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ENHANCING POINT-TO-POINT PERFORMANCE IN LOW-POWER AND LOSSY NETWORKS BASED ON GROUP AD HOC ON-DEMAND DISTANCE VECTOR AND PROJECTED DESTINATION ADVERTISEMENT OBJECT

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ABSTRACT

Techniques are described herein for enhancing the performance of Point-to-Point (P2P) performance in Low-power and Lossy Networks (LLNs) based on Ad-hoc On-demand Distance Vector (AODV) and Projected Destination Advertisement Object (P-DAO). These techniques may restrict the flooding range of AODV and reduce the computational complexity of P-DAO.

DETAILED DESCRIPTION

There exist alliances that promote interoperable wireless standards-based solutions for the Internet of Things (IoT), such as Distribution Automation (DA). The DA network usually consists of a Border Router (BR) as the root, and multiple nodes forming a multi-hop Low-power and Lossy Network (LLN). In DA applications, Point-to-Point (P2P) communication is an important feature because DA applications have Quality of Service (QoS) requirements in terms of latency and reliability.

For the P2P traffic within a Direction-Oriented Directed Acyclic Graph (DODAG), the packets either have to route through the root in non-storing mode or through a common ancestor in storing mode. Such traffic is likely to traverse a longer routing path, which can impact the latency, reliability throughput, and packet delivery ratio. Furthermore, all P2P packets passing through the root or common ancestor can cause congestion at that root or common ancestor.

There are two main mechanisms for P2P: Ad-hoc On-demand Distance Vector based Routing Protocol for LLNs (AODV-RPL) and Projected Destination Advertisement Object (P-DAO). AODV-RPL is based on the flooding of DODAG Information Objects (DIOs) to find the target node; however, it is difficult to control the range of flooding. For

P-DAO, the Path Computation Element (PCE) may compute the optimal route depending on the topology of LLNs to improve P2P performance. As such, each node should report its neighbor information to the PCE. However, the BR is usually the choke point in the network and any addition of periodic upstream/downstream communication takes away from (precious) available capacity.

Accordingly, described herein is a mechanism that combines the benefits of AODV-RPL and P-DAO to enhance P2P performance. In particular, the P2P techniques are a combination of P-DAO and AODV-RPL. Unlike other group division approaches, which are based on the local tree or sub-DAG, mechanisms are provided herein to define groups based on geographical location, PHY mode, and AODV hop counts. For geographical location, AODV-RPL is based on the flooding of DIO messages, so the nodes in the same groups are sufficiently close to each other. Intuitively, Global Positioning System (GPS) or other positioning methods may be used to divide the nodes.

In mesh networks, there are different PHY modes to be used for communication. Because the broadcasting messages (DIO) are applied to look for the P2P route in AODV-RPL, collisions between neighboring nodes may be considered. Higher data rates may accommodate more Route Request (RREQ) messages with fewer collisions. Therefore, the higher the data rate used, the larger the group size defined.

With respect to AODV hop counts, AODV-RPL is based on the flooding of DIO messages to find the P2P route. Thus, the range of groups may be limited according to hop counts to minimize the negative impact of message flooding. The exact number of permissible hop counts may be configured depending on the application and environment.

Therefore, for AODV-RPL, nodes inside the group transmit broadcast messages to neighbors (and not only to the parents or children) to search for the P2P route. The groups may be better defined by the aforementioned rules rather than a local RPL tree or sub-DAG.

In one example, nodes may only report neighbor information that is from different groups. After the group is defined, each node may report neighbor information to the PCE periodically, but only the neighbors from different groups. Unlike standard P-DAO, which sends all neighbor information to the root, these techniques mitigate the burden of the BR.

The PCE may calculate the group route for the LLN environment. Figure 1 below illustrates example group selection. To build a P2P route from node A to node B, intermediate groups may first need to be selected. An adjacent relation may be generated from the neighbor's report. The center of the node may be estimated based on the location information by the nodes in the same group. The distance of each group may be calculated based on the Dijkstra algorithm. In the example of Figure 1, the shortest path from node A to node B is highlighted as red. The group route is G1 to G2 to G3 to G4.

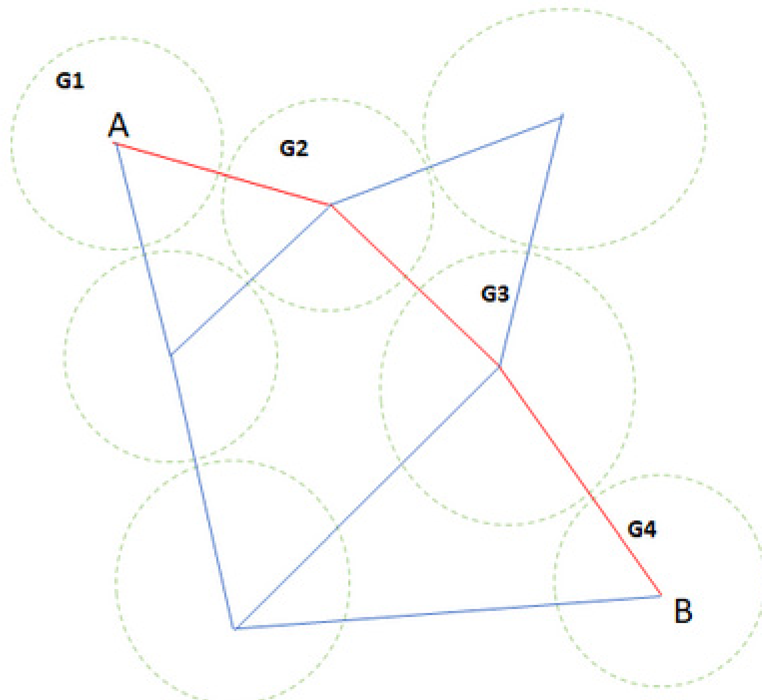

Figure 1

Figure 2 below illustrates an example LLN topology in which the route between groups is selected. For Group 1 to Group 3, routes B-K, C-J, D-J, E-I, and F-I are the potential routes. Two or three routes are necessary in some situations. For example, assume that route B-K is the only route installed. If node A is the original node, route B-K is acceptable, but, route B-K is unsatisfactory when node Z is the original node. However, it is also inefficient to install all the routes because each different route destination will trigger a new AODV flooding. Thus, rules are provided to optimize the route selection between the groups. One rule is that the Expected Transmission Count (ETX) should be limited. Another rule is that the node with more neighbors in a group should be given preference. For example, nodes D and E have greater probabilities of being detected when AODV flooding occurs in Group 1 than node B. The route with different coverage should also be given preference. For example, if route C-J has been chosen, route E-I should have higher priority than route D-J because is node D is closer to node C than node F. Additionally, the route with the lower burden may be given preference. If several routes are similar, the PCE may balance the load between candidate routes.

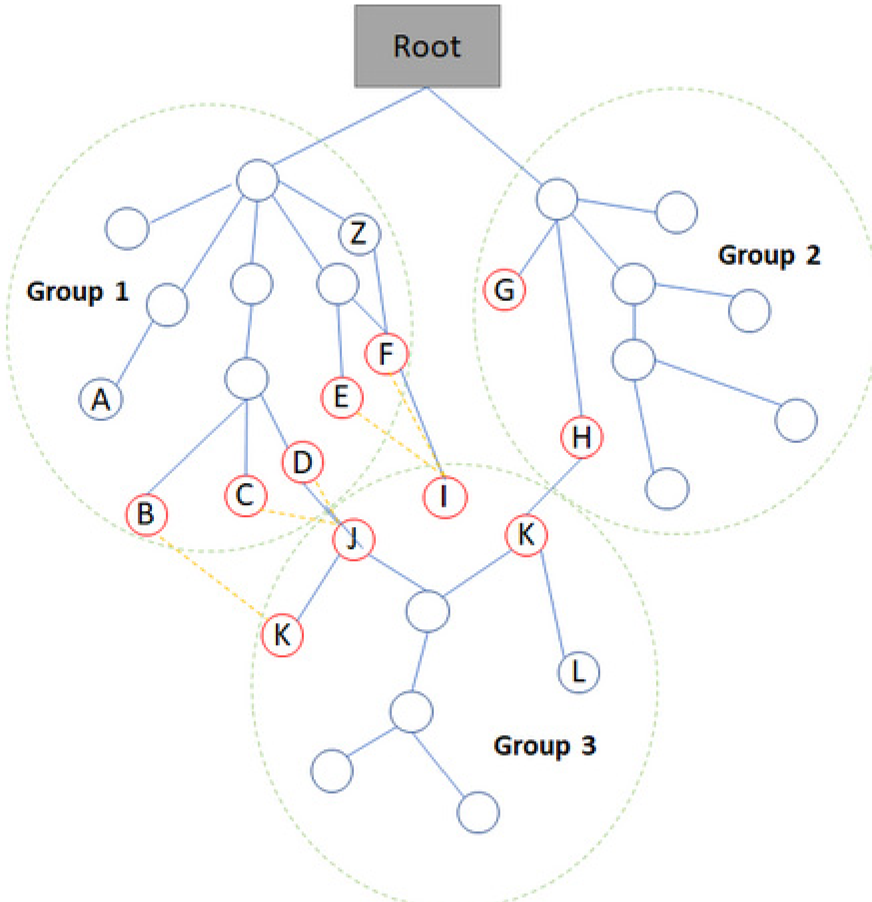

Figure 2

The node may broadcast DIO messages in the same group until the group destination or target destination address is found. It should also follow the installed group route when the packet is transmitted to another group. In one example, a P2P route from node A to node L is desired. Here, the PCE has already obtained, from the report of the node, information indicating that two routes to proceed from Group 1 to Group 3 include route D-J and route F-I. The PCE may install the best route to the source node. Thereafter, node A may begin to broadcast with the installed route.

Figure 3 below illustrates an example P2P message format. If node D or node F receives the broadcast message, it will find the first group source address that matches its own address, and then send the message to the corresponding group destination address (node J or node I) by unicast. The destination node may extract the first group route line, replace the source address and current group ID with its own address and group ID, and then continue to broadcast the message in its group to determine the next group destination node or final destination node (node L). Furthermore, to achieve the reverse P2P route, each node may add its address to the address vectors in the P2P message when it transmits the message. Thus, the route between different groups may be similar to the P-DAO method, and broadcasting the message inside a group to find the group source address may be similar to the AODV method.

Source address	Current Group ID	MaxRank		
Source Group ID	Group source Address	Destination Group ID	Group destination Address	1
Source Group ID	Group source Address	Destination Group ID	Group destination Address	2
		⋮		
Source Group ID	Group source Address	Destination Group ID	Group destination Address	N
Address Vectors(1…n)				
Destination Address				

Figure 3

The maximum rank may be set lower than the cost of the original route based on non-storing mode. That is, to optimize the P2P transmission, the rank cost of P2P route must not be larger than the original route based on the non-storing mode. Thus, the maximum rank parameter may be set in the P2P packet from the PCE. For each hop in the P2P route, the increased rank may be updated and the packet may stop in the P2P process when the actual rank is larger than the maximum rank set by PCE.

The PCE may also control the P2P message flooding for each group. For example, the PCE may dynamically adjust the P2P message flow for each group by planning the specific P2P route. For example, if it finds that one group ID has been carried by many previous P2P messages, the PCE may generate the specific P2P route without the group ID for the new P2P route request.

Described herein are techniques to define groups based on the characteristics of the mesh network and AODV-RPL. These techniques may enable dividing and maintaining the group, and may be adjusted flexibly according to network changes. AODV-RPL may be more appropriate for smaller networks to find the P2P route due to the flooding of broadcast messages. Also, the calculation algorithm of the group route performed by the PCE is helpful because there are several potential routes between two groups. Example rules are provided to optimize the route selection, though there may be many different methods to improve the algorithm.

Techniques described herein combine the AODV-RPL and P-DAO for internal and external groups respectively, and use rules to define the group division and calculate the group routes based on the advantages of AODV and P-DAO. AODV-RPL may be used inside the group because the size of the group is limited to minimize the negative effects of flooding DIO messages. AODV may maximize its advantages to determine the P2P route inside the group. On the other hand, outside the group, the burden of the BR may be mitigated and the computational complexity for P-DAO may be reduced. The PCE may calculate the best route between groups to achieve the best P2P performance.

Furthermore, a P2P route may be long-lived due to its expensive consumption. The establishment and maintenance of the P2P route should take a relatively short time, which may depend on primary mesh network performance. These techniques may also apply to fog nodes, which may be significant if P-DAO is applied inside the group. For example, a fog node may have a higher probability of becoming the bridge node between two groups to improve P2P performance. The computational complexity for P-DAO may be reduced and the flooding of DIO messages for AODV may be controlled using the mechanisms described herein, although it will be appreciated that improved algorithms may be considered as well.

In summary, techniques are described herein for enhancing the performance of P2P performance in LLNs based on AODV and P-DAO. These techniques may restrict the flooding range of AODV and reduce the computational complexity of P-DAO.