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Applicability Statement for the Routing Protocol for Low Power and Lossy Networks (RPL) in AMI Networks
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Abstract

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

Status of this Memo

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1. Introduction

Advanced Metering Infrastructure (AMI) systems measure, collect, and analyze energy consumption information. An AMI system enables two-way communication with electricity, water, gas, and/or heat meters. The communication may be scheduled, on exception, or on-demand.

AMI networks are composed of millions of endpoints, including meters, distribution automation elements, and home area network devices, typically inter-connected using some combination of wireless technologies and power-line communications, along with a wired or wireless 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, including 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 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) node. 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 wired or cellular backhaul. Each electric meter mesh typically has in the order of several thousand wireless endpoints, with densities varying based on the area and the terrain, with apartment buildings in urban centers

having possibly hundreds of meters in close proximity, and rural areas having sparse node distributions, including nodes that only have one or two network neighbors. Mesh deployments can exhibit tens of hops between a network device and the nearest aggregation point.

1.2. Gas and Water Metering

While electric meters can 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 certain scenarios, gas and water meters are integrated with electric meters in the same AMI network. In this scenario, gas and water meters typically do not route messages or operate as hosts to prolong their lifetime.

In other scenarios, however, gas and water meters do not have the luxury of communicating with a powered routing infrastructure. Instead, they must communicate through other battery powered devices (i.e. through other gas and water meters) to reach a NAP. Alternative scenarios also include water and/or gas meters communicating directly to a sparsely deployed network infrastructure, requiring increased transmit power levels for increased range that significantly impacts energy consumption and battery lifetime. For such networks, the routing protocol must configure routes with energy consumption in mind. The NAPs, however, are typically mains powered as in AMI networks with electric meters.

RPL is designed to operate in energy-constrained environments and includes energy-saving mechanisms (e.g. Trickle timers) and energy-aware metrics. By supporting a number of different metrics and constraints, RPL is also designed to support networks composed of nodes that have 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. Constrained devices within the same network typically communicate through a common aggregation point (e.g., a border router). RPL builds a Directed Acyclic Graph (DAG) routing structure rooted at the aggregation point. It ensures loop-free routing, support for alternate routes, and a wide range of routing metrics and policies.

This note describes the applicability of RPL 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 is most applicable to AMI networks.

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 in-home 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). Network elements may not only source and sink packets, but must also forward packets to reduce the need for dedicated routers and associated deployment costs.

In a typical AMI deployment, groups of meters within physical proximity form routing domains. The size of each group in a typical AMI deployment can be from 1000 to 10000 or 15000 meters

Powered from the main line electric meters have less energy constraints than battery powered devices and can afford the additional resources required for routing packets. In mixed environments, electric meters provide the routing topology while gas and water meters operate as leaves. However, in networks that cannot

afford a powered infrastructure, gas and water meters must either talk directly to a network infrastructure or form their own routing topology, albeit with energy consumption in mind.

Each meter routing domain is connected to a larger IP infrastructure through one or more LLN Border Routers (LBRs). The LBRs provide Wide Area Network (WAN) connectivity through more traditional links (e.g. Ethernet, Cellular, Private WAN) or other wireless technologies.

The meter networks may also serve as transit networks for other devices, including battery powered gas and water meters, distribution automation elements (i.e. distribution sensors and actuators), and in-home devices. These other devices may utilize a different link-layer technology than the one used in the metering 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 flows through the LBRs. In general, the vast majority of traffic flows from smart meter devices to the head-end servers with limited traffic flowing from head-end servers to smart meter devices. In RPL terminology, this traffic flow is also referred to as Multipoint-to-point Traffic (MP2P).

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

Head-end servers may generate traffic to configure smart metering devices or initiate queries. Head-end servers generate both unicast and multicast traffic to efficiently communicate with a single device or groups of devices. In RPL terminology, this traffic flow is also referred to as Point-to-Multipoint Traffic (P2MP). 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 large packets in sequence (e.g. a firmware upgrade across one or 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. Some applications also have stringent latency requirements to function properly.

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 (e.g. Electric Vehicle charging) that may involve P2P communication as well. These applications 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 direct 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 efficiently supports scalability and highly directed traffic flows between every smart meter and the few head-end servers by building a Directed Acyclic Graph (DAG) rooted at each LBR.

RPL supports zero-touch configuration by providing in-band methods

for configuring RPL variables using DIO messages.

RPL supports time-varying link qualities by allowing the use of metrics that effectively characterize the quality of a path (e.g. Estimated Transmission Count (ETX)). RPL limits the impact of changing local conditions by discovering and maintaining multiple DAG parents and providing a local repair mechanism when all parents have been dropped.

4. RPL Profile

This section outlines a RPL profile for most representative AMI deployments.

4.1. RPL Features

4.1.1. Storing vs. Non-Storing Mode

In most scenarios, electric meters can utilize the power they are monitoring for their own processing and computation and are not as constrained in energy consumption. Instead, the capabilities of an electric meter are primarily constrained by cost. As a result, different AMI deployments can vary significantly in terms of the memory, computational, and communication trade-offs that were made for their devices. 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 shorter paths and reduce channel utilization near the root.

4.1.2. DAO Policy

Two-way communication is required in AMI systems. As a result, electric meters SHOULD send DAO messages to establish downward paths back to themselves.

4.1.3. 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 metrics may be vendor-specific or defined at a later time into companion RFCs.

4.1.4. 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 but also from the metrics in use in the network. Two objective functions for RPL have been defined:

- o OF0 which does not deal with any metric,
- o MRHOF which deals with a single metric.

Both of them define the selection of a preferred parent and backup parents. Note that these Objective Functions do not support multiple metrics that might be required in heterogeneous networks (i.e. networks composed of devices with varying energy constraints). While RPL provides the flexibility to support additional metrics, a new Objective Function MAY be specified to properly handle additional metrics.

4.1.5. DODAG Repair

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

The first mechanism for local repair when a node loses its parents is to detach from a DODAG then re-attach to the same or 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 mechanism is a limit on how much a node can increase its rank within a given DODAG Version. Setting the DAGMaxRankIncrease to a non-zero value enables this local repair mechanism. Setting DAGMaxRankIncrease to a value less than infinity limits the cost of count-to-infinity scenarios when they occur.

The third mechanism is loop detection, enabled by including the rank value of a node in packets forwarded towards the root in RPL Packet Information [I-D.ietf-6man-rpl-option]. Note that loop detection is not needed when sending packets using strict source routing.

4.1.6. 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, giving a Trickle Imin of 1 minute or more. For low-energy consumption operations, such networks SHOULD set DIOIntervalMin 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. For low-energy consumption operations, such networks SHOULD set DIOIntervalDoublings to a value that gives a Trickle Imax of 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, giving 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. Other Related Protocols

This document contains no other related protocols.

6. IANA Considerations

This memo includes no request to IANA.

7. Security Considerations

This memo includes no security considerations.

8. Acknowledgements

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