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Energy Management Framework
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Status of this Memo

Abstract

This document defines a framework for providing Energy Management for devices within or connected to communication networks, and components thereof. 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

- Add figures to the section 10 examples
- The figure 5 and 6 from the framework must be updated with the notion of power interfaces
- Aggregation Relationship is different compared to the other Relationships. There are some use cases: a building mediator implementing the MIB, with some subtended devices, a meter for many devices, etc... However, this

is also a generic function. We could argue that an aggregation function is something that is not particular to the EMAN context.

- Since we speak about Power Interface now, we need to double the EO Relationships here and in [EMAN-AWARE-MIB]: Example: poweredBy versus providingPower.
- Energy Interface or Power Interface, which term is best?
- The UML must be aligned with the latest [EMAN-AWARE-MIB] and [EMAN-AWARE-MIB] document versions.
- JOHN: Does the multiple URIs requirement apply to all of the defined relationship fields? For example, can eoProxyBy have multiple URIs? What about the other relationships? Answer: yes, but need to be explained
- Needs scrub for terminology and new "provide and receive energy" consensus. Power and energy also incorrectly used interchangeably from merged text.
- Some reference in the terminology section will certainly have to be removed.
- Complete the section "Energy Object Relationship Guidelines and Conventions"

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 (Energy Device) or identified components within a device (Energy Device Component) can then be monitored for Energy Management by obtaining

measurements for Power, Energy, Demand and Power Quality. If a device contains batteries, they can be also be monitored and 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 received by 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, and Proxy 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, a cross-reference between existing standards and the EMAN standard, and shows how this framework relates to other frameworks.

The Energy-aware Networks and Devices MIB [EMAN-AWARE-MIB] specifies objects for addressing Energy Object Identification, classification, context information, and relationships from 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 States.

Further, the battery monitoring MIB [EMAN-BATTERY-MIB] defines managed objects that provide information on the status of batteries in managed devices.

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].

EDITOR'S NOTE:

- All terms are copied over from the version 5 of the [EMAN-TERMINOLOGY] draft. The only differences in definition are
  - o Dependency Relationship is removed
  - o Energy Object Relationship improved to remove the Dependency Relationship
  - o "Reference: herein" has not been copied over from the terminology draft.
- "All" terms have been copied. Potentially, some unused terms might have to be removed. Alternatively, as this document is the first standard track document in the EMAN WG, it may become the reference document for the terminology (instead of cutting/pasting the terminology in all drafts)
- RFC-EDITOR: the Relationships need to be updated.
- The Power Interface definition has been added

Energy Device

An Energy Device is an Energy Object that may be monolithic or contain Energy Device Components

Energy Device Component

An Energy Device Component is an Energy Object contained in an Energy Device, for which the containing Energy Device provides individual energy management functions. Typically, the Energy Device Component is part the Energy Device physical containment tree in the ENTITY-MIB [RFC4133].

Energy Management

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]
Example: A set of computer systems that will poll electrical meters and store the readings
NOTES:

1. 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 [NMF].
2. Energy Management is a management domain which is 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.

Energy Management System (EnMS)

An Energy Management System is a combination of hardware and software used to administer a network with the primary purpose being Energy Management.
Reference: Adapted from [1037C]
Example: A single computer system that polls data from devices using SNMP
NOTES:

1. An Energy Management System according to [ISO50001] (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.

2. Example ISO-EnMS: 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.
3. 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]

Energy

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]
NOTES
1. Energy is the capacity of a system to produce external activity or perform work [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.

Reference: [IEEE100]
NOTES:
1. typically kilowatts
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.

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.

Electrical Energy Object

An Electrical Energy Object (EEO) is an Energy Object that is a piece of Electrical Equipment

Non-Electrical Energy Object

A Non-Electrical Energy Object (NEEO) an Energy Object that is a piece of 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.

NOTES:
1. This could include Energy, Power, Demand, Power Quality, Context and/or Battery information.

Energy Control

Energy Control is a part of Energy Management that deals with directing influence over Energy Objects.

NOTES:
1. Typically in order to optimize or ensure its efficiency.

Energy Management Domain

An Energy Management Domain is a set of Energy Objects where all objects in the domain are considered one unit of management.

For example, power distribution units and all of the attached Energy Objects are part of the same Energy Management Domain.

For 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.

NOTES:
1. Typically, this set will have as members all EO's that are powered from the same source.

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

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.

NOTES:

1. 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.

Energy Object Relationship

An Energy Object Relationship is a functional association among Energy Objects

NOTES

1. Relationships can be named and could include Aggregation, Metering, Power Source, Proxy and Dependency.
2. The Energy Object is the noun or entity in the relationship with the relationship described as the verb.

Example: If EO x is a piece of Electrical Equipment and EO y is an electrical meter clamped onto x's power cord, then x and y have a Metering Relationship. It follows that y meters x and that x is metered by y.
Reference: Adapted from [CHEN]

Aggregation Relationship

An Aggregation Relationship is an Energy Object Relationship where one Energy Object aggregates the Energy Management information of one or more other Energy Objects. These Energy Objects are referred to as having an Aggregation Relationship.

NOTES:

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 [SQL].

Metering Relationship

A Metering Relationship is an Energy Object Relationship where one Energy Object measures the Power or Energy of one or more other Energy Objects. These Energy Objects are referred to as having a Metering Relationship.

Example: a PoE port on a switch measures the Power it provides to the connected Energy Object.

Power Source Relationship

A Power Source Relationship is an Energy Object Relationship where one Energy Object is the source of or distributor of Power to one or more other Energy Objects. These Energy Objects are referred to as having a Power Source Relationship.

Example: a PDU provides power for a connected device.

Proxy Relationship

A Proxy Relationship is an Energy Object Relationship where one Energy Object provides the Energy Management capabilities on behalf of one or more other Energy Objects. These Energy Objects are referred to as having a Proxy Relationship.

Example: a protocol gateways device for Building Management Systems (BMS) with subtended devices.

Energy Object Parent

An Energy Object Parent is an Energy Object that participates in an Energy Object Relationships and is considered as providing the capabilities in the relationship.

Example: in a Metering Relationship, the Energy Object that is metering is called the Energy Object Parent, while the Energy Object

that is metered is called the Energy Object Child.

Energy Object Child

An Energy Object Child is an Energy Object that participates in an Energy Object Relationships and is considered as receiving the capabilities in the relationship.

Example: in a Metering Relationship, the Energy Object that is metering is called the Energy Object Parent, while the Energy Object that is metered is called the Energy Object Child.

Power Interface

A power interface is an Energy Object that serves as a interconnection among Energy Objects, and participates in a
Power Source Relationship.

Power State

A Power State is a condition or mode of a device that broadly characterizes its capabilities, power consumption, and responsiveness to input.

Reference: Adapted from [IEEE1621]

NOTES:

1. A Power State can be seen as a power setting of an Energy Object that influences the power consumption, the available functionality, and the responsiveness of the Energy Object.

2. A Power State can be viewed as one method for Energy Control

Power State Set

A collection of Power States that comprise one named or logical grouping of control is a Power State Set.

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.

NOTES:

1. 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.

3. 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 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
- A component within devices, such as a battery inside a PC, a line card inside a switch, etc...
- Power over Ethernet (PoE) endpoints
- Power Distribution Units (PDU)
- Protocol gateway 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.

This is the first version of the IETF Energy Management framework. Though it already covers a wide range of use cases, there are still a lot of potential ones that are not covered, yet. A simple example is the limitation to discrete power states without parameters. Some devices have energy-related properties that not well described with discrete power states, for example a dimmer with a continuous power range from 0%-100%. Other devices may have even more parameters than just a single percentage value.

Also policy-controlled energy management functions at Energy Devices are not covered. An example would be a policy telling a Energy Device not to raise its power above a given power value. These and further use cases would need an extension of the framework described in this document. It is up to future updates of this document to select more of such use-cases and to cover them by extensions or revisions of the present framework.

4. 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 receives Energy and that reports energy-related information about itself to an Energy Management System (EnMS), see Figure 1

```
+--------------------------+
| Energy Management System |
+--------------------------+
           ^   ^
 monitoring |   | control
           v   v
     +-----------------+
     | powered device  |
     +-----------------+
```

Figure 1: Basic energy management scenario

The powered 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 the EnMS. Information reported from a powered device to the EnMS includes at least the Power State of the powered 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 1.

4.1. 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 EnMS 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 EnMS 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 (in this case, the PDU). Note that those external power supply devices 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 the basic scenario from Figure 1 by a power supply device, see Figure 2.

```
            +-----------------------------------------+
            |         energy management system        |
            +-----------------------------------------+
                  ^  ^                       ^  ^
       monitoring |  | control    monitoring |  | control
                  v  v                       v  v
            +---------------+        +------------------+
            | power supply |########| powered device   |
            +---------------+        +------------------+
```

```
                     ######## power supply line

                   Figure 2: Power Supply
```

The power supply device can be as simple as a plain power switch. It may offer interfaces to the EnMS 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.

4.1.1 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 the consequences of switching power on or off may be hard to predict.

Even in well organized operations, powered devices' power cords can be plugged into the wrong socket, or wiring plans changed without updating the EnMS 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.

4.1.2 Multiples 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 EnMS has the full list of powered devices connected to a single outlet as in Figure 3.

```
                 +----------------------------------------+
                 |       energy management system         |
                 +----------------------------------------+
                    ^  ^                          ^  ^
         monitoring |  | control    monitoring |  | control
                    v  v                          v  v
                 +---------+        +------------------+
                 | power   |########| powered device 1 |
                 | supply  |   #    +------------------+-+
                 +---------+   #######| powered device 2 |
                                 #    +------------------+-+
                                 #######| powered device 3 |
                                        +------------------+
```

Figure 3: 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 devices powered by a single supply line is not known by the controlling power supply device, then control of power supply is problematic, because the consequences of control actions can only be partially known.

4.1.3 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 4: Multiple Power Supply for Single Powered Device

The example in Figure 4 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.

4.1.4 Bidirectional Power Interfaces

Low wattage DC systems may allow power to be delivered bi-directionally. Energy stored in batteries on one device can be delivered back to a power hub which redirects the current to power another device. In this situation, the interface can function as both an inlet and outlet.

The framework for Energy Management introduces the notion of Power Interface, which can model a power inlet and a power outlet, depending on the conditions. The Power Interface reports power direction, as well as the energy received, supplied and the net result.

4.1.5 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.

4.1.6 Remote Power Supply Control

There are three ways for an energy management system to change the Power State of an powered devices. First is for the EnMS 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 powered devices a command to switch to another Power 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 Energy Objects do not have capabilities for receiving commands or changing their Power States by themselves. Such Energy Objects may be controlled by switching on and off the power supply for them and so have particular need for the third method.

In Figure 4, 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.

4.2. 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. 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.

4.2.1 Local Estimates

One solution to this problem is for the powered 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 scenarios above. However, the powered device needs an energy model of itself to make estimates.

4.2.2 Management System Estimates

Another approach to the lack of instrumentation is estimation by the EnMS. The EnMS 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 EnMS 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.

4.3. 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 powered device sends out notifications of power state changes.

4.4. Energy Device and Energy Device Components

While the primary focus of energy management is entire powered devices, i.e. Energy Devices, sometimes it is necessary or desirable to manage Energy Device Components such as line cards, fans, disks, etc.

The concept of a Power Interface may not apply to Energy Device Components since they may receive Energy from a pool available from the encompassing device. For example, a DC-powered blade server in a chassis may have its own identity on the network and be managed as a single device but its energy may be received from a shared power source among all blades in the chassis.

4.5. Non-Electrical Equipment

The primary focus of this framework is for the management of Electrical Equipment. Some Non-Electrical Equipment may be connected to a communication networks and could have their energy managed if normalize to the electrical units for power and energy.

Some examples of Non-Electrical Equipment that may be connected to a communication network are:

1) A controller for compressed air. The controller is electrical only for its network connection. The controller is fueled by natural gas and produces compressed air. The energy transferred via compressed air is distributed to devices on a factory floor via a Power Interface: tools (drills, screwdrivers, assembly line conveyor belts). The energy measured is non-electrical (compressed air).
   EDITOR'S NOTE: Note that, in such as case, some might argue that the "energy interface" term might be more accurate than Power Interface. To be discussed.

2) A controller for steam. The controller is electrical for its network attachment but it burns tallow and produces steam to subtended boilers. The energy is non-electrical (steam).

5. 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 Figure 5, the most basic energy management 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 requires support for a push model distribution of time series values. The following diagrams mention IPFIX [RFC5101] as one possible solution for implementing a push mode transfer, however this is for illustration purposes only. The EMAN standard does not require the use of IPFIX and acknowledges that other alternative solutions may also be acceptable.

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

Figure 5: Simple Energy Management

As displayed in the Figure 5, 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          ||
                 ||       +-----------------------+
                 ||-------| EO Child 2            |
                 |        +-----------------------+
                 |
                 |
                 |--------           ...
                 |
                 |
                 |        +-----------------------+
                 |--------| EO Child M            |
                          +-----------------------+
```

Figure 6: 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 centralized EnMS or one with distributed Energy Management via the Energy Objects within the deployment.

Given the pattern in Figure 6, 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 one or more Energy Object Children
- A PDU modeled as an Energy Object Parent with the Power Source and Metering Relationships for the plugged in Electrical Equipment (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 to the managed Electrical Equipment
- Etc.

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

5.1. Energy Object, Energy Object Components and Containment Tree

The framework for Energy Management manages two different types of Energy Objects: Energy Device and Energy Device Components. A typical example of anEnergy Device is a switch. However, a port within the switch, which provides Power to one end point, is also an Energy Object if it meters the power provided. A second example is PC, which is a typical Energy Device, while the battery inside the PC is a Energy Object Component, managed as an individual Energy Object. Some more examples of Energy Device Components: power supply within a router, an outlet within a smart PDU, etc...

In the [EMAN-AWARE-MIB], each Energy Object is managed with an unique value of the entPhysicalIndex index from the ENTITY-MIB [RFC4133]

The ENTITY-MIB [RFC4133] specifies the notion of physical containment tree, as:

"Each physical component may be modeled as 'contained' within
another physical component. A "containment-tree" is the conceptual sequence of entPhysicalIndex values that uniquely specifies the exact physical location of a physical component within the managed system. It is generated by 'following and recording' each 'entPhysicalContainedIn' instance 'up the tree towards

the root', until a value of zero indicating no further containment is found."

A Energy Object Component in the Energy Management context is a special Energy Object that is a physical component as specified by the ENTITY-MIB physical containment tree.

6. 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
- Supply chain analysis of energy sources for 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

6.1. 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 MAY be configured on an Energy Object: the default value is a zero-length string.

If all Energy Objects in the physical containment tree (see ENTITY-MIB) are part of the same Energy Management Domain, then it is safe to state that the Energy Object at the root of that containment tree is in that Energy Management Domain.

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.

6.2. Power Interface

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. The Power Interface can be receiving or 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 is 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.

6.3. Energy Object Identification and Context

6.2.1 Energy Object Identification

Energy Objects MUST be associated with a value that uniquely identifies the Energy Object among all the Energy Management Domains within an EnMS. A Universal Unique Identifier (UUID) [RFC4122] MUST be used to uniquely identify an Energy Object.

Every Energy Object SHOULD have a unique printable name within the Energy Management Domain. 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's DNS name.

6.2.2 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.

6.2.3 Context: Importance

An Energy Object can provide an importance value in the range of 1 to 100 to help rank 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

6.2.4 Context: Keywords

An Energy Object can provide a set of keywords. These keywords are a list of tags that can be used for grouping, summary reporting within or between Energy Management Domains, and for searching. All alphanumeric characters and symbols (other than a comma), 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. White spaces before and after the commas are excluded, as well as within a keyword itself. In such cases, the keywords are separated by commas and no spaces between keywords are allowed. For example, "HR,Bldg1,Private".

6.2.5 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".

6.4. 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.

The Power Source Relationship gives the view the wiring topology. For example: a data center server receiving power from two specific Power Interfaces from two different PDUs.

The Metering Relationship gives the view of the metering topology. Standalone meters can be placed anywhere in a power distribution tree. For example, utility meters monitor and report accumulated power consumption of the entire building. Logically, the metering topology overlaps with the wiring topology, as meters are connected to the wiring topology. A typical example is meters that clamp onto the existing wiring.

The Proxy Relationship allows software objects to be inserted into the wiring or metering topology to aid in managing (monitoring and/or control) the Energy Domain.

From a EnMS management point of view, this implies that there is yet another management topology that EnMS will need to be aware of.

In the ideal situation, the wiring, the metering, and the management topologies overlap. 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 port is the source of power for the attached device, so the Energy Object Parent is the switch port, which acts as a Power Interface, and the Energy Object Child is the device attached to the switch. This Energy Object Parent (the switch) has three Energy Object Relations with this Energy Object Child (the remote Energy Object): Power Source Relationship, Metering Relationship, and Proxy Relationship.

However, the three topologies (wiring, metering, and management) don't always overlap. For example, when a protocol gateways device for Building Management Systems (BMS) controls subtended devices, which themselves receive Power from PDUs or wall sockets.

Note: The Aggregation Relationship is slightly different compared to the other relationships (Power Source, Metering, and Proxy Relationships) as this refers more to a management function.

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

6.4.1 Energy Object Children Discovery

There are multiple ways that the Energy Object Parent can discover its Energy Object Children: :

- 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 to a 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.
- A different protocol between the Energy Object Parent and the Energy Object Children. Note that the communication specifications between the Energy Object Parent and Children is out of the scope of this document.

However, in some situations, it is not possible to discover the Energy Object Relationships, and they must be set manually. For example, in today' network, an administrator must assign the connected Energy Object to a specific PDU Power Interface, with no means of discovery other than that manual connection.

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.

6.4.2 Energy Object Relationship Conventions and Guidelines

EDITOR'S NOTE: this section needs to be completed

This Energy Management framework doesn't impose too many "MUST" rules related to the Energy Object Relationships. Indeed, there are always corner cases that would be excluded with too strict specifications. However, this Energy Management framework proposes a series of guidelines, indicated with "SHOULD" and "MAY":

- The Energy Device SHOULD NOT establish Power Source Relationship with Energy Device Component
- Power Source Relationship SHOULD be established with next known Power Interface in the wiring topology. It may happen that the some Energy Objects in the wiring topology are not known to the administrator. Therefore, it may happen that a Power Source Relationship is established between two non connected Power Interfaces.
- If an Energy Object A has a Power Source Relationship "Poweredby" with the Energy Object B, and if the Energy Object B has a Power Source Relationship "Poweredby" with the Energy Object C, then the Energy Object A SHOULD NOT have a Power Source Relationship "PoweredBby" the Energy Object C.

6.5. 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 (See Section 4.5.) 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 (actual measurement, estimated, or presumed). 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 with a description of accuracy.

Optionally, an Energy Object can provide demand information over time.

6.5.1 Power Measurement

A power measurement MUST be qualified with the units, magnitude, direction of power flow, and SHOULD be qualified 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 EnMS.

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 ^ 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. 3W implies that the BaseValue is 3 and Scale = 0, whereas 3mW implies BaseValue = 3 and ScaleFactor = -3.

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

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

6.5.2 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 includes 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 EnMS.

Optional Demand

It is well known in commercial electrical utility rates that demand is part of the calculation for billing. 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 the state information as defined in [EMAN-REQ].

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.

6.6. Energy Control

Energy Objects can be controlled by setting it to a specific Power State. Power States Set 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 an 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 Sets. An Energy Object can support one or multiple Power State Set implementations concurrently.

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

IEEE1621 - [IEEE1621]

DMTF - [DMTF]

EMAN - Specified here

6.5.1 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.

6.5.2 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     ACPI            EMAN
Power
                     State       State            State
Name

Non-operational states:

          1        Off-Hard      G3, S5
MechOff(1)
```

```
           2        Off-Soft      G2, S5
   SoftOff(2)
           3        Hibernate     G1, S4
   Hibernate(3)
           4        Sleep-Deep    G1, S3            Sleep(4)
           5        Sleep-Light   G1, S2
   Standby(5)
           6        Sleep-Light   G1, S1            Ready(6)

   Operational states:
           7        On            G0, S0, P5
   LowMinus(7)
           8        On            G0, S0, P4        Low(8)
           9        On            G0, S0, P3
   MediumMinus(9)
          10        On            G0, S0, P2
   Medium(10)
          11        On            G0, S0, P1
   HighMinus(11)
          12        On            G0, S0, P0        High(12)
```

Figure 7: DMTF / ACPI Power State Mapping

6.5.3 EMAN Power State Set

The EMAN Power State Set represents an attempt for a 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 incorporates 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). Each operational state represents 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:

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. 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, such as 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, such as 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, such as 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. 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.

The Figure 8 displays the mappings from the IEEE1621 Power State Series to the EMAN Power State Series, showing that the EMAN twelve Power States expand on [IEEE1621] on, sleep and off.

```
        IEEE1621               EMAN Power State Name

Non-operational states:

        Power(off)             MechOff(1)
        Power(off)             SoftOff(2)
        Power(sleep)            Hibernate(3)
        Power(sleep)            Sleep(4)
        Power(sleep)            Standby(5)
        Power(sleep)            Ready(6)

Operational states:
        Power(on)              LowMinus(7)
        Power(on)               Low(8)
        Power(on)              MediumMinus(9)
        Power(on)              Medium(10)
        Power(on)              HighMinus(10)
        Power(on)              High(11)
```

Figure 8: DMTF / ACPI Power State Mapping

6.7. Energy Objects Relationship Extensions

This framework for Energy Management, is based on four Energy Objects Relationships: Aggregation Relationship, Metering Relationship, Power Source Relationship, and Proxy Relationship.

This framework is defined with possible extension of new Energy Objects Relationships in mind. 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, could be modeled with a future extension based on "gang relationship", whose semantic would specify the Energy Objects grouping.

7. 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 a 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. Also, received the following comment referring to the arrows in the following figure: "It is not clear to me what UML relationships are being specified here in the ASCIIfied UML relationships. Please provide a legend to make your conventions for mapping to UML clear."

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 9: Information Model UML Representation

8. 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 for the Energy Object.
. Demand parameters: For example, which interval length to report the Demand 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 Objects. 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.

9. 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].

10. Examples

In this section we will give examples of how to use the Energy Management framework. In each example we will show how it can be applied when Energy Devices have the capability to model Power Interfaces. We will also show in each example how the framework can be applied when devices cannot support Power Interfaces but only monitor information or control the Energy Device as a whole. For instance a PDU may only be able to measure power and energy for the entire unit without the ability to distinguish among the inlets or outlet.

Together these examples show how the framework can be adapted for Energy Devices with different capabilities (typically hardware) for Energy Management.

Given for all Examples:

Energy Device W: A computer with one power supply. Power interface 1 is an inlets for Device W.

Energy Device X: A computer with two power supplies. Power interface 1 and power interface 2 are both inlets for Device X.

Energy Device Y: A PDU with multiple Power Interfaces numbered 0..10, Power interface 0 is an inlet and power interface 1..10 are outlets.

Energy Device Z: A PDU with multiple Power Interfaces numbered 0..10, Power interface 0 is an inlet and power interface 1..10 are outlets.

Example I: Simple Device with one Source

Topology:
Energy Device W inlet 1 is plugged into Device Y outlet 8.

With Power Interfaces:

Device W has an Energy Object representing the computer itself as well as one Power Interface defined as an inlet.

Device Y would have an Energy Object representing the PDU itself (the Energy Device) with a Power Interface 0 defined as an inlet and Power Interfaces 1..10 defined as outlets.

The interfaces of the devices would have a Power Source Relationship such that:
Device W inlet 1 is powered by Device Y outlet 8

Without Power Interfaces:

In this case Device W has an Energy Object representing the computer. Device Y would have an Energy Object representing the PDU.

The devices would have a Power Source Relationship such that:
Device W is powered by Device Y.

Example II: Multiple Inlets

Topology:
Energy Device X inlet 1 is plugged into Device Y outlet 8.
Energy Device X inlet 2 is plugged into Device Y outlet 9.

With Power Interfaces:

Device X has an Energy Object representing the computer itself. It contains two Power Interface defined as inlets.

Device Y would have an Energy Object representing the PDU itself (the Energy Device) with a Power Interface 0

defined as an inlet and Power Interface 1..10 defined as outlets.

The interfaces of the devices would have a Power Source Relationship such that:
Device X inlet 1 is powered by Device Y outlet 8
Device X inlet 2 is powered by Device Y outlet 9

Without Power Interfaces:

In this case Device X has an Energy Object representing the computer. Device Y would have an Energy Object representing the PDU.

The devices would have a Power Source Relationship such that:
Device X is powered by Device Y.

Example III: Multiple Sources

Topology:
Energy Device X inlet 1 is plugged into Device Y outlet 8.
Energy Device X inlet 2 is plugged into Device Z outlet 9

With Power Interfaces:

Device X has an Energy Object representing the computer itself. It contains two Power Interface defined as inlets.

Device Y would have an Energy Object representing the PDU itself (the Energy Device) with a Power Interface 0 defined as an inlet and Power Interface 1..10 defined as outlets.

Device Z would have an Energy Object representing the PDU itself (the Energy Device) with a Power Interface 0 defined as an inlet and Power Interface 1..10 defined as outlets.

The interfaces of the devices would have a Power Source Relationship such that:
Device X inlet 1 is powered by Device Y outlet 8
Device X inlet 2 is powered by Device Z outlet 9

Without Power Interfaces:

In this case Device X has an Energy Object representing the computer. Device Y and Z would both have respective Energy Objects representing each entire PDU.

The devices would have a Power Source Relationship such that:
Device X is powered by Device Y and powered by Device Z.

11. Relationship with Other Standards Development Organizations

11.1. 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 and 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.

12. 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.

12.1. 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.

13. IANA Considerations

Initial values for the Power State Sets, together with the considerations for assigning them, are defined in [EMAN-MON-MIB].

14. Acknowledgments

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