February 14, 2019

CONTROLLING ROUTING FOR POWER OUTAGE NOTIFICATION TRANSMISSION

Zaochun Zhang

Rui Huang

Zhanwu Wang

Xiaopu Zhang

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AUTHORS:
Zaochun Zhang
Rui Huang
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ABSTRACT

Techniques are described herein to equip backup power for some key nodes and form the local Directed Acyclic Graphs (DAGs) rooted at the first hop node with backup power. Nodes have different preferred parents in different work states. In normal state, nodes behave like existing mesh networks and have no performance sacrifice. In Power Outage Notification (PON) state, nodes can unicast the PON messages to their PON state's parents to improve PON message transmission efficiency and reliability.

DETAILED DESCRIPTION

Low-power and Lossy Networks (LLNs) may be used in a variety of applications, including smart grid, smart cities, home and building automation, and in the Internet of Things in general.

Power Outage Notification (PON) is a critical function in Smart Grid Advanced Metering Infrastructure (AMI) networks. Electric meters typically contain some small amount of energy storage (e.g., in the form of super capacitors) that allows a handful of PON transmissions. These PON messages notify neighbors that the device is experiencing a power outage. The neighbors then forward the messages to an outage management system that allows an electric utility to track the power outage. While experiencing a power outage, a meter does not perform any other communication functions (e.g., receiving, forwarding, transmitting messages other than PON, etc.) as they would consume the limited energy budget.

In mesh networks, PON is a critical function. A device splits one 30-second window into three 10-second windows. Within each window, the device randomly chooses a broadcast slot and time within the broadcast slot to transmit a PON. The device transmits

PONs using a broadcast slot in an attempt to reach any neighboring device that still has main power.

As illustrated in Figure 1 below, nodes I, J, L, M, and N lose their main power and they try to broadcast the PON message to their neighbors within a limited time window. Their neighbors who received the PON message try to forward the PON messages to the outage management system. Here, the root is used instead.

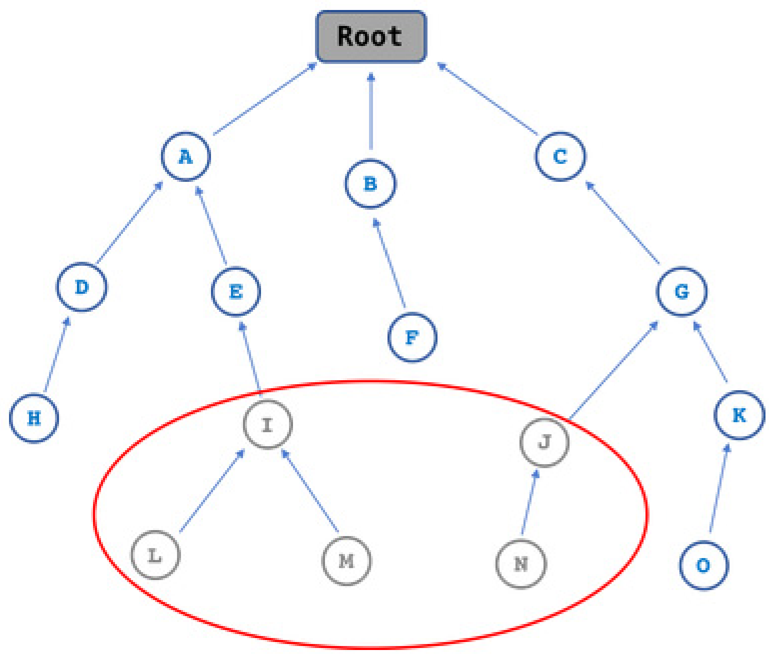

Figure 1

The root may receive the PON messages of nodes I, J, L, M, and N only if the following conditions are met:

- The PON messages are received by their neighbors.
- Routing paths to the root exist, so the neighbors can forward the PON messages to the root.

These conditions are met in most cases. But, as illustrated in Figure 2 below, they are not met in every case.

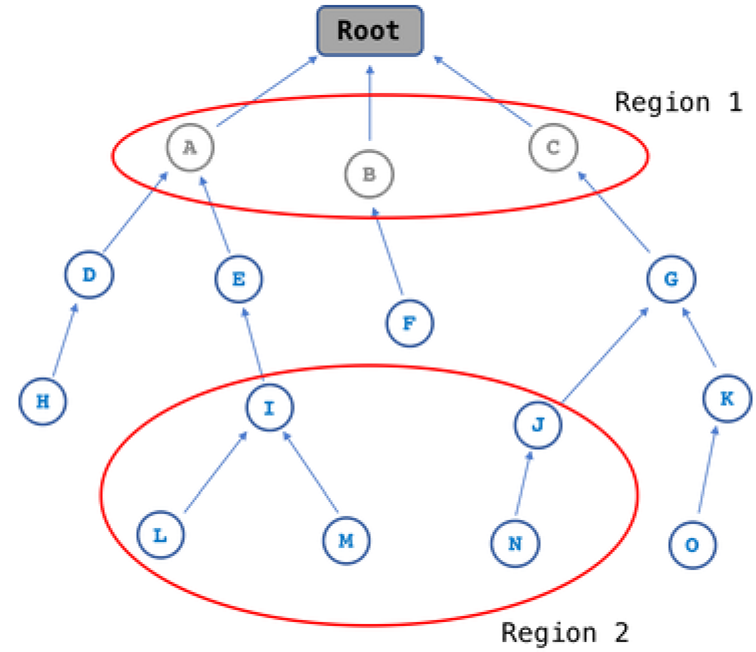

Figure 2

Nodes in region1 lose their main power before nodes in region2. Nodes in region2 broadcast the PON messages to their neighbors, but neighbors are not able to forward these PON messages to the root. As such, the root may only be aware of the power issues in region1 but not in region2. This is a bigger issue and cannot be acceptable, especially for the AMI solution.

In addition, PON messages are transmitted in broadcast which is not a reliable communication mechanism. It cannot guarantee that the PON messages are received by their neighbors.

Accordingly, techniques are described herein to provide an efficient and reliable mechanism to transmit a PON message to the power management system in different situations.

Briefly, some key nodes equipped with backup power (e.g., batteries) are deployed. The backup power can support the node to enable it to work for several minutes or hours after the main power is lost based on customer requirements. The key nodes may be selected based on network topology, scale, density, geographic or Routing Protocol for LLN (RPL) tree information, etc.

As illustrated in Figure 3 below, one or several first hop nodes may be selected to be equipped with backup power, which will form one or several local DAG roots. The local hop number starts from these nodes.

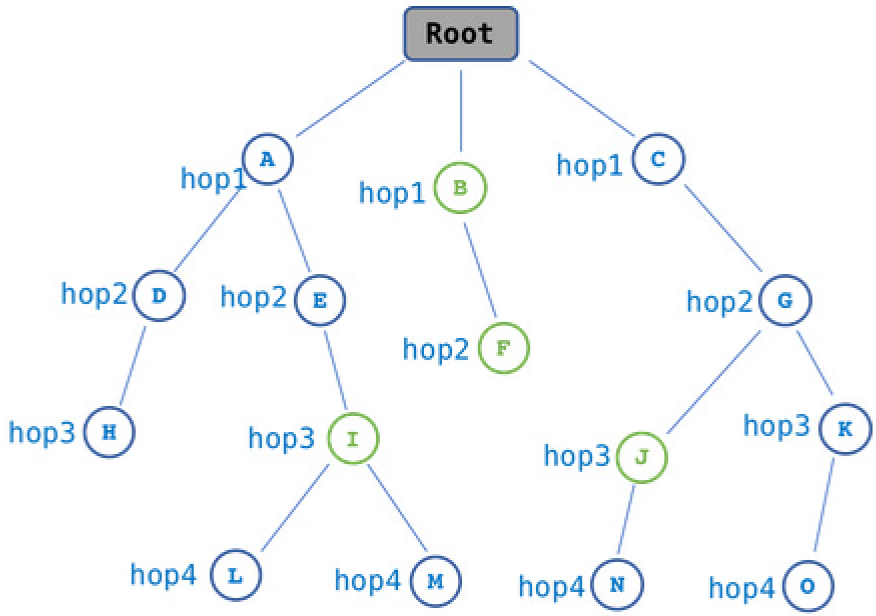

Figure 3

Here, only one first hop node B is selected to be equipped with backup power. Nodes F, I, and J are also selected to be equipped with backup power based on network topology.

A local DAG may be formed and rooted at node B.

Two work states on nodes may be implemented: one is the normal state and the other is the PON state.

Most of the time, nodes work in normal state. Nodes change to PON state when they lose main power or receive PON messages. Nodes have different criteria to select their parents for different work states, so a node may have different parents for different states. The first hop nodes only have the root as their parent.

As illustrated in Figure 4 below, the local DAG root leverages existing Destination-Oriented DAG (DODAG) Information Object (DIO) messages to build a local DAG by adding some options to the DIO message indicating whether the node has backup power. It does not bring much overhead when building the local DAG.

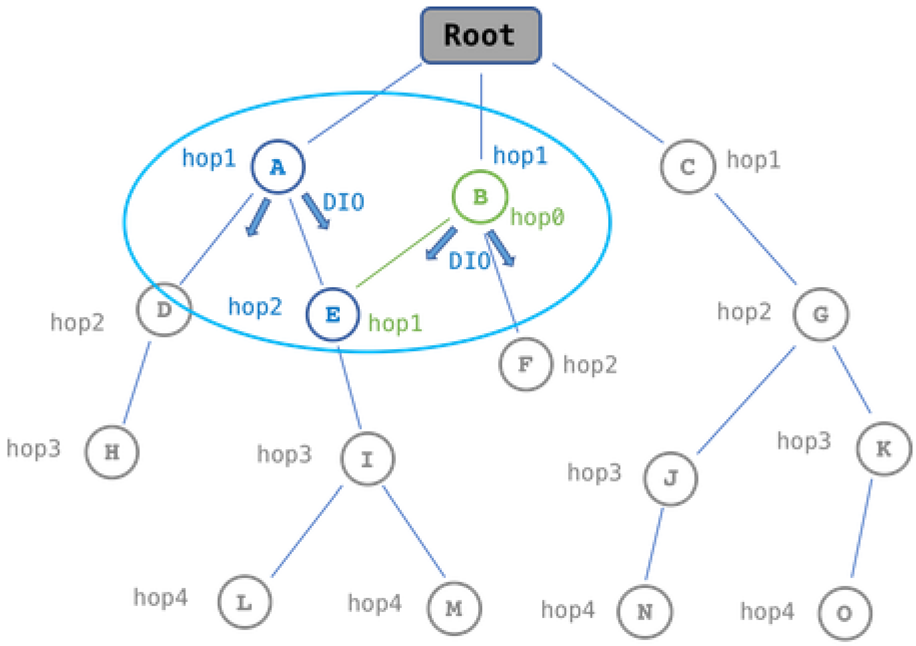

Figure 4

Node E receives global DAG DIOs from both node A and node B. The DIO from node B has some options indicating that it has backup power. Node A has better metrics, such as Received Signal Strength Indication (RSSI), Link Quality Indicator (LQI), etc. than node B, so node E selects node A as its preferred parent. Since node B has backup power, node E also selects node B as its preferred parent for PON state. Thus, node E has two parents: one is node A for normal state and the other is node B for PON state. Node E is the second hop node in the global DAG and also the first hop node in the local DAG rooted in node B. There are some extra options to indicate the local DAG information when node E broadcasts DIOs.

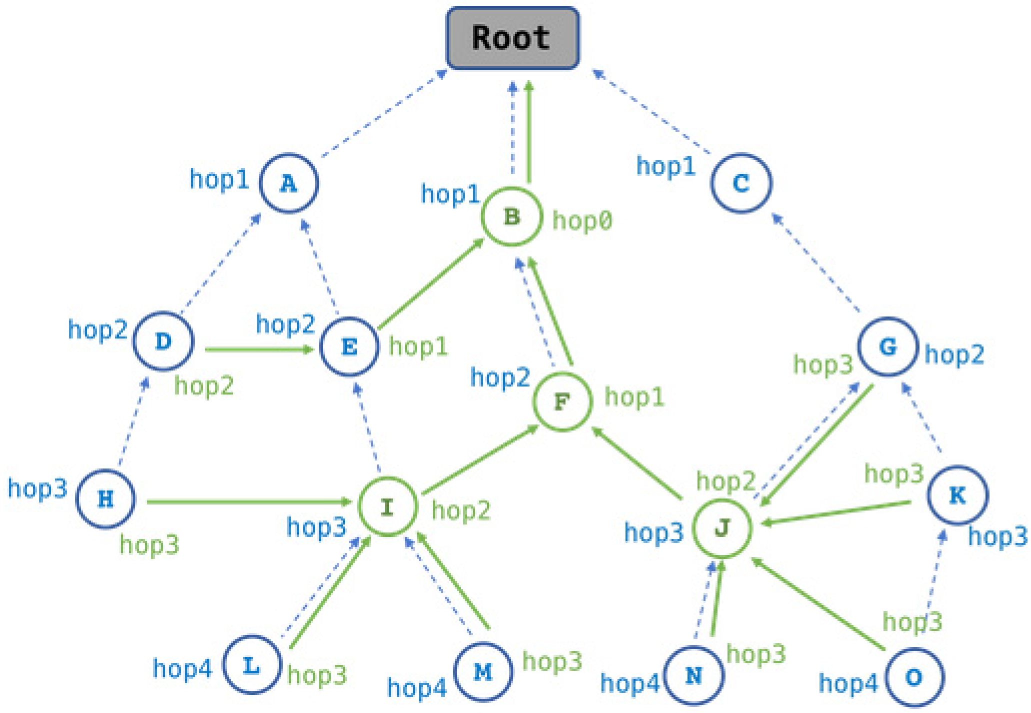

Figure 5

As illustrated in Figure 5 above, the dashed lines are the routing path in normal state and the green solid lines are the routing path in PON state.

For example, in normal states, the routing path between node L and the root is L→I→E→A→Root while the routing path is L→I→F→B in PON states, with node B forwarding the PON messages to the root.

PON message transmissions follow existing transmission strategies, but try unicast at least once. It may depend on the network deployment to decide how many times to transmit in unicast or broadcast. This parameter is configurable and can be adjusted in the field.

When nodes with backup power receive PON messages via unicast or broadcast, they forward those PON messages to their preferred PON state parents. They may not forward the messages immediately, but may remain in a listening state for a pre-configured time to receive as many PON messages as possible and then aggregating all the PON messages they received and forward them together to their parents.

In summary, techniques are described herein to equip backup power for some key nodes and form the local DAGs rooted at the first hop node with backup power. Nodes have different preferred parents in different work states. In normal state, nodes behave like existing mesh networks and have no performance sacrifice. In PON state, nodes can unicast the PON messages to their PON state's parents to improve PON message transmission efficiency and reliability.