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Applicability Statement for the Routing Protocol for Low Power and Lossy
                    Networks (RPL) in AMI Networks
                  draft-ietf-roll-applicability-ami-01

Abstract

   This document discusses the applicability of RPL in Advanced Metering
   Infrastructure (AMI) networks.

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1. Introduction

   Advanced Metering Infrastructure (AMI) systems enable the
   measurement, configuration, and control of energy, gas and water
   consumption and distribution, through two-way scheduled, on
   exception, and on-demand communication.

   AMI networks are composed of millions of endpoints, including meters,
   distribution automation elements, and home area network devices.
   They are typically inter-connected using some combination of wireless
   technologies and power-line communications, along with backhaul
   network providing connectivity to "command-and-control" management
   software applications at the utility company back office.

1.1. Electric Metering

   In many deployments, in addition to measuring energy consumption, the
   electric meter network plays a central role in the Smart Grid since
   it enables the utility company to control and query the electric
   meters themselves and also since it can serve as a backhaul for all
   other devices in the Smart Grid, e.g., water and gas meters,
   distribution automation and home area network devices. Electric
   meters may also be used as sensors to monitor electric grid quality
   and to support applications such as Electric Vehicle charging.

   Electric meter networks are composed of millions of smart meters (or
   nodes), each of which is resource-constrained in terms of processing
   power, storage capabilities, and communication bandwidth, due to a
   combination of factors including Federal Communications Commission
   (FCC) or other continents' regulations on spectrum use, American
   National Standards Institute (ANSI) standards or other continents'
   regulation on meter behavior and performance, on heat emissions
   within the meter, form factor and cost considerations. This results
   in a compromise between range and throughput, with effective link
   throughput of tens to a few hundred kilobits per second per link, a
   potentially significant portion of which is taken up by protocol and
   encryption overhead when strong security measures are in place.

   Electric meters are often interconnected into multi-hop mesh
   networks, each of which is connected to a backhaul network leading to
   the utility network through a network aggregation point (NAP). These
   kinds of networks increase coverage and reduce installation cost,
   time and complexity, as well as operational costs, as compared to
   single-hop wireless networks, relying on a wireline or cellular
   backhaul. Each electric meter mesh typically has on the order of
   several thousand wireless endpoints, with densities varying based on
   the area and the terrain. Apartment buildings in urban centers may
   have hundreds of meters in close proximity, whereas rural areas may

have sparse node distributions and include nodes that only have one
or two network neighbors. Paths in the mesh between a network device
and the nearest aggregation point may be composed of several hops or
even tens of hops.

1.2. Gas and Water Metering

While electric meters typically consume electricity from the same
electric feed that they are monitoring, gas and water meters
typically run on a modest source of stored energy (i.e. batteries).

In some scenarios, gas and water meters are integrated into the same
AMI network as the electric meters and may operate as network
endpoints (rather than routers) in order to prolong their own
lifetime. In other scenarios, such meters may not have the luxury of
relying on a powered routing infrastructure but must communicate
through other energy-constrained devices (i.e., through other gas and
water meters) to reach a NAP. In some cases, battery-powered meters
need to communicate directly with a sparsely deployed network
infrastructure, requiring them to use high transmit power levels (and
thus more energy) in order to achieve the necessary range to reach
the infrastructure. In all of these types of networks, the routing
protocol must operate with energy consumption in mind.

RPL is designed to operate in energy-constrained environments and
includes energy-saving mechanisms (e.g. Trickle timers) and energy-
aware metrics. Its ability to support multiple different metrics and
constraints at the same time enables it to run efficiently in
heterogeneous networks composed of nodes and links with vastly
different characteristics. [I-D.ietf-roll-routing-metrics].

1.3. Routing Protocol for LLNs (RPL)

RPL provides routing functionality for mesh networks composed of a
large number of resource-constrained devices, interconnected by low
power and lossy links, and communicating with the external network
infrastructure through a common aggregation point (e.g., a border
router).

RPL builds a Directed Acyclic Graph (DAG) routing structure rooted at
the aggregation point, ensures loop-free routing, and provides
support for alternate routes, as well as, for a wide range of routing
metrics and policies.

This note describes the applicability of RPL (as defined in
[I-D.ietf-roll-rpl]) to AMI deployments. RPL was designed to meet
the following application requirements:

   o Routing Requirements for Urban Low-Power and Lossy Networks
      [RFC5548].

   o Industrial Routing Requirements in Low-Power and Lossy Networks
      [RFC5673].

   o Home Automation Routing Requirements in Low-Power and Lossy
      Networks [RFC5826].

   o Building Automation Routing Requirements in Low-Power and Lossy
      Networks [RFC5867].

   The Routing Requirements for Urban Low-Power and Lossy Networks are
   applicable to AMI networks as well.

   The terminology used in this document is defined in
   [I-D.ietf-roll-terminology].

1.4. Requirements Language

   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].

2. Deployment Scenarios

2.1. Network Topology

   AMI networks are composed of millions of endpoints distributed across
   both urban and rural environments. Such endpoints include electric,
   gas, and water meters, distribution automation elements, and home
   area network devices. Devices in the network communicate directly
   with other devices in close proximity using a variety of low-power
   and/or lossy link technologies that are both wired and wireless (e.g.
   IEEE 802.15.4, IEEE P1901.2, and WiFi). In addition to serving as
   sources and destinations of packets, many network elements typically
   also forward packets to reduce the need for dedicated network
   infrastructure and the associated deployment and operational costs.

   In a typical AMI deployment, groups of meters within physical
   proximity form routing domains, each in the order of a 1,000 to
   10,000 meters. These routing domains are connected to the larger IP
   infrastructure through one or more LLN Border Routers (LBRs), which
   provide Wide Area Network (WAN) connectivity through various
   traditional network technologies, e.g., Ethernet, Cellular, private
   WAN.

Powered from the main line, electric meters have less energy
constraints than battery powered devices and can afford the
additional resources required to route packets. In mixed
environments, electric meters provide the routing topology while gas
and water meters operate as leaf nodes. However, in the absence of a
co-located electric meter network, gas and water meters must either
connect directly to the larger IP network infrastructure or form
their own routing topology, albeit with energy consumption in mind.

Meter networks may also serve as transit networks for other types of
devices, including distribution automation elements (e.g., sensors
and actuators), and in-home devices. These other devices may utilize
a different link-layer technology than the one used in the meter
network.

2.2. Traffic Characteristics

2.2.1. Meter Data Management

Meter Data Management (MDM) applications typically require every
smart meter to communicate with a few head-end servers deployed in a
utility data center. As a result, all smart metering traffic
typically goes through the LBRs, with the vast majority of traffic
flowing from smart meter devices to the head-end servers, i.e., in a
Multipoint-to-Point (MP2P) fashion.

Smart meters may generate traffic according to a schedule (e.g.,
periodic meter reads), in response to on-demand queries (e.g., on-
demand meter reads), or in response to events (e.g., power outages,
leak detections). Such traffic is typically unicast since it is sent
to a single head-end server.

Head-end servers generate traffic to configure smart metering devices
or initiate queries, and use unicast and multicast to efficiently
communicate with a single device (i.e., Point-to-Point (P2P)
communication) or groups of devices respectively (i.e., Point-to-
Multipoint (P2MP) communication). The head-end server may send a
single small packet at a time (e.g., a meter read request, or small
configuration change) or many consecutive large packets (e.g., a
firmware upgrade across one or even thousands of devices).

While smart metering applications typically do not have hard real-
time constraints, they are often subject to stringent latency and
reliability service level agreements.

2.2.2. Distribution Automation

   Distribution Automation (DA) applications typically involve a small
   number of devices that communicate with each other in a Point-to-
   Point (P2P) fashion. The DA devices may or may not be in close
   physical proximity.

   DA applications typically have more stringent latency requirements
   than MDM applications.

2.2.3. Emerging Applications

   There are a number of emerging applications such as electric vehicle
   charging. These applications may require P2P communication and may
   eventually have more stringent latency requirements than MDM
   applications.

3. Using RPL to Meet Functional Requirements

   The functional requirements for most AMI deployments are similar to
   those listed in [RFC5548]:

   o The routing protocol MUST be capable of supporting the
      organization of a large number of nodes into regions containing on
      the order of 10^2 to 10^4 nodes each.

   o The routing protocol MUST provide mechanisms to support
      configuration of the routing protocol itself.

   o The routing protocol SHOULD support and utilize the large number
      of highly directed flows to a few head-end servers to handle
      scalability.

   o The routing protocol MUST dynamically compute and select effective
      routes composed of low-power and lossy links. Local network
      dynamics SHOULD NOT impact the entire network. The routing
      protocol MUST compute multiple paths when possible.

   o The routing protocol MUST support multicast and anycast
      addressing. The routing protocol SHOULD support formation and
      identification of groups of field devices in the network.

   RPL supports:

   o Large-scale networks characterized by highly directed traffic
      flows between each smart meter and the head-end servers in the
      utility network. To this end, RPL builds a Directed Acyclic Graph

(DAG) rooted at each LBR.

o Zero-touch configuration. This is done through in-band methods
   for configuring RPL variables using DIO messages.

o The use of links with time-varying quality characteristics. This
   is accomplished by allowing the use of metrics that effectively
   capture the quality of a path (e.g., Expected Transmission Count
   (ETX)) and by limiting the impact of changing local conditions by
   discovering and maintaining multiple DAG parents, and by using
   local repair mechanisms when DAG links break.

4. RPL Profile

   This section outlines a RPL profile for a representative AMI
   deployment.

4.1. RPL Features

4.1.1. RPL Instances

   RPL operation is defined for a single RPL instance. However,
   multiple RPL instances can be supported in multi-service networks
   where different applications may require the use of different routing
   metrics and constraints, e.g., a network carrying both MDM and DA
   traffic.

4.1.2. Storing vs. Non-Storing Mode

   In most scenarios, electric meters are powered by the electric grid
   they are monitoring and are not energy-constrained. Instead, the
   capabilities of an electric meter are primarily determined by cost.
   As a result, different AMI deployments can vary significantly in
   terms of the memory, computation, and communication trade-offs that
   they embody. For this reason, the use of RPL storing or non-storing
   mode SHOULD be deployment specific.

   When meters are memory constrained and cannot adequately store route
   tables to support downward routing, non-storing mode is preferred.
   However, when nodes are capable of adequately storing such routing
   tables, storing mode can lead to reduced overhead and shorter route
   repair latency.

4.1.3. DAO Policy

   Two-way communication is a requirement in AMI systems. As a result,
   nodes SHOULD send DAO messages to establish downward paths from the

root to themselves.

4.1.4. Path Metrics

Smart metering deployments utilize link technologies that can exhibit
significant packet loss. To characterize a path over such link
technologies, AMI deployments can use the Expected Transmission Count
(ETX) metric as defined in[I-D.ietf-roll-routing-metrics].

For water- and gas-only networks that cannot rely on a powered
infrastructure, energy constraints may require simpler metrics that
do not require as much energy to compute. In particular, hop count
and link quality level may be more suitable in such deployments.
Other possible metrics to use may be vendor-specific or defined at a
later time in companion RFCs.

4.1.5. Objective Function

RPL relies on an Objective Function for selecting parents and
computing path costs and rank. This objective function is decoupled
from the core RPL mechanisms and also from the metrics in use in the
network. Two basic objective functions for RPL have been defined at
the time of this writing, OF0 and MRHOF, both of which define the
selection of a preferred parent and backup parents, and are suitable
for a basic AMI deployment. Neither of these supports multiple
metrics that might be required in heterogeneous networks (i.e.
networks composed of devices with different energy constraints). A
new objective function can be defined to meet this requirement.

4.1.6. DODAG Repair

To effectively handle time-varying link characteristics and
availability, AMI deployments SHOULD utilize the local repair
mechanisms in RPL.

The first mechanism for local repair when a node loses connectivity
to its parents is to detach from a DODAG then re-attach to the same
or to a different DODAG at a later time. While detached, a node
advertises an infinite rank value so that its children can select a
different parent. This process is known as poisoning and described
in Section 8.2.2.5 of [I-D.ietf-roll-rpl]. While RPL provides an
option to form a local DODAG, doing so in AMI deployments is of
little benefit since AMI applications typically communicate through a
LBR. After the detached node has made sufficient effort to send
notification to its children that it is detached, the node can rejoin
the same DODAG with a higher rank value. Note that when joining a
different DODAG, the node need not perform poisoning.

   The second local repair mechanism controls how much a node can
   increase its rank within a given DODAG Version. Setting the
   DAGMaxRankIncrease to a non-zero value enables this mechanism, and
   setting it to a value of less than infinity limits the cost of count-
   to-infinity scenarios when they occur.

   The third local repair mechanism enables loop detection, and is
   implemented by including the rank value of the transmitting node in
   packets forwarded towards the root (in the packet's RPL Packet
   Information option [I-D.ietf-6man-rpl-option]). Note that loop
   detection is not needed when sending packets using strict source
   routing.

4.1.7. Multicast

   RPL defines multicast support for its storing mode of operation. The
   DODAG structure built for unicast packet dissemination is used for
   multicast distribution as well. In particular, multicast forwarding
   state creation is done through DAO messages with multicast target
   options sent along the DODAG towards the root. Thereafter nodes with
   forwarding state for a particular group forward multicast packets
   along the DODAG by copying them to all children from which they have
   received a DAO with a multicast target option for the group.

   Multicast support for RPL in non-storing mode will be defined in
   companion RFCs.

4.1.8. Security

   AMI deployments operate in areas that do not provide any physical
   security. For this reason, the link technologies used within AMI
   deployments typically provide security mechanisms to ensure
   confidentiality, integrity, and freshness. As a result, AMI
   deployments may not need to implement RPL's security mechanisms and
   could rely on link-layer security features.

4.2. RPL Options

4.3. Recommended Configuration Defaults and Ranges

   o AMI deployments can involve densities of hundreds of devices
      within communication range. As a result, such networks SHOULD set
      the DIOIntervalMin to 16 or more, resulting in a Trickle Imin of 1
      minute or more. In networks with low-energy consumption
      requirements, DIOIntervalMin SHOULD be set to a higher value.

   o AMI deployments SHOULD set DIOIntervalDoublings to a value that
      gives a Trickle Imax of 2 hours or more. In networks with low-

energy consumption requirements, DIOIntervalDoublings SHOULD be
set to a value that results in a Trickle Imax of several (e.g., 2)
days.

o AMI deployments SHOULD set DIORedundancyConstant to a value of 10
   or more.

o AMI deployments SHOULD set MinHopRankIncrease to 256, resulting in
   8 bits of resolution (e.g. for the ETX metric).

o To enable local repair, AMI deployments SHOULD set MaxRankIncrease
   to a value that allows a device to move a small number of hops
   away from the root. With a MinHopRankIncrease of 256, a
   MaxRankIncrease of 1024 would allow a device to move up to 4 hops
   away.

5. Manageability Considerations

   Network manageability is a critical aspect of smart grid network
   deployment and operation. With millions of devices participating in
   the smart grid network, many requiring real-time reachability,
   automatic configuration, and lightweight network health monitoring
   and management, are crucial for achieving network availability and
   efficient operation.

   RPL enables automatic and consistent configuration of RPL routers
   through parameters specified by the DODAG root and disemintated
   through DIO packets. The use of Trickle for scheduling DIO
   transmissions ensures lightweight yet timely propagation of important
   network and parameter updates.

   RPL specifies a number of variables and events that can be tracked
   for purposes of network fault and performance monitoring of RPL
   routers. Depending on the memory and processing capabilities of each
   smart grid device, various subsets of these can be employed in the
   field.

   The CoRE Working Group is developing lightweight resource management
   mechanisms for LLNs that are applicable to smart grid RPL networks as
   well.

6. Security Considerations

   Smart grid networks are subject to stringent security requirements as
   they are considered a critical national infrastructure component. At
   the same time, since they are composed of large numbers of resource-

constrained devices inter-connected with limited-throughput links,
many available security mechanisms are not practical for use in such
networks. As a result, the choice of security mechanisms is highly
dependent on the device and network capabilities characterizing a
particular deployment.

In contrast to other types of LLNs, in smart grid networks
centralized administrative control and access to a permanent secure
infrastructure is available. As a result link-layer security
mechanisms are typically in place and using RPL's secure mode is not
necessary. Smart grid networks are often secured at other layers as
well, including end-to-end at the application layer.

7. Other Related Protocols

   This document contains no other related protocols.

8. IANA Considerations

   This memo includes no request to IANA.

9. Security Considerations

   This memo includes no security considerations.

10. Acknowledgements

   The authors would like to acknowledge the review, feedback, and
   comments from Dominique Barthel.

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