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A NOVEL TECHNIQUE TO ENHANCE POWER OUTAGE NOTIFICATION (PON) SUCCESS RATE UNDER A NESTED OUTAGE

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ABSTRACT

Described herein is a novel technique to enhance outage success rate under a hybrid network, such as a hybrid Low-Power and Lossy Network (LLN). The technique involves creating another Routing Protocol for LLN (RPL) instance whose object function is a combination of Expected Transmission Count (ETX) and power capability.

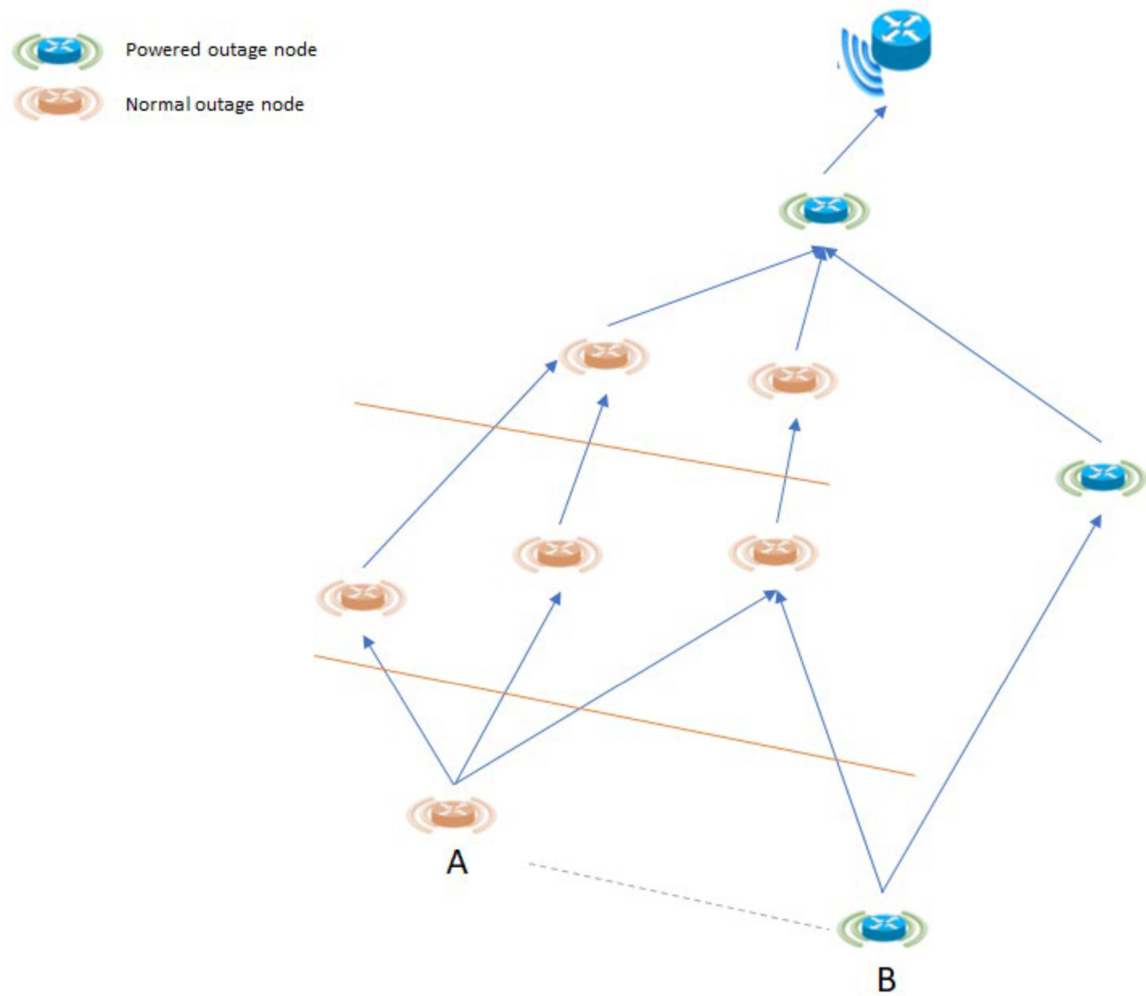
DETAILED DESCRIPTION

An important application of advanced metering infrastructure (AMI) networks is to report a Power Outage Notification (PON). Timely delivery of a PON allows a utility to efficiently identify the occurrence of power outages and quickly react to such events.

There are typically two kinds of nodes that may be utilized when an outage occurs. One kind of node has a large storage capacitor (sometimes referred to as a 'super-cap') or battery power that allows it to work normally for one or two minutes during which it can forward packets when an outage. For simplicity, this type of node may be referred to herein as a 'powered outage node'. Another kind of node has a limited power which can only broadcast its dying gasp for several seconds. This type of node may be referred to herein as a 'normal outage node'.

One problem that may be solved using the novel technique proposed herein may be the timely delivery of PON messages in a Low-Power and Lossy Network (LLN) consisting of powered outage nodes and normal outage nodes.

Consider an example involving a node, say Node A, as shown in Figure 1 below. When an outage occurs, Node A should forward PON messages to an outage server. Sometimes, outages may occur for many nodes at a similar time, which may be referred to herein as a 'nested outage'.



Consider for the example of Figure 1 that each node is experiencing an outage. In this example, Node A cannot forward a PON message to the outage server because none of its parent nodes has a power capability when the outage occurs. However, there is Node B, which help could forward the PON message, yet it cannot be chosen as a Routing Protocol for LLN (RPL) parent because of higher rank. Finding a reliable parent could greatly increase the PON success rate when a nested outage occurs.

Normally, there is a RPL instance whose object function is based on an expected transmission count (ETX), but this is not suitable for the nested PON situation. The technique proposed herein involves creating another RPL instance whose object function is a combination of ETX and power capability. For simplicity, this RPL instance may be referred to as a 'PON RPL instance', whereas the original RPL instance may be referred to as a 'normal RPL instance', which should still be maintained because it is optimized for less retransmission times under normal situations.

Power capability, as referred to herein, is the hold-up time when outage occurs. For example, if an outage node has no ability to receive and forward a PON message, the holdup time is 0. In contrast, if an outage node could work normally for 1 minute, the holdup time is 60.

The Mode of Operation (MOP) of the PON RPL instance must be 0, which means that no downward route is needed. This could help eliminate the unnecessary Destination Advertisement Object (DAO) messages. An energy node object will be contained in a Destination Oriented Directed Acyclic Graph (DODAG) Information Object (DIO) with the hold-up time inside it. A DIO with Energy node object will be treated as the PON RPL instance's DIO. With this PON RPL instance, a node can find a reliable node to forward a PON with much higher probability when a nested outage occurs.

A PON packet should include a RPL option carried in an Internet Protocol version 6 (IPv6) HOP-by-HOP Options header immediately following the IPv6 header. The target node could get the RPL instance identifier (ID) and sender rank from the header.

Figure 2, below, shows the typical situation of a hybrid network with two RPL instances.

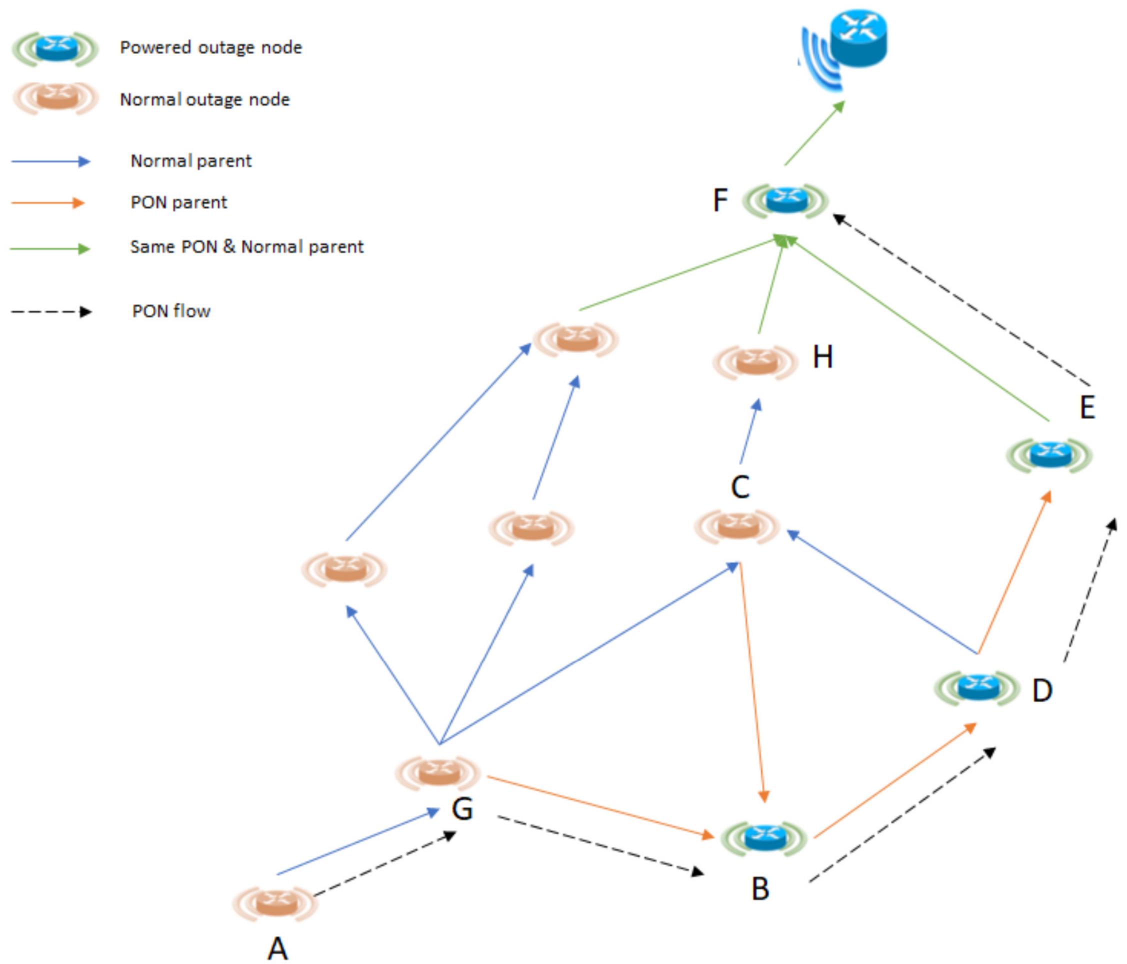


Figure 2

For Figure 2, consider that Node A only has a normal RPL instance, Node D has two RPL instances with different parents, and Node E has two RPL instances with a same parent. Thus, Node A has to select Node G as its PON parent, while Node C and Node E are Node D's potential parent. If Node A is transmitting the PON to the outage server, the PON flow should be A->G->B->D>E->F.

Generally, a PON RPL instance can be selected based on the ability to send a PON an outage server with higher probability. However, in order to avoid creating loops, the following rules should be obeyed for PON RPL instance selection:

1. If a node's PON RPL instance is valid and with at least one parent, the node must select the parent from the PON RPL instance.

2. If a node's PON RPL instance is invalid or with no parent, the node could select the parent from Normal RPL instance.

3. If a node's PON RPL instance is invalid or with no parent and the node receives a packet with PON RPL instance ID, the receiving node must drop the packet and send an Internet Control Message Protocol (ICMP) destination unreachable message to the source node from which the packet was received.

Without rule 1 a loop can occur. For example, if an outage occurs on Node D and Node D sends the PON to Node C from the normal RPL instance, then Node C may choose Node B as the destination and Node B will select Node D as its next hop thereby creating a loop.

There is an option that a source node's RPL instance could be followed to avoid a loop. However, similar to the previous example, if Node C received a PON from Node D and learned the instance is a normal RPL instance, it will send the PON to Node H also from a normal RPL instance. Yet Node H cannot not relay when an outage occurs, so in the nested outage situation, Node H will be a black hole with high probability. Thus, it is a better choice that Node E is selected as Node D's PON forwarder thereby obeying rule 1.

Without rule 2, it is obvious that any node without a parent from a PON RPL instance could not forward the PONs to the outage server and this is unacceptable. For example, Node A has only Node G as its parent from the normal RPL instance. Without Node G, Node A could do nothing but drop the packets.

Without rule 3 a loop can also occur. As shown in Figure 3, below, consider a case in which Node E is no longer Node D's PON parent.

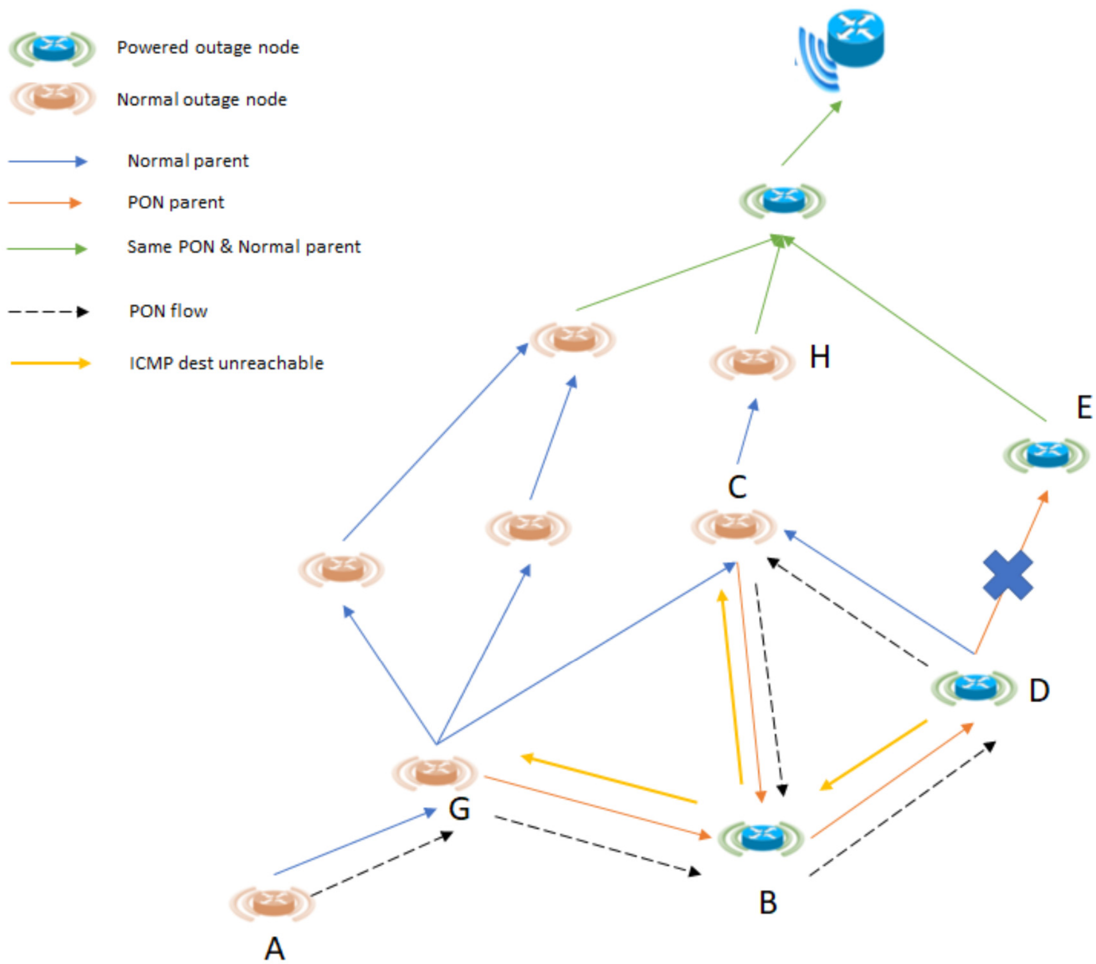


Figure 3

Because Node E is Node D's only parent from the PON instance, Node D should send a broadcast poison DIO and delete the PON instance. However, in a LLN it may not be confirmed that the notification would be received by its children. For example, Node B may miss the poison DIO and still treat Node D as its PON parent. In this example, when a PON is generated from Node A, the PON may follow the path A->G->B->D. However, because Node D does not have a PON RPL instance, it will choose Node C as its next hop following rule 2 and Node C will choose Node B as its next hop following rule1. Similarly, Node B can choose Node D as its destination and Nodes B, C, and D will form a loop.

Thus, the correct behavior for Node D should be to drop the packet from Node B and send an ICMP message to Node B informing Node B that Node D does not have a valid PON RPL instance. Because Node D is Node B's only parent from the PON RPL instance, it should also delete the PON RPL instance and send the broadcast poison DIO.

If Node G also misses the poison DIO from Node B, Node G may still forward the PON to Node B from the PON RPL instance. Node B could similarly send an ICMP destination unreachable message to Node G in order to notify Node G. After that, Node G can choose Node C as its next hop if there are more PONs to forward.

In summary, a novel technique is provided herein to enhance outage success rate under a nested outage in a hybrid network. The technique involves creating another Routing Protocol for LLN (RPL) instance whose object function is a combination of Expected Transmission Count (ETX) and power capability. In order to avoid creating loops, various rules can be followed for PON RPL instance selection.