The Need for *Efficient* Reliable Multicast in Smart Grid Networks

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1 Introduction

The emergence of the Smart Grid has paved the way for applications that are poised to revolutionize the way we view and use energy as individuals and as societies. With millions and ultimately billions of networked endpoints, smart meter networks present unprecedented challenges to network protocol designers and operators due to their scale, the resource limitations of each smart meter in terms of bandwidth, compute power and storage, and the significant security, reliability and communication latency requirements they pose.

Protocol standardization within the IETF has taken on some of the challenges of operating these types of networks, e.g., by developing mechanisms for supporting IPv6 over resource-constrained networks (6lowpan[1]), along with unicast mechanisms for routing in such networks (ROLL[2]), and creating frameworks for resource-oriented applications (CoRE[3]) and energy management (eman[4]). However, there are important aspects of the problem that have not yet been addressed. We would like to share some of our experiences deploying multi-million endpoint smart meter networks, draw attention to the importance and complexity of supporting applications requiring efficient reliable multicast data delivery, and challenge the IETF community to develop standards to enable these applications.

2 Smart Grid Network Characteristics

Smart Grid 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 wireline or wireless backhaul network providing connectivity to a "command-and-control" management software application(s) at the utility company back office (Figure 1).

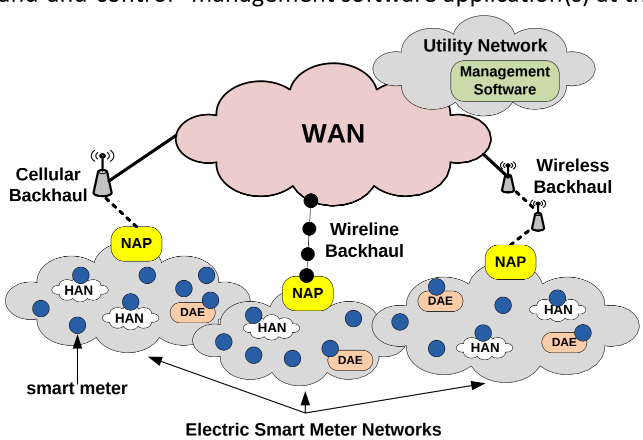

Figure 1: Smart Grid Network Example. Acronym definitions: HAN (Home Area Network), DAE (Distribution Automation Element), NAP (Network Aggregation Point), WAN (Wide Area Network).

In this paper, we focus on the portion of the smart grid network composed of electric smart meters. The electric smart meter network plays a central role in the Smart Gird since it enables the utility company to control and query the electric meters themselves and also since it typically serves as a backhaul for all other devices in the Smart Grid, including water and gas meters, distribution automation and home area network devices. Smart meter networks are composed of millions of smart meters (or nodes), each of which is extremely resource constrained in terms of processing power, storage capabilities, and communication bandwidth, due to a combination of factors including FCC regulations on spectrum use, ANSI standards on heat emissions within the meter, form factor and cost considerations. This results in bandwidths in the tens to a few hundred kilobits per second per link, a significant portion of which is taken up by encryption bits when strong security measures are in place.

In our deployments, we have observed network densities that tend to vary 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.

Smart meters are often interconnected into multi-hop wireless mesh networks, each of which is connected to a backhaul network leading to the utility network through a network aggregation point (NAP) node. Multi-hop mesh networks 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.

3 Reliable Multicast Requirements and Challenges

A number of critical smart grid applications require that the utility management software be able to exchange information with groups of smart meters reliably. Examples of applications using multicast communication include periodic reads intended to gather metering data for billing purposes, network statistics queries, and firmware and configuration updates. While these applications are typically not required to have real-time response times, they are often subject to stringent latency and reliability service level agreements.

3.1 Multicast Group Sizes

Many multicast operations require that a command from the utility management software is delivered to each meter in the network, and that the meter sends data back within some amount of time. In some cases, the meters are broken up into groups that are queried in stages, while in others all meters are addressed at the same time. The range of group sizes can thus be in the tens, hundreds, thousands, and even millions, posing a formidable scalability challenge to multicast group management and routing protocols.

3.2 Multicast Data Characteristics

The size of the data that needs to be delivered during each multicast session can be variable, ranging from a few bytes to hundreds of kilobytes, for query and response/update operations respectively.

3.3 Data Delivery within the Smart Meter Mesh

Multicast is a challenging problem in the mesh network environment, where data is forwarded along multiple hops and where different links in the network, sharing the same or overlapping channels, may interfere with each other and as a result experience congestion, collisions and packet loss, especially in cases where network density is high. As a result, packet transmissions and retransmissions affect the available bandwidth not only on the links on which they are transmitted but also on links on overlapping channels that are within interference range. These problems are even more pronounced for multicast communication because of its higher bandwidth usage as the presence of multiple destinations triggers transmissions along multiple paths in the network simultaneously. Efficient delivery of multicast data is essential due to the shared nature of the wireless medium and the scale of the smart meter network.

3.4 End-to-End Reliability

Supporting efficient reliable multicast within the smart meter network is only part of the puzzle, however. For multicast delivery to be reliable, it has to be reliable end-to-end – all the way from the utility management application to the meters themselves. This requires the design of network-level multicast protocols that operate across a set of heterogeneous networking technologies with potentially very different characteristics, working in concert with multicast applications to ensure the desired level of reliability as efficiently as possible.

3.5 Some Practical Considerations

The desire for reliable data delivery has to be balanced against real-world factors that prevent the reachability of network elements due to a range of external events. For example, meters are sometimes removed or stolen, or electric outages may disable portions of the network. Due to the scale of the network and the multicast group sizes, inability to deliver data to even a small percentage of the target meters results in a large number of meters that are missing a query or update -- 0.01% of a 5-million meter network translates to 500 meters! Attempts to reach a large number of meters that are not currently part of the network can result in a lot of unnecessary overhead. Distinguishing lack of reachability due to packet loss from that due to a meter being off-line is a challenge that would likely require cross-layer information and possible manual input through the utility management software.

4 The Need for Standardization

Existing standards and standards development efforts for routing in ad hoc and low power lossy networks within the IETF, e.g., the RPL protocol under development within the ROLL[2] group, have focused on the design of unicast routing mechanisms. Multicast delivery of data is possible in RPL but has not been the focus of design and optimization. In the current specification, each multicast packet is replicated to each multicast neighbor on a link, when in fact a single transmission would be sufficient to reach all wireless neighbors. Even in an ideal scenario with no packet loss, this would lead to several times more packet transmissions than the nominal number required, which itself is on the order of N, where N is the size of the network. This is a startling amount of overhead, given that smart meter networks number in the millions of nodes and are composed of bandwidth-constrained devices interconnected in multi-hop wireless topologies.

Application-level multicast has been discussed within the CoRE[3] group though reliable multicast is currently explicitly excluded from the group's charter.

Given the scale of the smart meter network as a whole, the scale of the multicast group sizes, and the challenges of delivering data across multiple wireless hops, designing and standardizing *efficient* reliable multicast protocols is essential for the successful operation of the network, and requires the conservative use of bandwidth through the minimal use of control packets and the judicious replication of multicast data within the network.

5 Summary and Conclusions

In this paper, we outline the need for reliable multicast in smart grid networks and challenge the Internet community to develop standards to meet this need.

Smart grid networks are a critical part of the utility infrastructure of the future and a prominent member of the Internet of Things. It is therefore essential that the IETF develop standard protocols that support the functionalities required for their efficient operation.

Bibliography

[1] 6lowpan Charter: http://datatracker.ietf.org/wg/6lowpan/charter/
[2] ROLL Charter: http://datatracker.ietf.org/wg/roll/charter/
[3] CoRE Charter: http://datatracker.ietf.org/wg/core/charter/
[4] eman Charter: http://datatracker.ietf.org/wg/eman/charter/