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**IPv6 over Constrained Node Networks (6lo) Applicability & Use cases**
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Abstract

   This document describes the applicability of IPv6 over constrained
   node networks (6lo) and provides practical deployment examples.  In
   addition to IEEE 802.15.4, various link layer technologies such as
   ITU-T G.9959 (Z-Wave), Bluetooth Low Energy, DECT-ULE, MS/TP, NFC,
   and PLC are used as examples.  The document targets an audience who
   would like to understand and evaluate running end-to-end IPv6 over
   the constrained node networks for local or Internet connectivity.

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## 1.  Introduction

Running IPv6 on constrained node networks presents challenges, due to
the characteristics of these networks such as small packet size, low
power, low bandwidth, low cost, and large number of devices, among
others [RFC4919][RFC7228].  For example, many IEEE 802.15.4 variants
[IEEE802154] exhibit a frame size of 127 octets, whereas IPv6

requires its underlying layer to support an MTU of 1280 bytes.
Furthermore, those IEEE 802.15.4 variants do not offer fragmentation
and reassembly functionality.  Therefore, an appropriate adaptation
layer supporting fragmentation and reassembly must be provided below
IPv6.  Also, the limited IEEE 802.15.4 frame size and low energy
consumption requirements motivate the need for packet header
compression.  The IETF IPv6 over Low-Power WPAN (6LoWPAN) working
group published a suite of specification that provide an adaptation
layer to support IPv6 over IEEE 802.15.4 comprising the following
functionality:

o  Fragmentation and reassembly, address autoconfiguration, and a
   frame format [RFC4944],

o  IPv6 (and UDP) header compression [RFC6282],

o  Neighbor Discovery Optimization for 6LoWPAN [RFC6775][RFC8505].

As Internet of Things (IoT) services become more popular, the IETF
6lo working group [IETF_6lo] has defined adaptation layer
functionality to support IPv6 over various link layer technologies
other than IEEE 802.15.4, such as Bluetooth Low Energy (Bluetooth
LE), ITU-T G.9959 (Z-Wave), Digital Enhanced Cordless
Telecommunications - Ultra Low Energy (DECT-ULE), Master-Slave/Token
Passing (MS/TP), Near Field Communication (NFC), and Power Line
Communication (PLC).  The 6lo adaptation layers use a variation of
the 6LoWPAN stack applied to each particular link layer technology.

The 6LoWPAN working group produced the document entitled "Design and
Application Spaces for 6LoWPANs" [RFC6568], which describes potential
application scenarios and use cases for low-power wireless personal
area networks.  The present document aims to provide guidance to an
audience who are new to the IPv6 over constrained node networks (6lo)
concept and want to assess its application to the constrained node
network of their interest.  This 6lo applicability document describes
a few sets of practical 6lo deployment scenarios and use cases
examples.  In addition, it considers various network design space
dimensions such as deployment, network size, power source,
connectivity, multi-hop communication, traffic pattern, security
level, mobility, and QoS requirements etc.

This document provides the applicability and use cases of 6lo,
considering the following aspects:

o  It covers various IoT-related wired/wireless link layer
   technologies providing practical information of such technologies.

   o  It provides a general guideline on how the 6LoWPAN stack can be
      modified for a given L2 technology.

   o  Various 6lo use cases and practical deployment examples are
      described.

## 2.  6lo Link layer technologies

### 2.1.  ITU-T G.9959

   The ITU-T G.9959 Recommendation [G.9959] targets low-power Wireless
   Personal Area Networks (WPANs), and defines physical layer and link
   layer functionality.  Physical layers of 9.6 kbit/s, 40 kbit/s and
   100 kbit/s are supported.  G.9959 defines how a unique 32-bit HomeID
   network identifier is assigned by a network controller and how an
   8-bit NodeID host identifier is allocated to each node.  NodeIDs are
   unique within the network identified by the HomeID.  The G.9959
   HomeID represents an IPv6 subnet that is identified by one or more
   IPv6 prefixes [RFC7428].  The ITU-T G.9959 can be used for smart home
   applications.

### 2.2.  Bluetooth LE

   Bluetooth LE was introduced in Bluetooth 4.0, enhanced in Bluetooth
   4.1, and developed further in successive versions.  Bluetooth SIG has
   also published the Internet Protocol Support Profile (IPSP).  The
   IPSP enables discovery of IP-enabled devices and establishment of
   link-layer connection for transporting IPv6 packets.  IPv6 over
   Bluetooth LE is dependent on both Bluetooth 4.1 and IPSP 1.0 or
   newer.

   Many devices such as mobile phones, notebooks, tablets and other
   handheld computing devices which support Bluetooth 4.0 or subsequent
   versions also support the low-energy variant of Bluetooth.  Bluetooth
   LE is also being included in many different types of accessories that
   collaborate with mobile devices.  An example of a use case for a
   Bluetooth LE accessory is a heart rate monitor that sends data via
   the mobile phone to a server on the Internet [RFC7668].  A typical
   usage of Bluetooth LE is smartphone-based interaction with
   constrained devices.  Bluetooth LE was originally designed to enable
   star topology networks.  However, recent Bluetooth versions support
   the formation of extended topologies, and IPv6 support for mesh
   networks of Bluetooth LE devices is being developed
   [I-D.ietf-6lo-blemesh]

## 2.3.  DECT-ULE

DECT-ULE is a low power air interface technology that is designed to
support both circuit switched services, such as voice communication,
and packet mode data services at modest data rate.

The DECT-ULE protocol stack consists of the physical layer operating
at frequencies in the dedicated 1880 - 1920 MHz frequency band
depending on the region and uses a symbol rate of 1.152 Mbps.  Radio
bearers are allocated by use of FDMA/TDMA/TDD techniques.

In its generic network topology, DECT is defined as a cellular
network technology.  However, the most common configuration is a star
network with a single Fixed Part (FP) defining the network with a
number of Portable Parts (PP) attached.  The Medium Access Control
(MAC) layer supports traditional DECT as this is used for services
like discovery, pairing, security features etc.  All these features
have been reused from DECT.

The DECT-ULE device can switch to the ULE mode of operation,
utilizing the new ULE MAC layer features.  The DECT-ULE Data Link
Control (DLC) provides multiplexing as well as segmentation and re-
assembly for larger packets from layers above.  The DECT-ULE layer
also implements per-message authentication and encryption.  The DLC
layer ensures packet integrity and preserves packet order, but
delivery is based on best effort.

The current DECT-ULE MAC layer standard supports low bandwidth data
broadcast.  However the usage of this broadcast service has not yet
been standardized for higher layers [RFC8105].  DECT-ULE can be used
for smart metering in a home.

## 2.4.  MS/TP

MS/TP is a MAC protocol for the RS-485 [TIA-485-A] physical layer and
is used primarily in building automation networks.

An MS/TP device is typically based on a low-cost microcontroller with
limited processing power and memory.  These constraints, together
with low data rates and a small MAC address space, are similar to
those faced in 6LoWPAN networks.  MS/TP differs significantly from
6LoWPAN in at least three respects: a) MS/TP devices are typically
mains powered, b) all MS/TP devices on a segment can communicate
directly so there are no hidden node or mesh routing issues, and c)
the latest MS/TP specification provides support for large payloads,
eliminating the need for fragmentation and reassembly below IPv6.

   MS/TP is designed to enable multidrop networks over shielded twisted
   pair wiring.  It can support network segments up to 1000 meters in
   length at a data rate of 115.2 kbit/s or segments up to 1200 meters
   in length at lower bit rates.  An MS/TP interface requires only a
   Universal Asynchronous Receiver-Transmitter (UART), an RS-485
   [TIA-485-A] transceiver with a driver that can be disabled, and a 5
   ms resolution timer.  The MS/TP MAC is typically implemented in
   software.

   Because of its superior "range" (~1 km) compared to many low power
   wireless data links, MS/TP may be suitable to connect remote devices
   (such as district heating controllers) to the nearest building
   control infrastructure over a single link [RFC8163].

## 2.5.  NFC

   NFC technology enables simple and safe two-way interactions between
   electronic devices, allowing consumers to perform contactless
   transactions, access digital content, and connect electronic devices
   with a single touch.  NFC complements many popular consumer level
   wireless technologies, by utilizing the key elements in existing
   standards for contactless card technology (ISO/IEC 14443 A&B and
   JIS-X 6319-4).

   Extending the capability of contactless card technology, NFC also
   enables devices to share information at a distance that is less than
   10 cm with a maximum communication speed of 424 kbps.  Users can
   share business cards, make transactions, access information from a
   smart poster or provide credentials for access control systems with a
   simple touch.

   NFC's bidirectional communication ability is ideal for establishing
   connections with other technologies by the simplicity of touch.  In
   addition to the easy connection and quick transactions, simple data
   sharing is also available [I-D.ietf-6lo-nfc].  NFC can be used for
   secure transfer in healthcare services.

## 2.6.  PLC

   PLC is a data transmission technique that utilizes power conductors
   as medium [I-D.ietf-6lo-plc].  Unlike other dedicated communication
   infrastructure, power conductors are widely available indoors and
   outdoors.  Moreover, wired technologies cause less interference to
   the radio medium than wireless technologies and are more reliable
   than their wireless counterparts.

   The below table shows some available open standards defining PLC.

```
+-------------+-----------------+------------+-----------+----------+
| PLC Systems | Frequency Range |    Type    | Data Rate | Distance |
+-------------+-----------------+------------+-----------+----------+
|   IEEE1901  |     <100MHz     | Broadband  |  200Mbps  |  1000m   |
|             |                 |            |           |          |
|  IEEE1901.1 |     <12MHz      |  PLC-IoT   |  10Mbps   |  2000m   |
|             |                 |            |           |          |
|  IEEE1901.2 |     <500kHz     | Narrowband |  200kbps  |  3000m   |
|             |                 |            |           |          |
|    G3-PLC   |     <500kHz     | Narrowband |  234kbps  |  3000m   |
+-------------+-----------------+------------+-----------+----------+
```

Table 1: Some Available Open Standards in PLC

IEEE 1901 [IEEE1901] defines a broadband variant of PLC but is
effective within short range.  This standard addresses the
requirements of applications with high data rate such as: Internet,
HDTV, Audio, Gaming etc.  Broadband operates on Orthogonal Frequency
Division Multiplexing (OFDM) modulation.

IEEE 1902.1 [IEEE1901.1] defines a medium frequency band (less than
12 MHz) broadband PLC technology for smart grid applications based on
OFDM.  By achieving an extended communication range with medium
speeds, this standard can be applied both in indoor and outdoor
scenarios, such as Advanced Metering Infrastructure (AMI), street
lighting, electric vehicle charging, smart city etc.

IEEE 1902.2 [IEEE1901.2] defines a narrowband variant of PLC with
less data rate but significantly higher transmission range that could
be used in an indoor or even an outdoor environment.  It is
applicable to typical IoT applications such as: Building Automation,
Renewable Energy, Advanced Metering, Street Lighting, Electric
Vehicle, Smart Grid etc.  Moreover, IEEE 1901.2 standard is based on
the 802.15.4 MAC sub-layer and fully endorses the security scheme
defined in 802.15.4 [RFC8036].  A typical use case of PLC is smart
grid.

G3-PLC [G3-PLC] is a narrowband PLC technology that is based on the
ITU-T G.9903 Recommendation [G.9903].  The ITU-T G.9903
Recommendation contains the physical layer and data link layer
specification for the G3-PLC narrowband OFDM power line communication
transceivers, for communications via alternating current and direct
current electric power lines over frequencies below 500 kHz.

**2.7**.  **Comparison between 6lo link layer technologies**

   In above clauses, various 6lo link layer technologies are described.
   The following table shows dominant parameters of each use case
   corresponding to the 6lo link layer technology.

| | Z-Wave | BLE | DECT-ULE | MS/TP | NFC | PLC |
|---|---|---|---|---|---|---|
| Usage | Home Auto-mation | Interact w/ Smart Phone | Meter Reading | Building Auto-mation | Health-care Service | Smart Grid |
| Topology & Subnet | L2-mesh or L3-mesh | Star & Mesh | Star No mesh | MS/TP No mesh | P2P L2-mesh | Star Tree Mesh |
| Mobility Requirement | No | Low | No | No | Moderate | No |
| Security Requirement | High + Privacy required | Partially | High + Privacy required | High + Authen. required | High | High + Encrypt. required |
| Buffering Requirement | Low | Low | Low | Low | Low | Low |
| Latency, QoS Requirement | High | Low | Low | High | High | Low |
| Data Rate | Infrequ-ent | Infrequ-ent | Infrequ-ent | Frequent | Small | Infrequ-ent |
| RFC # or Draft | RFC7428 | RFC7668, ietf-6lo-blemesh | RFC8105 | RFC8163 | draft-ietf-6lo-nfc | draft-ietf-6lo-plc |

                  Table 2: Comparison between 6lo link layer technologies

3.  **Guidelines for adopting IPv6 stack (6lo)**

   6lo aims at reusing and/or adapting existing 6LoWPAN functionality in
   order to efficiently support IPv6 over a variety of IoT L2
   technologies.  The following guideline targets new candidate
   constrained L2 technologies that may be considered for running a
   modified 6LoWPAN stack on top.  The modification of 6LoWPAN stack
   should be based on the following:

   o  Addressing Model: Addressing model determines whether the device
      is capable of forming IPv6 link-local and global addresses and
      what is the best way to derive the IPv6 addresses for the
      constrained L2 devices.  L2-address-derived IPv6 addresses are
      specified in [RFC4944], but there exist implications for privacy.
      For global usage, a unique IPv6 address must be derived using an
      assigned prefix and a unique interface ID.  [RFC8065] provides
      such guidelines.  For MAC-derived IPv6 addresses, please refer to
      [RFC8163] for IPv6 address mapping examples.  Broadcast and
      multicast support are dependent on the L2 networks.  Most low-
      power L2 implementations map multicast to broadcast networks.  So
      care must be taken in the design when to use broadcast and try to
      stick to unicast messaging whenever possible.

   o  MTU Considerations: The deployment should consider packet maximum
      transmission unit (MTU) needs over the link layer and should
      consider if fragmentation and reassembly of packets are needed at
      the 6LoWPAN layer.  For example, if the link layer supports
      fragmentation and reassembly of packets, then the 6LoWPAN layer
      may not need to support fragmentation/reassembly.  In fact, for
      most efficiency, choosing a low-power link layer that can carry
      unfragmented application packets would be optimum for packet
      transmission if the deployment can afford it.  Please refer to 6lo
      RFCs [RFC7668], [RFC8163], [RFC8105] for example guidance.

   o  Mesh or L3-Routing: 6LoWPAN specifications provide mechanisms to
      support mesh routing at L2, a configuration called mesh-under
      [RFC6606].  It is also possible to use an L3 routing protocol in
      6LoWPAN, an approach known as route-over.  [RFC6550] defines RPL,
      a L3 routing protocol for low power and lossy networks using
      directed acyclic graphs. 6LoWPAN is routing-protocol-agnostic and
      does not specify any particular L2 or L3 routing protocol to use
      with a 6LoWPAN stack.

   o  Address Assignment: 6LoWPAN developed a new version of IPv6
      Neighbor Discovery [RFC4861][RFC4862]. 6LoWPAN Neighbor Discovery
      [RFC6775][RFC8505] inherits from IPv6 Neighbor Discovery for
      mechanisms such as Stateless Address Autoconfiguration (SLAAC) and
      Neighbor Unreachability Detection (NUD).  A 6LoWPAN node is also

   expected to be an IPv6 host per [RFC8200] which means it should
   ignore consumed routing headers and Hop-by-Hop options; when
   operating in a RPL network [RFC6550], it is also beneficial to
   support IP-in-IP encapsulation [I-D.ietf-roll-useofrplinfo].  The
   6LoWPAN node should also support [RFC8505] and use it as the
   default Neighbor Discovery method.  It is the responsibility of
   the deployment to ensure unique global IPv6 addresses for Internet
   connectivity.  For local-only connectivity IPv6 Unique Local
   Address (ULA) may be used.  [RFC6775][RFC8505] specifies the
   6LoWPAN border router (6LBR), which is responsible for prefix
   assignment to the 6LoWPAN network.  A 6LBR can be connected to the
   Internet or to an enterprise network via one of the interfaces.
   Please refer to [RFC7668] and [RFC8105] for examples of address
   assignment considerations.  In addition, privacy considerations
   [RFC8065] must be consulted for applicability.  In certain
   scenarios, the deployment may not support IPv6 address
   autoconfiguration due to regulatory and business reasons and may
   choose to offer a separate address assignment service.  Address
   Protection for 6LoWPAN Neighbor Discovery (AP-ND) [RFC8928]
   enables Source Address Validation [RFC6620] and protects the
   address ownership against impersonation attacks.

o  Broadcast Avoidance: 6LoWPAN Neighbor Discovery aims at reducing
   the amount of multicast traffic of classical Neighbor Discovery,
   since IP-level multicast translates into L2 broadcast in many L2
   technologies. 6LoWPAN Neighbor Discovery relies on a proactive
   registration to avoid the use of multicast for address resolution.
   It also uses a unicast method for Duplicate Address Detection
   (DAD), and avoids multicast lookups from all nodes by using non-
   onlink prefixes.  Router Advertisements (RAs) are also sent in
   unicast, in response to Router Solicitations (RSs)

o  Host-to-Router interface: 6lo has defined registration extensions
   for 6LoWPAN Neighbor Discovery [RFC8505].  This effort provides a
   host-to-router interface by which a host can request its router to
   ensure reachability for the address registered with the router.
   Note that functionality has been developed to ensure that such a
   host can benefit from routing services in a RPL network
   [I-D.ietf-roll-unaware-leaves]

o  Proxy Neighbor Discovery: Further functionality also allows a
   device (e.g. an energy-constrained device that needs to sleep most
   of the time) to request proxy Neighbor Discovery services from a
   6LoWPAN Backbone Router (6BBR) [RFC8505][RFC8929].  The latter
   federates a number of links into a multilink subnet.

o  Header Compression: IPv6 header compression [RFC6282] is a vital
   part of IPv6 over low power communication.  Examples of header

compression over different link-layer specifications are found in
[RFC7668], [RFC8163], [RFC8105].  A generic header compression
technique is specified in [RFC7400].  For 6LoWPAN networks where
RPL is the routing protocol, there exist 6LoWPAN header
compression extensions which allow to compress also the RPL
artifacts used when forwarding packets in the route-over mesh
[RFC8138] [I-D.ietf-roll-turnon-rfc8138]

o  Security and Encryption: Though 6LoWPAN basic specifications do
   not address security at the network layer, the assumption is that
   L2 security must be present.  In addition, application-level
   security is highly desirable.  The working groups [IETF_ace] and
   [IETF_core] should be consulted for application and transport
   level security. 6lo working group is working on address
   authentication [RFC8928] and secure bootstrapping is also being
   discussed at IETF.  However, there may be different levels of
   security available in a deployment through other standards such as
   hardware-level security or certificates for initial booting
   process.  Encryption is important if the implementation can afford
   it.

o  Additional processing: [RFC8066] defines guidelines for ESC
   dispatch octets use in the 6LoWPAN header.  An implementation may
   take advantage of ESC header to offer a deployment specific
   processing of 6LoWPAN packets.

## 4.  6lo Deployment Scenarios

## 4.1.  Wi-SUN usage of 6lo in network layer

Wireless Smart Ubiquitous Network (Wi-SUN)[Wi-SUN] is a technology
based on the IEEE 802.15.4g standard.  Wi-SUN networks support star
and mesh topologies, as well as hybrid star/mesh deployments, but
these are typically laid out in a mesh topology where each node
relays data for the network to provide network connectivity.  Wi-SUN
networks are deployed on both powered and battery-operated devices
[RFC8376].

The main application domains targeted by Wi-SUN are smart utility and
smart city networks.  This includes, but is not limited to the
following applications:

o  Advanced Metering Infrastructure

o  Distribution Automation

o  Home Energy Management

o  Infrastructure Management

o  Intelligent Transportation Systems

o  Smart Street Lighting

o  Agriculture

o  Structural health (bridges, buildings)

o  Monitoring and Asset Management

o  Smart Thermostats, Air Conditioning and Heat Controls

o  Energy Usage Information Displays

The Wi-SUN Alliance Field Area Network (FAN) covers primarily outdoor
networks, and its specification is oriented towards meeting the more
rigorous challenges of these environments.  It has the following
features:

o  Open standards based on IEEE802, IETF, TIA, ETSI

o  Architecture based on an IPv6 frequency hopping wireless mesh
   network with enterprise-level security

o  Simple infrastructure of low cost, low complexity

o  Enhanced network robustness, reliability, and resilience to
   interference, due to high redundancy and frequency hopping

o  Enhanced scalability, long range, and energy friendliness

o  Supports multiple global license-exempt sub-GHz bands

o  Multi-vendor interoperability

o  Very low power modes in development permitting long term battery
   operation of network nodes

The Wi-SUN FAN specification defines an IPv6-based protocol suite
including TCP/UDP, IPv6, 6lo adaptation layer, DHCPv6 for IPv6
address management, RPL, and ICMPv6.

## 4.2.  Thread usage of 6lo in network layer

Thread is an IPv6-based networking protocol stack built on open
standards, designed for smart home environments, and based on low-
power IEEE 802.15.4 mesh networks.  Because of its IPv6 foundation,
Thread can support existing popular application layers and IoT
platforms, provide end-to-end security, ease development and enable
flexible and future-proof designs [Thread].

The Thread specification uses the IEEE 802.15.4 [IEEE802154] physical
and MAC layers operating at 250 kbps in the 2.4 GHz band.  The IEEE
802.15.4-2006 and IEEE 802.15.4-2015 versions of the specification
are used by Thread.

Thread devices use 6LoWPAN, as defined in [RFC4944][RFC6282], for
transmission of IPv6 Packets over IEEE 802.15.4 networks.  Header
compression is used within the Thread network and devices
transmitting messages compress the IPv6 header to minimize the size
of the transmitted packet.  The mesh header is supported for link-
layer (i.e., mesh under) forwarding.  The mesh header as used in
Thread also allows efficient end-to-end fragmentation of messages
rather than the hop-by-hop fragmentation specified in [RFC4944].
Mesh under routing in Thread is based on a distance vector protocol
in a full mesh topology.

## 4.3.  G3-PLC usage of 6lo in network layer

G3-PLC [G3-PLC] is a narrowband PLC technology that is based on the
ITU-T G.9903 Recommendation [G.9903].  G3-PLC supports multi-hop mesh
network topology, and facilitates highly-reliable, long-range
communication.  With the abilities to support IPv6 and to cross
transformers, G3-PLC is regarded as one of the next-generation
narrowband PLC technologies.  G3-PLC has got massive deployments over
several countries, e.g.  Japan and France.

The main application domains targeted by G3-PLC are smart grid and
smart cities.  This includes, but is not limited to the following
applications:

o  Smart Metering

o  Vehicle-to-Grid Communication

o  Demand Response

o  Distribution Automation

o  Home/Building Energy Management Systems

o  Smart Street Lighting

o  Advanced Metering Infrastructure (AMI) backbone network

o  Wind/Solar Farm Monitoring

In the G3-PLC specification, the 6lo adaption layer utilizes the
6LoWPAN functions (e.g. header compression, fragmentation and
reassembly).  However, due to the different characteristics of the
PLC media, the 6LoWPAN adaptation layer cannot perfectly fulfill the
requirements [I-D.ietf-6lo-plc].  The ESC dispatch type is used in
the G3-PLC to provide native mesh routing and bootstrapping
functionalities [RFC8066].

## 4.4.  Netricity usage of 6lo in network layer

The Netricity program in HomePlug Powerline Alliance [NETRICITY]
promotes the adoption of products built on the IEEE 1901.2 low-
frequency narrowband PLC standard, which provides for urban and long
distance communications and propagation through transformers of the
distribution network using frequencies below 500 kHz.  The technology
also addresses requirements that assure communication privacy and
secure networks.

The main application domains targeted by Netricity are smart grid and
smart cities.  This includes, but is not limited to the following
applications:

o  Utility grid modernization

o  Distribution automation

o  Meter-to-Grid connectivity

o  Micro-grids

o  Grid sensor communications

o  Load control

o  Demand response

o  Net metering

o  Street Lighting control

o  Photovoltaic panel monitoring

Netricity system architecture is based on the physical and MAC layers
of IEEE 1901.2 PLC standard.  Regarding the 6lo adaptation layer and
IPv6 network layer, Netricity utilizes IPv6 protocol suite including
6lo/6LoWPAN header compression, DHCPv6 for IP address management, RPL
routing protocol, ICMPv6, and unicast/multicast forwarding.  Note
that the L3 routing in Netricity uses RPL in non-storing mode with
the MRHOF objective function based on the own defined Estimated
Transmission Time (ETT) metric.

## [5](#).  6lo Use Case Examples

As IPv6 stacks for constrained node networks use a variation of the
6LoWPAN stack applied to each particular link layer technology,
various 6lo use cases can be provided.  In this section, various 6lo
use cases which are based on different link layer technologies are
described.

### [5.1](#).  Use case of ITU-T G.9959: Smart Home

Z-Wave is one of the main technologies that may be used to enable
smart home applications.  Born as a proprietary technology, Z-Wave
was specifically designed for this particular use case.  Recently,
the Z-Wave radio interface (physical and MAC layers) has been
standardized as the ITU-T G.9959 specification.

Example: Use of ITU-T G.9959 for Home Automation

Variety of home devices (e.g. light dimmers/switches, plugs,
thermostats, blinds/curtains and remote controls) are augmented with
ITU-T G.9959 interfaces.  A user may turn on/off or may control home
appliances by pressing a wall switch or by pressing a button in a
remote control.  Scenes may be programmed, so that after a given
event, the home devices adopt a specific configuration.  Sensors may
also periodically send measurements of several parameters (e.g. gas
presence, light, temperature, humidity, etc.) which are collected at
a sink device, or may generate commands for actuators (e.g. a smoke
sensor may send an alarm message to a safety system).

The devices involved in the described scenario are nodes of a network
that follows the mesh topology, which is suitable for path diversity
to face indoor multipath propagation issues.  The multihop paradigm
allows end-to-end connectivity when direct range communication is not
possible.  Security support is required, specially for safety-related
communication.  When a user interaction (e.g. a button press)
triggers a message that encapsulates a command, if the message is
lost, the user may have to perform further interactions to achieve
the desired effect (e.g. turning off a light).  A reaction to a user

interaction will be perceived by the user as immediate as long as the reaction takes place within 0.5 seconds [RFC5826].

## 5.2.  Use case of Bluetooth LE: Smartphone-based Interaction

The key feature behind the current high Bluetooth LE momentum is its support in a large majority of smartphones in the market.  Bluetooth LE can be used to allow the interaction between the smartphone and surrounding sensors or actuators.  Furthermore, Bluetooth LE is also the main radio interface currently available in wearables.  Since a smartphone typically has several radio interfaces that provide Internet access, such as Wi-Fi or 4G, the smartphone can act as a gateway for nearby devices such as sensors, actuators or wearables. Bluetooth LE may be used in several domains, including healthcare, sports/wellness and home automation.

Example: Use of Bluetooth LE-based Body Area Network for fitness

A person wears a smartwatch for fitness purposes.  The smartwatch has several sensors (e.g. heart rate, accelerometer, gyrometer, GPS, temperature, etc.), a display, and a Bluetooth LE radio interface. The smartwatch can show fitness-related statistics on its display. However, when a paired smartphone is in the range of the smartwatch, the latter can report almost real-time measurements of its sensors to the smartphone, which can forward the data to a cloud service on the Internet. 6lo enables this use case by providing efficient end-to-end IPv6 support.  In addition, the smartwatch can receive notifications (e.g. alarm signals) from the cloud service via the smartphone.  On the other hand, the smartphone may locally generate messages for the smartwatch, such as e-mail reception or calendar notifications.

The functionality supported by the smartwatch may be complemented by other devices such as other on-body sensors, wireless headsets or head-mounted displays.  All such devices may connect to the smartphone creating a star topology network whereby the smartphone is the central component.  Support for extended network topologies (e.g. mesh networks) is being developed as of the writing.

## 5.3.  Use case of DECT-ULE: Smart Home

DECT is a technology widely used for wireless telephone communications in residential scenarios.  Since DECT-ULE is a low-power variant of DECT, DECT-ULE can be used to connect constrained devices such as sensors and actuators to a Fixed Part, a device that typically acts as a base station for wireless telephones.  Therefore, DECT-ULE is specially suitable for the connected home space in application areas such as home automation, smart metering, safety, healthcare, etc.  Since DECT-ULE uses dedicated bandwidth, it avoids

the coexistence issues suffered by other technologies that use e.g.
ISM frequency bands.

Example: Use of DECT-ULE for Smart Metering

The smart electricity meter of a home is equipped with a DECT-ULE
transceiver.  This device is in the coverage range of the Fixed Part
of the home.  The Fixed Part can act as a router connected to the
Internet.  This way, the smart meter can transmit electricity
consumption readings through the DECT-ULE link with the Fixed Part,
and the latter can forward such readings to the utility company using
Wide Area Network (WAN) links.  The meter can also receive queries
from the utility company or from an advanced energy control system
controlled by the user, which may also be connected to the Fixed Part
via DECT-ULE.

## 5.4.  Use case of MS/TP: Building Automation Networks

The primary use case for IPv6 over MS/TP (6LoBAC) is in building
automation networks.  [BACnet] is the open international standard
protocol for building automation, and MS/TP is defined in [BACnet]
Clause 9.  MS/TP was designed to be a low cost multi-drop field bus
to inter-connect the most numerous elements (sensors and actuators)
of a building automation network to their controllers.  A key aspect
of 6LoBAC is that it is designed to co-exist with BACnet MS/TP on the
same link, easing the ultimate transition of some BACnet networks to
native end-to-end IPv6 transport protocols.  New applications for
6LoBAC may be found in other domains where low cost, long distance,
and low latency are required.  Note that BACnet comprises various
networking solutions other than MS/TP, including the recently emerged
BACnet IP.  However, the latter is based on high speed Ethernet
infrastructure, and thus it falls outside of the constrained node
network scope.

Example: Use of 6LoBAC in Building Automation Networks

The majority of installations for MS/TP are for "terminal" or
"unitary" controllers, i.e. single zone or room controllers that may
connect to HVAC or other controls such as lighting or blinds.  The
economics of daisy-chaining a single twisted-pair between multiple
devices is often preferred over home-run Cat-5 style wiring.

A multi-zone controller might be implemented as an IP router between
a traditional Ethernet link and several 6LoBAC links, fanning out to
multiple terminal controllers.

The superior distance capabilities of MS/TP (~1 km) compared to other
6lo media may suggest its use in applications to connect remote

devices to the nearest building infrastructure.  For example, remote
pumping or measuring stations with moderate bandwidth requirements
can benefit from the low cost and robust capabilities of MS/TP over
other wired technologies such as DSL, and without the line-of-sight
restrictions or hop-by-hop latency of many low cost wireless
solutions.

## 5.5.  Use case of NFC: Alternative Secure Transfer

In different applications, a variety of secured data can be handled
and transferred.  Depending on the security level of the data,
different transfer methods can be alternatively selected.

Example: Use of NFC for Secure Transfer in Healthcare Services with
Tele-Assistance

A senior citizen who lives alone wears one to several wearable 6lo
devices to measure heartbeat, pulse rate, etc.  The 6lo devices are
densely installed at home for movement detection.  A 6LBR at home
will send the sensed information to a connected healthcare center.
Portable base stations with LCDs may be used to check the data at
home, as well.  Data is gathered in both periodic and event-driven
fashion.  In this application, event-driven data can be very time-
critical.  In addition, privacy also becomes a serious issue in this
case, as the sensed data is very personal.

While the senior citizen is provided audio and video healthcare
services by a tele-assistance based on LTE connections, the senior
citizen can alternatively use NFC connections to transfer the
personal sensed data to the tele-assistance.  Hidden hackers can
overhear the data based on the LTE connection, but they cannot gather
the personal data over the NFC connection.

## 5.6.  Use case of PLC: Smart Grid

The smart grid concept is based on deploying numerous operational and
energy measuring sub-systems in an electricity grid system.  It
comprises multiple administrative levels/segments to provide
connectivity among these numerous components.  Last mile connectivity
is established over the Low Voltage (LV) segment, whereas
connectivity over electricity distribution takes place in the High
Voltage (HV) segment.  Smart grid systems include Advanced Metering
Infrastructure (AMI), Demand Response (DR), Home Energy Management
System (HEMS), Wide Area Situational Awareness (WASA), among others.

Although other wired and wireless technologies are also used in Smart
Grid, PLC enjoys the advantage of reliable data communication over
electrical power lines that are already present, and the deployment

cost can be comparable to wireless technologies.  The 6lo-related
scenarios for PLC mainly lie in the LV PLC networks with most
applications in the area of Advanced Metering Infrastructure,
Vehicle-to-Grid communications, in-home energy management and smart
street lighting.

Example: Use of PLC for Advanced Metering Infrastructure

Household electricity meters transmit time-based data of electric
power consumption through PLC.  Data concentrators receive all the
meter data in their corresponding living districts and send them to
the Meter Data Management System (MDMS) through WAN network (e.g.
Medium-Voltage PLC, Ethernet or GPRS) for storage and analysis.  Two-
way communications are enabled which means smart meters can do
actions like notification of electricity charges according to the
commands from the utility company.

With the existing power line infrastructure as communication medium,
cost on building up the PLC network is naturally saved, and more
importantly, labor operational costs can be minimized from a long-
term perspective.  Furthermore, this AMI application speeds up
electricity charge, reduces losses by restraining power theft and
helps to manage the health of the grid based on line loss analysis.

Example: Use of PLC (IEEE1901.1) for WASA in Smart Grid

Many sub-systems of Smart Grid require low data rate and narrowband
variants (e.g., IEEE1901.1) of PLC fulfill such requirements.
Recently, more complex scenarios are emerging that require higher
data rates.

WASA sub-system is an appropriate example that collects large amount
of information about the current state of the grid over wide area
from electric substations as well as power transmission lines.  The
collected feedback is used for monitoring, controlling and protecting
all the sub-systems.

## 6.  IANA Considerations

There are no IANA considerations related to this document.

## 7.  Security Considerations

Security considerations are not directly applicable to this document.
For the use cases, the security requirements described in the
protocol specifications apply.

## 8.  Acknowledgements

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## Appendix A.  Design Space Dimensions for 6lo Deployment

The [RFC6568] lists the dimensions used to describe the design space
of wireless sensor networks in the context of the 6LoWPAN working
group.  The design space is already limited by the unique
characteristics of a LoWPAN (e.g. low power, short range, low bit
rate).  In [RFC6568], the following design space dimensions are

described: Deployment, Network size, Power source, Connectivity,
Multi-hop communication, Traffic pattern, Mobility, Quality of
Service (QoS).  However, in this document, the following design space
dimensions are considered:

o  Deployment/Bootstrapping: 6lo nodes can be connected randomly, or
   in an organized manner.  The bootstrapping has different
   characteristics for each link layer technology.

o  Topology: Topology of 6lo networks may inherently follow the
   characteristics of each link layer technology.  Point-to-point,
   star, tree or mesh topologies can be configured, depending on the
   link layer technology considered.

o  L2-Mesh or L3-Mesh: L2-mesh and L3-mesh may inherently follow the
   characteristics of each link layer technology.  Some link layer
   technologies may support L2-mesh and some may not support.

o  Multi-link subnet, single subnet: The selection of multi-link
   subnet and single subnet depends on connectivity and the number of
   6lo nodes.

o  Data rate: Typically, the link layer technologies of 6lo have low
   rate of data transmission.  But, by adjusting the MTU, it can
   deliver higher upper layer data rate.

o  Buffering requirements: Some 6lo use case may require more data
   rate than the link layer technology support.  In this case, a
   buffering mechanism to manage the data is required.

o  Security and Privacy Requirements: Some 6lo use case can involve
   transferring some important and personal data between 6lo nodes.
   In this case, high-level security support is required.

o  Mobility across 6lo networks and subnets: The movement of 6lo
   nodes depends on the 6lo use case.  If the 6lo nodes can move or
   moved around, a mobility management mechanism is required.

o  Time synchronization requirements: The requirement of time
   synchronization of the upper layer service is dependent on the 6lo
   use case.  For some 6lo use case related to health service, the
   measured data must be recorded with exact time and must be
   transferred with time synchronization.

o  Reliability and QoS: Some 6lo use case requires high reliability,
   for example real-time service or health-related services.

o  Traffic patterns: 6lo use cases may involve various traffic
   patterns.  For example, some 6lo use case may require short data
   length and random transmission.  Some 6lo use case may require
   continuous data and periodic data transmission.

o  Security Bootstrapping: Without the external operations, 6lo nodes
   must have the security bootstrapping mechanism.

o  Power use strategy: to enable certain use cases, there may be
   requirements on the class of energy availability and the strategy
   followed for using power for communication [RFC7228].  Each link
   layer technology defines a particular power use strategy which may
   be tuned [RFC8352].  Readers are expected to be familiar with
   [RFC7228] terminology.

o  Update firmware requirements: Most 6lo use cases will need a
   mechanism for updating firmware.  In these cases support for over
   the air updates are required, probably in a broadcast mode when
   bandwidth is low and the number of identical devices is high.

o  Wired vs. Wireless: Plenty of 6lo link layer technologies are
   wireless, except MS/TP and PLC.  The selection of wired or
   wireless link layer technology is mainly dependent on the
   requirement of 6lo use cases and the characteristics of wired/
   wireless technologies.  For example, some 6lo use cases may
   require easy and quick deployment, whereas others may need a
   continuous source of power.

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