Set [IEEE1621] consists of 3 rudimentary states : on, off or sleep.

on(0)   - The device is fully On and all features of the device are in working mode.

off(1)   - The device is mechanically switched off and does not consume energy.

sleep(2) - The device is in a power saving mode, and some features may not be available immediately.

The Textual Convention IANAPowerStateSet provides the proposed numbering of the Power States within the IEEE1621 Power State Set.

5.2.3. DMTF Power State Set

DMTF [DMTF] standards organization has defined a power profile standard based on the CIM (Common Information Model) model that consists of 15 power states ON (2), SleepLight (3), SleepDeep (4), Off-Hard (5), Off-Soft (6), Hibernate(7), PowerCycle Off-Soft (8), PowerCycle Off-Hard (9), MasterBus reset (10), Diagnostic Interrupt (11), Off-Soft-Graceful (12), Off-Hard Graceful (13), MasterBus reset Graceful (14), Power-Cycle Off-Soft Graceful (15), PowerCycle-Hard Graceful (16). DMTF standard is targeted for hosts and computers. Details of the semantics of each Power State within the DMTF Power State Set can be obtained from the DMTF Power State Management Profile specification [DMTF].

DMTF power profile extends ACPI power states. The following table provides a mapping between DMTF and ACPI Power State Set:

DMTF Power State	ACPI Power State
Reserved(0)	
Reserved(1)	
ON (2)	G0-S0
Sleep-Light (3)	G1-S1 G1-S2
Sleep-Deep (4)	G1-S3
Power Cycle (Off-Soft) (5)	G2-S5
Off-hard (6)	G3
Hibernate (Off-Soft) (7)	G1-S4
Off-Soft (8)	G2-S5
Power Cycle (Off-Hard) (9)	G3
Master Bus Reset (10)	G2-S5
Diagnostic Interrupt (11)	G2-S5
Off-Soft Graceful (12)	G2-S5

Off-Hard Graceful (13)	G3
MasterBus Reset Graceful (14)	G2-S5
Power Cycle off-soft Graceful (15)	G2-S5
Power Cycle off-hard Graceful (16)	G3

Figure 3: DMTF and ACPI Powe State Set Mapping

The Textual Convention IANAPowerStateSet contains the proposed numbering of the Power States within the DMTF Power State Set.

5.2.4. EMAN Power State Set

The EMAN Power State Set represents an attempt for a uniform standard approach to model the different levels of power consumption of a device. The EMAN Power States are an expansion of the basic Power States as defined in IEEE1621 that also incorporate the Power States defined in ACPI and DMTF. Therefore, in addition to the non-operational states as defined in ACPI and DMTF standards, several intermediate operational states have been defined.

There are twelve Power States, that expand on IEEE1621 on,sleep and off. The expanded list of Power States are divided into six operational states, and six non-operational states. The lowest non-operational state is 1 and the highest is 6. Each non-operational state corresponds to an ACPI state [ACPI] corresponding to Global and System states between G3 (hard-off) and G1 (sleeping). For Each operational state represent a performance state, and may be mapped to ACPI states P0 (maximum performance power) through P5 (minimum performance and minimum power).

An Energy Object may have fewer Power States than twelve and would then map several policy states to the same power state. Energy Object with more than twelve states, would choose which twelve to represent as power policy states.

In each of the non-operational states (from mechoff(1) to ready(6)), the Power State preceding it is expected to have a lower power consumption and a longer delay in returning to an operational state:

IEEE1621 Power(off):

mechoff(1) : An off state where no entity features are available. The entity is unavailable. No energy is being consumed and the power connector can be removed. This corresponds to ACPI state G3.

softoff(2) : Similar to mechoff(1), but some components remain powered or receive trace power so that the entity can be awakened from its off state. In softoff(2), no context is saved and the device typically requires a complete boot when awakened. This corresponds to ACPI state G2.

IEEE1621 Power(sleep)

hibernate(3): No entity features are available. The entity may be awakened without requiring a complete boot, but the time for availability is longer than sleep(4). An example for state hibernate(3) is a save to-disk state where DRAM context is not maintained. Typically, energy consumption is zero or close to zero. This corresponds to state G1, S4 in ACPI.

sleep(4) : No entity features are available, except for out-of-band management, for example wake-up mechanisms. The time for availability is longer than standby(5). An example for state sleep(4) is a save-to-RAM state, where DRAM context is maintained. Typically, energy consumption is close to zero. This corresponds to state G1, S3 in ACPI.

standby(5) : No entity features are available, except for out-of-band management, for example wake-up mechanisms. This mode is analogous to cold-standy. The time for availability is longer than ready(6). For example, the processor context is not maintained. Typically, energy consumption is close to

```
                         zero. This corresponds to state G1, S2 in
                         ACPI.

            ready(6)    : No entity features are available, except
                          for out-of-band management, for example
                          wake-up mechanisms. This mode is
                          analogous to hot-standby.  The entity can
                          be quickly transitioned into an
                          operational state.  For example,
                          processors are not executing, but
                          processor context is maintained. This
                          corresponds to state G1, S1 in ACPI.

   IEEE1621 Power(on):

            lowMinus(7) : Indicates some entity features may not be
                          available and the entity has selected
                          measures/options to provide less than
                          low(8) usage.  This corresponds to
                          ACPI State G0. This includes operational
                          states lowMinus(7) to full(12).

            low(8)      : Indicates some features may not be
                          available and the entity has taken
                          measures or selected options to provide
                          less than mediumMinus(9) usage.

            mediumMinus(9): Indicates all entity features are
                          available but the entity has taken
                          measures or selected options to provide
                          less than medium(10) usage.

            medium(10)  : Indicates all entity features are
                          available but the entity has taken
                          measures or selected options to provide
                          less than highMinus(11) usage.

            highMinus(11): Indicates all entity features are
                           available and power usage is less
                           than high(12).

            high(12)    : Indicates all entity features are
                          available and the entity is consuming the
                          highest power.
```

The Textual Convention IANAPowerStateSet contains the proposed numbering of the Power States within the EMAN Power State Set.

5.3. Energy Object Usage Information

Refer to the "Energy Object Usage Measurement" section in [EMAN-FRAMEWORK] for background information.

For an Energy Object, power usage is reported using eoPower. The magnitude of measurement is based on the eoPowerUnitMultiplier MIB variable, based on the UnitMultiplier Textual Convention (TC). Power measurement magnitude should conform to the IEC 62053-21 [IEC.62053-21] and IEC 62053-22 [IEC.62053-22] definition of unit multiplier for the SI (System International) units of measure. Measured values are represented in SI units obtained by BaseValue * 10 raised to the power of the scale.

For example, if current power usage of an Energy Object is 3, it could be 3 W, 3 mW, 3 KW, or 3 MW, depending on the value of eoPowerUnitMultiplier. Note that other measurements throughout the two MIB modules in this document use the same mechanism, including eoPowerStatePowerUnitMultiplier, eoEnergyIntervalEnergyUnitMultiplier, and eoACPwrQualityPowerUnitMultiplier.

In addition to knowing the usage and magnitude, it is useful to know how a eoPower measurement was obtained. An NMS can use this to account for the accuracy and nature of the reading between different implementations. For this eoPowerOrigin describes whether the measurements were made at the device itself or from a remote source. The eoPowerMeasurementCaliber describes the method that was used to measure the power and can distinguish actual or estimated values. There may be devices in the network, which may not be able to measure or report power consumption. For those devices, the object eoPowerMeasurementCaliber shall report that measurement mechanism is "unavailable" and the eoPower measurement shall be "0".

The nameplate power rating of an Energy Object is specified in eoPowerNameplate MIB object.

5.4. Optional Power Usage Quality

Refer to the "Optional Power Usage Quality" section in [EMAN-FRAMEWORK] for background information.

The optional powerQualityMIB MIB module can be implemented to further describe power usage quality measurement. The powerQualityMIB MIB module adheres closely to the IEC 61850 7-2 standard to describe AC measurements.

The powerQualityMIB MIB module contains a primary table, the eoACPwrQualityTable table, that defines power quality measurements for supported eoPowerIndex entities, as a sparse extension of the eoPowerTable (with eoPowerIndex as primary index). This eoACPwrQualityTable table contains such information as the configuration (single phase, DEL 3 phases, WYE 3 phases), voltage, frequency, power accuracy, total active/reactive power/apparent power, amperage, and voltage.

In case of 3-phase power, the eoACPwrQualityPhaseTable additional table is populated with power quality measurements per phase (so double indexed by the eoPowerIndex and eoPhaseIndex). This table, which describes attributes common to both WYE and DEL configurations, contains the average current, active/reactive/apparent power, power factor, and impedance.

In case of 3-phase power with a DEL configuration, the eoACPwrQualityDelPhaseTable table describes the phase-to-phase power quality measurements, i.e., voltage and current.

In case of 3-phase power with a Wye configuration, the eoACPwrQualityWyePhaseTable table describes the phase-to-neutral power quality measurements, i.e., voltage and current.

5.5. Optional Energy Measurement

Refer to the "Optional Energy and demand Measurement" section in [EMAN-FRAMEWORK] for the definition and terminology information.

It is relevant to measure energy when there are actual power measurements from an Energy Object, and not when the power measurement is assumed or predicted as specified in the description clause of the object eoPowerMeasurementCaliber.

Two tables are introduced to characterize energy measurement of an Energy Object: eoEnergyTable and eoEnergyParametersTable. Both energy and demand information can be represented via the eoEnergyTable. Energy information will be an accumulation with no interval. Demand information can be represented as an average accumulation per interval of time.

The eoEnergyParametersTable consists of the parameters defining the duration of measurement intervals in seconds, (eoEnergyParametersIntervalLength), the number of successive intervals to be stored in the eoEnergyTable, (eoEnergyParametersIntervalNumber), the type of measurement technique (eoEnergyParametersIntervalMode), and a sample rate used to calculate the average (eoEnergyParametersSampleRate). Judicious choice of the sampling rate will ensure accurate measurement of energy while not imposing an excessive polling burden.

There are three eoEnergyParametersIntervalMode types used for energy measurement collection: period, sliding, and total. The choices of the the three different modes of collection are based on IEC standard 61850-7-4. Note that multiple eoEnergyParametersIntervalMode types MAY be configured simultaneously.

These three eoEnergyParametersIntervalMode types are illustrated by the following three figures, for which:

- The horizontal axis represents the current time, with the symbol <--- L ---> expressing the eoEnergyParametersIntervalLength, and the eoEnergyIntervalStartTime is represented by S1, S2, S3, S4, ..., Sx where x is the value of eoEnergyParametersIntervalNumber.

- The vertical axis represents the time interval of sampling and the value of eoEnergyIntervalEnergyUsed can be obtained at the end of the sampling period. The symbol =========== denotes the duration of the sampling period.

```
      |             |             | =========== |
      |============ |             |             |
      |             |             |             |
      |             |============ |             |
      |             |             |             |
      | <--- L ---> | <--- L ---> | <--- L ---> |
      |             |             |             |
     S1            S2            S3            S4
```

Figure 4 : Period eoEnergyParametersIntervalMode

A eoEnergyParametersIntervalMode type of 'period' specifies non-overlapping periodic measurements. Therefore, the next eoEnergyIntervalStartTime is equal to the previous

eoEnergyIntervalStartTime plus eoEnergyParametersIntervalLength.
S2=S1+L; S3=S2+L, ...

```
               |============ |
               |             |
               | <--- L ---> |
               |             |
               |   |============ |
               |   |             |
               |   | <--- L ---> |
               |   |             |
               |   |   |============ |
               |   |   |             |
               |   |   | <--- L ---> |
               |   |   |             |
               |   |   |   |============ |
               |   |   |   |             |
               |   |   |   | <--- L ---> |
              S1   |   |   |             |
                   |   |   |             |
                   |   |   |             |
                  S2   |   |             |
                       |   |             |
                       |   |             |
                      S3   |             |
                           |             |
                           |             |
                          S4
```

Figure 5 : Sliding eoEnergyParametersIntervalMode

A eoEnergyParametersIntervalMode type of ’sliding’ specifies overlapping periodic measurements.

```
|                          |
|========================= |
|                          |
|                          |
|                          |
|  <--- Total length --->  |
|                          |
                 S1
```

Figure 4 : Total eoEnergyParametersIntervalMode

A eoEnergyParametersIntervalMode type of 'total' specifies a continuous measurement since the last reset. The value of eoEnergyParametersIntervalNumber should be (1) one and eoEnergyParametersIntervalLength is ignored.

The eoEnergyParametersStatus is used to start and stop energy usage logging. The status of this variable is "active" when all the objects in eoEnergyParametersTable are appropriate which in turn indicates if eoEnergyTable entries exist or not.

The eoEnergyTable consists of energy measurements in eoEnergyIntervalEnergyUsed , the units of the measured energy eoEnergyIntervalEnergyUnitMultiplier, and the maximum observed energy within a window - eoEnergyIntervalMax.

Measurements of the total energy consumed by an Energy Object may suffer from interruptions in the continuous measurement of energy consumption. In order to indicate such interruptions, the object eoEnergyIntervalDiscontinuityTime is provided for indicating the time of the last interruption of total energy measurement. eoEnergyIntervalDiscontinuityTime shall indicate the sysUpTime [RFC3418] when the device was reset.

The following example illustrates the eoEnergyTable and eoEnergyParametersTable:

First, in order to estimate energy, a time interval to sample energy should be specified, i.e. eoEnergyParametersIntervalLength can be set to "900 seconds" or 15 minutes and the number of consecutive intervals over which the maximum energy is calculated (eoEnergyParametersIntervalNumber) as "10". The sampling rate internal to the Energy Object for measurement of power usage (eoEnergyParametersSampleRate) can be "1000 milliseconds", as set by the Energy Object as a reasonable value. Then, the eoEnergyParametersStatus is set to active (value 1) to indicate that the Energy Object should start monitoring the usage per the eoEnergyTable.

The indices for the eoEnergyTable are eoPowerIndex, which identifies the Energy Object, and eoEnergyIntervalStartTime, which denotes the start time of the energy measurement interval based on sysUpTime [RFC3418]. The value of eoEnergyIntervalEnergyUsed is the measured energy consumption over the time interval specified (eoEnergyParametersIntervalLength) based on the Energy Object internal sampling rate (eoEnergyParametersSampleRate). While choosing the values for the eoEnergyParametersIntervalLength and eoEnergyParametersSampleRate, it is recommended to take into consideration either the network element resources adequate to process and store the sample values, and the mechanism used to calculate the eoEnergyIntervalEnergyUsed. The units are derived from eoEnergyIntervalPowerUnitMultiplier. For example, eoEnergyIntervalPowerUsed can be "100" with eoEnergyIntervalPowerUnits equal to 0, the measured energy consumption of the Energy Object is 100 watt-hours. The eoEnergyIntervalMax is the maximum energy observed and that can be "150 watt-hours".

The eoEnergyTable has a buffer to retain a certain number of intervals, as defined by eoEnergyParametersIntervalNumber. If the default value of "10" is kept, then the eoEnergyTable contains 10 energy measurements, including the maximum.

Here is a brief explanation of how the maximum energy can be calculated. The first observed energy measurement value is taken to be the initial maximum. With each subsequent measurement, based on numerical comparison, maximum energy may be updated. The maximum value is retained as long as the measurements are taking place. Based on periodic polling of this table, an NMS could compute the maximum over a longer period, i.e. a month, 3 months, or a year.

5.6. Fault Management

[EMAN-REQ] specifies requirements about Power States such as "the current power state" , "the time of the last state change", "the total time spent in each state", "the number of transitions to each state" etc. Some of these requirements are fulfilled explicitly by MIB objects such as eoPowerOperState, eoPowerStateTotalTime and eoPowerStateEnterCount. Some of the other requirements are met via the SNMP NOTIFICATION mechanism. eoPowerStateChange SNMP notification which is generated when the value(s) of ,eoPowerStateIndex, eoPowerOperState, eoPowerAdminState have changed.

6. Discovery

6.1. ENERGY-AWARE-MIB Module Implemented

The NMS must first poll the ENERGY-AWARE-MIB module [EMAN-AWARE-MIB], if available, in order to discover all the Energy Objects and the relationships between those (notion of Parent/Child).

In the ENERGY-AWARE-MIB module tables, the Energy Objects are indexed by the eoIndex.

If an implementation of the ENERGY-AWARE-MIB module is available in the local SNMP context, for the same Energy Object , the eoIndex value (EMAN-AWARE-MIB) MUST be assigned to the eoPowerIndex. The eoPowerIndex characterizes the Energy Object in the energyObjectMib and powerQualityMIB MIB modules (this document).

From there, the NMS must poll the eoPowerStateTable (specified in the energyObjectMib module in this document), which enumerates, amongst other things, the maximum power usage. As the entries in eoPowerStateTable table are indexed by the Energy Object (eoPowerIndex), by the Power State Set (eoPowerStateIndex), the maximum power usage is discovered per Energy Object, per Power State Set, and per Power Usage. In other words, polling the eoPowerStateTable allows the discovery of each Power State within every Power State Set supported by the Energy Object.

If the Energy Object is an Aggregator or a Proxy, the MIB module would be populated with the Energy Object Parent and Children information, which have their own Energy Object index value (eoPowerIndex). However, the parent/child relationship must be discovered thanks to the ENERGY-AWARE-MIB module.

Finally, the NMS can monitor the Power Quality thanks to the powerQualityMIB MIB module, which reuses the eoPowerIndex to index the Energy Object.

6.2. ENERGY-AWARE-MIB Module Not Implemented, ENTITY-MIB Implemented

When the ENERGY-AWARE-MIB module [EMAN-AWARE-MIB] is not implemented, the NMS must poll the ENTITY-MIB [RFC4133] in order to discover some more information about the Energy Objects. Indeed, the index for the Energy Objects in the MIB modules specified in this document is the eoPowerIndex, which specifies: "If there is no implementation of the ENERGY-AWARE-MIB module but one of the ENTITY MIB module is available in the local SNMP context, then the same index of an entity MUST be chosen as assigned to the entity by object entPhysicalIndex in the ENTITY MIB module."

As described in Section 6.1. the NMS must then poll the eoPowerStateTable (specified in the energyObjectMib module in this document), indexed by the Energy Object (eoPowerIndex that inherited the entPhysicalIndex value), by the Power State (eoPowerStateIndex). Then the NMS has discovered every Power State within each Power State Set supported by the Energy Object.

Note that, without the ENERGY-AWARE-MIB module, the Energy Object acts as an standalone device, i.e. the notion of parent/child can’t be specified.

6.3. ENERGY-AWARE-MIB Module and ENTITY-MIB Not Implemented

If neither the ENERGY-AWARE-MIB module [EMAN-AWARE-MIB] nor of the ENTITY MIB module [RFC4133] are available in the local SNMP context, then this MIB module may choose identity values from a further MIB module providing entity identities.

Note that, without the ENERGY-AWARE-MIB module, the Energy Object acts as a standalone device, i.e. the notion of parent/child can’t be specified.

7. Link with the other IETF MIBs

7.1. Link with the ENTITY MIB and the ENTITY-SENSOR MIB

RFC 4133 [RFC4133] defines the ENTITY MIB module that lists the physical entities of a networking device (router, switch, etc.) and those physical entities indexed by entPhysicalIndex. From an energy-management standpoint, the physical entities that consume or produce energy are of interest.

RFC 3433 [RFC3433] defines the ENTITY-SENSOR MIB module that provides a standardized way of obtaining information (current value of the sensor, operational status of the sensor, and the data units precision) from sensors embedded in networking devices. Sensors are associated with each index of entPhysicalIndex of the ENTITY MIB [RFC4133]. While the focus of the Power and Energy Monitoring MIB is on measurement of power usage of networking equieoent indexed by the ENTITY MIB, this MIB proposes a customized power scale for power measurement and different power state states of networking equipment, and functionality to configure the power state states.

When this MIB module is used to monitor the power usage of devices like routers and switches, the ENTITY MIB and ENTITY-

SENSOR MIB SHOULD be implemented. In such cases, the Energy Objects are modeled by the entPhysicalIndex through the entPhysicalEntity MIB object specified in the eoTable in the ENERGY-AWARE-MIB MIB module [EMAN-AWARE-MIB].

However, the ENTITY-SENSOR MIB [RFC3433] does not have the ANSI C12.x accuracy classes required for electricity (i.e., 1%, 2%, 0.5% accuracy classes). Indeed, entPhySensorPrecision [RFC3433] represents "The number of decimal places of precision in fixed-point sensor values returned by the associated entPhySensorValue object". The ANSI and IEC Standards are used for power measurement and these standards require that we use an accuracy class, not the scientific-number precision model specified in RFC3433. The eoPowerAccuracy MIB object models this accuracy. Note that eoPowerUnitMultipler represents the scale factor per IEC 62053-21 [IEC.62053-21] and IEC 62053-22 [IEC.62053-22], which is a more logical representation for power measurements (compared to entPhySensorScale), with the mantissa and the exponent values X * 10 ^ Y.

Power measurements specifying the qualifier 'UNITS' for each measured value in watts are used in the LLDP-EXT-MED-MIB, POE [RFC3621], and UPS [RFC1628] MIBs. The same 'UNITS' qualifier is used for the power measurement values.

One cannot assume that the ENTITY MIB and ENTITY-SENSOR MIB are implemented for all Energy Objects that need to be monitored. A typical example is a converged building gateway, monitoring several other devices in the building, doing the proxy between SNMP and a protocol like BACNET. Another example is the home energy controller. In such cases, the eoPhysicalEntity value contains the zero value, thanks to PhysicalIndexOrZero textual convention.

The eoPowerIndex MIB object has been kept as the unique index of the Energy Object. The eoPower is similar to entPhySensorValue [RFC3433] and the eoPowerUnitMultipler is similar to entPhySensorScale.

7.2. Link with the ENTITY-STATE MIB

For each entity in the ENTITY-MIB [RFC4133], the ENTITY-STATE MIB [RFC4268] specifies the operational states (entStateOper: unknown, enabled, disabled, testing), the alarm (entStateAlarm: unknown, underRepair, critical, major, minor, warning, indeterminate) and the possible values of standby states (entStateStandby: unknown, hotStandby, coldStandby, providingService).

From a power monitoring point of view, in contrast to the entity operational states of entities, Power States are required, as proposed in the Power and Energy Monitoring MIB module. Those Power States can be mapped to the different operational states in the ENTITY-STATE MIB, if a formal mapping is required. For example, the entStateStandby "unknown", "hotStandby", "coldStandby", states could map to the Power State "unknown", "ready", "standby", respectively, while the entStateStandby "providingService" could map to any "low" to "high" Power State.

7.3. Link with the POWER-OVER-ETHERNET MIB

Power-over-Ethernet MIB [RFC3621] provides an energy monitoring and configuration framework for power over Ethernet devices. The RFC introduces a concept of a port group on a switch to define power monitoring and management policy and does not use the entPhysicalIndex as the index. Indeed, the pethMainPseConsumptionPower is indexed by the pethMainPseGroupIndex, which has no mapping with the entPhysicalIndex.

One cannot assume that the Power-over-Ethernet MIB is implemented for all Energy Objects that need to be monitored. A typical example is a converged building gateway, monitoring several other devices in the building, doing the proxy between SNMP and a protocol like BACNET. Another example is the home energy controller. In such cases, the eoethPortIndex and eoethPortGrpIndex values contain the zero value, thanks to new PethPsePortIndexOrZero and textual PethPsePortGroupIndexOrZero conventions.

However, if the Power-over-Ethernet MIB [RFC3621] is supported, the Energy Object eoethPortIndex and eoethPortGrpIndex contain the pethPsePortIndex and pethPsePortGroupIndex, respectively.

As a consequence, the eoIndex MIB object has been kept as the unique Energy Object index.

Note that, even though the Power-over-Ethernet MIB [RFC3621] was created after the ENTITY-SENSOR MIB [RFC3433], it does not reuse the precision notion from the ENTITY-SENSOR MIB, i.e. the entPhySensorPrecision MIB object.

7.4. Link with the UPS MIB

To protect against unexpected power disruption, data centers and buildings make use of Uninterruptible Power Supplies (UPS). To protect critical assets, a UPS can be restricted to a particular subset or domain of the network. UPS usage typically lasts only for a finite period of time, until normal power supply is restored. Planning is required to decide on the capacity of the UPS based on output power and duration of probable power outage. To properly provision UPS power in a data center or building, it is important to first understand the total demand required to support all the entities in the site. This demand can be assessed and monitored via the Power and Energy Monitoring MIB.

UPS MIB [RFC1628] provides information on the state of the UPS network. Implementation of the UPS MIB is useful at the aggregate level of a data center or a building. The MIB module contains several groups of variables:

- upsIdent: Identifies the UPS entity (name, model, etc.).

- upsBattery group: Indicates the battery state (upsbatteryStatus, upsEstimatedMinutesRemaining, etc.)

- upsInput group: Characterizes the input load to the UPS (number of input lines, voltage, current, etc.).

- upsOutput: Characterizes the output from the UPS (number of output lines, voltage, current, etc.)

- upsAlarms: Indicates the various alarm events.

The measurement of power in the UPS MIB is in Volts, Amperes and Watts. The units of power measurement are RMS volts and RMS Amperes. They are not based on the EntitySensorDataScale and EntitySensorDataPrecision of Entity-Sensor MIB.

Both the Power and Energy Monitoring MIB and the UPS MIB may be implemented on the same UPS SNMP agent, without conflict. In this case, the UPS device itself is the Energy Object Parent and any of the UPS meters or submeters are the Energy Object Children.

7.5. Link with the LLDP and LLDP-MED MIBs

The LLDP Protocol is a Data Link Layer protocol used by network devices to advertise their identities, capabilities, and interconnections on a LAN network.

The Media Endpoint Discovery is an enhancement of LLDP, known as LLDP-MED. The LLDP-MED enhancements specifically address voice applications. LLDP-MED covers 6 basic areas: capability discovery, LAN speed and duplex discovery, network policy discovery, location identification discovery, inventory discovery, and power discovery.

Of particular interest to the current MIB module is the power discovery, which allows the endpoint device (such as a PoE phone) to convey power requirements to the switch. In power discovery, LLDP-MED has four Type Length Values (TLVs): power type, power source, power priority and power value. Respectively, those TLVs provide information related to the type of power (power sourcing entity versus powered device), how the device is powered (from the line, from a backup source, from external power source, etc.), the power priority (how important is it that this device has power?), and how much power the device needs.

The power priority specified in the LLDP-MED MIB [LLDP-MED-MIB] actually comes from the Power-over-Ethernet MIB [RFC3621]. If the Power-over-Ethernet MIB [RFC3621] is supported, the exact value from the pethPsePortPowerPriority [RFC3621] is copied over in the lldpXMedRemXPoEPDPowerPriority [LLDP-MED-MIB]; otherwise the value in lldpXMedRemXPoEPDPowerPriority is "unknown". From the Power and Energy Monitoring MIB, it is possible to identify the pethPsePortPowerPriority [RFC3621], thanks to the eoethPortIndex and eoethPortGrpIndex.

The lldpXMedLocXPoEPDPowerSource [LLDP-MED-MIB] is similar to eoPowerOrigin in indicating if the power for an attached device is local or from a remote device. If the LLDP-MED MIB is supported, the following mapping can be applied to the eoPowerOrigin: lldpXMedLocXPoEPDPowerSource fromPSE(2) and local(3) can be mapped to remote(2) and self(1), respectively.

8. Implementation Scenario

This section provides an illustrative example scenario for the implementation of the Energy Object, including Energy Object Parent and Energy Object Child relationships.

Example Scenario of a campus network: Switch with PoE Endpoints with further connected Devices

The campus network consists of switches that provide LAN connectivity. The switch with PoE ports is located in wiring closet. PoE IP phones are connected to the switch. The IP phones draw power from the PoE ports of the switch. In addition, a PC is daisy-chained from the IP phone for LAN connectivity.

The IP phone consumes power from the PoE switch, while the PC consumes power from the wall outlet.

The switch has implementations of Entity MIB [RFC4133] and energy-aware MIB [EMAN-AWARE-MIB] while the PC does not have implementation of the Entity MIB, but has an implementation of energy-aware MIB. The switch has the following attributes, eoPowerIndex "1", eoPhysicalEntity "2", and eoUUID "UUID 1000". The power usage of the switch is "440 Watts". The switch does not have an Energy Object Parent.

The PoE switch port has the following attributes: The switch port has eoPowerIndex "3", eoPhysicalEntity is "12" and eoUUID is "UUID 1000:3". The power metered at the POE switch port is "12 watts". In this example, the POE switch port has the switch as the Energy Object Parent, with its eoParentID of "1000".

The attributes of the PC are given below. The PC does not implementation of Entity MIB, and thus does not have eoPhysicalEntity. The eoPowerIndex (eoIndex) of the PC is "57", the eoUUID is "UUID 1000:57 ". The PC has an Energy Object Parent, i.e. the switch port whose eoUUID is "UUID 1000:3". The power usage of the PC is "120 Watts" and is communicated to the switch port.

This example illustrates the important distinction between the Energy Object Children: The IP phone draws power from the switch, while the PC has LAN connectivity from the phone, but is powered from the wall outlet. However, the Energy Object Parent sends power control messages to both the Energy Object Children (IP phone and PC) and the Children react to those messages.

```
   |---------------------------------------------------------------|
   |                            Switch                             |
   |===============================================================|
   |  Switch  | Switch   | Switch        | Switch     | Switch     |
   | eoIndex | eoPhyIdx  | eoUUID        |eoParentId  | eoPower    |
   | ============================================================= |
   |     1    |    2     | UUID 1000     |    null    |   440      |
   | ============================================================= |
   |                                                               |
   |                           SWITCH PORT                         |
   | ============================================================= |
   | | Switch  | Switch    | Switch        | Switch     | Switch     |
   | | Port    | Port      | Port          | Port       | Port     | |
   | | eoIndex| eoPhyIdx | eoUUID         | eoParentId | eoPower | |
   | ============================================================= |
   | |    3    |    12     | UUID 1000:3  | UUID 1000  |    12    | |
   | ============================================================= |
   |                                    ^                          |
   |                                    |                          |
   |------------------------------------|--------------------------|
                                        |
                                        |
                  POE IP PHONE          |
                                        |
                                        |
   ==============================================================
   | IP phone | IP phone |IP phone     | IP phone   |IP phone|
   | eoIndex  | eoPhyIdx |eoUUID       |eoParentID  |eoPower |
   ============================================================
   |  31       |     0   |UUID 1000:31 | UUID 1000:3 |  12   |
   =============================================================
                                         |
                                         |
   PC connected to switch via IP phone   |
                                         |
   ==============================================================
   | PC     | PC       |PC            |PC           | PC          |
   |eoIndex| eoPhyIdx |eoUUID        |eoParentID   | eoPower     |
   =============================================================
   | 57      |    0   | UUID 1000:57| UUID 1000:3| 120          |
   ==============================================================
```

Figure 1: Example scenario

9. Structure of the MIB

The primary MIB object in this MIB module is the energyObjectMibObject. The eoPowerTable table of energyObjectMibObject describes the power measurement attributes of an Energy Object entity. The notion of identity of the device in terms of uniquely identification of the Energy Object and its relationship to other entities in the network are addressed in [EMAN-AWARE-MIB].

The power measurement of an Energy Object contains information describing its power usage (eoPower) and its current power state (eoPowerOperState). In addition to power usage, additional information describing the units of measurement (eoPowerAccuracy, eoPowerUnitMultiplier), how power usage measurement was obtained (eoPowerMeasurementCaliber), the source of power (eoPowerOrigin) and the type of power (eoPowerCurrentTtype) are described.

An Energy Object may contain an optional eoPowerQuality table that describes the electrical characteristics associated with the current power state and usage.

An Energy Object may contain an optional eoEnergyTable to describe energy measurement information over time.

An Energy Object may also contain optional battery information associated with this entity.

10. MIB Definitions

```
-- ************************************************************
--
--
-- This MIB is used to monitor power usage of network
-- devices
--
-- *************************************************************

ENERGY-OBJECT-MIB DEFINITIONS ::= BEGIN

IMPORTS
    MODULE-IDENTITY,
    OBJECT-TYPE,
```

```
       NOTIFICATION-TYPE,
       mib-2,
       Integer32, Counter64, TimeTicks
           FROM SNMPv2-SMI
       TEXTUAL-CONVENTION, DisplayString, RowStatus, TimeInterval
           FROM SNMPv2-TC
       MODULE-COMPLIANCE, NOTIFICATION-GROUP, OBJECT-GROUP
           FROM SNMPv2-CONF
       OwnerString
           FROM RMON-MIB;

   energyObjectMib MODULE-IDENTITY
       LAST-UPDATED    "201110310000Z"     -- 31 October 2011

       ORGANIZATION    "IETF EMAN Working Group"
       CONTACT-INFO
               "WG charter:
               http://datatracker.ietf.org/wg/eman/charter/

             Mailing Lists:
                General Discussion: eman@ietf.org

                To Subscribe:
                https://www.ietf.org/mailman/listinfo/eman

                Archive:
                http://www.ietf.org/mail-archive/web/eman

             Editors:
                Mouli Chandramouli
                Cisco Systems, Inc.
                Sarjapur Outer Ring Road
                Bangalore,
                IN
                Phone: +91 80 4426 3947
                Email: moulchan@cisco.com

                Brad Schoening
                44 Rivers Edge Drive
                Little Silver, NJ 07739
                US
                Email: brad@bradschoening.com

                Juergen Quittek
                NEC Europe Ltd.
                NEC Laboratories Europe
                Network Research Division
                Kurfuersten-Anlage 36
```

```
                Heidelberg  69115
                DE
                Phone: +49 6221 4342-115
                Email: quittek@neclab.eu

                Thomas Dietz
                NEC Europe Ltd.
                NEC Laboratories Europe
                Network Research Division
                Kurfuersten-Anlage 36
                69115 Heidelberg
                DE
                Phone: +49 6221 4342-128
                Email: Thomas.Dietz@nw.neclab.eu

                Benoit Claise
                Cisco Systems, Inc.
                De Kleetlaan 6a b1
                Degem 1831
                Belgium
                Phone:  +32 2 704 5622
                Email: bclaise@cisco.com"

       DESCRIPTION
          "This MIB is used to monitor power and energy in
          devices."
       REVISION
           "201110310000Z"     -- 31 October 2011

       DESCRIPTION
          "Initial version, published as RFC XXXX."

      ::= { mib-2 xxx }


   energyObjectMibNotifs OBJECT IDENTIFIER
       ::= { energyObjectMib 0 }

   energyObjectMibObjects OBJECT IDENTIFIER
       ::= { energyObjectMib 1 }

   energyObjectMibConform  OBJECT IDENTIFIER
       ::= { energyObjectMib 2 }


   -- Textual Conventions
```

```
   IANAPowerStateSet ::= TEXTUAL-CONVENTION
       STATUS  current
       DESCRIPTION

          "IANAPowerStateSet is a textual convention that describes
   Power State Sets and Power State Set Values an Energy Object
   supports. IANA has created a registry of Power State supported
   by an Energy Object and IANA shall administer the list of Power
   State Sets and Power States.

     The textual convention assumes that power states in a power
     state set are limited to 255 distinct values. For a Power
     State Set S, the named number with the value S * 256 is
     allocated to indicate the power state set. For a Power State X
     in the Power State S, the named number with the value S * 256
     + X + 1 is allocated to represent the power state."

       REFERENCE
          "http://www.iana.org/assignments/eman
     RFC EDITOR NOTE: please change the previous URL if this is
     not the correct one after IANA assigned it."

       SYNTAX      INTEGER {
                      other(0),        -- indicates other set
                      unknown(255),    -- unknown power state

                      ieee1621(256), -- indicates IEEE1621 set
                      ieee1621On(257),
                      ieee1621Off(258),
                      ieee1621Sleep(259),

                      dmtf(512),   -- indicates DMTF set
                      dmtfOn(513),
                      dmtfSleepLight(514),
                      dmtfSleepDeep(515),
                      dmtfOffHard(516),
                      dmtfOffSoft(517),
                      dmtfHibernate(518),
                      dmtfPowerOffSoft(519),
                      dmtfPowerOffHard(520),
                      dmtfMasterBusReset(521),
                      dmtfDiagnosticInterrapt(522),
                      dmtfOffSoftGraceful(523),
```

```
                      dmtfOffHardGraceful(524),
                      dmtfMasterBusResetGraceful(525),
                      dmtfPowerCycleOffSoftGraceful(526),
                      dmtfPowerCycleHardGraceful(527),

                      eman(1024),       -- indicates EMAN set
                      emanmechoff(1025),
                      emansoftoff(1026),
                      emanhibernate(1027),
                      emansleep(1028),
                      emanstandby(1029),
                      emanready(1030),
                      emanlowMinus(1031),
                      emanlow(1032),
                      emanmediumMinus(1033),
                      emanmedium(1034),
                      emanhighMinus(1035),
                      emanhigh(1036)
                  }

   UnitMultiplier ::= TEXTUAL-CONVENTION
       STATUS          current
       DESCRIPTION
          "The Unit Multiplier is an integer value that represents
          the IEEE 61850 Annex A units multiplier associated with
          the integer units used to measure the power or energy.

          For example, when used with eoPowerUnitMultiplier, -3
          represents 10^-3 or milliwatts."
       REFERENCE
               "The International System of Units (SI),
               National Institute of Standards and Technology,
               Spec. Publ. 330, August 1991."
       SYNTAX INTEGER {
           yocto(-24),   -- 10^-24
           zepto(-21),   -- 10^-21
           atto(-18),    -- 10^-18
           femto(-15),   -- 10^-15
           pico(-12),    -- 10^-12
           nano(-9),     -- 10^-9
           micro(-6),    -- 10^-6
           milli(-3),    -- 10^-3
           units(0),     -- 10^0
           kilo(3),      -- 10^3
           mega(6),      -- 10^6
           giga(9),      -- 10^9
           tera(12),     -- 10^12
           peta(15),     -- 10^15
```

```
           exa(18),      -- 10^18
           zetta(21),    -- 10^21
           yotta(24)     -- 10^24
       }

   -- Objects


   eoPowerTable OBJECT-TYPE
       SYNTAX          SEQUENCE OF EoPowerEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "This table lists Energy Objects."
       ::= { energyObjectMibObjects 1 }


   eoPowerEntry OBJECT-TYPE
       SYNTAX          EoPowerEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "An entry describes the power usage of an Energy Object."
       INDEX           { eoPowerIndex}
       ::= { eoPowerTable  1 }

   EoPowerEntry ::= SEQUENCE {
           eoPowerIndex                    Integer32,
           eoPower                         Integer32,
           eoPowerNameplate                Integer32,
           eoPowerUnitMultiplier           UnitMultiplier,
           eoPowerAccuracy                 Integer32,
           eoPowerMeasurementCaliber       INTEGER,
           eoPowerCurrentType              INTEGER,
           eoPowerOrigin                   INTEGER,
           eoPowerAdminState               IANAPowerStateSet,
           eoPowerOperState                IANAPowerStateSet,
           eoPowerStateEnterReason         OwnerString
     }

   eoPowerIndex OBJECT-TYPE
       SYNTAX          Integer32 (0..2147483647)
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
         "A unique value, for each  Energy Object.
```

```
          If an implementation of the ENERGY-AWARE-MIB module is
          available in the local SNMP context, then the same index,
          eoIndex, as the one in the ENERGY-AWARE-MIB MUST be
          assigned for the identical Energy Object. In this case,
          entities without an assigned value for eoIndex cannot be
          indexed by the eoPowerStateTable.

          If there is no implementation of the ENERGY-AWARE-MIB
          module but one of the ENTITY MIB module is available in
          the local SNMP context, then the same index of an entity
          MUST be chosen as assigned to the entity by object
          entPhysicalIndex in the ENTITY MIB module. In this case,
          entities without an assigned value for entPhysicalIndex
          cannot be indexed by the eoPowerStateTable.

          If neither the ENERGY-AWARE-MIB module nor of the ENTITY
          MIB module are available in the local SNMP context, then
          this MIB module may choose identity values from a further
          MIB module providing entity identities.  In this case the
          value for each eoPowerIndex must remain constant at least
          from one re-initialization of the entity's network
          management system to the next re-initialization.

          In case that no other MIB modules have been chosen for
          providing entity identities, Power States can be reported
          exclusively for the local device on which this table is
          instantiated.  Then this table will have a single entry
          only and an index value of 0 MUST be used."

        ::= { eoPowerEntry 1 }



   eoPower OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "Watts"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object indicates the power measured for the Energy
          Object. For alternating current, this value is obtained
          as an average over fixed number of AC cycles.  .  This
          value is specified in SI units of watts with the
          magnitude of watts (milliwatts, kilowatts, etc.)
          indicated separately in eoPowerUnitMultiplier. The
          accuracy of the measurement is specfied in
          eoPowerAccuracy. The direction of power flow is indicated
          by the sign on eoPower. If the Energy Object is consuming
```

```
          power, the eoPower value will be positive. If the Energy
          Object is producing power, the eoPower value will be
          negative.

          The eoPower MUST be less than or equal to the maximum
          power that can be consumed at the power state specified
          by eoPowerState.

          The eoPowerMeasurementCaliber object specifies how the
          usage value reported by eoPower was obtained. The eoPower
          value must report 0 if the eoPowerMeasurementCaliber is
          'unavailable'.  For devices that can not measure or
          report power, this option can be used."
       ::= { eoPowerEntry 2 }


   eoPowerNameplate OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "Watts"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object indicates the rated maximum consumption for
          the fully populated Energy Object.  The nameplate power
          requirements are the maximum power numbers and, in almost
          all cases, are well above the expected operational
          consumption.  The eoPowerNameplate is widely used for
          power provisioning.  This value is specified in either
          units of watts or voltage and current.  The units are
          therefore SI watts or equivalent Volt-Amperes with the
          magnitude (milliwatts, kilowatts, etc.) indicated
          separately in eoPowerUnitMultiplier."
       ::= { eoPowerEntry 3 }

   eoPowerUnitMultiplier OBJECT-TYPE
       SYNTAX          UnitMultiplier
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The magnitude of watts for the usage value in eoPower
          and eoPowerNameplate."
       ::= { eoPowerEntry 4 }

   eoPowerAccuracy OBJECT-TYPE
       SYNTAX          Integer32 (0..10000)
       UNITS           "hundredths of percent"
       MAX-ACCESS      read-only
       STATUS          current
```

```
       DESCRIPTION
          "This object indicates a percentage value, in 100ths of a
          percent, representing the assumed accuracy of the usage
          reported by eoPower. For example: The value 1010 means
          the reported usage is accurate to +/- 10.1 percent.  This
          value is zero if the accuracy is unknown or not
          applicable based upon the measurement method.

          ANSI and IEC define the following accuracy classes for
          power measurement:
               IEC 62053-22  60044-1 class 0.1, 0.2, 0.5, 1  3.
               ANSI C12.20 class 0.2, 0.5"
       ::= { eoPowerEntry 5 }


   eoPowerMeasurementCaliber   OBJECT-TYPE
       SYNTAX          INTEGER  {
                           unavailable(1) ,
                           unknown(2),
                           actual(3) ,
                           estimated(4),
                           presumed(5)                     }
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object specifies how the usage value reported by
          eoPower was obtained:

          - unavailable(1): Indicates that the usage is not
          available. In such a case, the eoPower value must be 0
          For devices that can not measure or report power this
          option can be used.

          - unknown(2): Indicates that the way the usage was
          determined is unknown. In some cases, entities report
          aggregate power on behalf of another device. In such
          cases it is not known whether the usage reported is
          actual(2), estimated(3) or presumed (4).

          - actual(3):  Indicates that the reported usage was
          measured by the entity through some hardware or direct
          physical means. The usage data reported is not presumed
          (4) or estimated (3) but the real apparent current energy
          consumption rate.

          - estimated(4): Indicates that the usage was not
          determined by physical measurement. The value is a
          derivation based upon the device type, state, and/or
```

```
          current utilization using some algorithm or heuristic. It
          is presumed that the entity's state and current
          configuration were used to compute the value.

         - presumed(5): Indicates that the usage was not
         determined by physical measurement, algorithm or
         derivation. The usage was reported based upon external
         tables, specifications, and/or model information.  For
         example, a PC Model X draws 200W, while a PC Model Y
         draws 210W"

    ::= { eoPowerEntry 6 }

   eoPowerCurrentType OBJECT-TYPE
         SYNTAX      INTEGER  {
                          ac(1),
                          dc(2),
                          unknown(3)
                      }
          MAX-ACCESS  read-only
          STATUS      current
       DESCRIPTION
          "This object indicates whether the eoUsage for the
          Energy Object reports alternative current AC(1), direct
          current DC(2), or that the current type is unknown(3)."
    ::= { eoPowerEntry 7 }

   eoPowerOrigin  OBJECT-TYPE
       SYNTAX          INTEGER  {
                           self (1),
                           remote (2)
                       }
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object indicates the source of power measurement
          and can be useful when modeling the power usage of
          attached devices. The power measurement can be performed
          by the entity itself or the power measurement of the
          entity can be reported by another trusted entity using a
          protocol extension.  A value of self(1) indicates the
          measurement is performed by the entity, whereas remote(2)
          indicates that the measurement was performed by another
          entity."
       ::= { eoPowerEntry 8 }

   eoPowerAdminState OBJECT-TYPE
       SYNTAX          IANAPowerStateSet
```

```
        MAX-ACCESS      read-write
        STATUS          current
        DESCRIPTION

            "This object specifies the desired Power State and the
            Power State Set for the Energy Object. Note that
            other(0) is not a Power State Set and unknown(255) is
            not a Power State as such, but simply an indication that
            the Power State of the Energy Object is unknown.
            Possible values of eoPowerAdminState within the Power
            State Set are registered at IANA.
            A current list of assignments can be found at
            <http://www.iana.org/assignments/eman>
            RFC-EDITOR: please check the location after IANA"
        ::= { eoPowerEntry 9  }

   eoPowerOperState OBJECT-TYPE
        SYNTAX          IANAPowerStateSet
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION

            "This object specifies the current operational Power
            State and the Power State Set for the Energy Object.
            other(0) is not a Power State Set and unknown(255) is
            not a Power State as such, but simply an indication that
            the Power State of the Energy Object is unknown.

            Possible values of eoPowerAdminState within the Power
            State Set are registered at IANA.
            A current list of assignments can be found at
            <http://www.iana.org/assignments/eman>
            RFC-EDITOR: please check the location after IANA"

        ::= { eoPowerEntry 10   }

   eoPowerStateEnterReason OBJECT-TYPE
         SYNTAX     OwnerString
         MAX-ACCESS read-create
         STATUS     current
         DESCRIPTION
            "This string object describes the reason for the
            eoPowerAdminState
            transition Alternatively, this string may contain with
            the entity that configured this Energy Object to this
            Power State."
```

```
        DEFVAL { "" }
        ::= { eoPowerEntry 11  }

   eoPowerStateTable OBJECT-TYPE
       SYNTAX          SEQUENCE OF EoPowerStateEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "This table enumerates the maximum power usage, in watts,
          for every single supported Power State of each Energy
          Object.

          This table has an expansion-dependent relationship on the
          eoPowerTable, containing rows describing each Power State
          for the corresponding Energy Object. For every  Energy
          Object in the eoPowerTable, there is a corresponding
          entry in this table."
       ::= { energyObjectMibObjects 2 }

   eoPowerStateEntry OBJECT-TYPE
       SYNTAX          EoPowerStateEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "A eoPowerStateEntry extends a corresponding
          eoPowerEntry.  This entry displays max usage values at
          every single possible Power State supported by the Energy
          Object.
          For example, given the values of a Energy Object
          corresponding to a maximum usage of 11W at the
          state 1 (mechoff), 6 (ready), 8 (mediumMinus), 12 (High):

               State         MaxUsage Units
                1 (mechoff       0       W
                2 (softoff)      0       W
                3 (hibernate)    0       W
                4 (sleep)        0       W
                5 (standby)      0       W
                6 (ready)        8       W
                7 (lowMinus)     8       W
                8 (low)         11       W
                9 (medimMinus)  11       W
               10 (medium)      11       W
               11 (highMinus)   11       W
               12 (high)        11       W
```

```
          Furthermore, this table extends to return the total time
          in each Power State, along with the number of times a
          particular Power State was entered."

                   INDEX   { eoPowerIndex,
                             eoPowerStateIndex
                           }
       ::= { eoPowerStateTable 1 }

   EoPowerStateEntry ::= SEQUENCE {
           eoPowerStateIndex                  IANAPowerStateSet,
           eoPowerStateMaxPower               Integer32,
           eoPowerStatePowerUnitMultiplier   UnitMultiplier,
           eoPowerStateTotalTime              TimeTicks,
           eoPowerStateEnterCount             Counter64
   }

   eoPowerStateIndex OBJECT-TYPE
       SYNTAX          IANAPowerStateSet
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
           "
           This object specifies the index of the Power State of
           the Energy Object within a Power State Set. The
           semantics of the specific Power State can be obtained
           from the Power State Set definition."
       ::= { eoPowerStateEntry 1 }


   eoPowerStateMaxPower OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "Watts"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object indicates the maximum power for the Energy
          Object at the particular Power State. This value is
          specified in SI units of watts with the magnitude of the
          units (milliwatts, kilowatts, etc.) indicated separately
          in eoPowerStatePowerUnitMultiplier. If the maximum power
          is not known for a certain Power State, then the value is
          encoded as 0xFFFF.

          For Power States not enumerated, the value of
          eoPowerStateMaxPower might be interpolated by using the
          next highest supported Power State."
       ::= { eoPowerStateEntry 3 }
```

```
   eoPowerStatePowerUnitMultiplier OBJECT-TYPE
       SYNTAX          UnitMultiplier
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "The magnitude of watts for the usage value in
          eoPowerStateMaxPower."
       ::= { eoPowerStateEntry 4 }

   eoPowerStateTotalTime OBJECT-TYPE
       SYNTAX      TimeTicks
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
         "This object indicates the total time in hundreds
         of seconds that the Energy Object has been in this power
         state since the last reset, as specified in the
         sysUpTime."
       ::= { eoPowerStateEntry 5 }

   eoPowerStateEnterCount OBJECT-TYPE
       SYNTAX      Counter64
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
          "This object indicates how often the Energy
           Object has
           entered this power state, since the last reset of the
           device as specified in the sysUpTime."
       ::= { eoPowerStateEntry 6  }


   eoEnergyParametersTable OBJECT-TYPE
       SYNTAX          SEQUENCE OF EoEnergyParametersEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
      "This table is used to configure the parameters for Energy
      measurement collection in the table  eoEnergyTable."
       ::= { energyObjectMibObjects 4 }

   eoEnergyParametersEntry OBJECT-TYPE
       SYNTAX          EoEnergyParametersEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
```

```
          "An entry controls an energy measurement in
          eoEnergyTable."
       INDEX  { eoPowerIndex }
       ::= { eoEnergyParametersTable 1 }

   EoEnergyParametersEntry ::= SEQUENCE {
           eoEnergyParametersIntervalLength     TimeInterval,
           eoEnergyParametersIntervalNumber     Integer32,
           eoEnergyParametersIntervalMode       Integer32,
           eoEnergyParametersIntervalWindow     TimeInterval,
           eoEnergyParametersSampleRate         Integer32,
           eoEnergyParametersStatus             RowStatus
   }

   eoEnergyParametersIntervalLength OBJECT-TYPE
       SYNTAX          TimeInterval
       UNITS           "Seconds"
       MAX-ACCESS      read-create
       STATUS          current
       DESCRIPTION
          "This object indicates the length of time in seconds over
          which to compute the average eoEnergyIntervalEnergyUsed
          measurement in the eoEnergyTable table. The computation
          is based on the Energy Object's internal sampling rate of
          power consumed or produced by the Energy Object. The
          sampling rate is the rate at which the Energy Object can
          read the power usage and may differ based on device
          capabilities. The average energy consumption is then
          computed over the length of the interval."
       DEFVAL { 900 }
       ::= { eoEnergyParametersEntry 1 }

   eoEnergyParametersIntervalNumber OBJECT-TYPE
       SYNTAX          Integer32
       MAX-ACCESS      read-create
       STATUS          current
       DESCRIPTION
          "The number of intervals maintained in the eoEnergyTable.
          Each interval is characterized by a specific
          eoEnergyIntervalStartTime, used as an index to the table
          eoEnergyTable . Whenever the maximum number of entries is
          reached, the measurement over the new interval replaces
          the oldest measurement , except if the oldest measurement
          were to be the maximum eoEnergyIntervalMax, in which case
          the measurement the measurement over the next oldest
          interval is replaced."
        DEFVAL { 10 }
```

```
     ::= { eoEnergyParametersEntry 2 }

   eoEnergyParametersIntervalMode OBJECT-TYPE
     SYNTAX          INTEGER  {
                         period(1),
                         sliding(2),
                         total(3)
                     }
     MAX-ACCESS      read-create
     STATUS          current
     DESCRIPTION
       "A control object to define the mode of interval calculation
       for the computation of the average
       eoEnergyIntervalEnergyUsed measurement in the eoEnergyTable
       table.

         A mode of period(1) specifies non-overlapping periodic
         measurements.

         A mode of sliding(2) specifies overlapping sliding windows
         where the interval between the start of one interval and
         the next is defined in eoEnergyParametersIntervalWindow.

         A mode of total(3) specifies non-periodic measurement.  In
         this mode only one interval is used as this is a
         continuous measurement since the last reset. The value of
         eoEnergyParametersIntervalNumber should be (1) one and
         eoEnergyParametersIntervalLength is ignored. "
      ::= { eoEnergyParametersEntry 3 }

   eoEnergyParametersIntervalWindow OBJECT-TYPE
     SYNTAX          TimeInterval
     UNITS           "Seconds"
     MAX-ACCESS      read-create
     STATUS          current
     DESCRIPTION
        "The length of the duration window between the starting
        time of one sliding window and the next starting time in
        seconds, in order to compute the average
        eoEnergyIntervalEnergyUsed measurement in the eoEnergyTable
        table  This is valid only when the
        eoEnergyParametersIntervalMode is sliding(2). The
        eoEnergyParametersIntervalWindow value should be a multiple
        of eoEnergyParametersSampleRate."
          ::= { eoEnergyParametersEntry 4 }

   eoEnergyParametersSampleRate OBJECT-TYPE
       SYNTAX          Integer32
```

```
       UNITS           "Milliseconds"
       MAX-ACCESS      read-create
       STATUS          current
       DESCRIPTION
          "The sampling rate, in milliseconds, at which the  Energy
          Object should poll power usage in order to compute the
          average eoEnergyIntervalEnergyUsed measurement in the
          table eoEnergyTable.  The  Energy Object should initially
          set this sampling rate to a reasonable value, i.e., a
          compromise between intervals that will provide good
          accuracy by not being too long, but not so short that
          they affect the  Energy Object performance by requesting
          continuous polling. If the sampling rate is unknown, the
          value 0 is reported. The sampling rate should be selected
          so that eoEnergyParametersIntervalWindow is a multiple of
          eoEnergyParametersSampleRate."
        DEFVAL { 1000 }
       ::= { eoEnergyParametersEntry 5 }

   eoEnergyParametersStatus OBJECT-TYPE
       SYNTAX          RowStatus
       MAX-ACCESS      read-create
       STATUS          current
       DESCRIPTION
         "The status of this row. The eoEnergyParametersStatus is
         used to start or stop energy usage logging. An entry
         status may not be active(1) unless all objects in the
         entry have an appropriate value.  If this object is not
         equal to active(1), all associated usage-data logged into
         the eoEnergyTable will be deleted. The data can be
         destroyed by setting up the eoEnergyParametersStatus to
         destroy(2)."
       ::= {eoEnergyParametersEntry 6 }

   eoEnergyTable OBJECT-TYPE
       SYNTAX          SEQUENCE OF EoEnergyIntervalEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "This table lists Energy Object energy measurements.
          Entries in this table are only created if the
          corresponding value of object eoPowerMeasurementCaliber
          is active(2), i.e., if the power is actually metered."
       ::= { energyObjectMibObjects 5 }

   eoEnergyIntervalEntry OBJECT-TYPE
```

```
       SYNTAX          EoEnergyIntervalEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
           "An entry describing energy measurements."
       INDEX  { eoPowerIndex, eoEnergyParametersIntervalMode,
   eoEnergyIntervalStartTime }
       ::= { eoEnergyTable 1 }

   EoEnergyIntervalEntry ::= SEQUENCE {
        eoEnergyIntervalStartTime            TimeTicks,
        eoEnergyIntervalEnergyConsumed       Integer32,
        eoEnergyIntervalEnergyProduced       Integer32,
        eoEnergyIntervalEnergyNet            Integer32,
        eoEnergyIntervalEnergyUnitMultiplier UnitMultiplier,
        eoEnergyIntervalEnergyAccuracy       Integer32,
        eoEnergyIntervalMaxConsumed          Integer32,
        eoEnergyIntervalMaxProduced          Integer32,
        eoEnergyIntervalDiscontinuityTime    TimeTicks
   }

   eoEnergyIntervalStartTime OBJECT-TYPE
       SYNTAX          TimeTicks
       UNITS           "hundredths of seconds"
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "The time (in hundredths of a second) since the
          network management portion of the system was last
          re-initialized, as specified in the sysUpTime [RFC3418].
          This object is useful for reference of interval periods
          for which the energy is measured."
       ::= { eoEnergyIntervalEntry 1 }



   eoEnergyIntervalEnergyConsumed OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "Watt-hours"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
   "This object indicates the energy consumed in units of watt-
   hours for the Energy Object over the defined interval.
   This value is specified in the common billing units of watt-
   hours with the magnitude of watt-hours (kW-Hr, MW-Hr, etc.)
```

```
   indicated separately in eoEnergyIntervalEnergyUnitMultiplier."
       ::= { eoEnergyIntervalEntry 2 }


   eoEnergyIntervalEnergyProduced OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "Watt-hours"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
   "This object indicates the energy produced in units of watt-
   hours for the Energy Object over the defined interval.
   This value is specified in the common billing units of watt-
   hours with the magnitude of watt-hours (kW-Hr, MW-Hr, etc.)
   indicated separately in eoEnergyIntervalEnergyUnitMultiplier."
       ::= { eoEnergyIntervalEntry 3 }


   eoEnergyIntervalEnergyNet OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "Watt-hours"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
   "This object indicates the resultant of the energy consumed and
   energy produced for an energy object in units of watt-hours for
   the Energy Object over the defined interval. This value is
   specified in the common billing units of watt-hours
   with the magnitude of watt-hours (kW-Hr, MW-Hr, etc.)
   indicated separately in eoEnergyIntervalEnergyUnitMultiplier."
       ::= { eoEnergyIntervalEntry 4 }

   eoEnergyIntervalEnergyUnitMultiplier OBJECT-TYPE
       SYNTAX          UnitMultiplier
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "This object is the magnitude of watt-hours for the
          energy field in eoEnergyIntervalEnergyUsed."
       ::= { eoEnergyIntervalEntry 5  }


   eoEnergyIntervalEnergyAccuracy OBJECT-TYPE
       SYNTAX          Integer32 (0..10000)
```

```
        UNITS           "hundredths of percent"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
    "This object indicates a percentage value, in 100ths of a
    percent, representing the presumed accuracy of Energy usage
    reporting. eoEnergyIntervalEnergyAccuracy is applicable to all
    Energy measurements in the eoEnergyTable.

    For example: 1010 means the reported usage is accurate to +/-
    10.1 percent.
    This value is zero if the accuracy is unknown."

        ::= { eoEnergyIntervalEntry 6 }

    eoEnergyIntervalMaxConsumed OBJECT-TYPE
        SYNTAX          Integer32
        UNITS           "Watt-hours"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "This object is the maximum energy ever observed in
           eoEnergyIntervalEnergyConsumed since the monitoring
           started. This value is specified in the common billing
           units of watt-hours with the magnitude of watt-hours (kW-
           Hr,   MW-Hr, etc.) indicated separately in
           eoEnergyIntervalEnergyUnits."
        ::= { eoEnergyIntervalEntry 7  }


    eoEnergyIntervalMaxProduced OBJECT-TYPE
        SYNTAX          Integer32
        UNITS           "Watt-hours"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
           "This object is the maximum energy ever observed in
           eoEnergyIntervalEnergyProduced since the monitoring
           started. This value is specified in the units of watt-
           hours with the magnitude of watt-hours (kW-Hr,   MW-Hr,
           etc.) indicated separately in
           eoEnergyIntervalEnergyUnits."
        ::= { eoEnergyIntervalEntry 8 }


     eoEnergyIntervalDiscontinuityTime OBJECT-TYPE
        SYNTAX      TimeTicks
        MAX-ACCESS  read-only
```

```
       STATUS      current
       DESCRIPTION
         "The value of sysUpTime [RFC3418] on the most recent
         occasion at which any one or more of this entity's energy
         consumption counters suffered a discontinuity. If no such
         discontinuities have occurred since the last re-
         initialization of the local management subsystem, then
         this object contains a zero value."
       ::= { eoEnergyIntervalEntry 9 }

   -- Notifications

   eoPowerStateChange NOTIFICATION-TYPE
       OBJECTS       {eoPowerAdminState, eoPowerOperState,
   eoPowerStateEnterReason}
       STATUS        current
       DESCRIPTION
           "The SNMP entity generates the eoPowerStateChange when
           the value(s) of eoPowerAdminState or eoPowerOperState,
          in the context of the Power State Set, have changed for
          the Energy Object represented by the eoPowerIndex."
      ::= { energyObjectMibNotifs 1 }

   -- Conformance

   energyObjectMibCompliances  OBJECT IDENTIFIER
       ::= { energyObjectMib 3 }

   energyObjectMibGroups  OBJECT IDENTIFIER
       ::= { energyObjectMib 4 }

   energyObjectMibFullCompliance MODULE-COMPLIANCE
       STATUS          current
       DESCRIPTION
           "When this MIB is implemented with support for
           read-create, then such an implementation can
           claim full compliance. Such devices can then
           be both monitored and configured with this MIB."
       MODULE          -- this module
       MANDATORY-GROUPS {
                   energyObjectMibTableGroup,
                   energyObjectMibStateTableGroup,
                   energyObjectMibEnergyTableGroup,
                   energyObjectMibEnergyParametersTableGroup,
                   energyObjectMibNotifGroup
                       }
       ::= { energyObjectMibCompliances 1 }
```

```
   energyObjectMibReadOnlyCompliance MODULE-COMPLIANCE
       STATUS          current
       DESCRIPTION
           "When this MIB is implemented without support for
           read-create (i.e. in read-only mode), then such an
           implementation can claim read-only compliance.  Such a
           device can then be monitored but cannot be
           configured with this MIB. "
       MODULE          -- this module
       MANDATORY-GROUPS {
                           energyObjectMibTableGroup,
                           energyObjectMibStateTableGroup,
                           energyObjectMibNotifGroup
                       }

       OBJECT          eoPowerOperState
       MIN-ACCESS      read-only
       DESCRIPTION
           "Write access is not required."
       ::= { energyObjectMibCompliances 2 }

   -- Units of Conformance

   energyObjectMibTableGroup OBJECT-GROUP
       OBJECTS         {
                           eoPower,
                           eoPowerNameplate,
                           eoPowerUnitMultiplier,
                           eoPowerAccuracy,
                           eoPowerMeasurementCaliber,
                           eoPowerCurrentType,
                           eoPowerOrigin,
                           eoPowerAdminState,
                           eoPowerOperState,
                           eoPowerStateEnterReason
                       }
               STATUS          current
       DESCRIPTION
           "This group contains the collection of all the objects
           related to the PowerMonitor."
       ::= { energyObjectMibGroups 1 }

   energyObjectMibStateTableGroup OBJECT-GROUP
          OBJECTS      {
                            eoPowerStateMaxPower,
                            eoPowerStatePowerUnitMultiplier,
                            eoPowerStateTotalTime,
                            eoPowerStateEnterCount
```

```
                     }
               STATUS          current
               DESCRIPTION
                   "This group contains the collection of all the
                   objects related to the Power State."
               ::= { energyObjectMibGroups 2 }




   energyObjectMibEnergyParametersTableGroup OBJECT-GROUP
       OBJECTS         {
                           eoEnergyParametersIntervalLength,
                           eoEnergyParametersIntervalNumber,
                           eoEnergyParametersIntervalMode,
                           eoEnergyParametersIntervalWindow,
                           eoEnergyParametersSampleRate,
                           eoEnergyParametersStatus
                       }
       STATUS          current
       DESCRIPTION
           "This group contains the collection of all the objects
           related to the configuration of the Energy Table."
       ::= { energyObjectMibGroups 3 }

   energyObjectMibEnergyTableGroup OBJECT-GROUP
       OBJECTS         {
                           -- Note that object
                           -- eoEnergyIntervalStartTime is not
                           -- included since it is not-accessible

                           eoEnergyIntervalEnergyConsumed,
                           eoEnergyIntervalEnergyProduced,
                           eoEnergyIntervalEnergyNet,
                           eoEnergyIntervalEnergyUnitMultiplier,
                           eoEnergyIntervalEnergyAccuracy,
                           eoEnergyIntervalMaxConsumed,
                           eoEnergyIntervalMaxProduced,
                           eoEnergyIntervalDiscontinuityTime
                       }
       STATUS          current
       DESCRIPTION
           "This group contains the collection of all the objects
           related to the Energy Table."
       ::= { energyObjectMibGroups 4 }

   energyObjectMibNotifGroup NOTIFICATION-GROUP
```

```
      NOTIFICATIONS    {
                           eoPowerStateChange
                       }
       STATUS          current
       DESCRIPTION
           "This group contains the notifications for the power and
           energy monitoring MIB Module."
       ::= { energyObjectMibGroups 5 }

   END


   -- ***********************************************************
   --
   -- This MIB module is used to monitor power quality of networked
   -- devices with measurements.
   --
   -- This MIB module is an extension of energyObjectMib module.
   --
   -- ************************************************************

   POWER-QUALITY-MIB DEFINITIONS ::= BEGIN

   IMPORTS
       MODULE-IDENTITY,
       OBJECT-TYPE,
       mib-2,
       Integer32
          FROM SNMPv2-SMI
       MODULE-COMPLIANCE,
       OBJECT-GROUP
           FROM SNMPv2-CONF
       UnitMultiplier, eoPowerIndex
           FROM ENERGY-OBJECT-MIB
       OwnerString
           FROM RMON-MIB;

   powerQualityMIB MODULE-IDENTITY

       LAST-UPDATED    "201110310000Z"     -- 31 October 2011

       ORGANIZATION    "IETF EMAN Working Group"
       CONTACT-INFO
               "WG charter:
               http://datatracker.ietf.org/wg/eman/charter/

             Mailing Lists:
                General Discussion: eman@ietf.org
```

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Editors:

Mouli Chandramouli
Cisco Systems, Inc.
Sarjapur Outer Ring Road
Bangalore,
IN
Phone: +91 80 4426 3947
Email: moulchan@cisco.com

Brad Schoening
44 Rivers Edge Drive
Little Silver, NJ 07739
US
Email: brad@bradschoening.com

Juergen Quittek
NEC Europe Ltd.
NEC Laboratories Europe
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE
Phone: +49 6221 4342-115
Email: quittek@neclab.eu

Thomas Dietz
NEC Europe Ltd.
NEC Laboratories Europe
Network Research Division
Kurfuersten-Anlage 36
69115 Heidelberg
DE
Phone: +49 6221 4342-128
Email: Thomas.Dietz@nw.neclab.eu

Benoit Claise
Cisco Systems, Inc.
De Kleetlaan 6a b1
Degem 1831
Belgium

```
                Phone:  +32 2 704 5622
                Email: bclaise@cisco.com"

       DESCRIPTION
              "This MIB is used to report AC power quality in
              devices. The table is a sparse augmentation of the
              eoPowerTable table from the energyObjectMib module.
              Both three-phase and single-phase power
              configurations are supported."
       REVISION

           "201110310000Z"    -- 31 October 2011



     DESCRIPTION
          "Initial version, published as RFC YYY."

      ::= { mib-2 yyy }


   powerQualityMIBConform  OBJECT IDENTIFIER
       ::= { powerQualityMIB 0 }


   powerQualityMIBObjects OBJECT IDENTIFIER
       ::= { powerQualityMIB 1 }

   -- Objects


   eoACPwrQualityTable OBJECT-TYPE
       SYNTAX          SEQUENCE OF EoACPwrQualityEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
           "This table defines power quality measurements for
           supported eoPowerIndex entities. It is a sparse
           extension of the eoPowerTable."
       ::= { powerQualityMIBObjects 1 }

   eoACPwrQualityEntry OBJECT-TYPE
       SYNTAX          EoACPwrQualityEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
           "This is a sparse extension of the eoPowerTable with
           entries for power quality measurements or
```

```
           configuration.  Each measured value corresponds to an
           attribute in IEC 61850-7-4 for non-phase measurements
           within the object MMUX."
       INDEX { eoPowerIndex }
       ::= { eoACPwrQualityTable 1 }

   EoACPwrQualityEntry ::= SEQUENCE {
       eoACPwrQualityConfiguration       INTEGER,
       eoACPwrQualityAvgVoltage          Integer32,
       eoACPwrQualityAvgCurrent          Integer32,
       eoACPwrQualityFrequency           Integer32,
       eoACPwrQualityPowerUnitMultiplier UnitMultiplier,
       eoACPwrQualityPowerAccuracy       Integer32,
       eoACPwrQualityTotalActivePower    Integer32,
       eoACPwrQualityTotalReactivePower  Integer32,
       eoACPwrQualityTotalApparentPower  Integer32,
       eoACPwrQualityTotalPowerFactor    Integer32,
       eoACPwrQualityThdAmpheres         Integer32,
       eoACPwrQualityThdVoltage          Integer32
   }

   eoACPwrQualityConfiguration OBJECT-TYPE
       SYNTAX INTEGER {
           sngl(1),
           del(2),
           wye(3)
              }
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
            "Configuration describes the physical configurations
            of the power supply lines:

               * alternating current, single phase (SNGL)
               * alternating current, three phase delta (DEL)
               * alternating current, three phase Y (WYE)

            Three-phase configurations can be either connected in
            a triangular delta (DEL) or star Y (WYE) system.  WYE
            systems have a shared neutral voltage, while DEL
            systems do not.  Each phase is offset 120 degrees to
            each other."
       ::= { eoACPwrQualityEntry 1 }

   eoACPwrQualityAvgVoltage OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "0.1 Volt AC"
       MAX-ACCESS      read-only
```

```
        STATUS          current
        DESCRIPTION
            "A measured value for average of the voltage measured
            over an integral number of AC cycles   For a 3-phase
            system, this is the average voltage (V1+V2+V3)/3.  IEC
            61850-7-4 measured value attribute 'Vol'"
        ::= { eoACPwrQualityEntry 2 }

   eoACPwrQualityAvgCurrent OBJECT-TYPE
        SYNTAX          Integer32
        UNITS           "Ampheres"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
            "A measured value of the current per phase. IEC 61850-
            7-4 attribute 'Amp'"
        ::= { eoACPwrQualityEntry 3 }

   eoACPwrQualityFrequency OBJECT-TYPE
        SYNTAX          Integer32 (4500..6500) -- UNITS 0.01 Hertz
        UNITS           "hertz"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
            "A measured value for the basic frequency of the AC
            circuit.  IEC 61850-7-4 attribute 'Hz'."
        ::= { eoACPwrQualityEntry 4 }

   eoACPwrQualityPowerUnitMultiplier OBJECT-TYPE
        SYNTAX          UnitMultiplier
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
            "The magnitude of watts for the usage value in
            eoACPwrQualityTotalActivePower,
            eoACPwrQualityTotalReactivePower
            and eoACPwrQualityTotalApparentPower measurements.  For
            3-phase power systems, this will also include
            eoACPwrQualityPhaseActivePower,
            eoACPwrQualityPhaseReactivePower and
            eoACPwrQualityPhaseApparentPower"
        ::= { eoACPwrQualityEntry 5 }

   eoACPwrQualityPowerAccuracy OBJECT-TYPE
        SYNTAX          Integer32 (0..10000)
        UNITS           "hundredths of percent"
        MAX-ACCESS      read-only
        STATUS          current
```

```
       DESCRIPTION
           "This object indicates a percentage value, in 100ths of
           a percent, representing the presumed accuracy of
           active, reactive, and apparent power usage reporting.
           For example: 1010 means the reported usage is accurate
           to +/- 10.1 percent.  This value is zero if the
           accuracy is unknown.

           ANSI and IEC define the following accuracy classes for
           power measurement: IEC 62053-22 & 60044-1 class 0.1,
           0.2, 0.5, 1 & 3.
           ANSI C12.20 class 0.2 & 0.5"
       ::= { eoACPwrQualityEntry 6 }

   eoACPwrQualityTotalActivePower OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           " watts"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
           "A measured value of the actual power delivered to or
           consumed by the load.  IEC 61850-7-4 attribute 'TotW'."
       ::= { eoACPwrQualityEntry 7 }

   eoACPwrQualityTotalReactivePower OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "volt-amperes reactive"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
           "A mesured value of the reactive portion of the
           apparent power.  IEC 61850-7-4 attribute 'TotVAr'."
       ::= { eoACPwrQualityEntry 8 }

   eoACPwrQualityTotalApparentPower OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "volt-amperes"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
           "A measured value of the voltage and current which
           determines the apparent power.  The apparent power is
           the vector sum of real and reactive power.

           Note: watts and volt-ampheres are equivalent units and
           may be combined.  IEC 61850-7-4 attribute 'TotVA'."
       ::= { eoACPwrQualityEntry 9 }
```

```
   eoACPwrQualityTotalPowerFactor OBJECT-TYPE
       SYNTAX          Integer32 (-10000..10000)
       UNITS           "hundredths of percent"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
           "A measured value ratio of the real power flowing to
           the load versus the apparent power. It is dimensionless
           and expressed here as a percentage value in 100ths of a
           percent. A power factor of 100% indicates there is no
           inductance load and thus no reactive power. Power
           Factor can be positive or negative, where the sign
           should be in lead/lag (IEEE) form.  IEC 61850-7-4
           attribute 'TotPF'."
       ::= { eoACPwrQualityEntry 10 }

   eoACPwrQualityThdAmpheres OBJECT-TYPE
       SYNTAX          Integer32 (0..10000)
       UNITS           "hundredths of percent"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
           "A calculated value for the current total harmonic
           distortion (THD).  Method of calculation is not
           specified.  IEC 61850-7-4 attribute 'ThdAmp'."
       ::= { eoACPwrQualityEntry 11 }

   eoACPwrQualityThdVoltage OBJECT-TYPE
       SYNTAX          Integer32 (0..10000)
       UNITS           "hundredths of percent"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
           "A calculated value for the voltage total harmonic
           distortion (THD).  Method of calculation is not
           specified.  IEC 61850-7-4 attribute 'ThdVol'."
       ::= { eoACPwrQualityEntry 12 }

   eoACPwrQualityPhaseTable OBJECT-TYPE
       SYNTAX          SEQUENCE OF EoACPwrQualityPhaseEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
           "This table describes 3-phase power quality
           measurements.  It is a sparse extension of the
           eoACPwrQualityTable."
       ::= { powerQualityMIBObjects 2 }
```

```
   eoACPwrQualityPhaseEntry OBJECT-TYPE
       SYNTAX          EoACPwrQualityPhaseEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
           "An entry describes common 3-phase power quality
           measurements.

           This optional table describes 3-phase power quality
           measurements, with three entries for each supported
           eoPowerIndex entity.  Entities having single phase
           power shall not have any entities.

           This table describes attributes common to both WYE and
           DEL.  Entities having single phase power shall not have
           any entries here.  It is a sparse extension of the
           eoACPwrQualityTable.

           These attributes correspond to IEC 61850-7.4 MMXU phase
           measurements."
       INDEX { eoPowerIndex, eoPhaseIndex }
       ::= { eoACPwrQualityPhaseTable 1 }

   EoACPwrQualityPhaseEntry ::= SEQUENCE {
           eoPhaseIndex                       Integer32,
           eoACPwrQualityPhaseAvgCurrent      Integer32,
           eoACPwrQualityPhaseActivePower     Integer32,
           eoACPwrQualityPhaseReactivePower   Integer32,
           eoACPwrQualityPhaseApparentPower   Integer32,
           eoACPwrQualityPhasePowerFactor     Integer32,
           eoACPwrQualityPhaseImpedance       Integer32
   }

   eoPhaseIndex OBJECT-TYPE
       SYNTAX          Integer32 (0..359)
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "A phase angle typically corresponding to 0, 120, 240."
        ::= { eoACPwrQualityPhaseEntry 1 }

   eoACPwrQualityPhaseAvgCurrent OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "Ampheres"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
```

```
            "A measured value of the current per phase. IEC 61850-
            7-4 attribute 'A'"
        ::= { eoACPwrQualityPhaseEntry 2 }

   eoACPwrQualityPhaseActivePower OBJECT-TYPE
        SYNTAX          Integer32
        UNITS           " watts"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
            "A measured value of the actual power delivered to or
            consumed by the load. IEC 61850-7-4 attribute 'W'"
        ::= { eoACPwrQualityPhaseEntry 3 }

   eoACPwrQualityPhaseReactivePower OBJECT-TYPE
        SYNTAX          Integer32
        UNITS           "volt-amperes reactive"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
            "A measured value of the reactive portion of the
            apparent power.  IEC 61850-7-4 attribute 'VAr'"
        ::= { eoACPwrQualityPhaseEntry 4 }

   eoACPwrQualityPhaseApparentPower OBJECT-TYPE
        SYNTAX          Integer32
        UNITS           "volt-amperes"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
            "A measured value of the voltage and current determines
            the apparent power.  Active plus reactive power equals
            the total apparent powwer.

            Note: Watts and volt-ampheres are equivalent units and
            may be combined.  IEC 61850-7-4 attribute 'VA'."
        ::= { eoACPwrQualityPhaseEntry 5 }

   eoACPwrQualityPhasePowerFactor OBJECT-TYPE
        SYNTAX          Integer32 (-10000..10000)
        UNITS           "hundredths of percent"
        MAX-ACCESS      read-only
        STATUS          current
        DESCRIPTION
            "A measured value ratio of the real power flowing to
            the load versus the apparent power for this phase.  IEC
            61850-7-4 attribute 'PF'. Power Factor can be positive
```

```
           or negative where the sign should be in lead/lag (IEEE)
           form."
       ::= { eoACPwrQualityPhaseEntry 6 }

   eoACPwrQualityPhaseImpedance OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "volt-amperes"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
   "A measured value of the impedance.  IEC 61850-7-4 attribute
   'Z'."
       ::= { eoACPwrQualityPhaseEntry 7 }

   eoACPwrQualityDelPhaseTable OBJECT-TYPE
       SYNTAX          SEQUENCE OF EoACPwrQualityDelPhaseEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "This table describes DEL configuration phase-to-phase
          power quality measurements.  This is a sparse extension
          of the eoACPwrQualityPhaseTable."
       ::= { powerQualityMIBObjects 3 }

   eoACPwrQualityDelPhaseEntry OBJECT-TYPE
       SYNTAX          EoACPwrQualityDelPhaseEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "An entry describes quality attributes of a phase in a
          DEL 3-phase power system.  Voltage measurements are
          provided both relative to each other and zero.

          Measured values are from IEC 61850-7-2 MMUX and THD from
          MHAI objects.

          For phase-to-phase measurements, the eoPhaseIndex is
          compared against the following phase at +120 degrees.
          Thus, the possible values are:

                        eoPhaseIndex        Next Phase Angle
                              0                  120
                            120                  240
                            240                    0
          "
       INDEX { eoPowerIndex, eoPhaseIndex}
       ::= { eoACPwrQualityDelPhaseTable 1}
```

```
   EoACPwrQualityDelPhaseEntry ::= SEQUENCE {
       eoACPwrQualityDelPhaseToNextPhaseVoltage      Integer32,
       eoACPwrQualityDelThdPhaseToNextPhaseVoltage   Integer32,
       eoACPwrQualityDelThdCurrent                   Integer32
   }

   eoACPwrQualityDelPhaseToNextPhaseVoltage OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "0.1 Volt AC"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "A measured value of phase to next phase voltages, where
          the next phase is IEC 61850-7-4 attribute 'PPV'."
       ::= { eoACPwrQualityDelPhaseEntry 2 }

   eoACPwrQualityDelThdPhaseToNextPhaseVoltage OBJECT-TYPE
       SYNTAX          Integer32 (0..10000)
       UNITS           "hundredths of percent"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "A calculated value for the voltage total harmonic
          disortion for phase to next phase. Method of calculation
          is not specified.  IEC 61850-7-4 attribute 'ThdPPV'."
       ::= { eoACPwrQualityDelPhaseEntry 3 }

   eoACPwrQualityDelThdCurrent OBJECT-TYPE
       SYNTAX          Integer32 (0..10000)
       UNITS           "hundredths of percent"
       MAX-ACCESS      read-only
       STATUS          current
     DESCRIPTION
          "A calculated value for the voltage total harmonic
          disortion (THD) for phase to phase.  Method of
          calculation is not specified.
          IEC 61850-7-4 attribute 'ThdPPV'."
       ::= { eoACPwrQualityDelPhaseEntry 4 }

   eoACPwrQualityWyePhaseTable OBJECT-TYPE
       SYNTAX          SEQUENCE OF EoACPwrQualityWyePhaseEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "This table describes WYE configuration phase-to-neutral
          power quality measurements.  This is a sparse extension
          of the eoACPwrQualityPhaseTable."
       ::= { powerQualityMIBObjects 4 }
```

```
   eoACPwrQualityWyePhaseEntry OBJECT-TYPE
       SYNTAX          EoACPwrQualityWyePhaseEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "This table describes measurements of WYE configuration
          with phase to neutral power quality attributes. Three
          entries are required for each supported eoPowerIndex
          entry.  Voltage measurements are relative to neutral.

          This is a sparse extension of the
          eoACPwrQualityPhaseTable.

          Each entry describes quality attributes of one phase of
          a WYE 3-phase power system.

          Measured values are from IEC 61850-7-2 MMUX and THD from
          MHAI objects."
       INDEX { eoPowerIndex, eoPhaseIndex }
       ::= { eoACPwrQualityWyePhaseTable 1}

   EoACPwrQualityWyePhaseEntry ::= SEQUENCE {
           eoACPwrQualityWyePhaseToNeutralVoltage       Integer32,
           eoACPwrQualityWyePhaseCurrent                Integer32,
           eoACPwrQualityWyeThdPhaseToNeutralVoltage    Integer32
   }

   eoACPwrQualityWyePhaseToNeutralVoltage OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "0.1 Volt AC"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "A measured value of phase to neutral voltage.  IEC
          61850-7-4 attribute 'PhV'."
       ::= { eoACPwrQualityWyePhaseEntry 1 }

   eoACPwrQualityWyePhaseCurrent OBJECT-TYPE
       SYNTAX          Integer32
       UNITS           "0.1 ampheres AC"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "A measured value of phase currents.  IEC 61850-7-4
          attribute 'A'."
       ::= { eoACPwrQualityWyePhaseEntry 2 }
```

```
   eoACPwrQualityWyeThdPhaseToNeutralVoltage OBJECT-TYPE
       SYNTAX          Integer32 (0..10000)
       UNITS           "hundredths of percent"
       MAX-ACCESS      read-only
       STATUS          current
       DESCRIPTION
          "A calculated value of the voltage total harmonic
          distortion (THD) for phase to neutral. IEC 61850-7-4
          attribute 'ThdPhV'."
       ::= { eoACPwrQualityWyePhaseEntry 3 }

   -- Conformance

   powerQualityMIBCompliances  OBJECT IDENTIFIER
       ::= { powerQualityMIB 2 }

   powerQualityMIBGroups  OBJECT IDENTIFIER
       ::= { powerQualityMIB 3 }

   powerQualityMIBFullCompliance MODULE-COMPLIANCE
       STATUS          current
       DESCRIPTION
          "When this MIB is implemented with support for read-
          create, then such an implementation can claim full
          compliance. Such devices can then be both monitored and
          configured with this MIB."
       MODULE          -- this module
       MANDATORY-GROUPS {
                           powerACPwrQualityMIBTableGroup,
                           powerACPwrQualityPhaseMIBTableGroup
                        }

       GROUP       powerACPwrQualityDelPhaseMIBTableGroup
       DESCRIPTION
          "This group must only be implemented for a DEL phase
          configuration."

       GROUP       powerACPwrQualityWyePhaseMIBTableGroup
       DESCRIPTION
          "This group must only be implemented for a WYE phase
          configuration."
       ::= { powerQualityMIBCompliances 1 }


   -- Units of Conformance

   powerACPwrQualityMIBTableGroup OBJECT-GROUP
       OBJECTS         {
```

```
                           -- Note that object eoPowerIndex is NOT
                           -- included since it is not-accessible
                           eoACPwrQualityConfiguration,
                           eoACPwrQualityAvgVoltage,
                           eoACPwrQualityAvgCurrent,
                           eoACPwrQualityFrequency,
                           eoACPwrQualityPowerUnitMultiplier,
                           eoACPwrQualityPowerAccuracy,
                           eoACPwrQualityTotalActivePower,
                           eoACPwrQualityTotalReactivePower,
                           eoACPwrQualityTotalApparentPower,
                           eoACPwrQualityTotalPowerFactor,
                           eoACPwrQualityThdAmpheres,
                           eoACPwrQualityThdVoltage
                       }    STATUS          current
       DESCRIPTION
          "This group contains the collection of all the power
          quality objects related to the Energy Object."
       ::= { powerQualityMIBGroups  1 }


   powerACPwrQualityPhaseMIBTableGroup OBJECT-GROUP
       OBJECTS         {
                           -- Note that object eoPowerIndex is NOT
                           -- included since it is not-accessible
                           eoACPwrQualityPhaseAvgCurrent,
                           eoACPwrQualityPhaseActivePower,
                           eoACPwrQualityPhaseReactivePower,
                           eoACPwrQualityPhaseApparentPower,
                           eoACPwrQualityPhasePowerFactor,
                           eoACPwrQualityPhaseImpedance
                       }
       STATUS          current
       DESCRIPTION
          "This group contains the collection of all 3-phase power
          quality objects related to the Power State."
       ::= { powerQualityMIBGroups  2 }

   powerACPwrQualityDelPhaseMIBTableGroup OBJECT-GROUP
       OBJECTS         {
                       -- Note that object eoPowerIndex and
                       -- eoPhaseIndex are NOT included
                       -- since they are not-accessible
                       eoACPwrQualityDelPhaseToNextPhaseVoltage ,
                       eoACPwrQualityDelThdPhaseToNextPhaseVoltage,
                       eoACPwrQualityDelThdCurrent
                       }
       STATUS          current
```

```
       DESCRIPTION
           "This group contains the collection of all quality
           attributes of a phase in a DEL 3-phase power system."
       ::= { powerQualityMIBGroups  3 }

   powerACPwrQualityWyePhaseMIBTableGroup OBJECT-GROUP
       OBJECTS          {
                           -- Note that object eoPowerIndex and
                           -- eoPhaseIndex are NOT included
                           -- since they are not-accessible
                           eoACPwrQualityWyePhaseToNeutralVoltage,
                           eoACPwrQualityWyePhaseCurrent,
                           eoACPwrQualityWyeThdPhaseToNeutralVoltage
                        }
       STATUS           current
       DESCRIPTION
           "This group contains the collection of all WYE
           configuration phase-to-neutral power quality
           measurements."
       ::= { powerQualityMIBGroups  4 }



   END
```

11. Security Considerations

Some of the readable objects in these MIB modules (i.e., objects with a MAX-ACCESS other than not-accessible) may be considered sensitive or vulnerable in some network environments. It is thus important to control even GET and/or NOTIFY access to these objects and possibly to even encrypt the values of these objects when sending them over the network via SNMP.

There are a number of management objects defined in these MIB modules with a MAX-ACCESS clause of read-write and/or read-create. Such objects MAY be considered sensitive or vulnerable in some network environments. The support for SET operations in a non-secure environment without proper protection can have a negative effect on network operations. The following are the tables and objects and their sensitivity/vulnerability:

- Unauthorized changes to the eoPowerOperState (via theeoPowerAdminState) MAY disrupt the power settings of the differentEnergy Objects, and therefore the state of functionality of the respective Energy Objects.
- Unauthorized changes to the eoEnergyParametersTable MAY disrupt energy measurement in the eoEnergyTable table.

SNMP versions prior to SNMPv3 did not include adequate security. Even if the network itself is secure (for example, by using IPsec), there is still no secure control over who on the secure network is allowed to access and GET/SET (read/change/create/delete) the objects in these MIB modules.

It is RECOMMENDED that implementers consider the security features as provided by the SNMPv3 framework (see [RFC3410], section 8), including full support for the SNMPv3 cryptographic mechanisms (for authentication and privacy).

Further, deployment of SNMP versions prior to SNMPv3 is NOT RECOMMENDED. Instead, it is RECOMMENDED to deploy SNMPv3 and to enable cryptographic security. It is then a customer/operator responsibility to ensure that the SNMP entity giving access to an instance of these MIB modules is properly configured to give access to the objects only to those principals (users) that have legitimate rights to GET or SET (change/create/delete) them.

12. IANA Considerations

12.1. IANA Considerations for the MIB Modules

The MIB modules in this document uses the following IANA-assigned OBJECT IDENTIFIER values recorded in the SMI Numbers registry:

Descriptor	OBJECT IDENTIFIER value
energyObjectMib	{ mib-2 xxx }
powerQualityMIB	{ mib-2 yyy }

Additions to the MIB modules are subject to Expert Review [RFC5226], i.e., review by one of a group of experts designated by an IETF Area Director. The group of experts MUST check the requested MIB objects for completeness and accuracy of the description. Requests for MIB objects that duplicate the functionality of existing objects SHOULD be declined. The smallest available OIDs SHOULD be assigned to the new MIB objects. The specification of new MIB objects SHOULD follow the structure specified in Section 10. and MUST be published using a well-established and persistent publication medium.

12.2. IANA Registration of new Power State Set

This document specifies an initial set of Power State Sets. The list of these Power State Sets with their numeric identifiers is given in Section 5.2.1. IANA maintains a Textual Convention IANAPowerStateSet with the initial set of Power State Sets and the Power States within those Power State Sets. The current version of Textual convention can be accessed http://www.iana.org/assignments/IANAPowerStateSet

New Assignments to Power State Sets shall be administered by IANA and the guidelines and procedures are listed in this Section.

New assignments for Power State Set will be administered by IANA through Expert Review [RFC5226], i.e., review by one of a group of experts designated by an IETF Area Director. The group of experts MUST check the requested state for completeness and accuracy of the description. A pure vendor specific implementation of Power State Set shall not be adopted; since it would lead to proliferation of Power State Sets.

12.2.1. IANA Registration of the IEEE1621 Power State Set

This document specifies a set of values for the IEEE1621 Power State Set [IEEE1621]. The list of these values with their identifiers is given in Section 5.2.1. The Internet Assigned Numbers Authority (IANA) created a new registry for IEEE1621 Power State Set identifiers and filled it with the initial listin the Textual Convention IANAPowerStateSet..

New assignments (or potentially deprecation) for IEEE1621 Power State Set will be administered by IANA through Expert Review [RFC5226], i.e., review by one of a group of experts designated by an IETF Area Director. The group of experts MUST check the requested state for completeness and accuracy of the description.

12.2.2. IANA Registration of the DMTF Power State Set

This document specifies a set of values for the DMTF Power State Set. The list of these values with their identifiers is given in Section 5.2.1. The Internet Assigned Numbers Authority (IANA) has created a new registry for DMTF Power State Set identifiers and filled it with the initial list in the Textual Convention IANAPowerStateSet.

New assignments (or potentially deprecation) for DMTF Power State Set will be administered by IANA through Expert Review [RFC5226], i.e., review by one of a group of experts designated by an IETF Area Director. The group of experts MUST check the conformance with the DMTF standard [DMTF], on the top of checking for completeness and accuracy of the description.

12.2.3. IANA Registration of the EMAN Power State Set

This document specifies a set of values for the EMAN Power State Set. The list of these values with their identifiers is given in Section 5.2.1. The Internet Assigned Numbers Authority (IANA) has created a new registry for EMAN Power State Set identifiers and filled it with the initial list in the Textual Convention IANAPowerStateSet.
New assignments (or potentially deprecation) for EMAN Power State Set will be administered by IANA through Expert Review [RFC5226], i.e., review by one of a group of experts designated by an IETF Area Director. The group of experts MUST check the requested state for completeness and accuracy of the description.

12. Contributors

This document results from the merger of two initial proposals. The following persons made significant contributions either in one of the initial proposals or in this document.

John Parello

Rolf Winter

Dominique Dudkowski

13. Acknowledgment

The authors would like to thank Shamita Pisal for her prototype of this MIB module, and her valuable feedback. The authors would like to Michael Brown for improving the text dramatically.

We would like to thank Juergen Schoenwalder for proposing the design of the Textual Convention for IANAPowerStateSet and Ira McDonald for his feedback.

14. Open Issues

OPEN ISSUE 1 : Double-check all the IEC references in the draft.

IEC 61850-7-4 has been widely referenced in many EMAN drafts. The other IEC references suggested in the email list are IEC 61000-4-30 and IEC 62053-21 and IEC 62301. It is important to resolve the correct IEC references soon.

OPEN ISSUE 2 : Description clause of eoPowerIndex. Do we need this text ? Juergen Quittek to comment:

"The identity provisioning method that has been chosen can be retrieved by reading the value of powerStateEnergyConsumerOid. In case of identities provided by the ENERGY-AWARE-MIB module, this OID points to an exising instance of eoPowerIndex, in case of the ENTITY MIB, the object points to a valid instance of entPhysicalIndex, and in a similar way, it points to a value of another MIB module if this is used for identifying entities. If no other MIB module has been chosen for providing entity identities, then the value of powerStateEnergyConsumerOid MUST be 0.0 (zeroDotZero).

OPEN ISSUE 3: Time Series of measurements required ? Mechanism pull or push ? What shall the table consist of ? Power, Voltage, Current, Energy and Demand.

OPEN ISSUE 4: Demand computation method

"Energy not obtained by periodically polling a power measurement with a eoEnergyParametersSampleRate ; Energy (E) is measured to the product’s certified IEC 62053-21 accuracy class"

Need to verify with IEC62053-21.

OPEN ISSUE 5: Consideration of IEEE-ISTO PWG in the IANA list of Power State Set ? Printer Power series could be added once the IANA procedure is in place.

OPEN ISSUE 6: check if all the requirements from [EMAN-REQ] are covered.

15. References

15.2. Normative References

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Authors' Addresses

Mouli Chandramouli
Cisco Systems, Inc.
Sarjapur Outer Ring Road
Bangalore,
IN

Phone: +91 80 4426 3947
Email: moulchan@cisco.com

Brad Schoening
44 Rivers Edge Drive
Little Silver, NJ 07739
US
Email: brad@bradschoening.com

Juergen Quittek
NEC Europe Ltd.
NEC Laboratories Europe
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE

Phone: +49 6221 4342-115
Email: quittek@neclab.eu

Thomas Dietz
NEC Europe Ltd.
NEC Laboratories Europe
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE

Phone: +49 6221 4342-128
Email: Thomas.Dietz@neclab.eu

Benoit Claise
Cisco Systems, Inc.
De Kleetlaan 6a b1
Diegem 1813
BE

Phone: +32 2 704 5622
Email: bclaise@cisco.com

Network Working Group   B. Claise
Internet-Draft   J. Parello
Intended Status: Informational   Cisco Systems, Inc.
Expires: April 30, 2012   B. Schoening
                                                  Independent Consultant
                                                              J. Quittek
                                                        NEC Europe Ltd.
                                                        October 31, 2011

Energy Management Framework
draft-ietf-eman-framework-03

Status of this Memo

Abstract

This document defines a framework for providing Energy Management for devices within or connected to communication networks. The framework defines an Energy Management Domain as a set of Energy Objects, for which each Energy Object is identified, classified and given context. Energy Objects can be monitored and/or controlled with respect to Power, Power State, Energy, Demand, Power Quality, and battery. Additionally the framework models relationships and capabilities between Energy Objects.

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TO DO/OPEN ISSUE

- Do we want to add some examples such as http://www.ietf.org/proceedings/81/slides/eman-4.pdf slide 14 to 1]? Proposal: add it to [EMAN-AS]
- Do we need variable range of states (i.e. dimmer)? Is this a requirement? How to model the batteries, as a component or a relationship? See the meeting minutes:

o "Modeling of the battery? If we are not modeling components then why model batteries? Use the Entity MIB"

- Comment from Prantl on the list, related to energy control: non-discrete power-states are not supported -> Section 5.5. specifies the possibility of mapping "Manufacturer" Power States to the 12 Eman Power states, where there can be more than 12 Manufacturer Power States. However, in the context of power-capping of Servers we have a "non-discrete" floating cap corresponding to the Manufacturer Power State.

  The Problem is that different Servers will have completely different ranges of supported cap-values, e.g. Server 1 has a dynamic range of 300-500Watt, Server2 has a range of 70-270Watts. Now let's assume Powerstate 9=400 Watts for Server1, but would be 170Watts for Server2. Which would mean I have to specify a Mapping for each Server-Model.

  It would be far more practical if it would be possible to supply a key-value-pair with a certain power-state in Case the State needs context such as a power-cap, I would then specify a state of e.g. 7 and supply the desired Cap in the kvp-field.

  PROPOSAL:

  1. decide if we need a variable power state that is a percent of maximum.
  2. Power-capping can be done by the EnMS. [EMAN-AS] to document this use case.

1. Introduction

Network management is divided into the five main areas defined in the ISO Telecommunications Management Network model: Fault, Configuration, Accounting, Performance, and Security Management (FCAPS) [X.700]. Absent from this management model is any consideration of Energy Management, which is now becoming a critical area of concern worldwide as seen in [ISO50001].

Note that Energy Management has particular challenges in that a power distribution network is responsible for the supply of energy to various devices and components, while a separate communication network is typically used to monitor and control the power distribution network.

This document defines a framework for providing Energy Management for devices within or connected to communication networks. The framework describes how to identify, classify and provide context for a device in a communications network from the point of view of Energy Management.

The identified device, called Energy Objects, can then be monitored for Energy Management by obtaining measurements for Power, Energy, Demand and Power Quality. If a device contains a battery(s) the characteristics and performance of the battery(s) can also be managed. An Energy Object state can be monitored or controlled by providing an interface expressed as one or more Power State Sets. The most basic example of Energy Management is a single Energy Object reporting information about itself. However, in many cases, Energy is not measured by the Energy Object itself, but by a meter located upstream in the power distribution tree. An example is a power distribution unit (PDU) that measures Energy consumption of attached devices and may report this to an Energy Management System (EnMS). Therefore, Energy Objects are recognized as having relationships to other devices in the network from the point of view of Energy Management. These relationships include Aggregation Relationship, Metering Relationship, Power Source Relationship , Proxy Relationship , and Dependency Relationship.

1.1. Energy Management Document Overview

The EMAN standard provides a set of specifications for Energy Management. This document specifies the framework, per the Energy Management requirements specified in [EMAN-REQ]

The applicability statement document [EMAN-AS] provides a list of use cases, cross-reference between existing standards and the EMAN standard, and shows how the this relates to other frameworks.

The [EMAN-AWARE-MIB] specifies objects for addressing Energy Object Identification, classification, context information, and relationships form the point of view of Energy Management.

The Power and Energy Monitoring MIB [EMAN-MON-MIB] contains objects for monitoring of Power, Energy, Demand, Power Quality and Power State Sets.

Definition of Managed Objects for Battery Monitoring [EMAN-BATTERY-MIB] defines managed objects that provide information on the status of batteries in managed devices.

2. Requirements & Use Cases

Requirements for Power and Energy monitoring for networking devices are specified in [EMAN-REQ]. The Energy Management use cases covered by this framework are covered in the EMAN applicability statement document in [EMAN-AS]. Typically requirements and use cases for communication networks cover the devices that make up the communication network and endpoints.

With Energy Management, there exists a wide variety of devices that may be contained in the same deployments as a communication network but comprise a separate facility, home, or power distribution network.

Target devices for the Energy Management are all Energy Objects that can directly or indirectly be monitored or controlled by an Energy Management System (EnMS) using the Internet protocol, for example:

- Simple electrical appliances / fixtures
- Hosts, such as a PC, a datacenter server, or a printer
- Routers
- Switches
- Switches with line card components
- Power over Ethernet (PoE) endpoints,
- Power Distribution Units (PDU)
- Protocol gateways devices for Building Management Systems (BMS)
- Electrical Meters
- Sensor controllers with subtended sensors

There may also exist varying protocols deployed among these power distributions and communication networks.

For an Energy Management framework to be useful, it should also apply to these types of separate networks as they connect and interact with a communications network.

3. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

This section contains definitions of terms used throughout this specification. Defined terms have their first letter capitalized.

Energy Management System (EnMS)

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Energy Management

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Energy Monitoring

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Energy

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Power

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Demand

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Power Quality

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Energy Control

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Energy Object

EDITOR'S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Electrical Equipement

EDITOR'S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Energy Object Identification

EDITOR'S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions
EDITOR'S NOTE: the uniqueness must be clarified in [EMAN-REQ]

Energy Object Context

EDITOR'S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Energy Management Domain

EDITOR'S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Energy Object Relationships

EDITOR'S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Aggregation Relationship

EDITOR'S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Metering Relationship

EDITOR'S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Power Source Relationship

EDITOR'S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Proxy Relationship

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Dependency Relationship

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Energy Object Parent

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Energy Managed Object Child

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Power State

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Manufacturer Power State

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Power State Set

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

Nameplate Power

EDITOR’S NOTE: use the latest definition from the [draft-parello-eman-definitions-03] definitions

4. Energy Management Reference Model

The scope of this framework is to enable network and network-attached devices to be administered for Energy Management. The framework recognizes that in complex deployments Energy Objects may communicate over varying protocols. For example the communications network may use IP Protocols (SNMP) but attached Energy Object Parent may communicate to Energy Object Children over serial communication protocols like BACNET, MODBUS etc. The likelihood of getting these different topologies to convert to a single protocol is not very high considering the rate of upgrades of facilities and energy related devices. Therefore the framework must address the simple case of a uniform IP network and a more complex mixed topology/deployment.

As displayed in the Figure 1, the most basic energy reference model is composed of an EnMS that obtains Energy Management information from Energy Objects. The Energy Object (EO) returns information for Energy Management directly to the EnMS.

The protocol of choice for Energy Management is SNMP, as three MIBs are specified for Energy Management: the energy-aware MIB [EMAN-AWARE-MIB], the energy monitoring MIB [EMAN-MON-MIB], and the battery MIB [EMAN-BATTERY-MIB]. However, the EMAN requirement document [EMAN-REQ] also require the push of time series of power values. Therefore, IPFIX [RFC5101] is also mentioned as the appropriate solution in the following figures, even if there are no documents describing the IPFIX solution at the time of writing these lines. Note that this framework doesn’t exclude another solution than IPFIX.

```
                       +---------------+
                       |      EnMS     |                -   -
                       +-----+---+-----+                ^   ^
                             |   |                      |   |
                             |   |                      |S  |I
                   +---------+   +----------+           |N  |P
                   |                        |           |M  |F
                   |                        |           |P  |I
          +-----------------+      +--------+--------+  |   |X
          | EO            1 |  ... | EO            N |  v   |
          +-----------------+      +-----------------+  -   -
```

Figure 1: Simple Energy Management

As displayed in the Figure 2, a more complex energy reference model includes Energy Managed Object Parents and Children. The Energy Managed Object Parent returns information for themselves as well as information according to the Energy Managed Object Relationships.

```
                      +---------------+
                      |      EnMS     |               -   -
                      +-----+--+------+               ^   ^
                            |  |                      |   |
                            |  |                      |S  |I
               +------------+  +--------+             |N  |P
               |                        |             |M  |F
               |                        |             |P  |I
       +------------------+     +------+------------+  |   |X
       | EO               |     | EO                |  v   |
       | Parent 1         | ... | Parent N          |  -   -
       +------------------+     +-------------------+
                      |||                   .
     One or           |||                   .
     Multiple         |||                   .
     Energy           |||                   .
     Object           |||                   .
     Relationship(s): |||
     - Aggregation    |||      +-----------------------+
     - Metering       |||------| EO Child 1            |
     - Power Source   ||       +-----------------------+
     - Proxy          ||
     - Dependency     ||       +-----------------------+
                      ||-------| EO Child 2            |
                      |        +-----------------------+
                      |
                      |
                      |--------          ...
                      |
                      |
                      |        +-----------------------+
                      |--------| EO Child M            |
                               +-----------------------+
```

Figure 2: Complex Energy Management Model

While both the simple and complex Energy Management models contain an EnMS, this framework doesn’t impose any requirements regarding a topology with a centralize EnMS or one with a distributed Energy Management via the Energy Objects within the deployment.

Given the pattern in figure 2, the complex relationships between Energy Objects can be modeled (refer also to section 5.3):

- A PoE device modeled as an Energy Object Parent with the Power Source, Metering, and Proxy Relationships for this Energy Object Child
- A PDU modeled as an Energy Object Parent with the Power Source and Metering Relationships for the plugged in host (the Energy Object Children)
- A PC with line cards modeled as an Energy Object Parent with Dependency Relationships for the line cards (the Energy Object Children)
- Building management gateway, used as proxy for non IP protocols, is modeled as an Energy Object Parent with the Proxy Relationship, and potentially the Aggregation Relationship
- Etc.

The communication between the Energy Object Parent and Energy Object Children is out of the scope of this framework.

5. Framework High Level Concepts and Scope

Energy Management can be organized into areas of concern that include:

- Energy Object Identification and Context - for modeling and planning
- Energy Monitoring - for energy measurements
- Energy Control - for optimization
- Energy Procurement - for optimization of resources

While an EnMS may be a central point for corporate reporting, cost, environmental impact, and regulatory compliance, Energy Management in this framework excludes Energy procurement and the environmental impact of energy use. As such the framework does not include:

- Manufacturing costs of an Energy Object in currency or environmental units
- Embedded carbon or environmental equivalences of an Energy Object
- Cost in currency or environmental impact to dismantle or recycle an Energy Object
- Relationship or capabilities of an Energy Object to an electrical or smart grid
- Supply chain analysis of energy sources or Energy Object deployment

- Conversion of the usage or production of energy to units expressed from the source of that energy (such as the greenhouse gas emissions associated with 1000kW from a diesel source).

The next sections describe Energy Management organized into the following areas:

- Energy Object and Energy Management Domain
- Energy Object Identification and Context
- Energy Object Relationships
- Energy Monitoring
- Energy Control
- Deployment Topologies

5.1. Energy Object and Energy Management Domain

In building management, a meter refers to the meter provided by the utility used for billing and measuring power to an entire building or unit within a building. A sub-meter refers to a customer or user installed meter that is not used by the utility to bill but instead used to get readings from sub portions of a building.

An Energy Management Domain should map 1-1 with a metered or sub-metered portion of the site. An Energy Object is part of a single Energy Management Domain. The Energy Management Domain should be configured on an Energy Object. An Energy Object Child may inherit the domain value from an Energy Object Parent or the Energy Management Domain may be configured directly in an Energy Object Child.

5.2. Energy Object Identification and Context

5.2.1 Energy Object Identification

Energy Objects MUST contain a value that uniquely identifies the Energy Object among all the Energy Management Domains within an EnMS. A universal identifier (UUID) [RFC4122] MUST be used to uniquely identify an Energy Object.

Every Energy Object should have a unique printable name. Possible naming conventions are: textual DNS name, MAC-address of the device, interface ifName, or a text string uniquely identifying the Energy Object. As an example, in the case of IP phones, the Energy Object name can be the device DNS name.

5.2.2 Context in General

In order to aid in reporting and in differentiation between Energy Objects, each Energy Object optionally contains information establishing its business, site, or organizational context within a deployment, i.e. the Energy Object Context.

5.2.3 Context: Importance

An Energy Object can provide an importance value in the range of 1 to 100 to help differentiate a device's use or relative value to the site. The importance range is from 1 (least important) to 100 (most important). The default importance value is 1.

For example: A typical office environment has several types of phones, which can be rated according to their business impact. A public desk phone has a lower importance (for example, 10) than a business-critical emergency phone (for example, 100). As another example: A company can consider that a PC and a phone for a customer-service engineer is more important than a PC and a phone for lobby use.

Although EnMS and administrators can establish their own ranking, the following is a broad recommendation:

. 90 to 100 Emergency response

. 80 to 90 Executive or business-critical

. 70 to 79 General or Average

. 60 to 69 Staff or support

. 40 to 59 Public or guest

. 1 to 39 Decorative or hospitality

5.2.4 Context: Keywords

An Energy Object can provide a set of keywords. These keywords are a list of tags that can be used for grouping and summary reporting within or between Energy Management Domains. All alphanumeric characters and symbols, such as #, (, $, !, and &, are allowed. Potential examples are: IT, lobby, HumanResources, Accounting, StoreRoom, CustomerSpace, router, phone, floor2, or SoftwareLab. There is no default value for a keyword.

Multiple keywords can be assigned to a device. In such cases, the keywords are separated by commas and no spaces between keywords are allowed. For example, "HR,Bldg1,Private".

Another keyword use case is the virtual grouping of Energy Objects. For example, a Power Distribution Unit (PDU) that allows physical entities like outlets to be "ganged" together as a logical entity for simplified management purposes. This is particularly useful for servers with multiple power supplies, where each power supply is connected to a different physical outlet. Other implementations allow "gangs" to be created based on common ownership of outlets, such as business units or load shed priority or other non-physical relationships. For example, current PDU implementations allow for an "M-to-N" mapping between outlet "gangs" and physical outlets:

```
Outlet 1            (physical entity)

Outlet 2            (physical entity)

Outlet 3            (physical entity)

Outlet 4            (physical entity)

Outlet Gang A       (virtual entity)

Outlet Gang B       (virtual entity)

Gang A -> Outlets 1, 2 and 3

Gang B -> Outlets 3 and 4
```

Note the allowed overlap on Outlet 3, where Outlet 3 belongs to both "gangs". The keywords concept for this specific example would be used as such:

```
Outlet 1        Energy Object 1, keywords: gangA
```

Outlet 2	Energy Object 2, keywords: gangA
Outlet 3	Energy Object 3, keywords: gangA, gangB
Outlet 4	Energy Object 4, keywords: gangB

Each "Outlet Gang" virtual entity, aggregated based on the value of the keywords, reports the aggregated data from the individual outlet entities that comprise it. The same concept enables a single point of control for all the individual outlet entities. For example, turning "Outlet Gang A" to the "off" state would turn outlets 1, 2, and 3 "off" in some implementations. Note that the impact of this action on "Outlet Gang B" is out of scope of this document.

5.2.5 Context: Role

An Energy Object can provide a "role description" string that indicates the purpose the Energy Object serves in the EnMS. This could be a string describing the context the device fulfills in deployment.

Administrators can define any naming scheme for the role of a device. As guidance a two-word role that combines the service the device provides along with type can be used [IPENERGY]

Example types of devices: Router, Switch, Light, Phone, WorkStation, Server, Display, Kiosk, HVAC.

Example Services by Line of Business:

Line of Business	Service
Education	Student, Faculty, Administration, Athletic
Finance	Trader, Teller, Fulfillment
Manufacturing	Assembly, Control, Shipping
Retail	Advertising, Cashier
Support	Helpdesk, Management
Medical	Patient, Administration, Billing

Role as a two-word string: "Faculty Desktop", "Teller Phone", "Shipping HVAC", "Advertising Display", "Helpdesk Kiosk", "Administration Switch".

5.3. Energy Object Relationships

Two Energy Objects MAY establish an Energy Object Relationship. Within a relationship one Energy Object becomes an Energy Object Parent while the other becomes an Energy Object Child. .

For Example: A Power-over-Ethernet (PoE) device (such as an IP phone or an access point) is attached to a switch port. The switch is the source of Power for the attached device, so the Energy Object Parent is the switch, and the Energy Object Child is the device attached to the switch.

The communication between the parent and child for monitoring or collection of power data is left to the device manufacturer. For example: A parent switch may use LLDP to communicate with a connected child, and a parent lighting controller may use BACNET to communicate with child lighting devices.

The Energy Object Child MUST keep track of its Energy Object Parent(s) along with the Energy Object Relationships type. The Energy Object Parent MUST keep track of its Energy Object Child(ren).

While the Energy Object Relationships provide the different topologies information to all the EnMS in a consistent way, their implementation is optional.

5.3.1 Energy Object Children Discovery

There are multiple ways that the Energy Object Parent can discover its Energy Object Children, if they are not present on the same physical network:

- In case of PoE, the Energy Object Parent automatically discovers an Energy Object Child when the Child requests power.
- The Energy Object Parent and Children may run the Link Layer Discovery Protocol [LLDP], or any other discovery

protocol, such as Cisco Discovery Protocol (CDP). The Energy Object Parent might even support the LLDP-MED MIB [LLDP-MED-MIB], which returns extra information on the Energy Object Children.

- The Energy Object Parent may reside on a network connected facilities gateway. A typical example is a converged building gateway, monitoring several other devices in the building, and serving as a proxy between SNMP and a protocol such as BACNET.
- Energy Object Parent/Energy Object Child relationships may be set by manual or automatic network configuration functions.

Note that the communication specifications between the Energy Object Parent and Children is out of the scope of this document.

When an Energy Object Parent is a Proxy, the Energy Object Parent should enumerate the capabilities it is providing for the Energy Object Child. The child would express that it wants its parent to proxy capabilities such as, energy reporting, power state configurations, non physical wake capabilities (such as WoL)), or any combination of capabilities.

5.4. Energy Monitoring

For the purposes of this framework Energy will be limited to electrical energy in watt hours. Other forms of Energy Objects that use or produce non-electrical energy may be part of an Energy Management Domain but MUST provide information converted to and expressed in watt hours.

Each Energy Object will have information that describes Power information along with how that measurement was obtained or derived. For Energy Objects that can report actual Power readings an optional Energy measurement can be provided.

Optionally, an Energy Object can further describe the Power information with Power Quality information reflecting the electrical characteristics of the measurement.

Optionally, an Energy Object that can report actual Power readings can have odometers that provide the Energy used, produced, and net Energy in Kwh. These values are odometers that accumulate the Power readings. If Energy values are returned then the three odometers must be provided along a description of accuracy.

Optionally, an Energy Object can provide Demand information over time

5.4.1 Power Measurement

A Power measurement must be qualified with the units, magnitude, direction of power flow, and by what means the measurement was made (ex: Root Mean Square versus Nameplate).

In addition, the Energy Object should describe how it intends to measure Power as one of consumer, producer or meter of usage. Given the intent readings can be summarized or analyzed by an EnMS. For example metered usage reported by a meter and consumption usage reported by a device connected to that meter may naturally measure the same usage. With the two measurements identified by intent a proper summarization can be made by an EMS.

Power measurement magnitude should conform to the IEC 61850 definition of unit multiplier for the SI (System International) units of measure. Measured values are represented in SI units obtained by BaseValue * 10 raised to the power of the scale. For example, if current power usage of an Energy Object is 3, it could be 3 W, 3 mW, 3 KW, or 3 MW, depending on the value of the scaling factor. Energy is often billed in kilowatt-hours instead of megajoules from the SI units. Similarly, battery charge is often measured as miliamperes-hour (mAh) instead of coulombs from the SI units. The units used in this framework are: W, A, Wh, Ah, V. A conversion from Wh to Joule and from Ah to Coulombs is obviously possible, and can be described if required.

In addition to knowing the usage and magnitude, it is useful to know how an Energy Object usage measurement was obtained:

. Whether the measurements were made at the device itself or from a remote source.

. Description of the method that was used to measure the power and whether this method can distinguish actual or estimated values.

An EMS can use this information to account for the accuracy and nature of the reading between different implementations.

The EMS can use the Nameplate Power for provisioning, capacity planning and potentially billing.

5.4.2 Optional Power Quality

Given a Power measurement, it may in certain circumstances be desirable to know the Power Quality associated with that measurement. The information model must adhere to the IEC 61850 7-2 standard for describing AC measurements. Note that the Power Quality include two sets of characteristics: characteristics as received from the utility, and characteristics depending on how the Power is used.

In some Energy Management Domains, the power quality may not be needed, available, or relevant to the EMS.

Optional Demand

It is well known in commercial electrical utility rates that Demand is used as a measurement for billing. Also the highest peak demand measured over a time horizon, such as 1 month or 1 year, is often the basis for charges. A single window of time of high usage can penalize the consumer with higher energy consumption charges. However, it is relevant to measure the Demand only when there are actual power measurements from an Energy Object, and not when the power measurement is assumed or predicted.

Optional Battery

Some Energy Objects may use batteries for storing Energy and for receiving power supply. These Energy Objects should report their current power supply (battery, power line, etc.) and the battery status for each contained battery. Battery-specific information to be reported should include the number of batteries contained in the device and per battery

. battery type

. nominal and remaining capacity

. current charge

. current state (charging, discharging, not in use, etc.)

. number of charging cycles

. expected remaining time that the battery can serve as power supply

. expected remaining lifetime of the battery

Beyond that a device containing a battery should be able to generate alarms when the battery charge falls below a given threshold and when the battery needs to be replaced.

5.5. Energy Control

Energy Objects can be controlled by setting it to a Power State. Power States Sets can be seen as an interface by which an Energy Object can be controlled. Each Energy Object should indicate the Power State Sets that it implements. Well known Power State Sets should be registered with IANA

When and individual Power State is configured from a specific Power State Set, an Energy Object may be busy at the request time. The Energy Object will set the desired state and then update the actual Power State when the priority task is finished. This mechanism implies two different Power State variables: actual versus desired

There are several standards and implementations of Power State Set. An Energy Object can support one or multiple Power State Set implementations concurrently.

This framework list three initial possible Power State Series that can be supported by an Energy Object:

IEEE1621 - [IEEE1621]

DMTF - [DMTF]

EMAN - Specified here

5.5.1 IEEE1621 Power State Series

The IEEE1621 Power State Series [IEEE1621] consists of 3 rudimentary states : on, off or sleep.

on(0) - The device is fully On and all features of the device are in working mode.

off(1) - The device is mechanically switched off and does not consume energy.

sleep(2) - The device is in a power saving mode, and some features may not be available immediately.

5.5.2 DMTF Power State Series

DMTF [DMTF] standards organization has defined a power profile standard based on the CIM (Common Information Model) model that consists of 15 power states ON (2), SleepLight (3), SleepDeep (4), Off-Hard (5), Off-Soft (6), Hibernate(7), PowerCycle Off-Soft (8), PowerCycle Off-Hard (9), MasterBus reset (10), Diagnostic Interrupt (11), Off-Soft-Graceful (12), Off-Hard Graceful (13), MasterBus reset Graceful (14), Power-Cycle Off-Soft Graceful (15), PowerCycle-Hard Graceful (16). DMTF standard is targeted for hosts and computers. Details of the semantics of each Power State within the DMTF Power State Series can be obtained from the DMTF Power State Management Profile specification [DMTF].

DMTF power profile extends ACPI power states. The following table provides a mapping between DMTF and ACPI Power State Series and EMAN Power State Sets (described in the next section):

State	DMTF Power State	ACPI State	EMAN Power State Name
Non-operational states:			
1	Off-Hard	G3, S5	MechOff
2	Off-Soft	G2, S5	SoftOff
3	Hibernate	G1, S4	Hibernate
4	Sleep-Deep	G1, S3	Sleep
5	Sleep-Light	G1, S2	Standby
6	Sleep-Light	G1, S1	Ready
Operational states:			
7	On	G0, S0, P5	LowMinus
8	On	G0, S0, P4	Low
9	On	G0, S0, P3	MediumMinus
10	On	G0, S0, P2	Medium
11	On	G0, S0, P1	HighMinus
12	On	G0, S0, P0	High

Figure 3: DMTF / ACPI Power State Mapping

5.5.3 EMAN Power State Set

The EMAN Power State Set represents an attempt for a uniform standard approach to model the different levels of Power of a device. The EMAN Power States are an expansion of the basic Power States as defined in [IEEE1621] that also incorporate the Power States defined in [ACPI] and [DMTF]. Therefore, in addition to the non-operational states as defined in [ACPI] and [DMTF] standards, several intermediate operational states have been defined.

There are twelve Power States, that expand on [IEEE1621] on, sleep and off. The expanded list of Power States are divided into six operational states, and six non-operational states. The lowest non-operational state is 1 and the highest is 6. Each non-operational state corresponds to an [ACPI] Global and System states between G3 (hard-off) and G1 (sleeping). For each operational state represent a performance state, and may be mapped to [ACPI] states P0 (maximum performance power) through P5 (minimum performance and minimum power).

In each of the non-operational states (from mechoff(1) to ready(6)), the Power State preceding it is expected to have a lower Power value and a longer delay in returning to an operational state:

IEEE1621 Power(off):

mechoff(1) : An off state where no Energy Object features are available. The Energy Object is unavailable. No energy is being consumed and the power connector can be removed. This corresponds to ACPI state G3.

softoff(2) : Similar to mechoff(1), but some components remain powered or receive trace power so that the Energy Object can be awakened from its off state. In softoff(2), no context is saved and the device typically requires a complete boot when awakened. This corresponds to ACPI state G2.

IEEE1621 Power(sleep)

hibernate(3): No Energy Object features are available. The Energy Object may be awakened without requiring a complete boot, but the time for availability is longer than sleep(4). An example for state hibernate(3) is a save to-disk state where DRAM context is not maintained. Typically, energy consumption is zero or close to zero. This corresponds to state G1, S4 in ACPI.

sleep(4) : No Energy Object features are available, except for out-of-band management, for example wake-up mechanisms. The time for availability is longer than standby(5). An example for state sleep(4) is a save-to-RAM state, where DRAM context is maintained. Typically, energy consumption is close to zero. This corresponds to state G1, S3 in ACPI.

standby(5) : No Energy Object features are available, except for out-of-band management, for example wake-up mechanisms. This mode is analogous to cold-standy. The time for availability is longer than ready(6). For example, the processor context is not maintained. Typically, energy consumption is close to zero. This corresponds to state G1, S2 in ACPI.

ready(6) : No Energy Object features are available, except for out-of-band management, for example wake-up mechanisms. This mode is analogous to hot-standby. The Energy Object can be quickly transitioned into an operational state. For example, processors are not executing, but processor context is maintained. This corresponds to state G1, S1 in ACPI.

IEEE1621 Power(on):

lowMinus(7) : Indicates some Energy Object features may not be available and the Energy Object has selected measures/options to provide less than low(8) usage. This corresponds to ACPI State G0. This includes operational states lowMinus(7) to full(12).

low(8) : Indicates some features may not be available and the Energy Object has taken measures or selected options to provideless than mediumMinus(9) usage.

mediumMinus(9): Indicates all Energy Object features are available but the Energy Object has taken measures or selected options to provide less than medium(10) usage.

medium(10) : Indicates all Energy Object features are available but the Energy Object has taken measures or selected options to provide less than highMinus(11) usage.

highMinus(11): Indicates all Energy Object features are available and power usage is less than high(12).

high(12) : Indicates all Energy Object features are available and the Energy Object is consuming the highest power.

6. Structure of the Information Model: UML Representation

The following basic UML represents an information model expression of the concepts in this framework. This information model, provided as a reference for implementers, is represented as an MIB in the different related IETF Energy Monitoring documents. However, other programming structure with different data models could be used as well.

Notation is a shorthand UML with lowercase types considered platform or atomic types (i.e. int, string, collection). Uppercase types denote classes described further. Collections and cardinality are expressed via qualifier notation. Attributes labeled static are considered class variables and global to the class. Algorithms for class variable initialization, constructors or destructors are not shown

EDITOR'S NOTE: the first part of the UML must be aligned with the latest [EMAN-AWARE-MIB] document version.

```
                EO RELATIONSHIPS AND CONTEXT

                              +-----------------------------+
                              | _Child Specific Info __     |
                              |-----------------------------|
+----------------------------+ |  parentId : UUID            |
|    Context Information     | |  parentProxyAbilities       |
|----------------------------| |           : bitmap          |
|  roleDescription : string  | | _mgmtMacAddress : octets    |
|  keywords[0..n] : string   | |  mgmtAddress : inetaddress  |
|  importance : int          | |  mgmtAddressType : enum     |
|  category :  enum          | |  mgmtDNSName : inetaddress  |
+----------------------------+ +-----------------------------+
          |                             |
          |                             |
          |                             |
```

```
             v                             v
     +-----------------------------------------+
     |  Energy Object Information              |
     |-----------------------------------------|
     | index : int                             |
     | energyObjectId | UUID                   |
     | name : string                           |
     | meterDomainName | string                |
     | alternateKey | string                   |
     +-----------------------------------------+
             ^
             |
             |
             |
   +-------------------------+
   |    Links Object         |
   |-------------------------|
   |  physicalEntity : int   |
   |  ethPortIndex : int     |
   |  ethPortGrpIndex : int  |
   |  lldpPortNumber : int   |
   +-------------------------+
```

```
                EO AND MEASUREMENTS


   +-----------------------------------------------+
   |                 Energy Object                 |
   |-----------------------------------------------|
   |  nameplate : Measurement                      |
   |  battery[0..n]: Battery                       |
   |  measurements[0..n]: Measurement              |
   | --------------------------------------------- |
   | Measurement instantaneousUsage()              |
   | DemandMeasurement historicalUsage()           |
   +-----------------------------------------------+

     +------------------------------------+
     |  Measurements                      |
     | __________________________________ |
     +------------------------------------+
                       ^
                       |
                       |
    +------------------+----------------------------+
    |         PowerMeasurement                      |
```

```
    |------------------------------------------------|
    | value : long                                   |
    | rate : enum {0,millisecond,seconds,            |
    |              minutes,hours,...}                |
    | multiplier : enum {-24..24}                    |
    | units : "watts"                                |
    | caliber : enum { actual, estimated,            |
    |                  trusted, assumed...}          |
    | accuracy : enum { 0..10000}                    |
    | current :  enum {AC, DC}                       |
    | origin : enum { self, remote }                 |
    | time : timestamp                               |
    | quality : PowerQuality                         |
    +------------------------------------------------+
                       |
                       |
    +------------------+-----------------------------+
    |        EnergyMeasurement                       |
    |------------------------------------------------|
    | consumed : long                                |
    | generated : long                               |
    | net : long                                     |
    | accuracy : enum { 0..10000}                    |
    +------------------------------------------------+


    +------------------------------------------------+
    |        TimeMeasurement                         |
    |------------------------------------------------|
    | startTime : timestamp                          |
    | usage : Measurement                            |
    | maxUsage : Measurement                         |
    +------------------------------------------------+
                       |
                       |
    +-----------------------------------------+
    |       TimeInterval                      |
    |--------------------------------------   |
    |value : long                             |
    |units : enum { seconds, miliseconds..}   |
    +-----------------------------------------+
                       |
                       |
    +-----------------------------------------+
    |       DemandMeasurement                 |
    |-----------------------------------------|
    |intervalLength :  TimeInterval           |
    |intervalNumbers: long                    |
```

```
    |intervalMode :  enum { period, sliding, |
    |total }                                 |
    |intervalWindow : TimeInterval           |
    |sampleRate : TimeInterval               |
    |status : enum {active, inactive }       |
    |measurements : TimedMeasurement[]       |
    +-----------------------------------------+


                  QUALITY

    +-----------------------------------------+
    |            PowerQuality                 |
    |-----------------------------------------|
    |                                         |
    +-----------------------------------------+
                       ^
                       |
                       |
    +------------------+--------------------+
    |         ACQuality                     |
    |---------------------------------------|
    | acConfiguration : enum {SNGL, DEL,WYE}|
    | avgVoltage   : long                   |
    | avgCurrent   : long                   |
    | frequency    : long                   |
    | unitMultiplier  : int                 |
    | accuracy  : int                       |
    | totalActivePower  : long              |
    | totalReactivePower : long             |
    | totalApparentPower : long             |
    | totalPowerFactor : long               |
    +---------+-----------------------------+
              | 1
              |
              |
              |
              |        +-------------------------------------+
              |        |         ACPhase                     |
              |     *  |-------------------------------------|
              +--------+ phaseIndex : long                   |
                       | avgCurrent : long                   |
                       | activePower : long                  |
                       | reactivePower : long                |
                       | apparentPower : long                |
                       | powerFactor : long                  |
                       +-------------------------------------+
```

```
                                 ^           ^
                                 |           |
                                 |           |
                                 |           |
                                 |           |
   +-------------------------------+---+       |
   |        DelPhase                   |       |
   |-----------------------------------|       |
   |phaseToNextPhaseVoltage  : long    |       |
   |thdVoltage : long                  |       |
   |thdCurrent : long                  |       |
   +-----------------------------------+       |
                                               |
                        +----------------+-----------+
                        |        WYEPhase              |
                        |------------------------------|
                        |phaseToNeutralVoltage : long  |
                        |thdCurrent : long             |
                        |thdVoltage : long             |
                        +------------------------------+



                    EO & STATES

      +---------------------------------------------+
      |             Energy Object                   |
      |---------------------------------------------|
      | currentLevel : int                          |
      | configuredLevel : int                       |
      | configuredTime : timestamp                  |
      | reason: string                              |
      | emanLevels[0..11] : State                   |
      | levelMappings[0..n] : LevelMapping          |
      +---------------------------------------------+

       +-------------------------------+
       |        State                  |
       |-------------------------------|
       | name : string                 |
       | cardinality : int             |
       | maxUsage : Measurement        |
       +-------------------------------+
```

Figure 8: Information Model UML Representation

7. Configuration

This power management framework allows the configuration of the following key parameters:

- Energy Object name: A unique printable name for the Energy Object.
- Energy Object role: An administratively assigned name to indicate the purpose an Energy Object serves in the network.
- Energy Object importance: A ranking of how important the Energy Object is, on a scale of 1 to 100, compared with other Energy Objects in the same Energy Management Domain.
- Energy Object keywords: A list of keywords that can be used to group Energy Objects for reporting or searching.
- Energy Management Domain: Specifies the name of an Energy Management Domain for the Energy Object.
- Energy Object Power State: Specifies the current Power State (0..12) for the Energy Object.
- Demand parameters: For example, which interval length to report the Deman over, the number of intervals to keep, etc.
- Assigning an Energy Object Parent to an Energy Object Child
- Assigning an Energy Object Child to an Energy Object Parent.

This framework supports multiple means for setting the Power State of a specific Energy Object. However, the Energy Object might be busy executing an important task that requires the current Power State for some more time. For example, a PC might have to finish a backup first, or an IP phone might be busy with a current phone call. Therefore a second value contains the actual Power State. A difference in values between the two objects indicates that the Energy Object is currently in Power State transition.

Other, already well established means for setting Power States, such as DASH [DASH], already exist. Such a protocol may be implemented between the Energy Object Parent and the Energy Object Child, when the Energy Object Parent acts as a Proxy.

Note that the Wake-up-on-Lan (WoL) mechanism allows to transition a device out of the Off Power State.

8. Fault Management

[EMAN-REQ] specifies some requirements about Power States such as "the current state - the time of the last change", "the total time spent in each state", "the number of transitions to each state", etc. Such requirements are fulfilled via the pmPowerStateChange NOTIFICATION-TYPE [EMAN-MON-MIB]. This SNMP notification is generated when the value(s) of Power State has changed for the Energy Object.

Regarding high and low thresholding mechanism, the RMON alarm and event [RFC2819] allows to periodically takes statistical samples from Energy Object variables, compares them to previously configured thresholds, and to generate an event (i.e. an SNMP notification) if the monitored variable crosses a threshold. The RMON alarm can monitor variables that resolve to an ASN.1 primitive type of INTEGER (INTEGER, Integer32, Counter32, Counter64, Gauge32, or TimeTicks), so basically most the variables in [EMAN-MON-MIB].

9. Relationship with Other Standards Development Organizations

9.1. Information Modeling

This power management framework should, as much as possible, reuse existing standards efforts, especially with respect to information modeling and data modeling [RFC3444].

The data model for power, energy related objects is based on IEC 61850.

Specific examples include:

- The scaling factor, which represents Energy Object usage magnitude, conforms to the IEC 61850 definition of unit multiplier for the SI (System International) units of measure.

- The electrical characteristic is based on the ANSI and IEC Standards, which require that we use an accuracy class for power measurement. ANSI and IEC define the following accuracy classes for power measurement:

. IEC 62053-22 60044-1 class 0.1, 0.2, 0.5, 1 3.

. ANSI C12.20 class 0.2, 0.5

- The electrical characteristics and quality adheres closely to the IEC 61850 7-2 standard for describing AC measurements.

- The power state definitions are based on the DMTF Power State Profile and ACPI models, with operational state extensions.

10. Security Considerations

Regarding the data attributes specified here, some or all may be considered sensitive or vulnerable in some network environments. Reading or writing these attributes without proper protection such as encryption or access authorization may have negative effects on the network capabilities.

10.1. Security Considerations for SNMP

Readable objects in a MIB modules (i.e., objects with a MAX-ACCESS other than not-accessible) may be considered sensitive or vulnerable in some network environments. It is thus important to control GET and/or NOTIFY access to these objects and possibly to encrypt the values of these objects when sending them over the network via SNMP.

The support for SET operations in a non-secure environment without proper protection can have a negative effect on network operations. For example:

- Unauthorized changes to the Power Domain or business context of an Energy Object may result in misreporting or interruption of power.
- Unauthorized changes to a power state may disrupt the power settings of the different Energy Objects, and therefore the state of functionality of the respective Energy Objects.
- Unauthorized changes to the demand history may disrupt proper accounting of energy usage.

With respect to data transport SNMP versions prior to SNMPv3 did not include adequate security. Even if the network itself is secure (for example, by using IPsec), there is still no secure control over who on the secure network is allowed to access and GET/SET (read/change/create/delete) the objects in these MIB modules.

It is recommended that implementers consider the security features as provided by the SNMPv3 framework (see [RFC3410], section 8), including full support for the SNMPv3 cryptographic mechanisms (for authentication and privacy).

Further, deployment of SNMP versions prior to SNMPv3 is not recommended. Instead, it is recommended to deploy SNMPv3 and to enable cryptographic security. It is then a customer/operator responsibility to ensure that the SNMP entity giving access to an instance of these MIB modules is properly configured to give access to the objects only to those principals (users) that have legitimate rights to GET or SET (change/create/delete) them.

11. IANA Considerations

Initial values for the Power State Sets, together with the considerations for assigning them, are defined in [EMAN-MON-MIB].

12. Acknowledgments

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Authors' Addresses

Benoit Claise
Cisco Systems, Inc.
De Kleetlaan 6a b1
Diegem 1813
BE

Phone: +32 2 704 5622
Email: bclaise@cisco.com

John Parello
Cisco Systems, Inc.

3550 Cisco Way
San Jose, California 95134
US

Phone: +1 408 525 2339
Email: jparello@cisco.com

Brad Schoening
44 Rivers Edge Drive
Little Silver, NJ 07739
US

Phone:
Email: brad@bradschoening.com

Juergen Quittek
NEC Europe Ltd.
Network Laboratories
Kurfuersten-Anlage 36
69115 Heidelberg
Germany

Phone: +49 6221 90511 15
EMail: quittek@netlab.nec.de

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J. Quittek, Ed.
R. Winter
T. Dietz
NEC Europe Ltd.
B. Claise
M. Chandramouli
Cisco Systems, Inc.
November 1, 2011

Requirements for Energy Management
draft-ietf-eman-requirements-05

Abstract

This document defines requirements for standards specifications for energy management. The requirements presented in this document include monitoring functions as well as control functions. In detail, the focus of the requirements is on the following features: identification of powered entities, monitoring of their power state, power inlets, power outlets, actual power, power quality, consumed energy, and contained batteries. Further, requirements are included to enable control of powered entities' power supply and power state. This document does not specify the features that must be implemented by compliant implementations but rather features that must be supported by standards for energy management.

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1. Introduction

With rising energy cost and with an increasing awareness of the ecological impact of running IT and networking equipment, energy management is becoming an additional basic requirement for the network devices and the associated network management systems.

This document defines requirements for standards specifications for energy management. This doccument contains the requirements that concern monitoring functions as well as control functions. In detail, the requirements listed are focussed on the following features: identification of powered entities, monitoring of their power state, power inlets, power outlets, actual power, power quality, consumed energy, and contained batteries. Further included is control of powered entities' power supply and power state.

The main subject of energy management are powered entities that consume electric energy. Powered entities include devices that have an IP address and can be addressed directly, such as hosts, routers, and middleboxes, as well as devices indirectly connected to an IP network, for which a proxy with an IP address provides a management interface, for example, devices in a building management infrastructure using the BACnet [ANSI/ASHRAE-135-2010] or MODBUS [MODBUS-Protocol] protocols.

The requirements specified in this document explicitly concern the standards specification process and not the implementation of specified standards. All requirements in this document must be reflected by standards specifications to be developed. But which of the features specified by these standards will be mandatory, recommended, or optional for compliant implementations is to be defined by the concrete standards track document(s) and not in this document.

This document first elaborates a set of general considerations related to energy management in Section 3. Requirements for an energy management standard are specified in Sections 4 to 8.

Sections 4 to 6 contain rather conventional requirements specifying which information on powered entities needs to be covered by an energy management standard, and which control functions are needed.

Sections 7 and 8 contain requirements that are very specific to energy management. They result from the fact that due to the nature of power supply, some of the monitoring and control functions are not conducted by interacting with the powered entity of interest, but with other entities, for example, with entities upstream in the power distribution tree.

1.1. Conventional requirements for energy management

The specification of requirements for an energy management standard starts with Section 4 addressing the identification of powered entities and the granularity of reporting of energy-related information. A standard must support unique identification of powered entities. Furthermore, it must support more than just reporting per powered device. Support is required for also reporting energy-related information on individual components of a device or subtended devices. This is why this draft uses the more general term "powered entity" rather than "powered device". A powered entity may be a device or a component of a device.

Section 5 specifies requirements related to monitoring of powered entities. This includes general (type, context) information and specific information on power states, power inlets, power outlets, power, energy, and batteries. Control power state and power supply of powered entities is covered by requirements specified in Section 6.

1.2. Specific requirements for energy management

At first glance the rather conventional requirements summarized above seem to be all that would be needed for energy management. But it turns out that there are some significant differences between energy management and most of the well known conventional network management functions. The most significant difference from many other management functions is the need for some devices to report on other entities. There are three major reasons for this.

- o For monitoring a particular powered entity in general it is not sufficient to communicate with the powered entity only, particularly if the powered entity has no instrumentation for measuring power. In such cases it might still be possible to obtain power values for the entity by communication with other entities in the same power distribution tree.
  A very simple example would be retrieving power values from a dedicated power meter at the power line of the powered entity. More common examples are a Power Distribution Unit (PDU) and a Power over Ethernet (PoE) switch. Both supply power to other entities at sockets or ports, respectively, and are often instrumented to measure power per socket or port.
- o Similar considerations apply to controlling power supply of a powered entity which often needs direct or indirect communication with another entity upstream in the power distribution tree. Again, a PDU and a PoE switch are common examples, if they have the capability to switch on or off power at their sockets or ports, respectively.

- o Energy management often extends its scope beyond powered entities with IP network interfaces, for example toward non-IP building networks, that are accessed via an IP gateway. Requirements in this document do not fully cover all these networks, but they cover means for opening IP network management towards them.
- o For monitoring of particular powered entities, it is sometimes not a scalable approach to communicate directly with all the powered entities directly from a central energy management system as the number of powered entities keeps increasing.

This specific issue of energy management and a set of further ones are covered by requirements specified in Sections 7 and 8.

For meeting the requirements specified in these sections first a new energy management framework needs to be specified that gives directions on how to deal with the specific nature of energy management. Based on such a framework, energy management standards can be specified that meet the requirements below. The actual standards documents, such as, for example, MIB module specifications, will address conformance issues by specifying which feature must, should, or may to be implemented by compliant implementations.

2. Terminology

Terminology to be used by the eman WG is currently discussed in [I-D.parello-eman-definitions]. After final definitions of terms have been agreed, they will be listed here.

3. General Considerations Related to Energy Management

The basic objective of energy management is operating sets of devices with minimal amount of energy, while maintaining a certain level of service. A set of use cases and the target devices for the application of energy management can be found in [I-D.tychon-eman-applicability-statement].

3.1. Power states

One approach to achieve this goal is by setting all powered entities to an operational state that results in lower energy consumption, but still meets the service level performance objectives. The sufficient performance level may vary over time and can depend on several factors. In principle, there are four basic types of power states for a powered entity or for a whole system:

- full power state
- reduced power states (lower clock rate for processor, lower data rate on a link, etc.)
- sleep state (not functional, but immediately available)
- off state (may imply requiring significant time for becoming operational)

In actual implementations the number of power states and their properties vary a lot. Very simple powered entities may just have only the extreme states, full power and off state. Some implementations might use the IEEE 1621 [IEEE-1621] model of three states on, off, and sleep. However, more finely grained power states can be implemented with many levels of off, sleep, and reduced power states.

3.2. Saving energy versus maintaining service level agreements

While the general objective of energy management is quite clear, the way to attain that goal is often difficult. In many cases there is no way of reducing power consumption without the consequence of a potential performance, service, or capacity degradation. Then a trade-off needs to be dealt with between service level objectives and energy efficiency. In other cases a reduction of energy consumption can easily be achieved while still maintaining sufficient service level performance, for example, by switching powered entities to lower power states when higher performance is not needed.

3.3. Local versus network-wide energy management

Many energy saving functions can be executed locally by a powered entity. The basic principle is that a powered entity monitors its usage and dynamically adapts its energy consumption according to the required performance. It may, for example, switch to a sleep state when it is not in use or out of scheduled business hours. Potential interactions with an energy management system for such an entity include the observation of the entity’s power state and the configuration of power saving policies, for example, by setting thresholds or schedules for power state changes.

Energy savings can also be achieved with policies implemented by a network management system that controls power states of managed entities. In order to make policy decisions properly, information about the energy consumption of powered entities in different power states is required. Often this information is acquired best through monitoring.

Both methods, network-wide and local energy management, have advantages and disadvantages and often it is a good choice to combine them. Central management is often favorable for setting power states of a large number of entities at the same time, for example, at beginning and end of business hours in a building. Local management appears often to be preferable for dynamic power saving measures based on local observations, such as high or low load of an entity.

3.4. Energy monitoring versus energy saving

It should be noted that only monitoring energy consumption and power states is obviously not a means to reduce the energy consumption of a powered entity. In fact, it is likely to increase the power consumption of a powered entity slightly because monitoring energy may require instrumentation that consumes energy when in use. And also reporting of measured quantities over the network consumes energy. However, the acquired energy consumption and power state information is essential for defining energy saving policies and can be used as input to power state control loops that in total can lead to energy savings.

Monitoring operational power states and energy consumption can also be required for other energy management purposes including but not limited to:

- investigating power saving potential
- evaluating the effectiveness of energy saving policies and measures
- deriving, implementing, and testing power management strategies
- accounting for the total power consumption of a powered entity, a network, or a service
- predicting a powered entity’s reliability based on power usage
- choosing time of next maintenance cycle for a powered entity

3.5. Overview of energy management requirements

From the considerations described above the following basic management functions appear to be required for energy management:

- monitoring power states
- monitoring power (energy consumption rate)
- monitoring (accumulated) energy consumption
- monitoring power quality
- setting power states
- setting and enforcing power saving policies

It should be noted that power control is complementary (but essential) to other energy savings measures such as low power electronics, energy saving protocols (for example, Energy-Efficient Ethernet [IEEE-802.3az]), energy-efficient device design (for example, sleep and low-power modes for individual components of a device), and energy-efficient network architectures. Measurement of energy consumption may also provide useful input for developing these technologies.

4. Identification of Powered Entities

As already stated in Section 1.1, powered entities on which energy-related information is provided, are identified in a sufficiently unique way. This holds in particular for powered entities that are components of managed devices and in case that one powered entity reports information on another one, see Section 7. For powered entities that control other powered entities it is important to identify the powered entities they control, see Section 8.

Also stated already in Section 1.1 is the requirement of providing means for reporting energy-related information on components of a managed device. An entity in this document may be an entire managed device or just a component of it. Examples of components of interest are a hard drive, a battery, or a line card. For controlling entities it may be required to be able to address individual components in order to save energy. For example, server blades can be switched off when the overall load is low or line cards at switches may be powered down at night times.

Identifiers to other devices and to components of devices are already defined in standard MIB modules, such as the LLDP MIB module [IEEE-802.1AB] and the LLDP-MED MIB module [ANSI/TIA-1057] for devices and the Entity MIB module [RFC4133] and the Power Ethernet MIB [RFC3621] for components of devices. For energy management it is necessary to have means for linking energy-related information to such identifiers.

Instrumentation for measuring energy consumption of a device is typically more expensive than instrumentation for retrieving the devices power state. It may be a reasonable compromise in many cases to provide power state information for all individually switchable components of a device separately, while the energy consumption is only measured for the entire device.

Detailed Requirements:

4.1. Identifying powered entities

The energy management standard must provide means for uniquely identifying powered entities that are monitored or controlled by an energy management system. Uniqueness must be preserved in a domain that is large enough to avoid collisions of identities at potential receivers of monitored information.

4.2. Identifying components of powered devices

The energy management standard must provide means for identifying individual sub-components of powered devices.

4.3. Persistency of identifiers

The energy management standard must provide means for indicating whether identifiers of powered entities are persistent across a re-start of the powered entity.

4.4. Using entity identifiers of other MIB modules

The energy management standard must provide means for re-using entity identifiers from other standards including at least the following:

- o the LldpPortNumber in the LLDP MIB module [IEEE-802.1AB]and in the LLDP-MED MIB module [ANSI/TIA-1057]
- o the entPhysicalIndex in the Entity MIB module [RFC4133]
- o the pethPsePortIndex and the pethPsePortGroupIndex in the Power Ethernet MIB [RFC3621]

Additionally, generic means for re-using further entity identifiers must be provided.

5. Information on Powered Entities

This section describes energy-related information on powered entities for which an energy management standard must provide means for retrieving and reporting.

Required information on powered entities can be structured into six groups. Section 5.1 specifies requirements for general information on powered entities, such as type of powered entity or context information. Section 5.2 covers requirements related to entities' power states. Requirements for information on power inlets and power outlets of powered entities are specified in Section 5.3. Monitoring of power and energy is covered by Sections 5.4 and 5.5, respectively. Finally, Section 5.6 specified requirements for monitoring batteries.

5.1. General information on powered entities

For energy management it may be required to understand the role and context of a powered entity. From the point of view of monitoring and management of a large network perspective, it may be helpful to aggregate the energy consumption according to a defined grouping of entities. When controlling and setting power states it may be helpful to understand the the grouping of the entity and role of a powered entity in a network, for example, in order to avoid switching off vital network components.

Detailed Requirements:

5.1.1. Type of powered entity

The energy management standard must provide means to retrieve and report the type of powered entities according to a standardized classification scheme.

YCM --- This issue has been discussed and the feeling was that type may not be needed and thus it is better to drop this requirement. --- YCM

The energy management standard must provide means to configure, retrieve and report a textual name or a description of a powered entity. In addition to the unique identity, such a textual description shall be useful.

5.1.2. Context information on powered entities

The energy management standard must provide means for retrieving and reporting context information on powered entities, for example, tags associated with a powered entity that indicate the powered entity’s role, or importance.

5.1.3. Grouping of powered entities

The energy management standard must provide means for grouping powered entities, for example, into energy monitoring domains, energy control domains, power supply domains, groups of powered entities of the same type, etc.

5.2. Power state

Many powered entities have a limited number of discrete power states, such as, for example, full power, low power, sleep, and off.

Obviously, there is a need to report the actual power state of a powered entity. Beyond that, there is also a requirement for standardizing means for retrieving the list of all supported power states of a powered entity.

Presently, different standards bodies have already defined their own sets of power states for some powered entities. Beyond those, other standards organizations are in the process of adding more of these power state sets for the devices considered in their scope. Given this context, it is desirable that the energy management standard shall be interoperable across these multiple power state standards. In order to support multiple management systems possibly using different power state sets, while simultaneously interfacing with a particular powered entity, the energy management standard must provide means for supporting multiple power state sets used simultaneously at a powered entity.

Power states have parameters that describe its properties. It is required to have standardized means for reporting some key properties, such as average power and maximum power of a powered entity in a certain state.

There also is a need to report statistics on power states including the time spent and the energy consumed in a power state.

For some network management tasks, it may be desirable to receive notifications from powered entities, for example, when the entire entity or some of the components of the entity change their power state.

Detailed Requirements:

5.2.1. Actual power state

The energy management standard must provide means for reporting the actual power state of a powered entity.

5.2.2. List of supported power states

The energy management standard must provide means for retrieving the list of all potential power states of a powered entity.

5.2.3. Multiple power state sets

The energy management standard must provide means for supporting multiple power state sets simultaneously at a powered entity.

5.2.4. List of supported power state sets

The energy management standard must provide means for retrieving the list of all power state sets supported by a powered entity.

5.2.5. List of supported power states within a set

Referring to the "list of supported power state sets" requirement, the energy management standard must provide means for retrieving the list of all potential power states of a powered entity that belong to a given power state set.

5.2.6. Maximum and average power per power state

The energy management standard must provide means for retrieving the maximum power and the average power as a for each supported power state. These values may be static properties of a power state.

5.2.7. Power state statistics

The energy management standard must provide means for monitoring statistics per power state including at least the total time spent in a power state, the number of times a state was entered and the last time a state was entered. More power state statistics are addressed by requirement 5.5.3.

5.2.8. Power state changes

The energy management standard must provide means for generating a notification when the actual power state of a powered entity changes.

5.3. Power inlet and power outlet

Powered entities have power inlets at which they are supplied with electric power. Most powered entities just have a single power inlet, while some have multiple ones. Often different power inlets are connected to separate power distribution trees. For energy monitoring, it is useful to retrieve information on the number of inlets of a powered entity, the availability of power at inlets and which of them are actually in use.

Some powered entities have power outlets for supplying other powered entities with electric power. A powered entity may have multiple power outlets.

For identifying and potentially controlling the source of power received at an inlet, it may be required to identify the power outlet of another powered entity at which the received power is provided. Analogously, for each outlet it is of interest to identify the power inlets that receive the power provided at a certain outlet.

Static properties of each power inlet and each power outlet are required information for energy management. Static properties include the kind of electric current (Alternating Current (AC) or Direct Current (DC)), the nominal voltage, the nominal AC frequency, and the number of AC phases.

Detailed Requirements:

5.3.1. List of power inlets and power outlets

The energy management standard must provide means for monitoring the list of power inlets and power outlets at a powered entity.

5.3.2. Corresponding power outlet

The energy management standard must provide means for identifying the power outlet that provides the power received at a power inlet.

5.3.3. Corresponding power inlets

The energy management standard must provide means for identifying the list of power inlets that receive the power provided at a power outlet.

5.3.4. Availability of power

The energy management standard must provide means for monitoring the availability of power at each power inlet and at each power outlet. This information indicates whether at a power providing outlet power supply is switched on or off.

5.3.5. Use of power

The energy management standard must provide means for monitoring for each power inlet and each power outlet if it is in actual use. For the inlet this means that the powered entity actually receives power at the inlet. For the outlet this means that power is actually provided to one or more powered entities at the outlet.

5.3.6. Type of current

The energy management standard must provide means for reporting the type of current (Alternating Current (AC) or Direct Current (DC)) for each power inlet and each power outlet of a powered entity.

5.3.7. Nominal voltage

The energy management standard must provide means for reporting the nominal voltage for each power inlet and each power outlet of a powered entity.

5.3.8. Nominal AC frequency

The energy management standard must provide means for reporting the nominal AC frequency for each power inlet and each power outlet of a powered entity.

5.3.9. Number of AC phases

The energy management standard must provide means for reporting the number of AC phases for each power inlet and each power outlet of a powered entity.

5.4. Power

Power is a quantity measured as instantaneous power or as average power over a time interval. In contrast to power state values, this quantity may change continuously.

Obtaining highly accurate values for power and energy may be costly. Often dedicated metering hardware is needed for this purpose. Powered entities without the ability to measure their power and energy consumption with high accuracy may just report estimated values, for example based on load monitoring or even just the entity type. Measuring and estimating power must be sensitive to detect and report if the energy is consumed or produced.

Depending on how power and energy consumption values are obtained the confidence in the reported value and its accuracy may vary. Powered entities reporting such values should qualify the confidence in the reported values and quantify the accuracy of measurements. For reporting accuracy, the accuracy classes specified in IEC 62053-21 [IEC.62053-21] and IEC 62053-22 [IEC.62053-22] should be considered.

In addition to the plain real power measurements, qualitative properties of the supplied power are of interest from a monitoring point of view. In case of AC power supply, there are more power values beyond the real power to be reported including the apparent power, the reactive power, and the phase angle of the current or the power factor. For both AC and DC power the power quality is also subject of monitoring. Power quality parameters include the actual voltage, the actual frequency, the Total Harmonic Distortion (THD) of voltage and current, the impedance of an AC phase or of the DC supply. Power quality monitoring should be in line with existing standards, such as [IEC.61850-7-4].

For some network management tasks, it is required to obtain time series of power values (or energy consumption values). In general these could be obtained in many different ways. It should be avoided that such time series can only be obtained by regular polling by the energy management system. Means should be provided to either push such values from the place they are available to the management system or to have them stored at the powered entity for a sufficiently long period of time such that a management system can retrieve a stored time series of values.

Detailed Requirements:

5.4.1. Real power

The energy management standard must provide means for reporting the real power for each power inlet and each power outlet of a powered entity, including whether the energy is produced or consumed.

5.4.2. Power measurement interval

The energy management standard must provide means for reporting the corresponding time or time interval for which a power value is reported. The power value can be measured at the corresponding time or averaged over the corresponding time interval.

5.4.3. Power measurement method

The energy management standard must provide means to indicating the method how these values have been obtained. Based on how the measurement was obtained, it is possible to associate a certain degree of confidence on the reported power value. For example, there are methods of measurement such as direct power measurement, or by estimation based on performance values, or hard coding average power values for a powered entity.

5.4.4. Accuracy of power and energy values

The energy management standard must provide means for reporting the accuracy of reported power values.

5.4.5. Complex power

The energy management standard must provide means for reporting the complex power for each power inlet and each power outlet of a powered entity. Besides the real power, at least two out of the following three quantities need to be reported: apparent power, reactive power, phase angle. The phase angle can be substituted by the power factor. In case of AC power supply, means must be provided for reporting the complex power per phase.

5.4.6. Actual voltage and current

The energy management standard must provide means for reporting the actual voltage and actual current for each power inlet and each power outlet of a powered entity. In case of AC power supply, means must be provided for reporting the actual voltage and actual current per phase.

5.4.7. Actual AC frequency

The energy management standard must provide means for reporting the actual AC frequency for each power inlet and each power outlet of a powered entity.

5.4.8. Total harmonic distortion

The energy management standard must provide means for reporting the Total Harmonic Distortion (THD) of voltage and current for each power inlet and each power outlet of a powered entity. In case of AC power supply, means must be provided for reporting the THD per phase.

5.4.9. Power supply impedance

The energy management standard must provide means for reporting the impedance of power supply for each power inlet and each power outlet of a powered entity. In case of AC power supply, means must be provided for reporting the impedance per phase.

5.4.10. Time series of power values

The energy management standard must provide means for collecting time series of real power values for each power inlet and for each power outlet of a powered entity without requiring to regularly poll the powered entity from an energy management station. A solution for this is that the concerned powered entity or another powered entity closely interacting with the concerned powered entity collect time series of power values and make them available via push or pull mechanisms to receivers of the information.

5.5. Energy

Monitoring of electrical energy consumed (or converted) at a powered entity can be done in various ways. One is collecting time series of power values for the powered entity and calculating the consumed energy from these values. An alternative is the powered entity itself or another powered entity taking care of energy measurement and reporting energy consumption values for certain time intervals. Time intervals of interest are the time from the last restart of the powered entity to the reporting time, the time from another past event to the reporting time, or the last given amount of time before the reporting time.

In order to monitor energy consumption in different power states, it is useful if powered entities record their energy consumption per power state and report these quantities.

For some network management tasks, it is required to obtain time series of energy values. In general these could be obtained in many different ways. It should be avoided that such time series can only be obtained by regular polling by the energy management system. Means should be provided to either push such values from the place they are available to the management system or to have them stored at the powered entity for a sufficiently long period of time such that a management system can retrieve a stored time series of values.

Detailed Requirements:

5.5.1. Energy

The energy management standard must provide means for reporting the consumed energy received at a power input or provided at a power outlet of a powered entity. Reports must be made for a clearly specified time interval.

5.5.2. Time intervals

The energy management standard must provide means for reporting the consumed energy of a powered entity for certain time intervals.

- o Reports must be supported for the time interval starting at the last restart of the powered entity and ending at a certain point in time, such as the time when a report was delivered.
- o Reports must be supported for a sequence of consecutive non-overlapping time intervals of fixed size (periodic reports).
- o Reports must be supported for a sequence of consecutive overlapping time intervals of fixed size (periodic reports).
- o Reports must be supported for an interval of given length ending at a certain point in time, such as the time when a report was delivered (sliding window)

5.5.3. Energy per power state

The energy management standard must provide means for reporting the consumed energy individually for each power state. This extends the requirement 5.2.7 on power state statistics.

5.5.4. Time series of energy values

The energy management standard must provide means for collecting time series of energy values for each power inlet and for each power outlet of a powered entity without requiring to regularly poll the powered entity from an energy management station. A solution for this is that the concerned powered entity or another powered entity closely interacting with the concerned powered entity collect time series of energy values and make them available via push or pull mechanisms to receivers of the information.

5.6. Battery state

Today more and more powered entities contain batteries that supply them with power when disconnected from electrical power distribution grids. Common examples are nomadic and mobile devices, such as notebook computers, netbooks, and smart phones. The status of batteries in such a powered entity, particularly the charging status is typically controlled by automatic functions that act locally on the powered entity and manually by users of the powered entity. In addition to this, there is a need to monitor the battery status of these entities by network management systems.

The management requirements discussed above in Sections 5.1 to 5.5 concern energy-related information on powered entities. Devices containing batteries can be modeled in two ways. The entire device can be modeled as a single powered entity on which energy-related information is reported or the battery can be modeled as an individual powered entity for which energy-related information is monitored individually according to requirements in Sections 5.1 to 5.5.

In both cases further information on batteries is of interest for energy management, such as the current charge of the battery, the number of completed charging cycles, the charging state of the battery, and further static and dynamic battery properties. Also desirable is to receive notifications if the charge of a battery becomes very low or if a battery needs to be replaced.

Detailed Requirements:

5.6.1. Battery charge

The energy management standard must provide means for reporting the current charge of a battery.

5.6.2. Battery charging state

The energy management standard must provide means for reporting the charging state (charging, discharging, etc.) of a battery.

5.6.3. Battery charging cycles

The energy management standard must provide means for reporting the number of completed charging cycles of a battery.

5.6.4. Actual battery capacity

The energy management standard must provide means for reporting the actual capacity of a battery.

5.6.5. Static battery properties

The energy management standard must provide means for reporting static properties of a battery, including the nominal capacity, the number of cells, the nominal voltage, and the battery technology.

5.6.6. Low battery charge notification

The energy management standard must provide means for generating a notification when the charge of a battery decreases below a given threshold.

5.6.7. Battery replacement notification

The energy management standard must provide means for generating a notification when the number of charging cycles of battery exceeds a given threshold.

5.6.8. Multiple batteries

The energy management standard must provide means for meeting requirements 5.6.1 to 5.6.7 for each individual battery contained in a single powered entity.

5.7. Notifications

Often it is needed to check if values of monitored energy-related quantities rise or fall above or below certain thresholds. In such cases, polling these values is a very inefficient way. Preferable, values should be checked locally and notifications should be send when thresholds get exceeded. This can be achieved by using generic mechanism that are not specific to energy management.

Detailed Requirement:

5.7.1. High/low value notifications

The energy management standard must provide means for creating notifications if values of measured quantities are above or below given thresholds.

6. Control of Powered Entities

Many powered entities control their power state locally by self-managed dynamic adaptation to the environment. But other powered entities without that capability need interfaces for a energy management system to control their power states in order to save energy. Even for self-managed powered entities such interfaces may be required for configuring local policy parameters and for overruling local policy decisions by global ones from an energy management system.

Power supply is typically not self-managed by powered entities. And controlling power supply is typically not conducted as interaction between energy management system and the powered entity itself. It is rather an interaction between the management system and an entity providing power at its power outlets. Similar to power state control, power supply control may be policy driven. Note that shutting down the power supply abruptly may have severe consequences for the powered entity.

Detailed Requirement:

6.1. Controlling power states

The energy management standard must provide means for setting power states of powered entities.

6.2. Controlling power supply

The energy management standard must provide means for switching power supply off or turning power supply on at power outlets providing power to one or more powered entity.

7. Reporting on Other Powered Entities

As already discussed in the introduction of Section 5, not all energy-related information may be available at the concerned powered entity. Such information may be provided by other powered entities, such as a Power Distribution Unit (PDU), external power meter, or a Power over Ethernet (PoE) Power Sourcing Equipment (PSE). Some of these entities (PDU, PSE) can also control the power provided to the other powered entities, while some can just report on the remote powered entities (external power meter). This section covers reporting of information (monitoring) only. See Section 8 for requirements on controlling other powered entities.

There are cases where a power supply unit switches power for several powered entities by turning power on or off at a single power outlet or where a power meter measures the accumulated power of several powered entities at a single power line. Consequently, it should be possible to report that a monitored value does not relate to just a single powered entity, but is an accumulated value for a set of powered entities. All of these powered entities belonging to that set need to be identified.

If a powered entity has information about where energy-related information on itself can be retrieved, then it would be very useful if it has a way to communicate this information to an energy management system. This applies even if the information only provides accumulated quantities for several powered entities.

Detailed Requirements:

7.1. Reports on other powered entities

The energy management standard must provide means for a powered entity to report energy-related information on another powered entity.

7.2. Identity of other powered entities on which is reported

For entities that report on one or more other entities, the energy management standard must provide means for reporting the identity of another powered entity on which energy-related information is reported.

7.3. Reporting quantities accumulated over multiple powered entities

For entities that report quantities accumulated over multiple powered entities, the energy management standard must provide means for reporting the list of all powered entities from which contributions are included in an accumulated value.

7.4. List of all powered entities on which is reported

For entities that report on other entities, the energy management standard must provide means for reporting the complete list of those powered entities on which energy-related information can be reported.

7.5. Content of reports on other powered entities

For entities that report on other entities, the energy management standard must provide means for indicating which energy-related information it can reported for which of those powered entities.

7.6. Indicating source of remote information

For an entity that has one or more other entities reporting on it, the energy management standard must provide means for the entity to indicate which information is available at which other entities.

7.7. Indicating content of remote information

For an entity that has one or more other entities reporting on it, the energy management standard must provide means for indicating the content that other designated entities can report on it.

8. Controlling Other Powered Entities

This section specifies requirements for controlling power states and power supply of powered entities by communicating not with these powered entities themselves, but with other powered entities that have means for controlling power state or power supply of others.

8.1. Controlling power states of other powered entities

Some powered entities may have control of power states of other powered entities. For example a gateway to a building network may have means to control the power state of powered entities in the building that do not have an IP interface. For this scenario and other similar cases means are needed to make this control accessible to the energy management system.

In addition to this, it is required that a powered entity that has its state controlled by other powered entities has means to report the list of these other powered entities.

Detailed Requirements:

8.1.1. Control of power states of other powered entities

The energy management standard must provide means for an energy management system to send power state control commands to a powered entity that concern the power states of other powered entities than the one the command was sent to.

8.1.2. Identity of other power state controlled entities

The energy management standard must provide means for reporting the identities of the powered entities for which the reporting powered entity has means to control their power states.

8.1.3. List of all power state controlled entities

The energy management standard must provide means for a powered entity to report the list of all powered entities for which it can control the power state.

8.1.4. List of all power state controllers

The energy management standard must provide means for a powered entity that receives commands controlling its power state from other powered entities to report the list of all those entities.

8.2. Controlling power supply of other powered entities

Some powered entities may have control of the power supply of other powered entities, for example, because the other powered entity is supplied via a power outlet of the powered entity. For this and similar cases means are needed to make this control accessible to the energy management system.

In addition to this, it is required that a powered entity that has its supply controlled by other powered entities has means to report the list of these other powered entities.

Detailed Requirements:

8.2.1. Control of power supply of other powered entities

The energy management standard must provide means for an energy management system to send power supply control commands to a powered entity that concern the power supply of other powered entities than the one the command was sent to.

8.2.2. Identity of other power supply controlled powered entities

The energy management standard must provide means for reporting the identity of another powered entity for which the reporting powered entity has means to control the power supply.

8.2.3. List of all power supply controlled powered entities

The energy management standard must provide means for a powered entity to report the list of all other powered entities for which it can control the power supply.

8.2.4. List of all power supply controllers

The energy management standard must provide means for a powered entity that has other powered entities controlling its power supply to report the list of all those powered entities.

9. Security Considerations

Controlling power state and power supply of powered entities are highly sensitive actions since they can significantly affect the operation of directly and indirectly affected devices. Therefore all control actions addressed in Sections Section 6 and Section 8 must be sufficiently protected through authentication, authorization, and integrity protection mechanisms.

Monitoring energy-related quantities of a powered entity addressed in Sections Section 5 - Section 8 can be used to derive more information than just the consumed power. Therefore, monitored data requires privacy protection. Since the monitored data may be used as input to control, accounting, and other actions, integrity of transmitted information and authentication of the origin may be needed.

Detailed Requirements:

9.1. Secure energy management

The energy management standard must provide privacy, integrity, and authentication mechanisms for all actions addressed in Sections Section 5 - Section 8. The security mechanisms must address all threats listed in Section 1.4 of [RFC3411].

10. IANA Considerations

This document has no actions for IANA.

11. Acknowledgements

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12. Open issues

12.1. Improve references

DC power quality covered by IEC standard?
Is there an IEC standard on DC power quality?

12.2. Do we need entity types?

Or shall we remove Section 5.1.1? The issue is unsolved on the mailing list.

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Appendix A. Existing Standards

This section analyzes existing standards for energy consumption and power state monitoring. It shows that there are already several standards that cover only some part of the requirements listed above, but even all together they do not cover all of the requirements for energy management.

A.1. Existing IETF Standards

There are already RFCs available that address a subset of the requirements.

A.1.1. ENTITY MIB

The ENTITY-MIB module defined in [RFC4133] was designed to model physical and logical entities of a managed system. A physical entity is an identifiable physical component. A logical entity can use one or more physical entities. From an energy monitoring perspective of a managed system, the ENTITY-MIB modeling framework can be reused and whenever RFC 4133 [RFC4133] has been implemented. The entPhysicalIndex from entPhysicalTable can be used to identify an entity/component. However, there are use cases of energy monitoring, where the application of the ENTITY-MIB does not seem readily apparent and some of those entities could be beyond the original scope and intent of the ENTITY-MIB.

Consider the case of remote devices attached to the network, and the network device could collect the energy measurement and report on behalf of such attached devices. Some of the remote devices such as PoE phones attached to a switch port have been considered in the Power-over-Ethernet MIB module [RFC3621]. However, there are many other devices such as a computer, which draw power from a wall outlet or building HVAC devices which seem to be beyond the original scope of the ENTITY-MIB.

Yet another example, is smart-PDUs, which can report the energy consumption of the device attached to the power outlet of the PDU. In some cases, the device can be attached to multiple to power outlets. Thus, the energy measured at multiple outlets need to be aggregated to determine the consumption of a single device. From mapping perspective, between the PDU outlets and the device this is a many-to-one mapping. It is not clear if such a many-to-one mapping is feasible within the ENTITY-MIB framework.

A.1.2. ENTITY STATE MIB

RFC 4268 [RFC4268] defines the ENTITY STATE MIB module. Implementations of this module provide information on entities including the standby status (hotStandby, coldStandby, providingService), the operational status (disabled, enabled, testing), the alarm status (underRepair, critical, major, minor, warning), and the usage status (idle, active, busy). This information is already useful as input for policy decisions and for other network management tasks. However, the number of states would cover only a small subset of the requirements for power state monitoring and it does not provide means for energy consumption monitoring. For associating the information conveyed by the ENTITY STATE MIB to specific components of a device, the ENTITY STATE MIB module makes use of the means provided by the ENTITY MIB module [RFC4133]. Particularly, it uses the entPhysicalIndex for identifying entities.

The standby status provided by the ENTITY STATE MIB module is related to power states required for energy management, but the number of states is too restricted for meeting all energy management requirements. For energy management several more power states are required, such as different sleep and operational states as defined by the Advanced Configuration and Power Interface (ACPI) [ACPI.R30b] or the DMTF Power State Management Profile [DMTF.DSP1027].

A.1.3. ENTITY SENSOR MIB

RFC 3433 [RFC3433] defines the ENTITY SENSOR MIB module. Implementations of this module offer a generic way to provide data collected by a sensor. A sensor could be an energy consumption meter delivering measured values in Watt. This could be used for reporting current power of an entity and its components. Furthermore, the ENTITY SENSOR MIB can be used to retrieve the accuracy of the used power meter.

Similar to the ENTITY STATE MIB module, the ENTITY SENSOR MIB module makes use of the means provided by the ENTITY MIB module [RFC4133] for relating provided information to components of a device.

However, there is no unit available for reporting energy quantities, such as, for example, watt seconds or kilowatt hours, and the ENTITY SENSOR MIB module does not support reporting accuracy of measurements according to the IEC / ANSI accuracy classes, which are commonly in use for electric power and energy measurements. The ENTITY SENSOR MIB modules only provides a coarse-grained method for indicating accuracy by stating the number of correct digits of fixed point values.

A.1.4. UPS MIB

RFC 1628 [RFC1628] defines the UPS MIB module. Implementations of this module provide information on the current real power of entities attached to an uninterruptible power supply (UPS) device. This application would require identifying which entity is attached to which port of the UPS device.

UPS MIB provides information on the state of the UPS network. The MIB module contains several variables that are used to identify the UPS entity (name, model,..), the battery state, to characterize the input load to the UPS, to characterize the output from the UPS, to indicate the various alarm events. The measurements of power in UPS MIB are in Volts, Amperes and Watts. The units of power measurement are RMS volts, RMS Amperes and are not based on Entity-Sensor MIB [RFC3433].

A.1.5. POWER ETHERNET MIB

Similar to the UPS MIB, implementations of the POWER ETHERNET MIB module defined in RFC3621 [RFC3621] provide information on the current energy consumption of the entities that receive Power over Ethernet (PoE). This information can be retrieved at the power sourcing equipment. Analogous to the UPS MIB, it is required to identify which entities are attached to which port of the power sourcing equipment.

The POWER ETHERNET MIB does not report power and energy consumption on a per port basis, but can report aggregated values for groups of ports. It does not use objects of the ENTITY MIB module for identifying entities, although this module existed already when the POWER ETHERNET MIB modules was standardized.

A.1.6. LLDP MED MIB

The Link Layer Discovery Protocol (LLDP) defined in IEEE 802.1AB [IEEE-802.1AB] is a data link layer protocol used by network devices for advertising of their identities, capabilities, and interconnections on a LAN network. The Media Endpoint Discovery (MED) is an enhancement of LLDP known as LLDP-MED [ANSI/TIA-1057]. The LLDP-MED enhancements specifically address voice applications. LLDP-MED covers 6 basic areas: capabilities discovery, LAN speed and duplex discovery, network policy discovery, location identification discovery, inventory discovery, and power discovery.

A.2. Existing standards of other bodies

A.2.1. DMTF

The DMTF has defined a power state management profile [DMTF.DSP1027] that is targeted at computer systems. It is based on the DMTF's Common Information Model (CIM) and it is rather an entity profile than an actual energy consumption monitoring standard.

The power state management profile is used to describe and to manage the power state of computer systems. This includes e.g. means to change the power state of an entity (e.g. to shutdown the entity) which is an aspect of but not sufficient for active energy management.

A.2.2. OVDA

ODVA is an association consisting of members from industrial automation companies. ODVA supports standardization of network technologies based on the Common Industrial Protocol (CIP). Within ODVA, there is a special interest group focused on energy and standardization and inter-operability of energy aware entities.

A.2.3. IEEE-ISTO Printer WG

The charter of the IEEE-ISTO Printer Working Group is for open standards that define printer related protocols, that printer manufacturers and related software vendors shall benefit from the interoperability provided by conformance to these standards. One particular aspect the Printer WG is focused on is power monitoring and management of network printers and imaging systems PWG Power Management Model for Imaging Systems [IEEE-ISTO]. Clearly, these devices are within the scope of energy management since these devices consume power and are attached to the network. In addition, there is ample scope of power management since printers and imaging systems are not used that often. IEEE-ISTO Printer working group has defined MIB modules for monitoring the power consumption and power state series that can be useful for power management of printers. The energy management framework should also take into account the standards defined in the Printer working group. In terms of other standards, IETF Printer MIB RFC3805 [RFC3805] has been standardized, however, this MIB module does not address power management of printers.

Authors' Addresses

Juergen Quittek (editor)
NEC Europe Ltd.
NEC Laboratories Europe
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE

Phone: +49 6221 4342-115
Email: quittek@neclab.eu

Rolf Winter
NEC Europe Ltd.
NEC Laboratories Europe
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE

Phone: +49 6221 4342-121
Email: Rolf.Winter@neclab.eu

Thomas Dietz
NEC Europe Ltd.
NEC Laboratories Europe
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE

Phone: +49 6221 4342-128
Email: Thomas.Dietz@neclab.eu

Benoit Claise
Cisco Systems, Inc.
De Kleetlaan 6a b1
Degem 1831
BE

Phone: +32 2 704 5622
Email: bclaise@cisco.com

Mouli Chandramouli
Cisco Systems, Inc.
Sarjapur Outer Ring Road
Bangalore,
IN

Phone: +91 80 4426 3947
Email: moulchan@cisco.com

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C. Jennings
Cisco
B. Nordman
Lawrence Berkeley National Laboratory

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Communication of Energy Price Information
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Abstract

This specification defines media types for representing the future price of energy in JSON. It also defines a way for a client device, such as a car, refrigerator, air conditioner, water heater, or display to discover a web server that can provide the future price for local electrical energy. This will allow the client device to make intelligent decisions about when to use energy, and enable price distribution when the building is off-grid. It enables obtaining price from a local or non-local price server.

This draft is an early skeleton of a draft to start discussion around this idea.

Status of this Memo

Copyright Notice

1. Overview

Many uses of energy can be shifted in time, or changed in quantity, based on price. Consider charging an electric car. For users that plug in cars at 9pm, they may not care when it actually charges, as long as it is ready at 8am when they need to go to work. This is a classic real time problem and can be optimized as long as the charger for the car has relevant information about how long it will take to charge and the cost of electricity between the current time and the time when the task needs to be complete.

Other devices such as refrigerators, air conditioners, and washers can similarly shift load. For their primary temperature regulation function, they can lower their setpoint (for cooling devices) when costs are low, and increase it when costs are high. The amount of deviation from the base target is keyed to the value of the price, operational considerations (e.g. not letting food freeze or spoil), or other non-price information available (e.g. occupancy). Devices such as displays (TV or computer) or lights can dim in some proportion to the electricity price, to balance cost and functionality. Devices with user-oriented time-outs (e.g. when an occupancy sensor’s lack of seeing anyone in a space leads to a light going off) can adjust the length of such time-outs in proportion to price. Periodic functions (e.g. a refrigerator defrost cycle) can be shifted to the lowest cost time in the relevant time horizon. In general, the end-use device itself usually has the most knowledge about how best to act, and the the best access to internal actuators to accomplish the change.

Development around "Demand Response (DR)" has been advancing since around 2000. Most work in that area involves sending signals from the grid (DR-service provider) to a large building (commercial/ industrial) or large device within it, to request load shedding or load shifting. There are then financial arrangements to pay the building owner for the service. More recently, the DR community and regulators have turned to enabling dynamic pricing so that the price customers actually pay at the meter more closely corresponds to the actual costs that the utility faces. Prices can be sent from the grid to an end use device, or from the grid to a gateway device (could be the meter) that then sends the prices to end use devices.

This specification defines a simple JSON[RFC4627]media type to provide the cost of energy at future points of time. It is an array of objects in which each object contains the time a new price will come into effect and the price at that time. JSON also defines a well known URL on a web server so that an HTTP client can retrieve this data. Finally as a way to automatically discover the web server, this specification defines a DHCP option to provide the host name of the web server.

At this time, only electricity is contemplated, but other resources do plausibly have time-varying prices, such as centrally provided steam or hot/cold water. Any resource (e.g. water) could use this mechanism to have a local price to distribute. Resources with a local supply constraint will then have a local price to ensure a balance with demand.

The base usage case for this specification is a time-varying electricity price with the current price and a set of future prices (confirmed or estimates), usually for a 24 hour period. This price comes from the electric utility. The price can be fetched directly from the utility. However, many alternate cases are also expected and supported. The building may have one entity (likely a piece of network equipment since it is always on already) that gets prices from the grid and all others get it from this building-local 'price server'. Both transactions use this mechanism.

The operator of the building may choose to present a higher price to devices in the building to take into account carbon emissions or other pollution from generating electricity. The building may also have local generation and/or storage, whose state and operation may indicate changes in price. For example, a building with an excess of solar power on-site may sell marginal electricity back to the grid at a low price. This would suggest lowering the price until supply and demand in the building were approximately in balance.

Some buildings operate off-grid, either all the time or intermittently. A building is a structure that uses resources and provides services. Common examples are homes, office, retail, and institutional buildings. Other building types include vehicles such as cars, ships, and airplanes. All these building types have electricity systems that would benefit from a price mechanism.

There are other protocols designed to get prices from the grid to a building, particularly to a building control system. One example of these is OpenADR. This mechanism complements rather than replaces these other mechanisms.

Electricity pricing has other aspects that complicate pricing. For example, in many places electricity use over a monthly billing period is sold in blocks, with the price increasing or decreasing with larger blocks depending on what the utility is trying to accomplish with the price. For example, the first five hundred kWh could be $0.10/kWh, the second 500 kWh $0.15, and so on. Thus, the monthly marginal price (what is paid if the consumption goes up or down modestly) is the last block used. This could be substantially different from an average price. There are many options for how utilities could combine blocks with dynamic prices. This specification is not attempting to provide a set of prices that are legally binding. Rather, it is intended to provide a simple and reasonably reliable set of prices that devices can use (when the alternative may be in fact no information at all).

Consider a typical residence with broadband Internet and a residential gateway that gets its IP address via DHCP from the service provider. The service provider would provide the domain of the local power provider via DHCP. The residential gateway would get this and provide it in DHCP requests sent to the residential gateway. The residential gateway would also be able to override this, so if the consumer had arranged power from an alternative power provider, the name of that provider could be configured in the device.

A device on the residential network, such as a dishwasher, could find the energy provider name via DHCP. The dishwasher would then make an HTTP GET request to the well known URI defined in this specification. In other words, it would do an HTTP GET to the /.well_known/ electricity-price.json and would receive back an energyprice+json media type. For example


```
{
"currency" : "USD",
"prices":[
    { "time": "2011-04-12T23:20:00.00Z", "price": "0.028" },
    { "time": "2011-04-12T23:21:00.00Z", "price": "0.025" },
    { "time": "2011-04-12T23:22:00.00Z", "price": "0.021" }
]}
```


The above example shows a case where at 21:00 UTC, the price falls from 2.8 cents per KWh to 2.5 cents per kWh. Using kWh is fixed.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",

"SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

3. Semantics

Each media type carries a single JSON object that represents a set of prices and times. This object contains optional attributes described below and a mandatory array of one or more measurements.

validTill: Time at which this data series will become invalid. UTC time in RFC 3339 format.
currency: Optional. Specify currency in ISO 4217 [REF] currency code.
prices: Array of price objects. Mandatory and there must be at least one object in the array. Objects MUST be ordered in this array by time.

Each price time object contains several attributes, some of which are optional and some of which are mandatory.

time: Time this price becomes effective. UTC time in RFC 3339 format.
price: Price per kWh. The cost of energy changes to this price at the time in this object and remains at this price until the time of the next object in the prices array.

Open Issue: What is the best representation for time?

Open Issue: Is it OK that currency is optional?

Open Issue: How many entries can the array have? It would be nice to have some maximum size.

The price in the last entry in the series is ignored. That is, the purpose of the last entry is to close the time of the last period. While 24 hours will be a typical time horizon, it could be shorter or longer.

Question: Can the request have a start time (zero for the present), so that if there is a limit on array size, one can get the rest?

Open Issue: should we be able to represent both buy and sell prices?

4. Well Known URL

A client that implements this specification uses the path "//.well-known/electricity-price.json" for the resource name unless the client has been configured with an alternative path.

5. DHCP

Open Issues: Is DHCP the best approach to discovery or would something else be better?

6. IANA Considerations

Note to RFC Editor: Please replace all occurrences of "RFC-AAAA" with the RFC number of this specification.

6.1. Well-Known URI Registration

IANA will make the following "Well Known URI" registration as described in RFC 5785:

URI suffix:	electricity-price.json
Change controller:	IETF <iesg@ietf.org>
Specification document(s):	[RFC-AAAA]
Related information:	None

6.2. DHCP Options

TBD

6.3. Media Type Registration

The following registrations are done following the procedure specified in [RFC4288] and [RFC3023].

Note to RFC Editor: Please replace all occurrences of "RFC-AAAA" with the RFC number of this specification.

6.3.1. energyprice+json Media Type Registration

TBD

7. Mapping to OpenADR

Lawrence Berkeley National Laboratory led the development of OpenADR initially (OpenADR v1.0), and it is now being formalized as an open standard through OASIS and national Smart Grid activity (OpenADR v2.0). At present, there are two relevant OASIS technical committees (TCs) that are relevant to the dynamic pricing (includes real-time prices) discussion: the Energy Interoperation TC (EI) and the Energy Market Information Exchange TC (EMIX). Each committee has a draft standard of the same name as the technical committee.

The OpenADR v2.0 standard will become a subset of what EI produces. EMIX is charged with defining a standard abstract form of price signaling. The details of how to represent a price product is defined in EMIX[EMIX] (then EI[EI] would reference and build implementation models, for e.g., XML schemas).

Both committees cover much more than just price (and price forecast) information. The discussion below focuses only on features relevant to this IETF specification. The OpenADR model uses XML as the data description language. OpenADR v1.0 and v2.0 can specify prices in different terms - absolute, multiple, or in relative terms to a base price (either additive or multiplicative).

Pricing can be a very complicated topic, but for the discussion here, we limit it to what this specification does- a schedule of time periods and a price for each period.

To represent time, EI and EMIX use WS-Calendar (also an OASIS standard), which provides for complex scheduling; simple price sequences use only a small part of this. Sequences are represented as a start time and a sequence of interval durations. As WS-Calendar builds on iCalendar (see RFC 5545) it uses the same date/time format as this draft.

A related issue is how to specify the current time to assure that the price source and user of the price have consistent time (or know how to adjust the schedule for a difference in time). This discussion does not consider this topic. So long as prices do not vary significantly from one time period to the next, and the time differences are not large, this issue is not of great concern.

EMIX can encode prices in several ways, including relative prices. For absolute prices, the price is simply a numeric value in cents/kWh for the U.S. Other additional attributes relevant to price representations are under consideration (e.g., currency). The following is a sample excerpt of an OpenADR v1.0 price schedule:

```
<p:drEventData>
  <p:notificationTime>2009-06-02T17:15:00.0</p:notificationTime>
  <p:startTime>2009-06-03T00:00:00.0</p:startTime>
  <p:endTime>2009-06-03T23:59:00.0</p:endTime>
  <p:eventInfoInstances>
     <p:eventInfoTypeID>PRICE_ABSOLUTE</p:eventInfoTypeID>
     <p:eventInfoName>Price</p:eventInfoName>
     <p:eventInfoValues>
        <p:value>0.0</p:value>
        <p:timeOffset>0</p:timeOffset>
     </p:eventInfoValues>
     <p:eventInfoValues>
        <p:value>0.0</p:value>
        <p:timeOffset>3600</p:timeOffset>
     </p:eventInfoValues>
     ...
     <p:eventInfoValues>
        <p:value>0.0</p:value>
        <p:timeOffset>82800</p:timeOffset>
     </p:eventInfoValues>
  </p:eventInfoInstances>
</p:drEventData>
```


TBD - define a simple mapping to and from OpenADR.

8. Security Considerations

TBD

Further discussion of security proprieties for media types can be found in Section 6.3.

9. Privacy Considerations

TBD

10. Acknowledgement

We would like to thank Girish Ghatikar at LBNL for information and text about OpenADR. Thanks for helpful comments from many people including Scott Brim, <get your name here>.

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Authors' Addresses

Cullen Jennings
Cisco
170 West Tasman Drive
San Jose, CA 95134
USA

Phone: +1 408 421-9990
Email: fluffy@cisco.com

Bruce Nordman
Lawrence Berkeley National Laboratory
1 Cyclotron Road
Berkeley, CA 94720
USA

Email: BNordman@LBL.gov

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Energy Management Terminology
draft-parello-eman-definitions-03

Status of this Memo

Copyright Notice

Abstract

This document contains definitions and terms used in the Energy Management Working Group. Each term contains a definition(s), example, and reference to a normative, informative or well know source. Terms originating in this draft should be either composed of or adapted from other terms in the draft with a source. The defined terms will then be used in other drafts as defined here.

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1. Introduction

Within Energy Management there are terms that may seem obvious to a casual reader but in fact require a rigorous and sourced definition. To avoid any confusion in terms among the working group drafts, one glossary / lexicon of terms should exist that all drafts can refer to. This will avoid a review of terms multiplied across drafts.

This draft will contain a glossary of definitions of terms that can be agreed upon by the working group outside of the context of drafts and then included in or sourced to this draft.

Each term will contain a definition(s), a normative or informative reference, an optional example, an optional comment(s) listed a note(s).

All terms should be rooted with a well-known reference. If a definition is taken verbatim from a reference then the source is listed in square brackets. If a definition is derived from a well-known reference then the source is listed as "Adapted from" with the reference listed in square brackets. If a defined term is newly defined here the reference will indicate as such by stating "herein" and if applicable list any composing terms from this document.

When applicable the [IEEE100] was used as the preferred source. If a term was not available from [IEEE100], then [IEC60050] was used. When there were multiple items from [IEEE100], [IEC60050] or [ISO50001], there were all included.

2. Terminology

Energy Management

1.Energy Management is a set of functions for measuring, modeling, planning, and optimizing networks to ensure that the network elements and attached devices use energy efficiently and is appropriate for the nature of the application and the cost constraints of the organization.

Reference: Adapted from [ITU-T-M-3400]
2. Energy management refers to the activities, methods, procedures and tools that pertain to measuring, modeling, planning, controlling and optimizing the use of energy in networked systems.

Reference: Adapted from [NMF]

NOTE: Energy Management is a system congruent to any of FCAPS areas of management in the ISO/OSI Network Management Model [TMN]. Energy Management for communication networks and attached devices is a subset or part of an organization's greater Energy Management Policies.

Example: A set of computer systems that will poll electrical meters and store the readings

Energy Management System (EnMS)

1. An Energy Management System is a combination of hardware and software used to administer a network with the primarily purpose being Energy Management.

Reference: Adapted from [1037C]

Example: A single computer system that polls data from devices using SNMP

2. An Energy Management System (ISO-EnMS) is a set of systems or procedures upon which organizations can develop and implement an energy policy, set targets, action plans and take into account legal requirements related to energy use. An EnMS allows organizations to improve energy performance and demonstrate conformity to requirements, standards, and/or legal requirements.

Reference: [ISO50001]

Example: Company A defines a set of policies and procedures indicating there should exist multiple computerized systems that will poll energy from their meters and pricing / source data from their local utility. Company A specifies that their CFO should collect information and summarize it quarterly to be sent to an accounting firm to produce carbon accounting reporting as required by their local government.

NOTE: For the purposes of EMAN, the definition from [1037C] is the preferred meaning of an Energy Management System (EnMS). The definition from [ISO50001] can be referred to as ISO Energy Management System (ISO-EnMS).

ISO Energy Management System

Energy Management System as defined by [ISO50001]

Reference: herein

Energy

1. That which does work or is capable of doing work. As used by electric utilities, it is generally a reference to electrical energy and is measured in kilo-watt hours (kWh).

Reference: [IEEE100]

2. Energy is the capacity of a system to produce external activity or perform work

Reference: [ISO50001]

Power

The time rate at which energy is emitted, transferred, or received; usually expressed in watts (or in joules per second). Reference: [IEEE100]

Demand

The average value of power or a related quantity over a specified interval of time. Note: Demand is expressed in kilowatts, kilovolt-amperes, kilovars, or other suitable units.

NOTE 1: typically kilowatts

NOTE 2: Energy providers typically bill by Demand measurements as well as for maximum Demand per billing periods. Power values may spike during short-terms by devices, but Demand measurements recognize that maximum Demand does not equal maximum Power during an interval.

Reference: [IEEE100]

Power Quality

Characteristics of the electric current, voltage and frequencies at a given point in an electric power system, evaluated against a set of reference technical parameters. These parameters might, in some cases, relate to the compatibility between electricity supplied in an electric power system and the loads connected to that electric power system.

Reference: [IEC60050]

Electrical Equipment

A general term including materials, fittings, devices, appliances, fixtures, apparatus, machines, etc., used as a part of, or in connection with, an electric installation.
Reference: [IEEE100]

Non-Electrical Equipment (Mechanical Equipment)

A general term including materials, fittings, devices appliances, fixtures, apparatus, machines, etc., used as a part of, or in connection with, non-electrical power installations.
Reference: Adapted from [IEEE100]

Energy Object

An Energy Object (EO) is a piece of equipment that is part of or attached to a communications network that is monitored, controlled, or aids in the management of another device for Energy Management.

Reference: herein

Electrical Energy Object

An Electrical Energy Object (EEO) is an Energy Object that is a piece of Electrical Equipment

Reference: herein, Electrical Equipment

Non-Electrical Energy Object

A Non-Electrical Energy Object (NEEO) an Energy Object that is a piece of Non-Electrical Equipment.

Reference: herein, Non-Electrical Equipment.

Energy Monitoring

Energy Monitoring is a part of Energy Management that deals with collecting or reading information from Energy Objects to aid in Energy Management.
NOTE: This could include Energy, Power, Demand, Power Quality, Context and/or Battery information.

Reference: herein

Energy Control

Energy Control is a part of Energy Management that deals with directing influence over Energy Objects.

NOTE: Typically in order to optimize or ensure its efficiency.

Reference: herein

Energy Management Domain

An Energy Management Domain is a set of Energy Objects.
NOTE: Typically, this set will have as members all EO's that are powered from the same source.

Reference: herein

Example: All EEO’s drawing power from the same distribution panel with the same AC voltage within a building, or all EEO’s in a building for which there is one main meter, would comprise an Energy Management Domain.

Energy Object Identification

Energy Object Identification is a set of attributes that enable an Energy Object to be: uniquely identified among all Energy Management Domains; linked to other systems; classified as to type, model, and or manufacturer.

Reference: herein

Energy Object Context

Energy Object Context is a set of attributes that allow an Energy Management System to classify the use of the Energy Object within an organization.

NOTE: The classification could contain the use and/or the ranking of the Energy Object as compared to other Energy Objects in the Energy Management Domain.

Reference: herein

Energy Object Relationships

Energy Objects may have functional relationships to each other within an Energy Management Domain.

NOTE 1: One Energy Object will provide a capability or functional value in the relationship and another will be the receiver of the capability.

NOTE 2: These capabilities could include Aggregation, Metering, Power Source, Proxy and Dependency.

Reference: herein

Aggregation Relationship

An Energy Object may aggregate the Energy Management information of one or more Energy Objects and is referred to as an Aggregation Relationship.

NOTE 1: An Energy Object may be aggregated by another Energy Object(s).

NOTE 2: Aggregate values may be obtained by reading values from multiple Energy Objects and producing a single value of more significant meaning such as average, count, maximum, median, minimum, mode and most commonly sum.

Reference: Adapted from [SQL]

Metering Relationship

An Energy Object may measure the Energy of another Energy Object(s) and is referred to as a Metering Relationship.

NOTE: An Energy Object may be metered by another Energy Object(s).

Reference: herein

Example: a PoE port on a switch measures the Power it provides to the connected Energy Object.

Power Source Relationship

An Energy Object may be the source of or distributor of power to another Energy Object(s) and is referred to as a Power Source Relationship.

NOTE: An Energy Object may be powered by another Energy Object(s).

Reference: herein

Example: a PDU provides power for a connected host.

Proxy Relationship

An Energy Object that provides Energy Management capabilities on behalf of another Energy Object so that is appears to be Energy Aware is referred to a Proxy Relationship.

NOTE: An Energy Object may be proxied by another Energy Object(s).

Reference: herein

Example: a protocol gateways device for Building Management Systems (BMS) with subtended devices.

Dependency Relationship

An Energy Object may be a component of or rely completely upon another Energy Object to operate and is referred to as a Dependency Relationship. An Energy Object may be dependent on another Energy Object(s).

Reference: herein

Example: A Switch chassis with multiple line cards.

Energy Object Parent

An Energy Object Parent is an Energy Object that provides one or more of the Energy Object Relationships capabilities.

Reference: herein

Energy Object Child

An Energy Object Child is an Energy Object that has at least one Energy Object Relationship capability provided by another Energy Object.

Reference: herein

Power State

A Power State is a generalized way to classify a setting on an Energy Object (e.g., on, off, or sleep).

NOTE: A Power State can be viewed as one method for Energy Control

Reference: herein

Manufacturer Power State

A Manufacturer Power State is a device-specific way to classify a setting implemented on an Energy Object.

Reference: herein

Power State Set

A collection of Power States that comprise one named or logical grouping of control is a Power State Set.

Reference: herein

Example: The states {on, off, and sleep} as defined in [IEEE1621], or the 16 power states as defined by the [DMTF] can be considered two different Power State Sets.

Nameplate Power

The Nameplate Power is the maximal (nominal) Power that a device can support.

NOTE: This is typically determined via load testing and is specified by the manufacturer as the maximum value required for operating the device. This is sometimes referred to as the worst-case Power. The actual or average Power may be lower. The Nameplate Power is typically used for provisioning and capacity planning.

Reference: herein

3. Security Considerations

None

4. IANA Considerations

None

5. Acknowledgments

The author would like to thank the authors of the current working group drafts for the discussions and definition clarifications

6. References

Normative References

Informative References

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Authors' Addresses

John Parello
Cisco Systems, Inc.
3550 Cisco Way
San Jose, California 95134
US

Phone: +1 408 525 2339
Email: jparello@cisco.com

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J. Quittek
NEC Europe Ltd.
B. Nordman
Lawrence Berkeley National Laboratory
R. Winter
NEC Europe Ltd.
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Reference Model for Energy Management
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Abstract

Managing energy consumption of devices is different from several well understood network management functions because of the special nature of energy supply and use. This document explains issues of energy management arising from its special nature and proposes a layered reference model for energy management addressing these issues.

Status of this Memo

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1. Introduction

Managing energy consumption of devices is different from several well understood network management functions because of the special nature of energy supply and use. This memo explains issues of energy management arising from its special nature and proposes a reference model for energy management addressing these issues.

Defining a suitable reference model for energy management has proven to be explorative work that cannot be done in a single step because the area is rather new to people at the IETF. Ideas for a reference model have been elaborated in [I-D.ietf-eman-framework] and previous versions of this draft.

This revision is an attempt to combine the relationship model proposed in the last version (-02) of [I-D.ietf-eman-framework] with the concept of power interfaces proposed in the previous version (-02) of this draft. The result is a four layer model of energy management.

This draft starts with identifying and describing in Section 2 the special issues of energy management that require the development of a new reference model. The issues concern power supply, power and energy metering, and the reporting of low-power states.

Section 3 addresses these issues and proposed a new four layer model for energy management, see Figure 1.

```
+-----------------------------------------------+
|        energy management system (EnMS)        |
+-----------------------------------------------+
          |||                     |||
+---------------------+           |||
|  energy management  |           |||
|   mediation (EMM)   |           |||
+---------------------+           |||
           ||                     |||
+-----------------------------------------------+
|   local energy management interface (LMI)     |
+-----------------------------------------------+
                        |
+-----------------------------------------------+
|          power supply and use (PSU)           |
+-----------------------------------------------+
```

Figure 1: Layers of the Energy Management Reference Model

- o Power supply and use (PSU) layer
  At the lowest layer electrical objects are physically connected by power supply lines, and these connections constitute an electric supply topology.
- o Local energy management interface (LMI) layer
  This layer provides access to local information and to local control functions at managed electrical devices.
- o Energy management mediation (EMM) layer
  At this layer management functions use topology information from the PSU layer to infer information on remote devices and to realize control functions for remote devices.
- o Energy management system layer
  This layer contains a centralized or distributed energy management system that manages powered devices.

All communication with the energy management system (drawn with three parallel lines) in Figure 1 is subject of standardization in the EMAN working group. Communication between the EMM layer and the LMI layer (drawn with two parallel lines) is an application area of standards developed in the EMAN WG, but here also proprietary protocols may be used. Communication between the LMI layer and the PSU layer (drawn with a single line) is not subject of standardization by EMAN.

At the core of this framework are just a few key concepts. Energy is used by Powered Devices, some of which supply power to other devices and so are a subset called a Power Supply. Devices have power interfaces, which are like network interfaces, through which power is transferred into (an "inlet") or out of (an "outlet") a device. Measurement occurs at interfaces so that the total or net consumption of a device can be determined.

2. Energy Management Issues

This section explains special issues of energy management particularly concerning power supply, power and energy metering, and the reporting of low-power states.

To illustrate the issues we start with a simple and basic scenario with a single powered device that consumes energy and that reports energy-related information about itself to an energy management system, see Figure 2.

```
+---------------------------+
| energy management system |
+---------------------------+
            ^  ^
 monitoring |  | control
            v  v
     +------------------+
     | powered device  |
     +------------------+
```

Figure 2: Basic energy management scenario

The device may have local energy control mechanisms, for example putting itself into a sleep mode when appropriate, and it may receive energy control commands for similar purposes from a management system. Information reported from a powered device to the energy management system includes at least the power state of the device (on, sleep, off, etc.).

This and similar cases are well understood and likely to become very common for energy management. They can be handled with well established and standardized management procedures. The only missing components today are standardized information and data models for reporting and configuration, such as, for example, energy-specific MIB modules [RFC2578] and YANG modules [RFC6020].

However, the nature of energy supply and use introduces some issues that are special to energy management. The following subsections address these issues and illustrate them by extending the basic scenario in Figure 2.

2.1. Power Supply

A powered device may supply itself with power. Sensors, for example, commonly have batteries or harvest energy. However, most powered devices that are managed by an energy management system receive external power.

While a huge number of devices receive power from unmanaged supply systems, the number of manageable power supply devices is increasing. In datacenters, many Power Distribution Units (PDUs) allow the network management system to switch power individually for each socket and also to measure the provided power. Here there is a big difference to many other network management tasks: In such and similar cases, switching power supply for a powered device or monitoring its power is not done by communicating with the actual powered device, but with an external power supply device (which may be an external power meter).

Consequently, a standard for energy management must not just cover the powered devices that provide services for users, but also the power supply devices (which are powered devices as well) that monitor or control the power supply for other powered devices.

A very simple device such as a plain light bulb can be switched on or off only by switching its power supply. More complex devices may have the ability to switch off themselves or to bring themselves to states in which they consume very little power. For these devices as well it is desirable to monitor and control their power supply.

This extends our basic scenario from Figure 2 by a power supply device, see Figure 3.

```
            +------------------------------------------+
            |         energy management system         |
            +------------------------------------------+
                  ^  ^                          ^  ^
       monitoring |  | control    monitoring |  | control
                  v  v                          v  v
            +--------------+        +------------------+
            | power supply |########| powered device   |
            +--------------+        +------------------+

                    ######## power supply line
```

Figure 3: Power Supply

The power supply device can be as simple as a plain power switch. It may offer interfaces to the energy management system to monitor and to control the status of its power outlets, as with PDUs and Power over Ethernet (PoE) [IEEE-802.3at] switches.

The relationship between supply devices and the powered devices they serve creates several problems for managing power supply:

- o Identification of corresponding devices
  * A given powered device may be need to identify the supplying power supply device.
  * A given power supply device may need to identify the corresponding supplied powered device(s).
- o Aggregation of monitoring and control for multiple powered devices
  * A power supply device may supply multiple powered devices with a single power supply line.
- o Coordination of power control for devices with multiple power inlets
  * A powered device may receive power via multiple power lines controlled by the same or different power supply devices.

2.1.1. Identification of Power Supply and Powered Devices

When a power supply device controls or monitors power supply at one of its power outlets, the effect on other devices is not always clear without knowledge about wiring of power lines. The same holds for monitoring. The power supplying device can report that a particular socket is powered, and it may even be able to measure power and conclude that there is a consumer drawing power at that socket, but it may not know which powered device receives the provided power.

In many cases it is obvious which other device is supplied by a certain outlet, but this always requires additional (reliable) information about power line wiring. Without knowing which device(s) are powered via a certain outlet, monitoring data are of limited value and switching on the consequences of switching power on or off may be hard to predict.

Even in well organized operations, powered devices’ power lines get plugged into the wrong socket, or wiring plans are changed without updating the energy management system accordingly.

For reliable monitoring and control of power supply devices, additional information is needed to identify the device(s) that receive power provided at a particular monitored and controlled socket.

This problem also occurs in the opposite direction. If power supply control or monitoring for a certain device is needed, then the supplying power supply device has to be identified.

To conduct energy management tasks for both power supply devices and other powered devices, sufficiently unique identities are needed, and knowledge of their power supply relationship is required.

2.1.2. Multiple Devices Supplied by a Single Power Line

The second fundamental problem is the aggregation of monitoring and control that occurs when multiple powered devices are supplied by a single power supply line. It is often required that the energy management system has the full list of powered devices connected to a single outlet as in Figure 4.

```
                 +----------------------------------------+
                 |       energy management system         |
                 +----------------------------------------+
                    ^  ^                       ^  ^
         monitoring |  | control    monitoring |  | control
                    v  v                       v  v
                 +--------+        +------------------+
                 | power  |########| powered device 1 |
                 | supply |   #    +------------------+-+
                 +--------+   #######| powered device 2 |
                                #    +------------------+-+
                                #######| powered device 3 |
                                       +------------------+
```

Figure 4: Multiple Powered Devices Supplied by Single Power Line

With this list, the single status value has clear meaning and is the sum of all powered devices. Control functions are limited by the fact that supply for the concerned devices can only be switched on or off for all of them at once. Individual control at the supply is not possible.

If the full list of powered devices powered by a single supply line is not known for the controlling power supply device, then control of power supply is problematic, because the consequences of control actions can only be partially known.

2.1.3. Multiple Power Supply for a Single Powered Device

The third problem arises from the fact that there are devices with multiple power supplies. Some have this for redundancy of power supply, some for just making internal power converters (for example, from AC mains power to DC internal power) redundant, and some because the capacity of a single supply line is insufficient.

```
              +----------------------------------------------+
              |          energy management system            |
              +----------------------------------------------+
                  ^  ^              ^  ^              ^  ^
             mon. |  | ctrl.   mon. |  | ctrl.   mon. |  | ctrl.
                  v  v              v  v              v  v
              +----------+      +----------+      +----------+
              | power    |######| powered  |######| power    |
              | supply 1 |######| device   |      | supply 2 |
              +----------+      +----------+      +----------+
```

Figure 5: Multiple Power Supply for Single Powered Device

The example in Figure 5 does not necessarily show a real world scenario, but it shows the two cases to consider:

- o multiple power supply lines between a single power supply device and a powered device
- o different power supply devices supplying a single powered device

In any such case there may be a need to identify the supplying power supply device individually for each power inlet of a powered device. Without this information, monitoring and control of power supply for the powered device may be limited.

2.1.4. Relevance of Power Supply Issues

In some scenarios, the problems with power supply do not exist or can be sufficiently solved. With Power over Ethernet (PoE) [IEEE-802.3at] there is always a one-to-one relationship between a Power Sourcing Equipment (PSE) and a Powered Device (PD). Also, the Ethernet link on the line used for powering can be used to identify the two connected devices.

For supply of AC mains power, the three problems described above cannot be solved in general. There is no commonly available protocol or automatic mechanism for identifying endpoints of a power line. And, AC power lines support supplying multiple powered devices with a single line and commonly do.

2.1.5. Remote Power Supply Control

There are three ways for an energy management system to change the power state of a managed entity. First is for a management system to provide policy or other useful information (like the electricity price) to the powered device for it to use in determining its power state. The second is sending the entity a command to switch to another state. The third is to utilize an upstream device (to the powered device) that has capabilities to switch on and off power at its outlet.

Some entities do not have capabilities for receiving commands or changing their power states by themselves. Such devices may be controlled by switching on and off the power supply for them and so have particular need for the third method.

In Figure 3 the power supply can switch on and off power at its power outlet and thereby switch on and off power supply for the connected powered device.

2.2. Power and Energy Measurement

Some devices include hardware to directly measure their power and energy consumption. However, most common networked devices do not provide an interface that gives access to energy and power measurements for the device. Hardware instrumentation for this kind of measurements is typically not in place and adding it incurs an additional cost.

With the increasing cost of energy and the growing importance of energy monitoring, it is expected that in future more devices will include instrumentation for power and energy measurements, but this may take quite some time.

2.2.1. Local Estimates

One solution to this problem is for the device to estimate its own power and consumed energy. For many energy management tasks, getting an estimate is much better than not getting any information at all. Estimates can be based on actual measured activity level of a device or it can just depend on the power state (on, sleep, off, etc.).

The advantage of estimates is that they can be realized locally and with much lower cost than hardware instrumentation. Local estimates can be dealt with in traditional ways. They don’t need an extension of the basic example above. However, the powered device needs an energy model of itself to make estimates.

2.2.2. Management System Estimates

Another approach to the lack of instrumentation is estimation by the energy management system. The management system can estimate power based on basic information on the powered device, such as the type of device, or also its brand/model and functional characteristics. Energy estimates can combine the typical power level by power state with reported data about the power state.

If the energy management system has a detailed energy model of the device, it can produce better estimates including the actual power state and actual activity level of the device. Such information can be obtained by monitoring the device with conventional means of performance monitoring.

2.3. Reporting Sleep and Off States

Low power modes pose special challenges for energy reporting because they may preclude a device from listening to and responding to network requests. Devices may still be able to reliably track energy use in these modes, as power levels are usually static and internal clocks can track elapsed time in these modes.

Some devices do have out-of-band or proxy abilities to respond to network requests in low-power modes. Others could use proxy abilities in an energy management protocol to improve this reporting, particularly if the device sends out notifications of power state changes.

2.4. Entities

The primary focus of energy management is entire devices, but in some applications it is necessary or desirable to also have visibility into energy use of internal components such as line cards, fans, disks, etc. Components lack some of the features of devices, such as having power interfaces; instead, they simply have a net total consumption from the pool of power available within a device. Note that a device need not have an AC power cord. For example, a DC-powered blade server in a chassis has its own identity on the network and reports for itself, and so is a separate device, not a component of the chassis.

3. Energy Management Reference Model

This section specifies a reference model for energy monitoring and explains how it solves the problems outlined above. It is structured into four layers:

```
+-----------------------------------------------+
|        energy management system (EnMS)        |
+-----------------------------------------------+
          |||                     |||
+----------------------+          |||
|  energy management   |          |||
|   mediation (EMM)    |          |||
+----------------------+          |||
           ||                     |||
+-----------------------------------------------+
|   local energy management interface (LMI)     |
+-----------------------------------------------+
                        |
+-----------------------------------------------+
|          power supply and use (PSU)           |
+-----------------------------------------------+
```

Figure 6: Layers of the Energy Management Reference Model

At the power supply and use (PSU) layer electrical objects (powered entities) are physically connected by power supply lines. Their connections constitute an electric supply and metering topology.

The local energy management interface (LMI) layer provides a set of functions for monitoring and controlling individual powered entities. These functions are local to the entity and restricted to only report properties and states of the entity, as with most common network management functions on managed entities today.

The energy management mediation (EMM) layer provides 'convenience' functions to the energy management system. It performs functions specific to energy management by utilizing information from the PSU layer to infer information on Electrical Objects (EOs) and to bundle control functions concerning the same EO. It also offers some more general functions such as proxying and aggregation on monitored information.

The energy management system (EnMS) layer contains a centralized or distributed energy management system that manages a set of powered devices.

3.1. Power Supply and Use (PSU) Layer

This layer models the electrical connections between electrical objects. "Electrical object" (EO) is used as general term for three kinds of objects. An EO is a powered entity (PE). Connections between them are made with power supply lines.

According to the general issues identified in Section 2.1 the following specific issues are addressed at this layer:

- Identification of electrical connection endpoints
- Supply relationships between connected EOs
- Aggregation of power supply for multiple PEs
- Metering at connection endpoints
- Metering relationships between connected EOs
- Aggregation of metering for multiple PEs

For the general problem of identifying EOs, there are many methods already in use by network management systems. Such methods include identification by IP addresses, by MAC addresses, by serial numbers, by assigned UUIDs, etc. Those can be re-used for identifying EOs.

There does not yet exist a commonly used way to address different power interfaces of the same device. There are power distribution units that enumerate their power outlets and Power over Ethernet switches that enumerate their ports and port groups.

The reference model for the PSU layer uses the concept of a power interface to address the identification of individual connection endpoints of power supply lines at EOs.

This term is not new. It is already used similarly by the IEEE standard for Power over Ethernet (PoE) [IEEE-802.3af] and [IEEE-802.3at] where a power interface denotes the interface between a device and the Ethernet transmission medium. The following terms for components of the PSU layer are derived from PoE terminology.

3.1.1. Components of the PSU Layer

o Power Interface (PI)
   A power interface is the interface between an EO and a power transmission medium. There are some similarities between power interfaces and network interfaces. A network interface can be used in different modes, such as sending or receiving on an attached line. A power interface (PI) has an attribute indicating its mode that can be one of the following:

   * inlet: receiving power
   * outlet: providing power

   Most power interfaces never change their mode, but as the mode is simply a recognition of the current direction of electricity flow, there is no barrier to a mode change.

   A power interface can have capabilities for metering power and other electric quantities at the shared power transmission medium. This capability it modeled by an association to a power meter.

   In analogy to MAC addresses of network interfaces, a globally unique identifier is assigned to each power interface.

   Physically, a power interface can be located at an AC power socket, an AC power cord attached to a device, an 8P8C (RJ45) PoE socket, etc.

o Powered Entity (PE)
   An entity which consumes or supplies power with one or more PIs in mode "inlet" is called a powered entity (PE). This extends the term powered device (PD) used in [IEEE-802.3af] and [IEEE-802.3at] to cover not only entities that are individual devices, but also entities that are just components of devices.

o Power Source (PS)
   An entity with one or more PIs in mode "outlet" is called a power source (PS). This extends the term Power Source Equipment (PSE)

used in the IEEE PoE standards [IEEE-802.3af] and [IEEE-802.3at] where at a single PI the PSE provides power to a single PD only. Here a PS may supply an arbitrary number of PEs at a single PI. Most PSs have also PIs in mode "inlet" and all are also a PE.

o Power Meter (PM)
A metering function attached to a power interface of an entity is called a power meter (PM). Power meters are contained within an entity and attached to one or more of the entity's power interfaces. A single PM can only provide a single meter reading at a time. Most PIs will be connected to a single other PI only, but those attached to multiple power interfaces only measure the aggregate use over all of the other interfaces. Components that lack interfaces have a meter for their total net consumption.

3.1.2. Power Supply Topology

Similar to network interfaces, power interfaces can be connected to each other via a shared (power) transmission medium. The most simple connection is a single outlet connected to a single inlet as shown in Figure 7.

```
+----------------+    +----------------+
| power source   |    | powered entity |
|   +----------+ |    | +----------+   |
|   | PI, ID 1 ########## PI, ID 2 |   |
|   | (outlet) | |    | | (inlet,  |   |
|   |          | |    | |  meter)  |   |
|   +----------+ |    | +----------+   |
+----------------+    +----------------+
```

Figure 7: Simple one-to-one power supply topology

This figure extends the PSU layer of Figure 3 by power interfaces. The power source has a single power interface in outlet mode connected to a power supply lime that connects it to the power interface of the powered entity in inlet mode. The corresponding PSU layer model of the topology in Figure 7 is shown by Figure 8.

```
PS ----- PI ID 1 ----- PI ID 2 ----- PE
         outlet        inlet
                         |
                         |
                        PM
```

Figure 8: PSU layer model for one-to-one supply topology

This model shows four relationships,

o a containment relationship modeling the power source PS containing the power interface PI with ID 1,
o a containment relationship modeling the powered entity PE containing the power interface PI with ID 2,
o a metering relationship between PI ID 2 and a power meter PM.
o a connection relation between PI ID 1 and PI ID 2.

Implicit in this model is a containment relationship between the PE and the PM. It is implicit, because the PI ID 2 is contained in the PE and the PI ID 2 has a metering relationship with the PM.

The model also shows that PIs have an attribute indicating the mode. In Figure 8 PI ID 1 is in mode "outlet" and PI ID 2 is in mode "inlet".

Figure 9 extends the PSU layer of the example from Figure 4 by power interfaces. A power source with a single outlet supplies three powered entities.

```
      +-----------------+        +-------------------+
      | power source    |        | powered entity I |
      |   +----------+ |        | +----------+      |
      |   | PI, ID 3 ############### PI, ID 4 |      |
      |   | (outlet) | |   #    | | (inlet)  |      |
      |   +----------+ |   #    | +----------+      |----+
      +-----------------+   #    +-------------------+ II |
                            #      | +----------+        |
                            ########## PI, ID 5 |        |
                              #    | | (inlet)  |        |
                              #    | +----------+        |-----+
                              #    +---------------------+ III |
                              #      | +----------+            |
                              ########## PI, ID 6 |            |
                                     | | (inlet)  |            |
                                     | +----------+            |
                                     +-------------------------+
```

Figure 9: PSU Layer for a Single PS Supplying Multiple PEs.

The corresponding PSU layer data model is shown by Figure 10.

```
               PS ----- PI ID 3 --+-- PI ID 4 ----- PE I
                        outlet    |   inlet
                                  |
                                  +-- PI ID 5 ----- PE II
                                  |   inlet
                                  |
                                  +-- PI ID 6 ----- PE III
                                      inlet
```

Figure 10: PSU Layer Model of a Single PS Supplying Multiple PEs.

Figure 11 shows the PSU layer model of the example from Figure 4. A PE with three inlets is supplied by two power sources PS I and PS II. There are two power supply connections between PS I and the PE.

```
               PS I  --+-- PI ID 7  ----- PI ID 8  --+-- PE
                       |   outlet         inlet      |
                       |                             |
                       +-- PI ID 9  ----- PI ID 10 --+
                           outlet         inlet      |
                                                     |
               PS II ----- PI ID 11 ----- PI ID 12 --+
                           outlet         inlet
```

Figure 11: Multiple Power Supply for Single Powered Device

3.1.3. Power Sources

In the PSU layer, a EO that is a power supply can be seen as having two roles in that it is also a PE. A good example is a PoE switch that is a PE supplied with AC power and a PS supplying other PEs with DC power. Examples which are pure AC devices include a UPS or a PDU.

```
        +--------------------------------------------------------+
        | powered entity / power source                          |
        |  +---------+    +---------+  +---------+  +---------+  |
      ###### PI ID 13|    | PI ID 14|  | PI ID 15|  | PI ID 16|  |
        |  | (inlet) |    | (outlet)|  | (outlet)|  | (outlet)|  |
        |  +---------+    +----#----+  +----#----+  +----#----+  |
        +----------------------#------------#------------#-------+
                               #            #            #
```

Figure 12: Power Source Roles

Figure 12 shows the example a power source with three power outlets and a power inlet and Figure 13 shows its PSU layer information model.

```
        EO -------+------------+------------+------------+
        PE        |            |            |            |
        PS     PI ID 13     PI ID 14     PI ID 15     PI ID 16
               inlet        outlet       outlet       outlet
```

Figure 13: PSU Layer Model of a Dual Role Power Source

3.1.4. Power Meters

On the PSU layer each power and energy meter is integrated with one or more power interfaces, though usually just with one, or with a component. A common case is shown by Figures 7 and 8 where the PE has metering capability at its power inlet. Power outlets can have metering capabilities as well.

When power meters are attached to more than one power interface within a single powered entity, the PM cannot report per power interface individually, but just the summed of multiple interfaces. A common example is a PoE switch that measures power per group of eight ports. Another example is a powered entity with two power inlets that only measures the total power input to the entity as illustrated by Figure 14 and modeled by Figure 15.

```
   +--------------+                                    +--------------+
   | power        |    +--------------------------+    | power        |
   | source 1     |    | powered entity           |    | source 2     |
   |  +---------+ |    | +---------+  +---------+ |    | +---------+  |
   |  | PI ID 17########## PI ID 18|  | PI ID 19########## PI ID 20|  |
   |  | (outlet)| |    | | (inlet) |  | (inlet) | |    | | (outlet)|  |
   |  +---------+ |    | +----#----+  +----#----+ |    | +---------+  |
   +--------------+    |      #            #      |    +--------------+
                       | +----#------------#----+ |
                       | |     power meter      | |
                       | +----------------------+ |
                       +--------------------------+
```

Figure 14: Dual power supply topology

```
               PS I  ----- PI ID 17 ----- PI ID 18 --+-- PE
                           outlet          inlet     |
                                             |       |
                                             |       |
                                            PM       |
                                             |       |
                                             |       |
               PS II ----- PI ID 19 ----- PI ID 20 --+
```

Figure 15: PSU Layer Model of a Dual Role Power Source

A power meter can cover any mixture of inlets and outlets and simply reports the sum. As an example, see the model of a the dual role PE and PS from Figure 13 extended by a power meter attached to all PIs in Figure 16.

```
EO -------+------------+------------+------------+
PE        |            |            |            |
PS     PI ID 13     PI ID 14     PI ID 15     PI ID 16
       inlet        outlet       outlet       outlet
          |            |            |            |
          +------------+------------+------------+----- PM
```

Figure 16: PSU Layer Model of a Dual Role Power Source

3.1.5. External Power Meters

A device which is only a power meter is modeled exactly as any other PS. It is modeled as a device that has an inlet power interface receiving power from a PS and one or more outlet power interfaces providing power to PEs, see, for example, Figure 17. The fact that a device may consume none of the energy that passes through it is not relevant to EMAN.

```
                +-------------------------------+
                | external power meter          |
                |  +---------+     +---------+  |
 from PS ###### PI ID 21|     | PI ID 22###### to PE(s)
                |  | (inlet) |     | (outlet,|  |
                |  |         |     |  meter) |  |
                |  +---------+     +---------+  |
                +-------------------------------+
```

Figure 17: External Power Meter

3.1.6. PSU Layer Relationships

The PSU topology is usually asymmetric. PS devices supply other PEs with power and meters may measure power that is consumed or provided by other entities than the one at which the measurement was conducted. This way we define two kinds of relationships between EOs in the PSU layer: power source relationships and power meter relationships

3.1.6.1. Power Source Relationship

A power source relationship exists between an outlet PI of a PS and an inlet PI of a PE. It is an asymmetric relationship. The role of the outlet is providing energy and the role of the inlet is receiving energy.

An outlet can be directly connected to multiple inlets and thus can have multiple power source relationships. An inlet is typically connected to a single outlets only and thus has only one power source relationship to a directly connected outlet. While not common, an inlet can be connected to multiple outlets.

The relationship is transitive. If an outlet PI acts as power source for an inlet PI of an entity that itself acts as PS for further PEs, then the outlet may have also power source relationships to inlets of entities supplied by the entity in the middle.

Figure 18 shows a simple example. PI ID 23 has a power source relationship with PI Id 24. But since the entity in the middle is a dual role device that also acts as PS, PI ID 23 has also a power source relationship with PI ID 26.

```
     PS 1             PE 1 / PS 2               PE 2
       |                   |                      |
       |              +-----+------+              |
       |              |            |              |
   PI ID 23 ----- PI ID 24     PI ID 25 ----- PI ID 26
   outlet         inlet        outlet         inlet
      |                                          |
     PM                                         PM
```

Figure 18: Relationships between Cascaded Power Sources

3.1.6.2. Power Meter Relationship

The power meter relationship is very similar to the power source relationship. It is asymmetric as well and it has two roles: the metering PI and the metered PI. Different from the power source relationship, the role of a PI does not depend on its mode. The metering PI can be an outlet PI or an inlet PI. The same holds for the metering PI. Thus this relationship works not just downstream but also upstream.

In Figure 18 PI ID 23 has a metering relationship as metering PI with PI ID 24 in the downstream direction. In the same way, PI ID 26 is the metering PI in a metering relationship with PI ID 25. Assuming that PE 1 / PS 2 is just a switch with no energy consumption, PI ID

23 and PI ID 26 have two metering relationship with each other with different directions. In one PI IS 23 measures power remotely for PI ID 26 and in the other one measured value at PI ID 26 can be used to report the power at PI ID 23.

3.1.7. PSU Layer Information Model

Figure 19 illustrates the information model of the PSU layer. Electrical objects (EOs) are a synony for powered entity.

```
         +---------------------+ 1      +------------+ 1..N   +--------+
      +->| electrical          |--------| power      |--------| power |
      |  | object              |   0..N | interface |   0..N | meter |
      |  +---------------------+        +------------+        +--------+
      |                                 | ID         |
      |  +---------------------+        | mode       |
      +--| powered entity      |        +------------+
         +---------------------+      0..N |    | 0..N
                                           +----+
```

Figure 19: Basic Information Model of the PSU Layer

Each EO contains a number of PIs. PIs have two attributes, their ID and their mode. Each PI may be attached to one or more PMs. A PM may be attached to one or more PIs. Finally, a PI may be connected to one or more PIs of other EOs.

3.2. Local Energy Management Interface (LMI) Layer

The local energy management interface (LMI) layer provides a set of interfaces for monitoring and controlling power and use of energy at EOs. These interfaces are offered by an EO and restricted to only report and control properties and states that are local to the EO, as do most of the common network management interfaces at managed entities today.

Interfaces at this layer deal components of the PSU layer at the local EO. They are structured into five specific interfaces:

```
           ^            ^            ^            ^           ^
           |            |            |            |           |
   +-------------------------------------------------------------------+
   | EO    |            |            |            |           |       |
   |       v            v            v            v           v       |
   | +----------+ +----------+ +----------+ +----------+ +----------+ |
   | |    PI    | |    PI    | |  meter   | |  power   | |  power   | |
   | |monitoring| | control  | | reading  | |  state   | |  state   | |
   | |          | |          | |          | |monitoring| | control  | |
   | +----------+ +----------+ +----------+ +----------+ +----------+ |
   +-------------------------------------------------------------------+
```

Figure 20: Interfaces of an EO at the LMI layer

o PI monitoring
   This interfaces provide methods for retrieving information on PIs contained in the EO. Particularly included is information on the mode of the PI (inlet or outlet) and its operational state (on, off, ready, etc.) and known power source relationships and power meter relationships.

o PI control
   PI control is limited to switching PIs on and off.

o Meter reading
   This interfaces includes methods for reporting quantities that are measured by power meters and that are related to power and to energy consumption.

o Power state monitoring
   Methods of this interface provide information on power states of PEs. These methods are only available at PEs. But since all EOs can be considered to be PEs they can in general be made available at any EO.

o Power state control
   The number of control methods at this interface may be very small. At least included is a method for setting the power state of a PE.

3.3. Energy Management Mediation (EMM) Layer

Information and control means provided by the LMI layer is local to the reporting EO. However, with information from the PSU layer, there are some obvious steps of processing this information to make it more useful or easier to digest by an energy management system. In general, all functions in this layer are 'convenience' functions and an energy management system can execute all of them directly.

This layer may contain various kinds of functions. The ones that are already known can be structured into 7 groups:

- o remote PE information
- o remote PE control
- o all available information on a PE
- o all available control affecting a PE
- o aggregated information from multiple PEs
- o aggregated control of multiple PEs
- o proxying for an EO

This list may not be complete, so that new 'convenience' functions may be added. Some of them may not match any of the groups listed above. Figure 21 shows (except for the proxying functions) how the groups are structured in the EMM layer and interact with the LMI layer.

```
   +---------------------------------------------------------------+
   |                   energy management system                    |
   +---------------------------------------------------------------+
             ^           ^    ^    ^    ^    ^           ^
             |           |    |    |    |    |           |
             v           |    |    |    |    |           v
   +------------------+  |    |    |    |    |  +------------------+
   |    aggregated    |  |    |    |    |    |  |    aggregated    |
   |     info on      |  |    |    |    |    |  |    control of    |
   |   multiple PEs   |  |    |    |    |    |  |   multiple PEs   |
   +------------------+  |    |    |    |    |  +------------------+
     |    |         |    |    |    |    |    |    |         |    |
     |    |         v    v    |    |    |    v    v         |    |
     |    |  +-------------+  |    |    |  +-------------+  |    |
     |    |  |  all info   |  |    |    |  | all control |  |    |
     |    |  |  on a PE    |  |    |    |  |   of a PE   |  |    |
     |    |  +-------------+  |    |    |  +-------------+  |    |
     |    |    |         |    |    |    |    |         |    |    |
     |    +---------+    |    |    |    |    |    +---------+    |
     |         |    v    v    v    |    v    v    v    |         |
     |         |  +-------------+  |  +-------------+  |         |
     |         |  |  remote PE  |  |  |  remote PE  |  |         |
     |         |  | information |  |  |   control   |  |         |
     |         |  +-------------+  |  +-------------+  |         |
     |         |         |         |         |         |         |
     v         v         v         v         v         v         v
   +----------------------------------------------------------------+
   |                           LMI layer                            |
   +----------------------------------------------------------------+
```

Figure 21: Groups of Functions in the LMI layer

In this layer, EOs offer functions to the EnMS that concern other PEs. By doing so, they establish a relationship to the respective PEs. Relationships on this layer include

- Reporting relationship
  This relationship is between a reporting EO and a PE on which it reports. It is an asymmetric relationship and the PE on which is reported may not even have any knowledge on the existence of the relationship. Subject of reporting can be the power supply status for PE, metered values for a PE, a power state information on a PE, and other information on the PE that is relevant for the energy management system.
- Control relationship
  Analogous to the reporting relationship, the control relationship is between a controlling EO and a controlled PE. Again, the PE does not necessary know of this relationship, for example, in case the controlling EO controls the power supply of a PE by communicating with the PS supplying the PE. This can be done in a way that is completely hidden from the PE. Subject of control can be the power supply of the PE, its power state, and other states relevant for the energy management system.
- Proxy relationship
  This is a relationship between a proxying EO and a proxied PE. The concept of a proxy relationship overlaps with the reporting relationship and the control relationship. A proxy relationship always includes one of the two or both. Characteristic for a proxy relationship is that it includes reporting or control function that the proxying EO cannot conduct without remotely retrieving data or remotely controlling other EOs.

The groups of the EMM layer are described individually in the following subsections.

3.3.1. Remote PE Information

This group contains functions that allow an EO to provide information about another PE. These functions are useful in scenarios like the ones described in Section 2.1 where an EO switches or measures power at an outlet PI. If the EO has information on the PSU layer topology, particularly about which PEs are connected to the outlet, then it can combine this information and report on the power supply for the connected PEs.

This way an EO uses local information and deduces information on other, remote PEs from it. Such information may not be as reliable as a direct report from the concerned PEs, but it is often valuable information for energy management. Such reporting must be cognizant of possibilities like devices with multiple power supplies.

The functions in this group can also be implemented by EOs that are neither one of the concerned PEs nor the EO at which the observation or measurement was conducted. In such a case the executing EOs of these functions act as a kind of mid-level manager between management system and managed devices and could, for example, be components of an conventional element management system.

Obviously, the EO that reports on a certain other PE has a reporting relationship to the PE. However, if the PE is aware of the relationship, the PE may have means to report which EO has which kind of relationship to it.

Like some other functions on the EMM layer, the remote PE functions are 'convenience' functions. Inferring available information from different EOs can also be done by the energy management system.

3.3.2. Remote PE Control

This group has some similarities to the previous one. Again, operations at an EO are combined with knowledge of the PSU layer topology in order to realize operations on a remote PE. In the example scenario from figures 7 and 8, power for the PE can be switching by switching the outlet PI ID 1 of the PS. On the LMI layer the offered function would be "switch of PI ID 1 at PS". This function can be offered by the PS at the EMM layer as "switch power for the PE". Both function would have the same technical effect, but they are semantically on different layers.

Here, the EO that controls an PE has a control relationship to the PE. If the PE is aware of the relationship, the PE may have means to report which EO has which kind of relationship to it.

Again, like in the previous group, these functions are convenience functions and they can be executed by the PS, by the PE or by any other EO.

3.3.3. Parent function: All Available Information on a PE

This group provides just a single logical function that we call the parent function for reporting: A parent EO makes all information on a PE, that is available somewhere in the network, but that might be distributed among several EOs, available at a single point of contact, the parent.

Realizing such a function would be expected to require to instantiate several of the functions in the "Remote PE Information" group described above.

The parent EO that provides all available information on a certain other PE has definitely a reporting relationship to it. In addition it may have a proxying relationship, for example if it reports the PE’s power state.

This function is again a ’convenience’ function for an energy management system that in some cases may be much easier done locally at involved EOs than within the energy management system.

3.3.4. All Available Control Affecting a PE

This group also provides just a single logical function: The parent control function: It makes all control functions affecting a PE, that are available somewhere in the network, but that might be distributed among several EOs, available at a single point of contact, the parent.

Realizing such a function would be expected to require to instantiate several of the functions in the "Remote PE Control" group described above.

Again, the parent EO that controls a certain other PE has a control relationship to it. If controls the power state, it may also be a proxy relationship.

This function is again a ’convenience’ function for an energy management system that in some cases may be much easier done locally at involved EOs than within the energy management system.

3.3.5. Aggregated Information from Multiple PEs

Functions in this group aggregate monitoring information from multiple PEs into more compact representations with potential loss of information.

For example, power measurements from a set of PEs may be summed up into a single value that is provided to an energy management system that does not need more detailed information. aggregating such information in the EMM layer is not just a convenience functions but may also increase scalability of the energy management system.

Aggregation is not necessarily limited to just summing up values. Also included, for example, are aggregation functions that give information on how many PEs of a group are in a certain power state. The range of potential functions in this group appears to be huge. However, it will probably sufficient to standardize the most commonly used ones only.

3.3.6. Aggregated Control of Multiple PEs

Like monitoring and reporting functions covered in the previous group, also control functions can be aggregated. Examples include switching power supply for all PEs in a given group or setting all of them to the same power state with a single command.

Again, this can be considered a convenience function, but at the same time increase scalability of the energy management system. And again it will probably be sufficient to standardize just a few of the wide range of possible functions in this group.

3.3.7. Proxying for an EO

This section still needs to be written. Summary: An EO can act as a proxy for an EO that cannot directly communicate with the energy management system.

3.4. Energy Management System Interface (EnMS) Layer

The EMS receives EMAN data directly from devices, or via the mediation layer. Similarly, it can exercise control directly or via the mediation layer. In many cases, the same action can be accomplished through either means, though some are only available via mediation.

4. Security Considerations

This memo currently does not impose any security considerations.

5. IANA Considerations

This memo has no actions for IANA.

6. Acknowledgements

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7. Open Issues

7.1. Devices or entities?

Entities expands on the category of devices by adding components. Do components have all the features of devices (including having power interfaces) or do they only have metering of their energy/power use? The relationships among powered devices, powered entities, components, and electrical objects needs to be clarified.

7.2. Add PM monitoring and control interfaces to LMI layer?

In earlier versions of this draft, monitoring and configuring the power meter have also been considered. Shall we list them as further local interfaces on the LMI layer?

7.3. Topology changes

Ideally topology would never change so the EMS need only query it once. A date/time stamp for time of last topology change would enable the EMS to know when it needs to rescan the topology.

7.4. Topology reporting

For each interface, there is a list of [device,interface] tuples that is connected to the interface. If one of these is listed as "unknown", then any number of unknown devices may be connected (that is, the device need not specify the number, since likely it will usually not know). Topology information need not be symmetric. A device providing power to the second may know the ID of the second while the second device may lack knowledge of the ID of the supplying device. The mediation layer brings together such information to form a more complete picture.

7.5. Proxying

Does all proxying occur at the mediation layer?

7.6. PSU Info Model

The PSU layer information model needs to be further elaborated.

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Authors' Addresses

Juergen Quittek
NEC Europe Ltd.
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE

Phone: +49 6221 4342-115
Email: quittek@neclab.eu

Bruce Nordman
Lawrence Berkeley National Laboratory
1 Cyclotron Road
Berkeley 94720
US

Phone: +1 510 486 7089
Email: bnordman@lbl.gov

Rolf Winter
NEC Europe Ltd.
Network Research Division
Kurfuersten-Anlage 36
Heidelberg 69115
DE

Phone: +49 6221 4342-121
Email: Rolf.Winter@neclab.eu

Energy Management Working Group E. Tychon
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Mouli Chandramouli
Cisco Systems Inc.
Bruce Nordman
Lawrence Berkeley National Laboratory
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Status of this Memo

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Abstract

The objective of Energy Management (EMAN)is to provide an energy management framework for networked devices. This document presents the applicability of the EMAN framework for a variety of scenarios. This document lists use cases and target devices that can potentially implement the EMAN framework and associated SNMP MIB modules. These use cases are useful for identifying monitoring requirements that need to be considered. Further, we describe the relationship of the EMAN framework to relevant other energy monitoring standards and architectures.

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1. Introduction

The focus of the Energy Management (EMAN) framework is energy monitoring and management of energy objects [EMAN-DEF]. The scope of devices considered are network equipment and its components, and devices connected directly or indirectly to the network. The EMAN framework enables monitoring i.e.; heterogeneous devices to report their energy consumption, and secondly, if permissible, enables control policies for energy savings. There are multiple scenarios where this is desirable, particularly considering the increased importance of limiting consumption of finite energy resources and reducing operational expenses.

The EMAN framework describes how energy information can be retrieved from IP-enabled devices using Simple Network Management Protocol (SNMP), specifically, Management Information Base (MIBs) for SNMP.

This document describes typical applications of the EMAN framework, as well as its opportunities and limitations. Other standards that are similar to EMAN but address different domains are described. This document contains references to those other standards and describes how they relate to the EMAN framework.

1.1. Energy Management Overview

First, a brief introduction to the definitions of Energy and Power are presented. A draft on terminology has been submitted so that to reach a consensus on the definitions of commonly used terms in the EMAN WG. While energy is available in many forms, EMAN addresses only the electrical energy consumed by devices connected to a network.

Energy is the capacity to perform work. Electrical energy is typically expressed in kilowatt-hour units (kWh) or other multiples of watt-hours (Wh). One kilowatt-hour is the electrical energy used by a 1 kilowatt device for one hour. Power is the rate of electrical energy flow. In other words, power = energy / time. Power is often measured in watts. Billing is based on electrical energy (measured in kWh) supplied by the utility.

Towards the goal of increasing the energy efficiency in networks and buildings, a first step is to enable energy objects to report their energy usage over time. The EMAN framework addresses this problem with an information model for some electrical equipment: energy object identification, energy object context, power measurement and power measurement attributes.

The EMAN WG framework defines SNMP MIB modules based on the information model. By implementing the SNMP MIB modules, any energy object can report its energy consumption according to the information model. In that context, it is important to distinguish energy objects that can report their own energy usage from parent devices that can also collect and aggregate energy usage of children energy objects.

The list of target devices and scenarios considered for Energy Management are presented in Section 2 with detailed examples.

1.2. Energy Measurement

More and more devices are able to measure and report their own energy consumption. Smart power strips and some Power over Ethernet (PoE) switches can meter consumption of connected devices. However, when managed and reported through proprietary means, this information is minimally useful at the enterprise level.

The primary goal of the EMAN MIBs is to enable reporting and management within a standard framework that is applicable to a wide variety of end devices, meters, and proxies. This enables a management system to know who's consuming what, when, and how at any time by leveraging existing networks, across various equipment, in a unified and consistent manner.

Given that an energy object can consume energy and/or provide energy to other devices, there are three types of meters for energy measurement: energy input to a device, energy supplied to other devices, and net (resultant) energy consumed (the difference between energy input and provided).

1.3. Energy Management

Beyond energy monitoring, the EMAN framework provides mechanisms for energy control.

There are many cases where reducing energy consumption of devices is desirable, such as when the device utilization islow or when the electricity is expensive or in short supply.

In some cases, energy control requires considering the energy object context. For instance, in a building: all phones would not usually be turned off to keep some still available in case of emergency; office cooling is usually not turned off totally during non-work hours, but the comfort level is reduced; and so on.

Energy object control requires flexibility and support for different polices and mechanisms: from centralized management with a network management station, to autonomous management by individual devices, and alignment with dynamic demand-response mechanisms.

The EMAN framework can be used as a tool for the demand/response scenario where in response to time-of-day fluctuation of energy costs or possible energy shortages, it is possible to respond and reduce the energy consumption for the network devices, effectively changing its power state.

1.4. EMAN Framework Application

A Network Management System (NMS) is the entity that requests information from compatible devices using SNMP protocol. It may be a system which also implements other network management functions, e.g. security management, identity management and so on), or one that only deals exclusively with energy in which case it is called EnMS, Energy Management System. It may be limited to monitoring energy use, or it may also implement control functions. In a typical application of the EMAN framework, management software collects energy information for devices in the network.

Energy management can be implemented by extending existing SNMP support to the EMAN specific MIBs. SNMP provides an industry proven and well-known mechanism to discover, secure, measure, and control SNMP-enabled end devices. The EMAN framework provides an information and data model to unify access to a large range of devices. The scope of the target devices and the network scenarios considered for energy management are listed in Section 2.

1.5. EMAN WG Document Overview

The EMAN working group charter calls for producing a series of Internet standard drafts in the area of energy management. The following drafts are currently under discussion in the working group.

Applicability Statement [EMAN-AS] This draft presents the use cases and scenarios for energy monitoring. In addition, other relevant energy standards and architectures are listed.

Requirements [EMAN-REQ] This draft presents the requirements of Energy Monitoring and the scope of the devices considered.

Framework [EMAN-FRAMEWORK] This draft defines the terminology and explains the different concepts associated with energy monitoring; these are used in the MIB modules.

Energy-Aware MIB [EMAN-AWARE-MIB] This draft proposes a MIB module that characterizes a device's identity and context.

Monitoring MIB [EMAN-MONITORING-MIB] This draft defines a MIB module for monitoring the power and energy consumption of a device. In addition, the MIB module contains an optional module for power quality metrics.

Battery MIB [EMAN-BATTERY-MIB] This draft contains a MIB module for monitoring characteristics of an internal battery.

Energy Management Terminology [EMAN-DEF] This draft lists the definitions and terms used in the Energy Management Working Group.

2. Scenarios and Target Devices

In this section a selection of scenarios for energy management are presented. The fundamental objective of the use cases is to list important network scenarios that the EMAN framework should solve. These use cases then drive the requirements for the EMAN framework.

Each scenario lists target devices for which the energy management framework can be applied, as well as how the reported-on devices are powered, and how the reporting is accomplished. While there may be some overlap between some of the use cases, the use cases serve as illustrative network scenarios EMAN framework should solve.

2.1. Network Infrastructure Energy Objects

This scenario covers network devices and their components. Power management of energy objects is considered as a fundamental requirement of energy management of networks.

It can be important to monitor the power state and energy consumption of these energy objects at a granularity level finer than just the entire device. For these devices, the chassis draws power from one or more sources and feeds all its internal components. It is highly desirable to have monitoring available for individual components, such as line cards, processors, and hard drives as well as peripherals like USB devices.

As an illustrative example, consider a switch with the following grouping of sub-entities for which energy monitoring could be useful.

- physical view: chassis (or stack), line cards, service modules of the switch
- component view: CPU, ASICs, fans, power supply, ports (single port and port groups), storage and memory
- logical view: system, data-plane, control-plane, etc.

The essential properties of this use case are:

- Target devices: Network devices such as routers, switches and their components.
- How powered: Typically by a PDU on a rack or from a wall outlet. The components of a device are powered by the device chassis.
- Reporting: Direct power measurement can be performed at a device level. Components can report their power consumption directly or the chassis/device that can report on behalf of some components.

2.2. Devices Powered and Connected to a Network Device

This scenario covers Power over Ethernet (PoE) devices. A PoE Power Sourcing Equipment (PSE) device (e.g. a PoE switch) provides power to a Powered Device (PD) (e.g. a desktop phone). For each port, the PSE can control the power supply (switching it on and off) and monitor actual power provided. PoE devices obtain network connectivity as well as the power supply for the device over a single connection so the PSE can determine which device to allocate each port’s power to.

PoE ports on a switch are commonly connected to IP phones, wireless access points, and IP cameras. The switch powers itself, as well as supplies power to downstream PoE ports. Monitoring the power consumption of the switch (Energy Object Parent) and the power consumption of the PoE end-points(Energy Object Children) is a simple use case of this scenario.

The essential properties of this use case are:

- Target devices: Power over Ethernet devices such as IP Phones, Wireless Access Points, and IP cameras.
- How powered: PoE devices are connected to the switch port which supplies power to those devices.
- Reporting: PoE device power consumption is often measured and reported at the switch (PSE) port which supplies power for the PoE device.

In this case, the PoE devices do not need to directly support the EMAN framework, only the Power Sourcing Equipment (PSE) does.

2.3. Devices Connected to a Network

The use case covers the metering relationship between an energy object receiving power from a source such as a power brick, and have an independent network connection to a parent energy object such as a switch.

In continuation to the previous example is a switch port that has both a PoE connection powering an IP Phone, and a PC has a daisy-chain connection to the IP Phone for network connectivity. The PC has a network connection from the switch, but draws power from the wall outlet, in contrast to the IP phone draws power from the switch.

It is also possible to consider a simple example of PC which has a network connection but draws power from the wall outlet or PDU.

The PC in this case, is an non-PoE device, can report power usage by itself, for instance through the EMAN framework.

The essential properties of this use case are:

. Target devices: Abroad set of energy objects that have a network connection, but receive power supply from the wall outlet.
. How powered: These devices receive power supply from the wall outlet or a PDU.
. Reporting: There are two models: devices that can measure and report the power consumption directly via the EMAN framework, and those that communicate it to the network device (switch) and the switch can report the device’s power consumption via the EMAN framework.

2.4. Power Meters

Some electrical devices are not equipped with instrumentation to measure their own power and accumulated energy consumption. External meters can be used to measure the power consumption of such electrical devices.

This use case covers the proxy relationship of energy objects able to measure or report the power consumption of external electrical devices, not natively connected to the network. Examples of such metering devices are smart PDUs and smart meters.

Three types of external metering are relevant to EMAN: PDUs, standalone meters, and utility meters. External meters can measure these properties for a single device or for a set of devices.

Power Distribution Unit (PDUs) in a rack have inbuilt meters for each socket and the PDUs can measure the power supplied to each device in an equipment rack. The PDUs have remote management functionality which can be used to measure and possibly control the power supply of each outlet.

Standalone meters can be placed anywhere in a power distribution tree, and can measure the power consumption.
Utility meters monitor and report accumulated power consumption of the entire building. There can be sub-meters to measure the power consumption of a portion of the building.

The essential properties of this use case are:

- Target devices: PDUs and Smart Meters.
- How powered: From traditional mains power but as passed through a PDU or meter.
- Reporting: The PDUs reports power consumption of downstream devices. There is commonly only one device downstream of each outlet, but there could be many. There can be external meters in between the power supply and device and the meters can report the power consumption of the device.

2.5. Mid-level Managers

This use case covers aggregation of energy management data at "mid-level managers" that can provide energy management functions for themselves as well as associated devices.

A switch can provide energy management functions for all devices connected to its ports, whether or not these devices are powered by the switch or whether the switch provides immediate network connectivity to the devices; such a switch is a mid-level manager, offering aggregation of power consumption data for devices it does not supply power to them. Devices report their

EMAN data to the switch and the switch aggregates the data for these data.

The essential properties of this use case are summarized as follows:

- . Target devices: network devices which can perform aggregation; commonly a switch or a proxy
- . How powered: Mid-level managers can be are commonly powered by a PDU or from a wall outlet but there is no limitation.
- . Reporting: The middle-manager aggregates the energy data and reports that data to a NMS or higher mid-level manager.

2.6. Gateways to Building Systems

This use case describes energy management of buildings. Building Management Systems (BMS) have been in place for many years using legacy protocols not based on IP. In these buildings, a gateway can provide a proxy relationship between IP and legacy building automation protocols. The gateway can provide an interface between the EMAN framework and relevant building management protocols.

Due to the potential energy savings, energy management of buildings has received significant attention. There are gateway network elements to manage the multiple components ofa building energy management system such as Heating, Ventilation, and Air Conditioning (HVAC), lighting, electrical, fire and emergency systems, elevators, etc. The gateway device uses legacy building protocols to communicate with those devices, collects their energy usage, and reports the results.

The gateway performs protocol conversion between many facility management devices. The gateway communicates via RS-232/RS-485 interfaces, Ethernet interfaces, and protocols specific to building management such as BACNET, MODBUS, or Zigbee.

The essential properties of this use case are :

- . Target devices: Building energy management devices - HVAC systems, lighting, electrical, fire and emergency systems. There are meters for each of the sub-systems and the energy data is communicated to the proxy using legacy protocols.
- . How powered: Any method, including directly from mains power or via a UPS.

- Reporting: The gateway collects energy consumption of non-IP systems and communicates the data via the EMAN framework.

2.7. Home Energy Gateways

This use case describes the scenario of energy management of a home. The home energy gateway is another example of a proxy that interfaces to the electrical appliances and other devices in a home and also has an interface to the utility. This gateway can monitor and manage electrical equipment (refrigerator, heating/cooling, washing machine etc.) possibly using one of the many protocols (ZigBee, Smart Energy, ...) that are being developed for the home area network products and considered in standards organizations.

In its simplest form, metering can be performed at home. Beyond the metering, it is also possible implement energy saving policies based on energy pricing from the utility grid. From an EMAN point of view, the information model that been investigated can be applied to the protocols under consideration for energy monitoring of a home.

The essential properties of this use case are:

- Target devices: Home energy gateway and Smart meters in a home.
- How powered: Any method.
- Reporting: Home energy gateway can collect power consumption of device in a home and possibly report the metering reading to the utility.

Beyond the canonical setting of a home drawing power from the utility, it is also possible to envision an energy neutral situation wherein the buildings/homes that can produce and consume energy without importing energy from the utility grid. There are many energy production technologies such as solar panels, wind turbines, or micro generators. This use case illustrates the concept of self-contained energy generation and consumption and possibly the aggregation of the energy use of homes.

2.8. Data Center Devices

This use case describes energy management of a Data Center network.

Energy efficiency of data centers has become a fundamental challenge of data center operation, as datacenters are big energy consumers and their infrastructure is expensive. The equipment generates heat, and heat needs to be evacuated though a HVAC system.

A typical data center network consists of a hierarchy of electrical energy objects. At the bottom are servers mounted on a rack; these are connected to the top-of-the-rack switches; these are connected to aggregation switches; those in turn connected to core switches. Power consumption of all network elements and the servers in the Data center should be measured. In addition, there are also network storage devices. Energy management can be implemented on different aggregation levels, such as network level, Power Distribution Unit (PDU) level, and server level.

The Data center network contains UPS to provide back-up power for the network devices in the event in the event of power outages. Thus from a Data center energy management point of view, in addition, to monitoring the energy usage of network devices, it is also important to monitor the remaining capacity of the UPS.

In addition to monitoring the power consumption, at a data center level, additional metrics such as power quality, power characteristics can be important metrics. The dynamic variations in the input power supply from the grid referred to as power quality is one metric. Secondly, how the devices use the power can be referred to as power characteristics and it is also useful to monitor these metrics. Lastly, the power plate set will make it possible to know an aggregate of the potential worst-case power usage and compare it to the budgeted power in the data center.

The essential properties of this use case are:

- Target devices: All network devices in a data center, such as network equipment, servers, and storage devices.
- How powered: Any method but commonly by a PDUs in racks.
- Reporting: Devices may report on their own behalf, or for other connected devices as described in other use cases.

2.9. Energy Storage Devices

There are two types of devices with energy storage: those whose primary function is to provide power to another device (e.g. a UPS), and those with a different primary function, but have an energy storage as a component as an alternate internal power source (e.g. a notebook). EMAN covers both types of products in this use case.

The energy storage can be a battery, or any other means to store electricity such as a hydrogen cell.

Some devices have an internal battery as a back-up or alternative source of power to mains power. When the connection to the power supply of the device is disconnected, the device can run on the internal battery. As batteries have a finite capacity and lifetime, means for reporting the actual charge, age, and state of a battery are required.

UPS can provide backup power for many devices in a data centers for a finite period of time. Energy monitoring of such energy storage devices is vital from a data center network operations point of view. The UPS MIB provides a framework for monitoring the remaining capacity of the UPS.

There are also battery systems for mobile towers particularly for use in remote locations. It is important to monitor the remaining battery life and raise an alarm when the battery life is below a threshold.

The essential properties of this use case are:

- Target devices: Devices that have an internal battery such as notebook PC and other mobile devices.
- How powered: From internal batteries or mains power.
- Reporting: The device reports on its internal battery.

2.10. Ganged Outlets on a PDU Multiple Power Sources

This use case describes the scenario of multiple power sources of a devices and logical groupings of devices in a PDU.

Some PDUs allow physical entities like outlets to be "ganged" together as a logical entity to simplify management.

This is particularly useful for servers with multiple power supplies, where each power supply is connected to a different physical outlet. Other implementations allow "gangs" to be created based on common ownership of outlets, such as business units, load shed priority, or other non-physical relationships.

Current implementations allow for an "M-to-N" mapping between outlet "gangs" and physical outlets, as with this example:

. Outlet 1 - physical entity
. Outlet 2 - physical entity
. Outlet 3 - physical entity
. Outlet 4 - physical entity
. Outlet Gang A - virtual entity
. Outlet Gang B - virtual entity

  o Gang A -> Outlets 1, 2 and 3
  o Gang B -> Outlets 3 and 4

Note the allowed overlap on Outlet 3, which belongs to both "gangs."

Each "Outlet Gang" entity reports the aggregated data from the individual outlet entities that comprise it and enables a single point of control for all the individual outlet entities.

2.11. Industrial Automation Networks

Energy consumption statistics in the industrial sector are staggering. The industrial sector alone consumes about half of the world's total delivered energy, making it the largest end-use sector. Thus, the need for optimization of energy usage in this sector is natural.
Industrial facilities consume energy in process loads, and in non-process loads.
The essential properties of this use case are:

. Target devices: Devices used in industrial automation
. How powered: Any method.
. Reporting: Currently, CIP protocol is currently used for reporting energy for these devices

2.12. Printers

This use case describes the scenario of energy monitoring and management of Printer devices.

Printers in this use case stand in for all imaging equipment, also including multi-function devices (MFDs), copiers, scanners, fax machines, and mailing machines. Energy use of printers has been an industry concern for several decades, and they usually have sophisticated power management with a variety of low-power modes, particularly for managing energy-intensive thermo-mechanical components. Printers also have long made extensive use of SNMP for end-user system interaction and for management generally, and cross-vendor management systems are available today to manage fleets of printers in enterprises. Power consumption during active modes can vary widely, with high peak levels.

Printers today can expose detailed power state information, distinct from operational state information, with some printers reporting transition states between stable long-term states. Many also support active setting of power states, and setting of policies such as delay times when no activity will cause automatic transition to a lower power mode. Other features include reporting on components of imaging equipment, counters for state transitions, and typical power levels by state, scheduling, and events/alarms.

Some large printers also have a "Digital Front End" which is a computer that performs functions on behalf of the physical imaging system. These will typically have their own presence on the network and are sometimes separately powered.

There are some unique characteristics of Printers from the point of view energy monitoring. While the printer is not in use, there are timer based low power states (sleep, stand-by), which consume very little power. On the other hand, while the printer is printing or copying the cylinder needs to be heated so that power consumption is quite high but only for a short period of time (duration of the print job). Given this work load, periodic polling of energy consumption would not suffice.

Target Devices: All imaging equipment.

How Powered: Typically via mains AC from a wall outlet

Reporting: Devices report for themselves

2.13. Off-Grid Devices

This use case concerns self-contained devices that use energy but are not connected to an infrastructure power delivery grid. These devices typically scavenge energy from environmental sources such as solar energy or wind power. The device generally contains a closely coupled combination of

- . power scavenging or generation component(s)
- . power storage component(s) (e.g., battery)
- . power consuming component(s)

With scavenged power, the energy input is often dependent on the random variations of the weather. These devices therefore require energy management both for internal control and remote reporting of their state. In order to optimize the performance of these devices and minimize the costs of the generation and storage components, it is desirable to vary the activity level, and, hopefully, the energy requirements of the consuming components in order to make best use of the available stored and instantaneously generated energy. With appropriate energy management, the overall device can be optimized to deliver an appropriate level of service without over provisioning the generation and storage components.

In many cases these devices are expected to operate autonomously, as continuous communications for the purposes of remote control is either impossible or would result in excessive power consumption. Non continuous polling requires the ability to store and access later the information collected while the communication was not possible.

Target Devices: Remote network devices (mobile network) that consume and produce energy

How Powered: Can be battery powered or using natural energy sources

Reporting: Devices report their power usage but only occasionally.

2.14. Demand/Response

Demand/Response from the utility or grid is a common theme that spans across some of the use cases. In some situations, in response to time-of-day fluctuation of energy costs or sudden energy shortages due power outages, it may be important to respond and reduce the energy consumption of the network. From EMAN use case perspective, the demand/response scenario can apply to a Data Center or a Building or a residential home. As a first step, it may be important to monitor the energy consumption in real-time of a Data center or a building or home which is already discussed in the previous use cases. Then based on the potential energy shortfall, the Energy Management System (EMS) could formulate a suitable response, i.e., the EMS could shut down some selected devices that may be considered discretionary or uniformly reduce the power supplied to all devices. For multi-site data centers it may be possible to formulate policies such as follow-the-moon type of approach, by scheduling the mobility of VMs across Data centers in different geographical locations.

2.15. Power Capping

Power capping is a technique to limit the total power consumption of a server. This technique can be useful for power limited data centers. Based on workload measurements, the server can choose the optimal power state of the server in terms of performance and power consumption. When the server operates at less than the power supply capacity, it runs at full speed. When the server power would be greater than the power supply capacity, it runs at a slower speed so that its power consumption matches the available power supply capacity. This gives vendors the option to use smaller, cost-effective power supplies that allow real world workloads to run at nominal frequency.

3. Use Case Patterns

The use cases presented above can be abstracted to the following broad patterns.

3.1. Metering

-energy objects which have capability for internal metering
- electrical devices which are metered by an external device

3.2. Metering and Control

- entities objects that do not supply power, butcan perform only power metering for other devices

- entities objects that do not supply power, can perform both metering and control for other devices

3.3. Power Supply, Metering and Control

- entities devices that supply power for other devices but do not perform power metering for those devices

- entities that supply power for other devices and also perform power metering

- entities supply power for other devices and also perform power metering and control for other devices

3.4. Multiple power sources

- entities that have multiple power sources and metering and control is performed by one source

- entities that have multiple power sources and metering is performed by one source and control another source

4. Relationship of EMAN to other Standards

EMAN as a framework is tied to other standards and efforts that deal with energy. Existing standards are leveraged when possible. EMAN helps enable adjacent technologies such as Smart Grid.

The standards most relevant and applicable to EMAN are listed below with a brief description of their objectives, the current state and how that standard can be applied to EMAN.

4.1. Data Model and Reporting

4.1.1. IEC - CIM

The International Electro-technical Commission (IEC) has developed a broad set of standards for power management. Among these, the most applicable to EMAN is IEC 61850,a standard for the design of electric utility automation. The abstract data model defined in 61850 is built upon and extends the Common Information Model (CIM). The complete 61850 CIM model includes over a hundred object classes and is widely used by utilities worldwide.

This set of standards was originally conceived to automate control of a substation (facilities which transfer electricity from the transmission to the distribution system). While the original domain of 61850 is substation automation, the extensive data model has been widely used in other domains, including Energy Management Systems (EMS).

IEC TC57 WG19 is an ongoing working group to harmonize the CIM data model and 61850 standards.

Concepts from IEC Standards have been reused in the EMAN WG drafts. In particular, AC Power Quality measurements have been reused from IEC 61850-7-4. The concept of Accuracy Classes for measurement of power and energy has been reused IEC 62053-21 and IEC 62053-22.

4.1.2. DMTF

The Distributed Management Task Force (DMTF)[DMTF] has standardized management solutions for managing servers and PCs, including power-state configuration and management of elements in a heterogeneous environment. These specifications provide physical, logical and virtual system management requirements for power-state control.

The EMAN standard references the DMTF Power Profile and Power State Series.

4.1.2.1. Common Information Model Profiles

The DMTF uses CIM-based (Common Information Model) 'Profiles' to represent and manage power utilization and configuration of managed elements (note that this is not the 61850 CIM). Key profiles for energy management are 'Power Supply' (DSP 1015), 'Power State' (DSP 1027) and 'Power Utilization Management' (DSP 1085).These profiles define monitoring and configuration of a Power Managed Element's static and dynamic power saving modes, power allocation limits and power states, among other features.

Reduced power modes can be established as static or dynamic. Static modes are fixed policies that limit power use or utilization. Dynamic power saving modes rely upon internal feedback to control power consumption.

Power states are eight named operational and non operational levels. These are On, Sleep-Light, Sleep-Deep, Hibernate, Off-Soft, and Off-Hard. Power change capabilities provide immediate, timed interval, and graceful transitions between on, off, and reset power states. Table 3 of the Power State Profile defines the correspondence between the ACPI and DMTF power state models, although it is not necessary for a managed element to support ACPI. Optionally, a TransitingToPowerState property can represent power state transitions in progress.

4.1.2.2. DASH

DMTF DASH (DSP0232) (Desktop And Mobile Architecture for System Hardware) addresses managing heterogeneous desktop and mobile systems (including power) via in-band and out-of-band communications. DASH provides management and control of managed elements like power, CPU, etc. using the DMTF's WS-Management web services and CIM data model.

Both in service and out-of-service systems can be managed with the DASH specification in a fully secured remote environment. Full power lifecycle management is possible using out-of-band management.

4.1.3. ODVA

The Open DeviceNet Vendors Association (ODVA) is an association for industrial automation companies and defines the Common Industrial Protocol (CIP). Within ODVA, there is a special interest group focused on energy.

There are many similar concepts between the ODVA and EMAN frameworks towards monitoring and management of energy aware devices. In particular, one of the concepts being considered different energy meters based on if the device consumes electricity or produces electricity or a passive device.

The Open DeviceNet Vendors Association (ODVA) is developing an energy management framework for the industrial sector. There are synergies between the ODVA and EMAN approaches to energy management.

ODVA defines a three-part approach towards energy management: awareness of energy usage, consuming energy more efficiently, and exchanging energy with the utility or others. Energy monitoring and management promote efficient consumption and enable automating actions that reduce energy consumption.

The foundation of the approach is the information and communication model for entities. An entity is a network-connected, energy-aware device that has the ability to either measure or derive its energy usage based on its native consumption or generation of energy, or report a nominal or static energy value.

4.1.4. Ecma SDC

The Ecma International committee on Smart Data Centre (TC38-TG2 SDC [Ecma-SDC]) is in the process of defining semantics for management of entities in a data center such as servers, storage, and network equipment. It covers energy as one of many functional resources or attributes of systems for monitoring and control. It only defines messages and properties, and does not reference any specific protocol. Its goal is to enable interoperability of such protocols as SNMP, BACNET, and HTTP by ensuring a common semantic model across them. Four power states are defined, Off, Sleep, Idle and Active. The standard does not include actual power measurements in kWor kWh.

The 14th draft of SDC process was published in March 2011 and the development of the standard is still underway. When used with EMAN, the SDC standard will provide a thin abstraction on top of the more detailed data model available in EMAN.

4.1.5. IEEE-ISTO Printer Working Group (PWG)

The IEEE-ISTO Printer Working Group (PWG) defines SNMP MIB modules for printer management and has recently defined a "PWG Power Management Model for Imaging Systems v1.0" [PWG5106.4] and a companion SNMP binding in the "PWG Imaging System Power MIB v1.0" [PWG5106.5]. This PWG model and MIB are harmonized with the DMTF CIM Infrastructure [DSP0004] and DMTF CIM Power State Management Profile [DSP1027] for power states and alerts.

The PWG would like its MIBs to be harmonized as closely as possible with those from EMAN. The PWG covers many topics in greater detail than EMAN, as well as some that are specific to imaging equipment. The PWG also provides for vendor-specific extension states (i.e., beyond the standard DMTF CIM states.)

4.1.6. ASHRAE

In the U.S., there is an extensive effort to coordinate and develop standards related to the "Smart Grid". The Smart Grid Interoperability Panel, coordinated by the government's National Institute of Standards and Technology, identified the need for a building side information model (as a counterpart to utility models) and specified this in Priority Action Plan (PAP) 17. This was designated to be a joint effort by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and National Electrical Manufacturers Association (NEMA), both ANSI approved SDO's. The result is to be an information model, not a device level monitoring protocol.

The ASHRAE effort addresses data used only within a building as well as data that may be shared with the grid, particularly as it relates to coordinating future demand levels with the needs of the grid. The model is intended to be applied to any building type, both residential and commercial. It is expected that existing protocols will be adapted to comply with the new information model, as would any new protocols.

There are four basic types of entities in the model: generators, loads, meters, and energy managers.

The metering part of this model overlaps with the EMAN framework to a large degree, though there are features unique to each. The load part speaks to control capabilities well beyond what EMAN covers. Details of generation and of the energy management function are outside of EMAN scope.

A public review draft of the ASHRAE standard is expected soon, and at that point detailed comparison of the two models can be made. There are no apparent major conflicts between the two approaches, but there are likely areas where some harmonization is possible, and regardless, a description of the correspondences would be helpful to create.

4.1.7. ZigBee

The Zigbee Smart Energy 2.0 effort[ZIGBEE] focuses on wireless communication to appliances and lighting. It is intended to enable building energy management and enable direct load control by utilities.

ZigBee protocols are intended for use in embedded applications requiring low data rates and low power consumption. ZigBee defines a general-purpose, inexpensive, self-organizing mesh network that can be used for industrial control, embedded sensing, medical data collection, smoke and intruder warning, building automation, home automation, etc.

Zigbee is currently not an ANSI recognized SDO.

The EMAN framework addresses the needs of IP-enabled networks through the usage of SNMP, while Zigbee looks for completely integrated and inexpensive mesh solution.

4.2. Measurement

4.2.1. ANSI C12

The American National Standards Institute (ANSI) has defined a collection of power meter standards under ANSI C12. The primary standards include communication protocols (C12.18, 21 and 22), data and schema definitions (C12.19), and measurement accuracy (C12.20). European equivalent standards are provided by IEC 62053-22.ANSI C12.20 defines accuracy classes for watt-hour meters.

All of these standards are oriented toward the meter itself, and are therefore very specific and used by electricity distributors and producers.

The EMAN standard references ANSI C12 accuracy classes.

4.2.2. IEC62301

IEC 62301, "Household electrical appliances Measurement of standby power", specifies a power level measurement procedure.

While nominally for appliances and low-power modes, many aspects of it apply to other device types and modes and it is commonly referenced in test procedures for energy using products.

While the standard is intended for laboratory measurements of devices in controlled conditions, many aspects of it are informative to those implementing measurement in products that ultimately report via EMAN.

4.3. Other

4.3.1. ISO

The ISO [ISO] is developing an energy management standard, ISO 50001, to complement ISO 9001 for quality management, and ISO 14001 for environment management. The intent of the framework is to facilitate the creation of energy management programs for industrial, commercial and other entities. The standard defines a process for energy management at an organization level. It does not define the way in which devices report energy and consume energy.

EMAN is complementary to ISO 9001.

ISO 50001 is based on the common elements found in all of ISO's management system standards, assuring a high level of compatibility with ISO 9001 (quality management) and ISO 14001 (environmental management). ISO 50001 benefits includes:

- o Integrating energy efficiency into management practices and throughout the supply chain
- o Energy management best practices and good energy management behaviors
- o benchmarking, measuring, documenting, and reporting energy intensity improvements and their projected impact on reductions in greenhouse gas (GHG) emissions
- o Evaluating and prioritizing the implementation of new energy-efficient technologies

ISO 50001 has been developed by ISO project committee ISO/PC 242, Energy management.

4.3.2. EnergyStar

The US Environmental Protection Agency (EPA) and US Department of Energy (DOE) jointly sponsor the Energy Star program [ESTAR]. The program promotes the development of energy efficient products and practices.

To qualify as Energy Star, products must meet specific energy efficiency targets. The Energy Star program also provides planning tools and technical documentation to encourage more energy efficient building design. Energy Star is a program; it is not a protocol or standard.

For businesses and data centers, Energy Star offers technical support to help companies establish energy conservation practices. Energy Star provides best practices for measuring current energy performance, goal setting, and tracking improvement. The Energy Star tools offered include a rating system for building performance and comparative benchmarks.

There is no immediate link between EMAN and EnergyStar, one being a protocol and the other a set of recommendations to develop energy efficient products. However, Energy Star could include EMAN standards in specifications for future products, either as required or rewarded with some benefit.

4.3.3. SmartGrid

The Smart Grid standards efforts underway in the United States are overseen by the US National Institute of Standards and Technology [NIST].NIST is responsible for coordinating a public-private partnership with key energy and consumer stakeholders in order to facilitate the development of smart grid standards. The NIST smart grid standards activities are monitored and facilitated by the SGIP (Smart Grid Interoperability Panel). This group has working groups for specific topics including homes, commercial buildings, and industrial facilities as they relate to the grid.

When a working group detects a standard or technology gap, the team seeks approval from the SGIP for the creation of a Priority Action Plan (PAP), a private-public partnership to close the gap. There are currently 17 PAPs. PAP 17 is discussed in section 4.1.6.

PAP 10 addresses "Standard Energy Usage Information".

Smart Grid standards will provide distributed intelligence in the network and allow enhanced load shedding. For example, pricing signals will enable selective shutdown of non critical activities during peak-load pricing periods. These actions can be effected through both centralized and distributed management controls.

There is an obvious functional link between SmartGrid and EMAN in the form of demand response, even if the EMAN framework does not take any specific step toward SmartGrid communication.

5. Limitations

EMAN Framework shall address the needs of energy monitoring in terms of measurement and, considers limited control capabilities of energy monitoring of networks.

EMAN does not create a new protocol stack, but rather defines a data and information model useful for measuring and reporting energy and other metrics over SNMP.

The EMAN framework does not address questions regarding SmartGrid, electricity producers, and distributors even if there is obvious link between them.

6. Security Considerations

EMAN shall use SNMP protocol for energy monitoring and thus has the functionality of SNMP’s security capabilities. SNMPv3 [RFC3411] provides important security features such as confidentiality, integrity, and authentication.

7. IANA Considerations

This memo includes no request to IANA.

8. Acknowledgements

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9. Open Issues

"EDITOR NOTE: use the latest definition from draft-parello-eman-definitions"

OPEN ISSUE 1: Relevant IEC standards for application for EMAN Applicability Statement document can provide guidance on the issue of what is appropriate standard used by EMAN

IEC 61850-7-4 has been extensively used in EMAN WG documents. The other IEC documents referred for possible use are IEC 61000-4-30, IEC 62053-21 and IEC 62301.

There is feedback that IEC 61850-7-4 applies only to sub-stations ?

OPEN ISSUE 2: Should review ASHRAE SPC 201P standard when it is released for public review

. Need to review ASHRAE information model and the use cases and how it relates to EMAN

OPEN ISSUE 3: Review ALL requirements to ensure that they can be traced to a use case

. Missing is an use case for power quality

OPEN ISSUE 4: Question for the WG. Should we have unique use cases that introduce specific requirements ? or can there be some overlap between use cases ?

Any use cases out of scope scenarios ?

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Authors’ Addresses

Emmanuel Tychon
Cisco Systems, Inc.
De Keleetlaan, 6A
B1831 Diegem
Belgium
Email: etychon@cisco.com

Brad Schoening
44 Rivers Edge Drive
Little Silver, NJ 07739
USA
Email:brad@bradschoening.com

MouliChandramouli
Cisco Systems, Inc.
Sarjapur Outer Ring Road
Bangalore,
India
Phone: +91 80 4426 3947
Email: moulchan@cisco.com

Bruce Nordman
Lawrence Berkeley National Laboratory
1 Cyclotron Road, 90-4000
Berkeley 94720-8136
USA

Phone: +1 510 486 7089
Email: bnordman@lbl.gov