Use There of Model Predictive Control (MPC) for Rocket Altitude Correction

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Abstract—**Reactive route discovery for Point-to-Point (P2P) traffic flows is crucial in Low power and Lossy Networks (LLNs) for several use cases including home and building automation. The Routing Protocol over LLNs (RPL) standardized by IETF cannot be efficiently used for P2P flows that result in network congestion at the DODAG (Destination Oriented Directed Acyclic Graph) root, and packet delays. While P2P-RPL protocol is designed to address this problem, both these routing protocols does not consider asymmetric wireless links in their route computation.**

The AODV-RPL protocol draft which has been adopted by the roll working group of IETF is a reactive P2P route discovery mechanism for hop-by-hop routing based on Ad Hoc On-demand Distance Vector Routing (AODV) works in conjunction with RPL operating in the storing mode. In this paper we evaluate the performance of AODV-RPL on Cooja simulator under different network topologies and node densities for symmetric and asymmetirc links. Our extensive simulations show that AODV-RPL provides better Packet Delivery Ratio (PDR) and delay performance for several source and destination pairs compared to traditional RPL. Our simulation experiments also indicate that while AODV-RPL P2P routes are better compared to traditional RPL, there are several node-pairs where the relative hop distance difference is close. Based on this important observation, we suggest a simple hybrid routing mechanism where RPL routes are re-used to reduce routing protocol overheads due to AODV-RPL.

KeywordsAODV, DODAG, RPL and P2P links.

I. Introduction

Internet of Things (IoT) consists of thousands of constrained devices that include sensors and actuators, interact with their environment and are inter-networked together, and become accessible through the internet [1–3]. Currently 6LoWPAN [4] is the proposed standard to translate the IPv6 packets to the IEEE 802.15.4 MAC frame through compression and fragmentation. The design of a robust routing protocol plays a pivotal role to enhance the performance of the memory and power constrained nodes in a dynamically changing network [5]. To achieve this, IETF proposed a proactive based IPv6 distance vector routing protocol for Low-power and Lossy Networks, named RPL [6].

The RPL is primarily designed to build and maintain loop-free routing paths over mutli-hop networks to cater to the requirements of many IoT real-world applications which are typically multi-point-to-point, or point-to-multipoint in nature. The assumptions that are made in the RPL have however been found to be limiting when applied to networks for home and building automation applications characterized by message reliability and latency requirements between communicating nodes that belong to the same network, in other words, P2P communication. For instance, a remote control operation for controlling home appliances. The reasons for this shortcoming is best explained by a short description of RPL with respect to P2P communication.

Constrained nodes within the LLN that are running RPL protocol are connected by construction of a Destination Oriented Directed Acyclic Graph (DODAG). The LLN border router, also referred to as the DODAG root, initiates the DIO control messages to form a DODAG for a specific instance requirement, termed Objective Function. With this, a node within the LLN is able to select its parent node, which is often the best candidate amongst a set of next-hop neighbours. A path is established from the nodes in the network through the DODAG root. For accommodating nodes of differing resource capabilities, RPL offers two modes of operation. In case of non-storing mode which is employed in situations where the nodes are constrained by processing and memory capabilities, all the routes are stored in the DODAG root. Because of this, every P2P communication takes place via the DODAG root. It results in longer routes between peers, and radio congestion at the root. On the other hand, in the storing mode of operation, where the nodes are resourceful, every node in the network maintains downward routes its child nodes. Here too, the routes are sub-optimal because the packet from the originating node ends up traversing upwards till it reaches a common ancestor that holds the downward path to the destination node.

To avoid such sub-optimal routes, a reactive Point to Point [7] protocol(P2P-RPL) has been proposed. Although P2P-RPL is more efficient for P2P traffic in non-storing mode, its address vector usage in storing mode causes large network overhead. Also, both traditional RPL and P2P-RPL does not consider the presence asymmetric links for the route computation.

AODV-RPL [8], is a reactive protocol that has been proposed for both symmetrical and asymmetrical links, and to overcome the disadvantages of RPL and P2P-RPL. In AODV-RPL, a temporary paired instance is created between source and destination nodes, in order to transport data packets between them. The source node which needs to send data initiates an AODV-RPL instance called RREQ-instance, by multi-casting DIO with the RREQ message. The destination node in turn multi-casts or uni-casts a response message, called the RREP message. The RREP message establishes a path from the source to destination node, and RREQ message establishes a path from destination to source.

This paper comprehensively evaluates the performance of RPL and AODV-RPL in a dense network of constrained nodes. An extensive set of experiments were conducted, having considered both symmetric and asymmetric links between multiple node-pairs in the network.

The rest of the paper is organized as follows. Section II briefly explains about the pros and cons of traditional RPL and P2P-RPL routing protocol. Section III briefly overviews of AODV-RPL protocol. Section IV explains about implementation and experimental results that are being tested in Cooja simulator with Contiki operating system. Section. V ends up with the Conclusion and Future work.

II. Related Work

RPL,the IPv6 distance vector routing protocol for LLNs, is designed to support multiple traffic flows through a root-based Destination-Oriented Directed Acyclic Graph (DODAG) [6]. With RPL protocol, the data packets have to either traverse the root in non-storing mode, or need to traverse a common ancestor in storing mode. RPL may suffer severe traffic congestion near the DAG root [7, 9] and routes may be sub-optimal.

To discover optimal paths for P2P traffic flows in RPL protocol, a reactive based P2P-RPL [7] protocol is proposed which specifies a temporary DODAG with SourceNode acts as temporary root.P2P-RPL uses address vector for routing in both stored and non-stored mode which makes it less efficient in stored mode. The protocol is been implemented and evaluated in [10].

Both RPL and P2P-RPL specify the use of a single DODAG in networks of symmetric links.

But, application-specific routing requirements that are defined in IETF ROLL Working Group for constrained networks [11–14] may need routing metrics and constraints related to bi-directional asymmetric links. For this, [**?**] describes the bi-directional asymmetric links for traditional RPL with Paired DODAGs, for which the DAG root (DODAGID) is common for two Instances. With this, application-specific routing requirements for bidirectional asymmetric links in base RPL can be satisfied. For bi-directional asymmetric links in constrained networks, AODV-RPL specifies P2P route discovery, utilizing RPL with a new Mode of Operation (MoP). For asymmetrical links, AODV-RPL has two multicast messages, one from SourceNode to TargetNode and another from TargetNode to SourceNode. With AODV-RPL,need of address vector is completely eliminated for symmetrical links which can significantly reduce the control packet size that is important for constrained LLN networks.

This paper compare RPL with AODV-RPL for both symmetric and asymmetric links with PDR, delay and number of hops using LLNs border router.

III. Overview of AODV-RPL

In AODV-RPL, reactive route discovery is initiated by creating a temporary DAG rooted at the SourceNode. Paired DODAGs (RREQ-Instance and RREP-Instance) are constructed according to AODV-RPL Mode of Operation (MoP) during route formation between the SourceNode and TargetNode. The RREQ-Instance is formed by multi-casting a route control messages from SourceNode to TargetNode whereas the RREP-Instance is formed by multi-casting (asymmetric)/unicasting(symmetric) route control messages from TargetNode to OrigNode. Intermediate routers in LLN changes join the Paired DODAGs based on the rank as calculated from the DIO message.

An LLN node originating the AODV-RPL message supplies the following information in the DIO header:

- S bit : Symmetric bit added in the traditional DIO object.
- MOP : Mode of Operation in the DIO object MUST be set to 5 for AODV-RPL DIO message.
- RPLInstanceID : Instance-ID of paired DODAGs of AODV-RPL Instance.
- DODAGID : IPv6 address of the device that initiates the AODV RREQ-Instance
- Rank : Node rank corresponding to AODV-RPL Instance.

The S bit in DIO base object is set to '1' mean that the route from SourceNode to TargetNode is symmetric. When the RREQ-Instance arrives over an interface that is known to be symmetric, and the S bit is set to 1,then it remains set at 1. When the RREQ-Instance arrives at any of the intermediate node that is not known to be symmetric, or is known to be asymmetric then the S bit in the DIO base object is set to be 0. The Expected Transmission Count (ETX) value is used to find out whether the link at the intermediate node is symmetric (S=1) or asymmetric (S=0). When the S bit arrives with already set to be 0 then it is set to be 0 on re-transmission at the intermediate nodes. Based on the S bit received in DIO-RREQ-Instance, the TargetNode decides whether or not the route is symmetric before transmitting the RREP-Instance message upstream towards the SourceNode.

The RREQ-Instance is used for application data transmission from TargetNode to SourceNode and RREP-Instance is used for application data transmission from SourceNode to TargetNode.

IV. Implementation

In order to study the behaviour of RPL and AODV-RPL, the AODV-RPL specification has been implemented on Contiki [15], an operating system for wireless sensor networks used and actively developed by a wide industrial and academic community. Contiki was chosen because it includes an IPv6 stack with 6LoWPAN support, as well as it had RPL implementation, which was used as basis for AODV-RPL implementation and simulations can be also be conducted using Cooja simulator.

A. Experiments

The experiments consisted 16 node and 38 node networks as shown in figures 1 and 2. Node-1 is assumed to be a LLN border where LLN traffic is re-routed through traditional wired backbone network.

The simulations were done in Cooja [15], an emulator for wireless sensor networks. The experimental setup used are tabulated in table I

Platform	MSP430 based motes
MAC	CSMA
Network stack	IPv6/6LoWPAN
Radio duty cycle (RDC)	null RDC
Application	UDP server/ UDP client
Application data length	40 Bytes
Application data rate	Fixed
MAC max retries	3

TABLE I: *Used COOJA Simulation configuration*

Radio medium used in Contiki is Directed Graph Radio Medium (DGRM) because it is easier to configure link states between nodes like RSSI, PRR and LQI so on. Random SourceNode and TargetNode pairs were considered and experiments are conducted making links symmetric and asymmetric between SourceNode and TargetNode. Links were made asymmetric between random SourceNode and TargetNode pairs by varying Packet Reception Ratio (PRR) values provided in DGRM configuration. With AODV-RPL, a route discovery to the TargetNode was initiated by the SourceNode node and route reply initiated by TargetNode to SourceNode was recorded. For RPL, a global DAG uses DIO to establish upward routes and the DAO mechanism in non-storing mode in order to provide paths from SourceNode to TargetNode as described in Section II. The number of hops taken to reach TargetNode,delay experienced and PDR achieved were recorded. Such experiments were repeated for different SourceNode and TargetNode pairs with varying link characteristics.

Fig. 1: Topology with 16 nodes

Fig. 2: Topology with 38 nodes

B. Experimental Results and Observation

Experiments with arbitrarily selected SourceNode and TargetNode pairs were conducted, and we recorded the data pertaining to the number of hops, PDR and the delay incurred. We categorized the total number of routes as a measure of the number of hops taken by both the protocols between multiple node-pairs. The table II shows the percentage of routes that AODV-RPL and RPL use, and the number of hops taken by each route. We present the individual performance of both the protocols below

It can be inferred from the table II that on an average, AODV-RPL takes far less number of hops than RPL. About 40% of AODV-RPL routes use 4 hops, whereas, about 38% of routes in RPL use 6 hops.

Another metric considered for comparison is the delay experienced by the packets traversing the network. We present

Number of hops used	*Percentage of AODV-RPL routes*	*Percentage of RPL routes*
2	5%	-
3	25%	7%
4	40%	30%
5	15	13%
6	15%	38%
7	-	10%

TABLE II: *Number of hops used by percentage of route by RPL and AODV-RPL*

Fig. 3: Summary: delay of RPL and AODV-RPL

the histogram of delay experienced by these packets as shown in the plot 3. The percentage of packets sent are plotted along the y-axis and the delay(ms) is along the x-axis. We observed from figure 3, that 45% of packets in AODV-RPL experience (40-50)ms delay and 29% of the packets experienced (52-60)ms delay. Whereas in RPL, 37% of packets experienced delay between (55-65)ms and 25% of packets experienced delay between (70-80) ms. Therefore, we can deduce from the data that AODV-RPL takes less delay compared to RPL.

One of the reasons for the increased delay in RPL is due to the fact that the packet must travel all the way to a common ancestor, or sometimes to the DODAG root itself. However, AODV-RPL on the other hand finds the shortest path on-demand. As the number of hops increase, the cumulative delay due to re-transmissions between every node-pair also increase. We can also observe that PDR is less in RPL compared to AODV-RPL, as packets are lost due to congestion at border-router.

Experimental results of a single SourceNode and TargetNode pair has been considered below. The histograms shown in figure 5 and figure 4 demonstrate the delay experienced when SourceNode with ID 13 sent packets to TargetNode with ID 10 and subsequent reply from Node-ID 10 to Node-ID 13 respectively. It can be observed that the reply packets take a different path than the sender packet. This is due to the asymmetric nature of the links.

Fig. 4: Packet delay: SourceNode 13 and TargetNode 10

Fig. 5: Packet delay: SourceNode 10 and TargetNode 13

From the above graph, it can be deduced that the delay experienced by RPL is higher than the delay experienced by AODV-RPL. Another observation is that the path in RPL changes over time. Initially, DODAG establishes the upward routes, after an exchange of few packets between a node-pair, RPL tries to find a better path. This causes a change in the parent and subsequently, a change in the path, and leads to packet loss. However, in AODV-RPL a direct path between the node-pairs will be established and the same path is retained throughout the instance. The change in delay due to symmetric and asymmetric links for the same node-pairs has also been observed.

We also noted that the time between originating the route request and receiving the route reply was measured to be 550 milliseconds on average, as trickle timer is not used for the first RREQ/RREP message, node thet received RREQ/RREP, immediately uni-cast/multi-cast RREQ/RREP. For RPL as in figure 2 the route taken by data packets from SourceNode 30 to target node 7 is to `30->25->22->17->12->13->10->1->2->7` and reply packet from node 7 to node 30 is `7->2->1->10>13->17->21->30`, ie in case of links being asymmetric, request and packets take different routes and number of hops are also different. In case of AODV-RPL, the path taken for request packet is `30->21->16->7` and relay packet takes`7->16->21->30`.

Fig. 6: Percentage of routes using RPL border router

In the overall simulation we can observe as in 6 that the percentage of routes pass through RPL-Border-router in case of AODV-RPL is significantly minimum RPL, which reduces congestion at RPL-Border-router.

Hop difference	*Percentage of routes experienced*
less than 2	42%
2 or more	58%

TABLE III: *Number of hops used by percentage of route by RPL and AODV-RPL*

We can observe from graph III that, 42% the AODV-RPL and RPL routes experience route length difference of 0 or 1 hops. Investigation provides the information that if the shortest hop distance between the node pairs is more,then even AODV-RPL can take route length as equal to RPL route length. Consider for example in figure 1 node pairs (10-16) experience 6 as shortest hop length, which is route length for both AODV-RPL and RPL. The route taken by RPL is (10-5-2-1-4-9-16) and for AODV-RPL is(10-11-12-13-14-15-16), and in topology 2 between node pair (35-33) AODV-RPL uses (35-36-32-37-33) and RPL uses (35-36-1-37-33), even though RPL uses border router, when network is not dense it And also when TargetNode is one of its parent towards DODAG root, then route length difference RPL and AODV-RPL are less than 2 hops. These situations AODV-RPL can be avoided,so that can reduce AODV-RPL control packet overhead.

From these we can conclude an hybrid approach of choosing between RPL and AODV-RPL, depend application requirement is recommended.

A few points to be noted here is that, the draft [8] doesn't specify behaviour of packets prior to the establishment of routes by AODV-RPL. The first AODV-RPL DIO received is used for path establishment, and the procedure for subsequent DIO is not addressed. The life time of the ADOV-RPL established routes are also not specified.

V. Conclusion

Through extensive simulatons on Cooja simulator we evaluated the performance of AODV-RPL, a P2P routing protocol draft standard that is adopted by IETF's roll working group. The message reliability and delay performance comparison between stored mode of traditional RPL operation and AODV-RPL for P2P flows between various node-pair combinations show that AODV-RPL performs better under different network toplogies, node densities, and links exhibiting symmetric and asymmetric properties. While this result is not surprising, we note that there are P2P routes where the hop distance difference between routes generated by traditional RPL and AODV-RPL is 2 and less. This crucial observation leads us to conclude that P2P flows between certain node pairs can reuse the routes already made available by traditional RPL instead of triggering reactive AODV-RPL routing mechanism with the associated routing protocol overhead, if the relative benefits offered by AODV-RPL is not significant. A simple hybrid routing strategy that uses combination of traditional RPL and AODV-RPL routes is proposed in the paper.

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