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PROACTIVE METHOD FOR FASTER REFORMATION IN LOW-POWER AND LOSSY NETWORKS

Xiaopu Zhang

Zaochun Zhang

Caijun Jiang

Dapeng Zhu

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AUTHORS:
Xiaopu Zhang
Zaochun Zhang
Caijun Jiang
Dapeng Zhu

ABSTRACT

Techniques are described herein for a proactive method to achieve faster reformation in Lower-power and Lossy Networks (LLNs). These techniques also provide reduced asynchronization and functions regardless of the number of powered-off nodes in the LLN.

DETAILED DESCRIPTION

A Connected Grid Mesh (CG-Mesh) may be used for Internet of Things (IoT) applications, such as smart grid Advanced Metering Infrastructure (AMI) networks. An important application of AMI networks is to report Power Outage Notification (PON) and Power Restoration Notification (PRN). Timely delivery of PON and PRN allows a utility to efficiently identify the occurrence of power outages and restorations. The utility can quickly react accordingly, such as recording the power outage duration for future analysis, providing real-time feedback of the fieldwork, and preventing unnecessary truck rolls that may be triggered by PONs. This is essential for optimizing utility operations.

Network reformation and operation after power restoration is desired to occur with minimal delay. For example, one goal is delivery of more than 90% of PRNs within less than thirty minutes, for a multi-hop network of thousands of nodes. This poses big challenges for a CG-Mesh. A typical smart grid AMI network contains one Field Area Router (FAR) and thousands of nodes, and a node may have hundreds of neighboring nodes. The normal network formation process (e.g., network discovery, authentication, network configuration, and routing configuration) is too slow to meet these requirements. Furthermore, due to the characteristics of Lower-power and Lossy Networks (LLNs), there is much interference and many collisions when hundreds of nodes power on simultaneously.

Some mechanisms which are dependent on the number of powered-off nodes in an LLN have been provided to speed up network reformation and operation after a power restoration event. Described herein is a proactive method which can support faster reformation regardless of the number of nodes that are powered off in the CG-Mesh. This method may include four steps.

The first step involves computing a hashed channel when a power outage occurs. In particular, the following information may be stored when power outage occurs: Personal Area Network Identifier (PANID), security keys, 64-Bit Extended Unique Identifier (EUI64) addresses of the preferred parent node, the Internet Protocol version 6 (IPv6) address, and a hashed channel.

The parent and child nodes may run the same algorithm, so as to obtain the same hashed channel. Child nodes that belong to the same parent may have the same hashed channel to enable child nodes to rejoin the CG-Mesh together. For example, if the hash algorithm is based on the parent node's EUI64 and child node's hop, the formula may be hash(parent_EUI64, child_hop). The hashed channel may be be used to exchange beacon requests between the parent node and the child node when power restoration occurs. The parent nodes that are not powered off but receive PON messages from their child nodes may compute the hashed channel for the child nodes.

In the second step, the parent node sends the beacon request in the hashed channel. As soon as the parent node receives the PON from its children and hashed channel computation is performed, the parent node begins sending a beacon request in the hashed channel at regular intervals. The beacon request may be sent in the hashed channel instead of in asynchronized mode, which can reduce bandwidth cost significantly.

As illustrated in Figure 1 below, parent node F computes the hashed channel as #3, and it sends synchronization beacons in channel #3 until child node J responds.

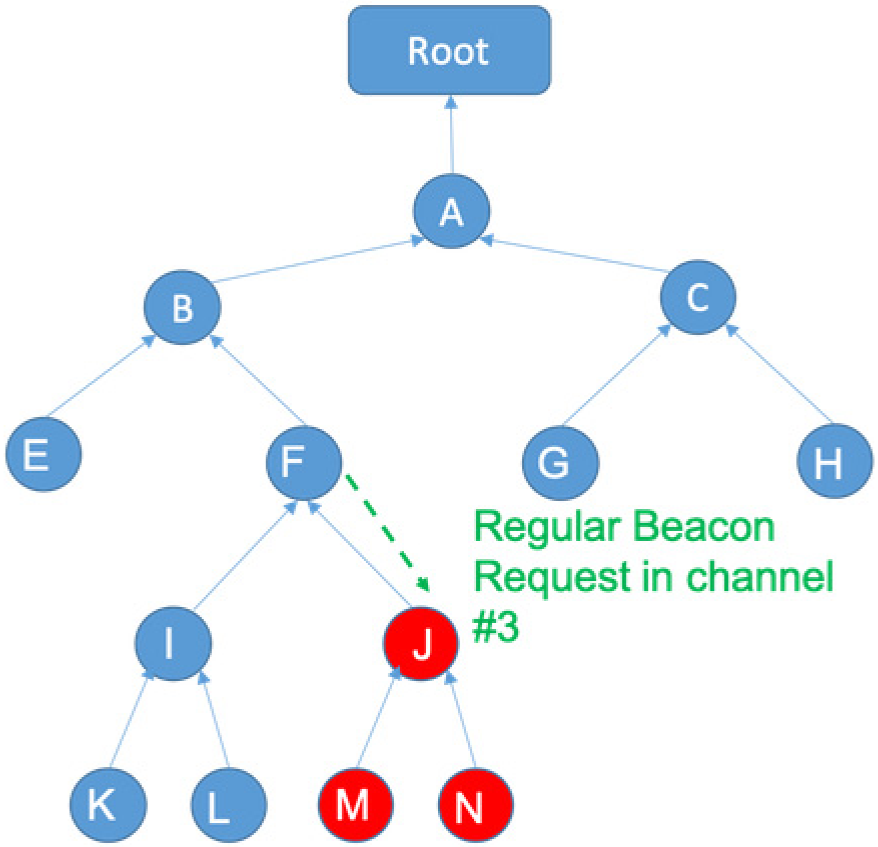

Figure 1

In the third step, the child node listens in the hashed channel. In particular, as soon as power is restored, the child node reads stored information and starts listening in the hashed channel immediately. The child node does not need to wait for a back-off window, and may instead listen in the hashed channel until it receives a synchronization beacon from its parent, which can reduce reformation time significantly.

As illustrated in Figure 2 below child node J computes the hashed channel as #3 (same as parent node F since they comprise a parent-child pair), and listens for a synchronization beacon in channel #3. As soon as the synchronization beacon is received from parent node F, child node J triggers fast reformation and quickly joins the CG-Mesh.

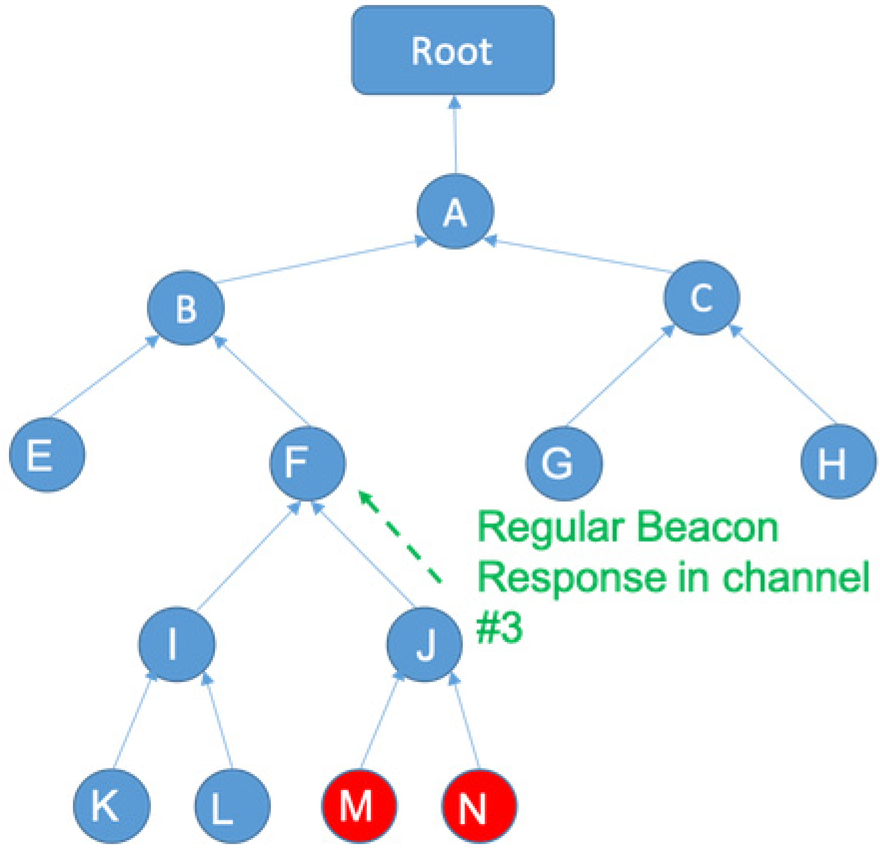

Figure 2

The fourth step involves repeating the second and third steps until all nodes successfully rejoin the CG-Mesh. As soon as a node rejoins the PAN successfully, it may repeat the second and third steps. For example, as illustrated in Figure 3 below, node J successfully rejoins the CG-Mesh, starts sending synchronization beacons in channel #6 immediately, and continues to do so until child nodes M and N respond.

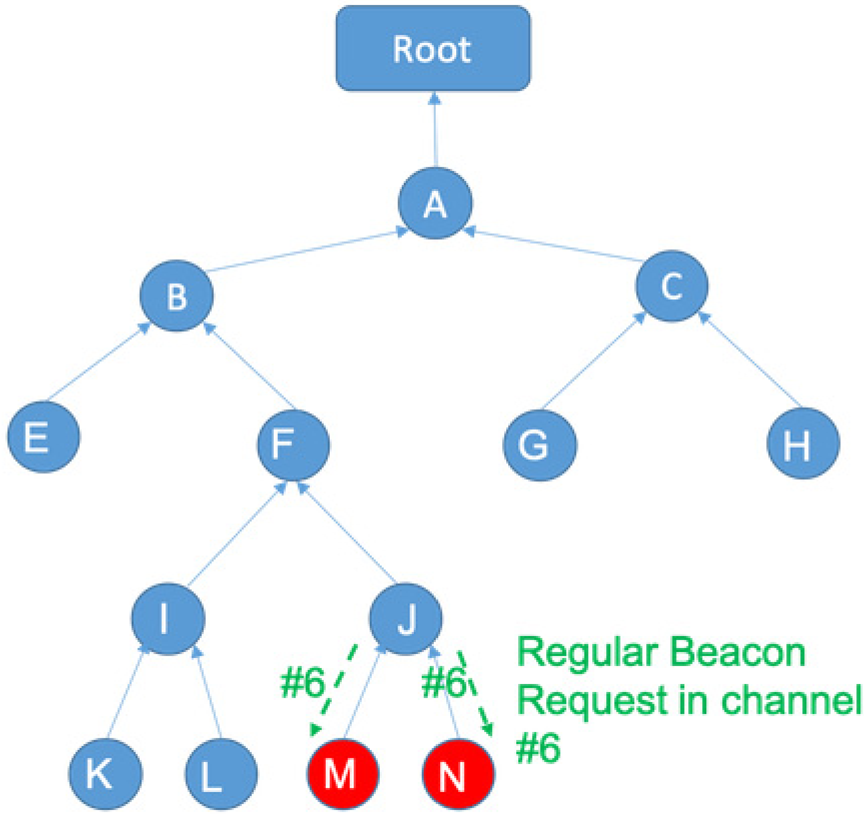

Figure 3

As illustrated in Figure 4 below, nodes M and N both keep listening on channel #6, and may rejoin the CG-Mesh together immediately as soon as they receive a synchronization beacon from node J. Thus, all the nodes can successfully rejoin the CG-Mesh.

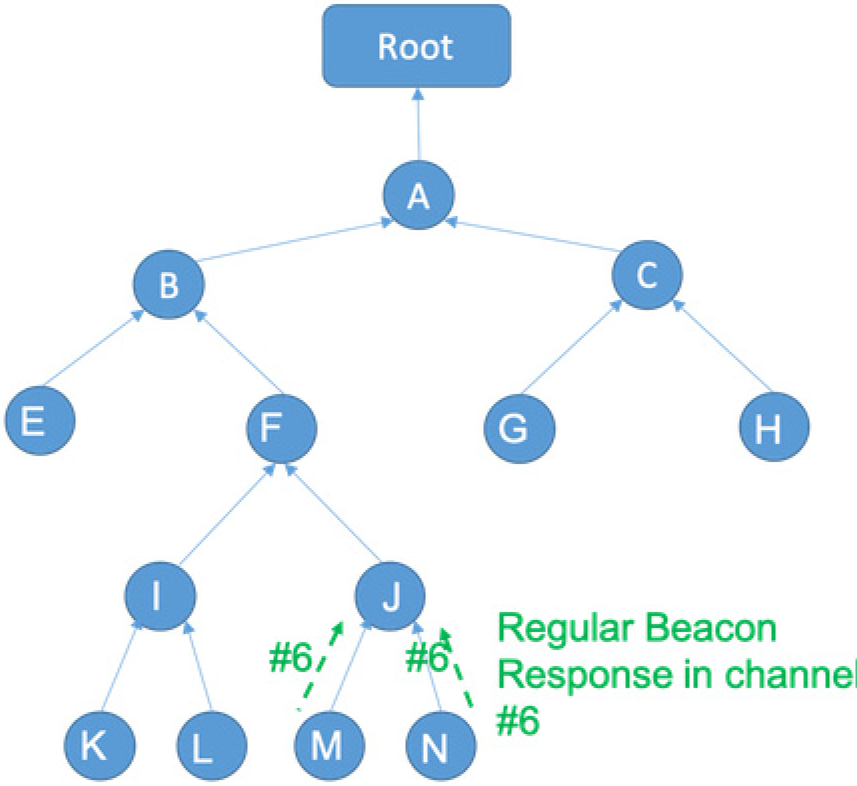

Figure 4

In summary, techniques are described herein for a proactive method to achieve faster reformation in LLNs. These techniques also provide reduced asynchronization and functions regardless of the number of powered-off nodes in the LLN.