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LOAD-BALANCING STRATEGY IN ROUTING PROTOCOL FOR LOW-POWER AND LOSSY NETWORKS BY EXPLOITING MULTIPLE PARENTS

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ABSTRACT

Techniques are described herein for an improved load-balancing strategy in a Connected Grid Mesh (CG-Mesh). This strategy may reduce residence time to the Border Router (BR) for each packet. The number of Destination Advertisement Object (DAO) messages may be decreased as well, thereby improving the stability and reliability of the network topology.

DETAILED DESCRIPTION

Node transmissions were infrequent in early Lower-power and Lossy Networks (LLNs). There was almost no residence time, meaning that the parent node may forward packets quickly after they have been received. But due to rapid growth requirements from industrial customers, more data needs to be transferred than ever before. In addition, with the development of hardware technology, nodes have enough buffer to conserve packets, creating longer residence times for each packet.

Connected Grid Mesh (CG-Mesh) provides reliable, high quality, and customer-satisfied wireless networks for Advanced Metering Infrastructure (AMI) and Distributed Automation (DA) customers. Furthermore, CG-Mesh adopts Routing Protocol for LLN (RPL) as the routing method to form tree-based topology wireless networks.

As illustrated in Figure 1 below, a node may select up to three parent nodes in RPL according to the value of the rank plus the Expected Transmission Count (ETX) from the neighbors. At time T0, node E has two parent nodes (nodes A and B). Node A is the preferred parent because the rank of node A (i.e., 342) is less than node B (i.e., 390). Similarly, node G selects node E as the preferred parent node and node F as the backup parent node because node E has the lower rank.

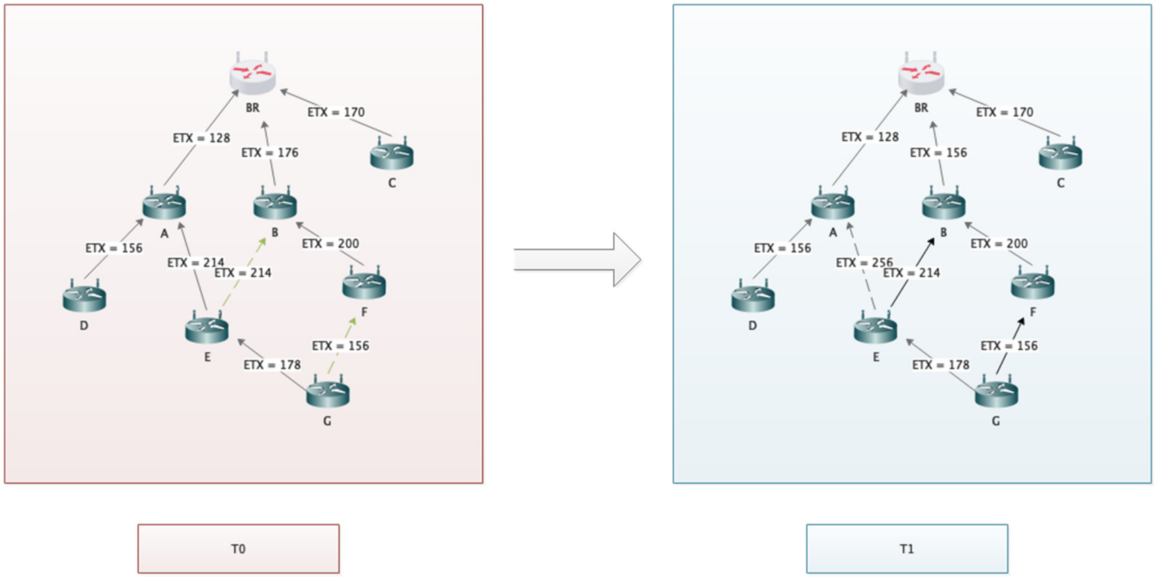

Figure 1

LLN topology often changes due to interference, collisions, and other environment conditions. Thus, at time T1, node E changes its preferred parent node to node B and consequently node G turns to node F as its new preferred parent node. This is because a node always transmits packets to its preferred parent node, and thus the ETX to the preferred parent node may change because only a fraction of packets could be received by the preferred parent node. Meanwhile, there is less traffic from the node to the backup parent nodes (e.g., only Neighbor Solicitation (NS) frames). Therefore, a node may switch its main parent node periodically, such as node E alternating between nodes A and B, leading to node G's change. Once a node changes its preferred parent node, it should send a Destination Advertisement Object (DAO) frame to the Border Router (BR) to update its downward routing path. This in turn increases the overhead required to maintain the CG-Mesh network as a whole.

Another problem is that ETX may denote only link quality without providing latency for a packet. That is, ETX may only provide the probability that a packet will be successfully received by a parent node rather than the duration of the packet from reception to egress on the parent node. For example, at time T1, node E wants to send a packet to the BR so that the packet is sent to node B in advance. Node B receives this packet successfully without re-transmission, but node B is very busy, there are too many packets required to be forwarded before this packet. As such, the packet needs to stay in node B for at least one minute. However, if node E sends the packet to node A, it may require one re-transmission. But if node A is idle, it may relay this packet to the BR as soon as possible, which means that the latency of path (E->A->BR) is less than path (E->B->BR).

Accordingly, described herein is a load-balancing strategy in RPL using multiple parents, which may reduce end-to-end latency as well as DAO traffic. To that end, a new index is provided to denote the Expected Residence Time (ERT), which is an indication of the level of activity of a given node.

As illustrated in Figure 2 below, node N receives packet P at time T and then forwards packet P to node M at time T'. the residence time of packet P on node N is delta_T (T'-T).

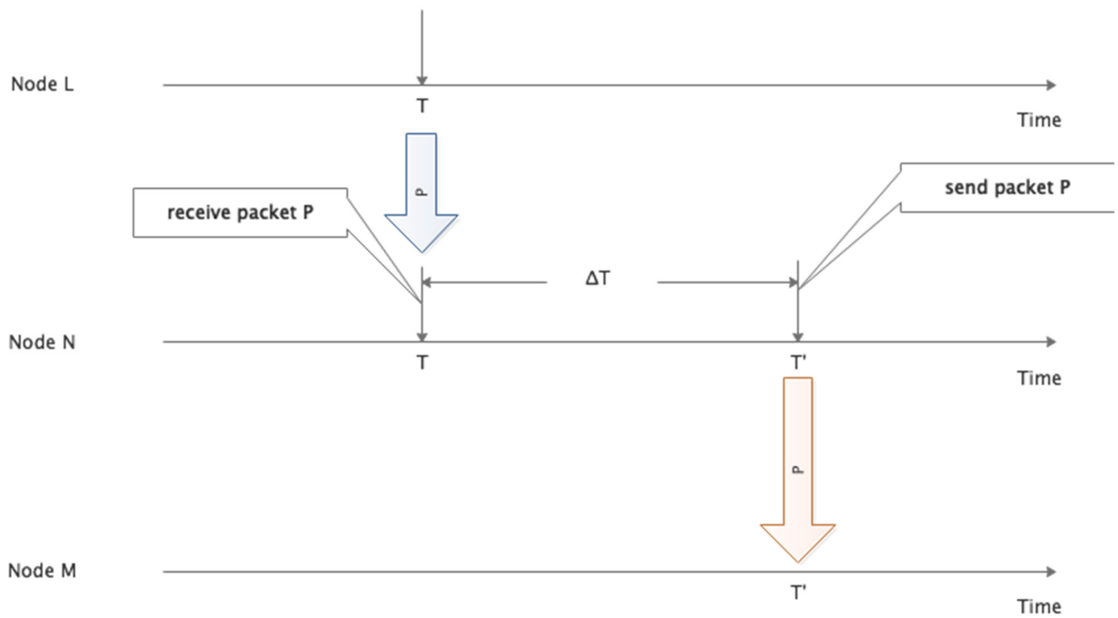

Figure 2

Therefore, given that node N sends k packets within a given unit of time (e.g., one minute), the residence times of all packets may be placed in a set S:

$$S = \{\Delta T_1, \Delta T_2, \Delta T_3, \ldots, \Delta T_k\} \tag{1}$$

Based on the known data set, the expectation E(delta_T) for set S during the given unit of time may be calculated:

$$E(\Delta T) = \frac{\sum_{i=1}^{k} \Delta T_i}{k} \tag{2}$$

E(delta_T) presents the immediate value of ERT in the latest unit of time. The following formula smooths the ERT with the historical value.

$$ERT = a * ERT_{previous} + (1 - a) * E(\Delta T) \qquad a \in (0, 1) \tag{3}$$

The previous ERT denotes the old ERT value generated before the given unit of time (e.g., one minute ago). The new ERT needs part of the old ERT to smooth the final value. "a" denotes a weight factor for the historical ERT and the current ERT. At the startup time, there is no existing old ERT, and the ERT is E(delta_T).

As illustrated in Figure 3 below, ERT information may be injected into a Direction-Oriented Directed Acyclic Graph (DODAG) Information Object (DIO) message for notifying its sub-nodes. A new DIO option may be added for ERT value propagation. Once a child receives the DIO message with an ERT option, it may update this information in its parent lists. In addition, the BR has no ERT because it does not have any upward traffic, and as such the DIOs generated by the BR do not have an ERT option.

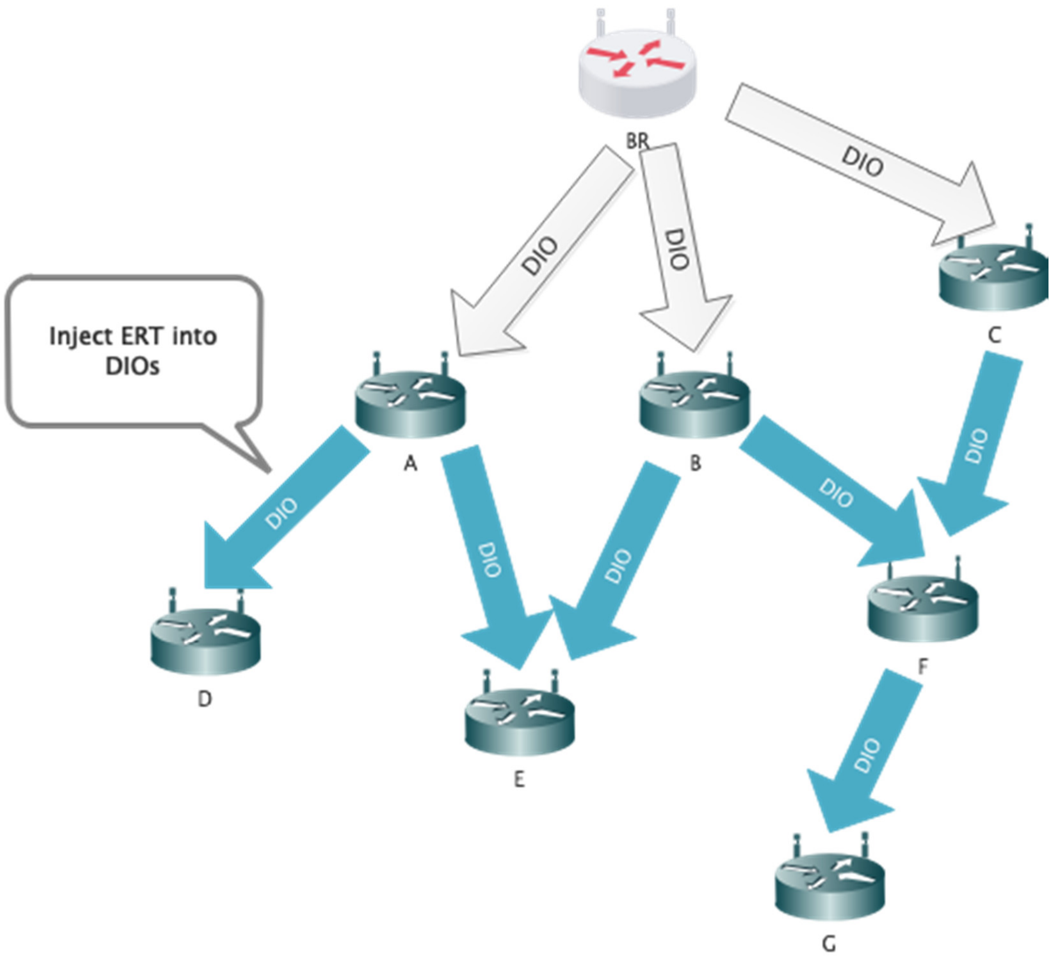

Figure 3

In a further example, a node may distribute packets with ERTs of its parent nodes. Currently, the child node always intends to transmit packets to its preferred parent node, even though the preferred parent node may not be the fastest path. Because the link metric ETX may guarantee lower probability of re-transmission, it does not consider the residence time for a packet on the parent node. For instance, as illustrated in Figure 4 below, node A has two parents: node B is the preferred parent node and node C is the backup parent node. At time T, node B is busy and will require on average one minute to forward a packet, but node C is idle and therefore could relay any packet shortly after the packet is received.

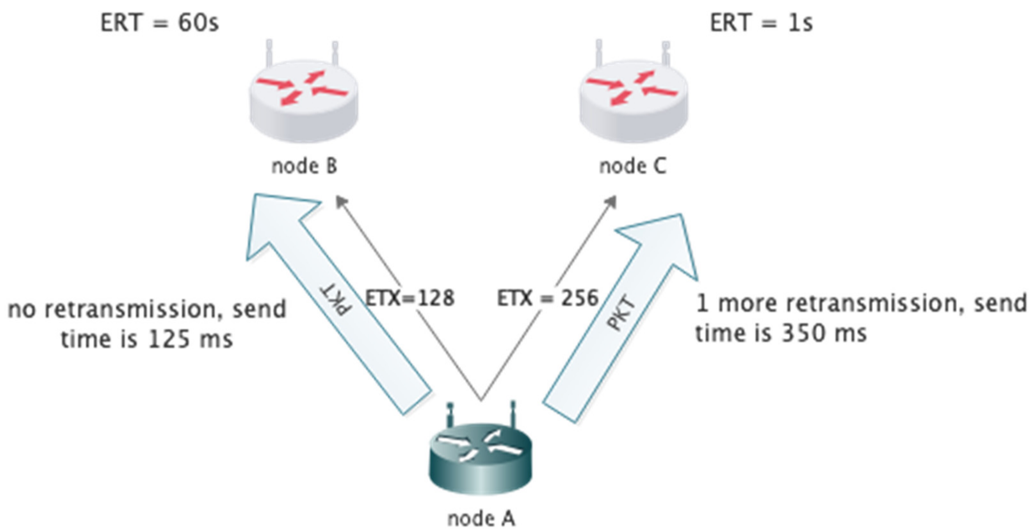

Figure 4

Even with the time of re-transmission for the path from node A to node C, the total spending time is far less than the path from node A to node B. However, a node need not send all unicast frames to the parent node with a lower ERT value. The interval of DIO propagation is not short, and as such the ERT may change since the DIO message is initially received. Otherwise, other children nodes may also have priority to select the parent node with the lower ERT, which means that this parent node may be occupied in the near future. This is analogous to drivers causing a traffic jam along a given route by simultaneously taking the given route to avoid a backup.

Furthermore, if all unicast traffic proceeds to the backup node, the child node may be delayed in determining the link quality to the preferred parent node. If the preferred parent node is lost, but most of the unicast traffic proceeds to another parent node with lower ERT, then the ETX to the preferred parent node will increase slowly. Therefore, the child node may not be aware of detaching from the current preferred parent, and as such may not send a DAO message for the changing parent node. The BR does not know that the previous downward routing could not work for the child node, and thus if the BR sends traffic to the child node it will fail.

For at least these reasons, the following rules are provided for a node to distribute multipath packets. First, a node must send at least 50% of the unicast traffic to the preferred parent. Second, the node may send unicast traffic to this parent node only when the ERT of the other parent node is less than the preferred parent. Third, the distribution probability may refer to the ratio of the preferred parent ERT to the backup parent ERT. The following formula may be used to calculate the transmission probability.

$$p = \begin{cases} 0, & ratio \leq 1 \\ a * ratio + b, & ratio > 1, (a, b) \in (0, 1) \end{cases} \quad (4)$$

Generally speaking, the probability of distribution to the alternative parent node is in direct proportion to the ratio, but must obey the first rule. Furthermore, if a packet transmission arrives at the alternative parent node in accordance with formula (4) but the unicast traffic sent to the preferred parent node is less than 50%, this unicast transmission is sent to the preferred parent node.

Using this algorithm, all parent nodes may have opportunities to receive unicast traffic. Thus, all ETX, rather than only that of the preferred parent node, will increase synchronously. Furthermore, the frequency of preferred parent node switching events is reduced, and therefore the number of DAO messages is reduced as well.

In summary, techniques are described herein for an improved load-balancing strategy in a CG-Mesh. This strategy may reduce the residence time to the BR for each packet. The number of DAO messages may be decreased as well, thereby improving the stability and reliability of the network topology.