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SELF ORGANISING MESH RADIO BASED SOLUTION FOR SMART METERING COMMUNICATION

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Abstract

This paper describes a mesh networking based solution on Routing Protocol for Low power and Lossy network to realize Automated Metering Infrastructure (AMI) network communication. Automated Metering Infrastructure is expected to facilitate the transport of meter readings from meters to the utility provider and control information in the other direction. The smart meters send the meter data to the concentrators over the mesh link. The concentrators would then send the metering data collected from smart meters to the meter data management system (MDMS). The technology used for this communication is based on IEEE 802.15.4. The routing protocol enables smart meter nodes augmented with the mesh radio to automatically discover concentrator nodes in the vicinity, setup a link to the best available concentrator. It has self-organizing algorithms to detect the loss of connectivity and automatically reestablish connectivity, to ensure reliable transport of meter data.

***Keywords*-- AMI, communication, Real Time Operating System, Priority Scheduling**

I. INTRODUCTION

In traditional Automatic Meter Reading (AMR) power consumption have been read once every month or even less often through physical inspection of the meter at the consumer's premises. This type of low frequency data is useful only for billing purposes and to calculate longer term load profiles. The main objective of automated metering is to enable applications requiring access to metering data on different time scales, varying from a few minutes up to a few hours/days. It meets the demand response applications which ascertain the load in real time and send appropriate pricing signals to motivate consumers to defer their consumption to times when the demand is low. This also helps to reduce the cost for the consumer, improve operational efficiencies for the energy provider and could potentially be a way of dealing with the increasing demand for energy amidst a limited supply. This necessitates the need for facilitating bidirectional communications between the consumer and the grid.

The AMI communication infrastructure supports continuous interaction between the utility, the consumer and the controllable electrical load. So, it must employ an open bi-directional communication standards. There are several communication technologies wired and wireless. In this paper wireless mesh radio networks [4] are used for deployment, for their low power, low cost radios especially because the utility provider will have complete control over the infrastructure. As a part of this solution, the utility provider deploys an aggregator node termed as a "concentrator" in each neighborhood.

The meter at the consumer premises, connected with a wireless radio, can discover and connect to this concentrator and in turn sends the metering data. The concentrator aggregate data from several meter nodes within the neighborhood and forward it to the utility provider's meter data management system using a wide area link. The nodes in the network are expected to discover the concentrator in their vicinity, connect to an appropriate one, and provide multihop connectivity to nodes that are not within direct radio range of the concentrator. It also recovers automatically from lost connectivity from node/link failures by switching over to other concentrators available in the vicinity. The IEEE 802.15.4 is chosen as the underlying radio technology [6].

II. MESH NETWORKS FOR REALIZING AMI

2.1. A Typical Deployment and Related Challenges

The solution entails setting up a network topology consisting of a number of trees, each rooted at the concentrator, with the meter nodes in a locality sending metering data over radio links (through multiple hops if necessary) to a concentrator in their vicinity. The concentrator in turn sends the data over a wide area network (WAN) connection to the MDMS. When smart meters are switched on, they need to discover the concentrators around them. If multiple concentrators are available, they need to choose the one that may offer the best connectivity.

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When a node/link failure occurs these nodes have to discover the lost connectivity and automatically recover from such events. A self-organizing solution can be very useful in such circumstances [1].

The requirement in AMI mesh networks is to transport a few bytes of metering data. Therefore, IEEE 802.15.4 appears to be suitable. When compared to WiFi, the 802.15.4 hardware tends to be low cost and uses lower power. Moreover, the 802.15.4 hardware tends to be resource constrained.

2.2. RPL, a Connectivity Enabling Mechanism in Low-Power and Lossy Networks

Routing Protocol for LLNs (RPL) [2], a routing protocol developed by the Internet Engineering Task Force (IETF) Routing over Low Power and Lossy Networks (ROLL) working group [3] is used to establish and maintain connectivity between nodes in an LLN. New enhancements have been done to support the self-organizing functionalities: automatic concentrator discovery and loss of connectivity detection. It employs a destination oriented directed acyclic graph (DAG) to maintain network state information. Each DAG is rooted at a concentrator. To construct a DAG, the root node will issue a control message called a DAG information object (DIO), as shown in Fig. 1a. A DIO message conveys information about the DAG and includes a DAGID used to identify the DAG as sourced from the DAG root. Any other node that receives a DIO message and is willing to join the DAG should add the DIO sender to its parent list, compute its own rank associated with the parent node and broadcast the DIO message with the updated rank information (as shown in Fig. 1c). A node may receive a DIO message either as a broadcast or in response to a DAG information solicitation (DIS) message that it sent on realizing that it does not have connectivity (either on startup or upon losing connectivity). Once the DAG is in place, any smart meter node wishing to send metering data will forward it to its parent who will then relay it on to its parent and so on until the data reaches the concentrator [5].To support the downward traffic from the root to a client node, the client node issues a control message called a destination advertisement object (DAO) as shown in Figs. 1b and 1d. This message travels along the upward path as specified by the DAG. While on its way to the root, each intermediate node on the path records reverse path information. Thus, by the time the message reaches the root, a complete downward path is established.

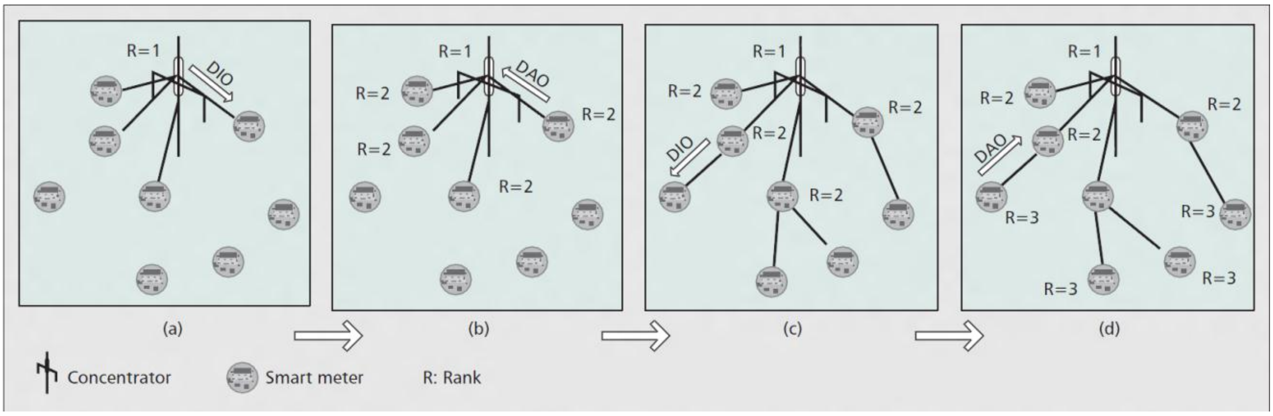

Fig. 1. Overview of RPL

This is sufficient for the case of a single tree with one root. A smart meter network may comprise several thousands of meter nodes. Thus, such a single tree rooted at one concentrator approach may not be scalable. One way to make the solution scalable would be to have multiple trees, each rooted at different concentrators, with each using different channels to avoid interfering with each other.

III. SELF-ORGANIZING AND SCALABLE MECHANISM TOFACILITATE CONNECTIVITY

3.1. Discovering Connectivity

When powered on, a smart meter node may not have any knowledge of the concentrators available around it. This leads to the node scanning the available channels (channels 11–26 in the 2.4GHz frequency band in the case of 802.15.4 networks).

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The node sends a DIS message and waits for time duration equal to a "LISTEN" period for a response. It receives a DIO message, in response to the DIS. The node computes a rank value and records both the rank information and the channel identifier. It then increments the channel number by 1 and continues with the channel scan. If one or more concentrators are found during the scanning process, it will choose the one with the best rank and tune itself to this channel. Fig. 2 summarizes the procedure as it would be followed in standard RPL and the extended RPL mechanism described above.

3.2. Detecting and Recovering From Lost Connectivity

Loss of connectivity is detected in two ways: when the smart meter node is not a part of a DAG (generally the case on startup) and when attempts to transmit smart metering data fail.

In the former case, the smart meter node uses the state information to detect the next best concentrator. If no information is available it triggers a channel scan. In the case of a failed transmission, the smart meter node does not immediately trigger a channel scan but initiates a connectivity test. As a part of this, the node waits for seconds and sends an ICMP_ECHO_REQUEST packet to its parent and waits for a reply. A receipt of reply terminates the connectivity test. In the absence of a reply, the node initiates a local repair as per the RPL specification. If local repair succeeds, the node terminates the connectivity test. If not, it will repeat the above process. If it does not succeed even after repeated test, the node frees the DAG structure and looks for alternative connectivity options if any.

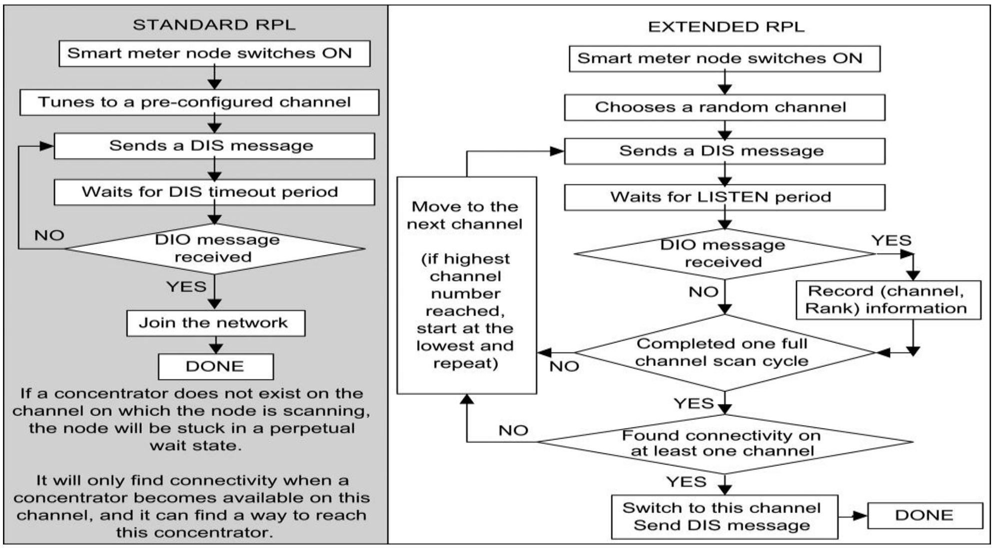

Fig. 2. Startup procedure in standard and extended RPL

Fig. 3 summarizes the procedure to recover from lost connectivity as it would be followed in the case of standard RPL and extended RPL respectively.

In summary, augmented with the above mechanisms, a smart meter node can automatically discover connectivity and recover from loss of connectivity thereby leading to simplified management in the mesh network and also ensures scalability as the algorithm operates in a distributed manner.

IV. PERFORMANCE EVALUATION THROUGH SIMULATIONS

To obtain insights into the behavior of the proposed mesh radio solution, it was implemented as modifications to the RPL code shipped with the µC/OSII operating system, a highly portable, ROMable, very scalable, preemptive real-time, multitasking kernel. As a starting point, one can study the protocol behavior via simulations and fine tune it. Subsequently, this can be verified through experiments using real hardware.

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Fig. 4 shows the topology used in the simulation based study. This topology consists of a concentrator with 50 smart meter nodes spread around and located at different distances. Experiments were conducted for this topology. It was found that with fewer numbers of nodes in an area, the opportunities for the nodes to find connectivity were limited and with an increase in the number of nodes, the probability of finding more nodes increases through which connectivity can be established. Fig. 5a shows how the discovery latency changes with an increase in the node density. An increase in the node density can help to speed up network discovery thereby reducing the discovery latency.

This is useful even in scenarios involving outage, e.g., if a node relies on another node for connectivity and if the latter is in outage, then in a network with higher node density, there will be a higher likelihood for the former node to find alternative nodes through which it can establish connectivity thereby quickly recovering from loss of connectivity.

It is also likely to find that the discovery latency increases for nodes which are farther from the concentrator (Fig. 5b).This is because when the nodes turn on, they will complete one full channel scan cycle irrespective of whether they do or do not discover a concentrator.

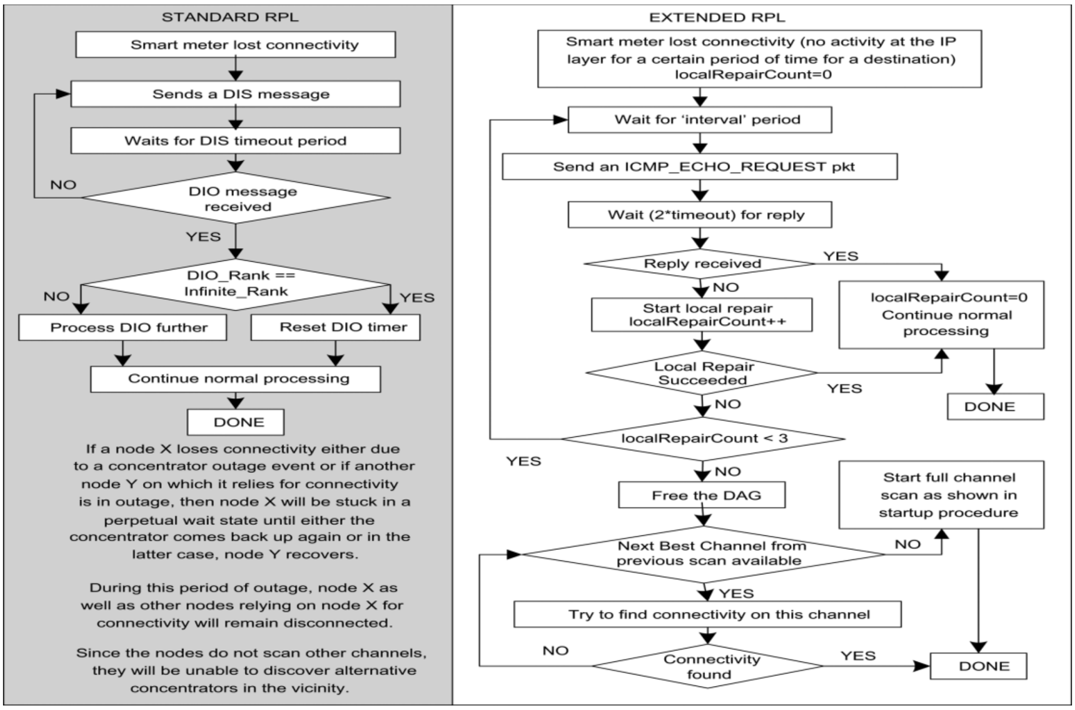

Fig. 3. Procedure to recover from lost connectivity

Those that discover a concentrator will jump straight to the channel of the concentrator upon completing the first scan cycle. Those that do not, starts the second cycle. This time, if they discover a concentrator, they will directly tune to the channel of the concentrator without completing the second scan cycle.

Fig. 5c shows the packet delivery ratio (PDR). From the fig. it is observed that the PDR is high for metering interval of 4 s and above whereas it is low for 1 s metering interval. Such a low PDR for high frequency metering update is a result of increased contention for the radio medium. Traffic originating from nodes far away from the concentrator has to be forwarded by the intermediate nodes.

Due to increased contention and lack of buffer space, this traffic maybe dropped thereby affecting the PDR achieved by these nodes. Fig. 5dshowsthat the PDR for nodes, which are farther from the concentrator, is lower than the PDR for nodes closer to the concentrator.

Suppose the concentrator in the center was turned off during the simulation so that all nodes connected to it would lose connectivity and initiate the network rediscovery process. In this scenario, if the standard RPL based solution is used, then these nodes will remain in outage until the concentrator goes back to normal operational state or another concentrator becomes available on the same channel.

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As the self-organizing mechanism is used, the nodes would start the network discovery process and connect to other available concentrators in the neighborhood.

Four set of experiments were run each comprising two, three, four, and five concentrators respectively. It was found that the recovery latency reduces with more concentrators. The recovery of nodes in outage would speed up with more concentrators available in the vicinity. The recovery latency values vary from 60 s to80 s depending on the topology.

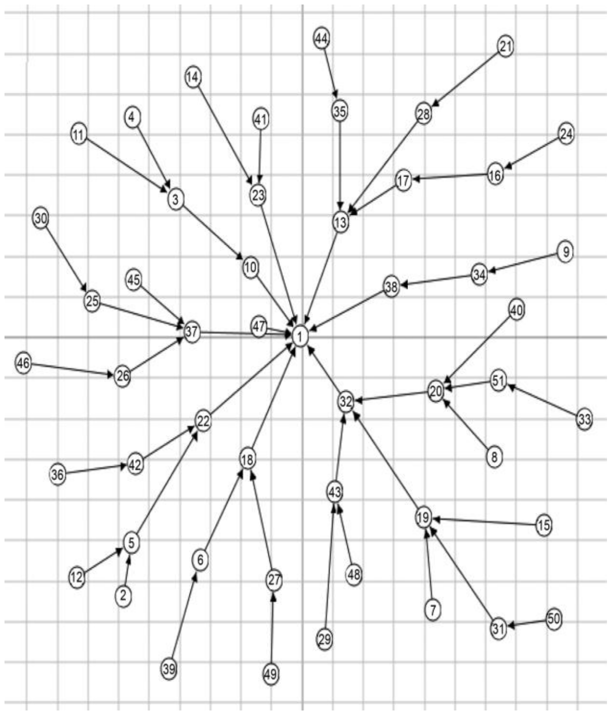

Fig. 4. Topology used in the simulation study.

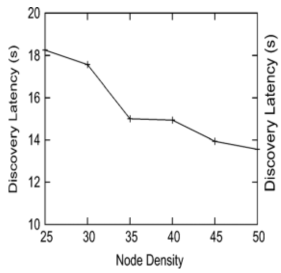

Fig. 5a. Discovery latency or varying node densities.

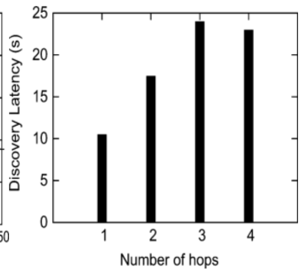

Fig. 5b. Discovery latency vs node distance from concentrator

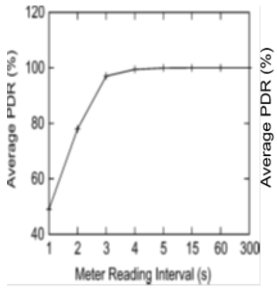

Fig. 5c.PDR for different Metering interval

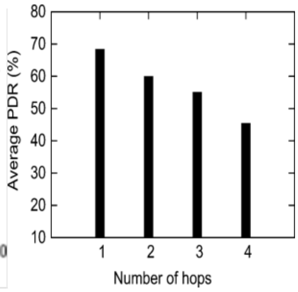

Fig. 5d. PDR vs. node distance from the concentrator

V. CONCLUSION

In this paper, a mesh radio based solution for realizing AMI is proposed. It is based on the Routing Protocol for Low power and lossy network and incorporates several enhancements such as utilization of multiple channels. In particular, a scalable and self-organizing approach to enable smart meters to automatically detect connectivity and recover from loss of connectivity has been presented. The effect of node density and network discovery latency has also been studied.

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