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Performance Analysis of IoT Routing Protocol: A Study

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***Abstract** - A standardized and flexible routing protocol enhances the performance of networks. IETF (International Engineering Task Force) standardized an RPL (Routing Protocol for Low Power and Lossy Networks) for low power and lossy networks. In this protocol, the ideal route is selected from source to destination. The paper evaluated the RPL performance in terms of average power and radio duty cycle. We simulate RPL with Cooja based on Contiki Operating System. This paper compares the average power and average duty cycle for nodes with a varying number of sinks. The proposed method decreases the consumption of power, listen (Rx), and transmit (Tx) duty cycle by increasing the number of sinks in the network.*

Keywords — *IETF, RPL, Cooja, Contiki, IoT.*

I. INTRODUCTION

The Internet of Things (IoT) refers to a network of interconnected objects capable of acquiring physical world data and making this data accessible on the Internet [1]. Group of infrastructures interconnecting linked items and enabling their management, data mining, and information generation access [2].

"An IoT is a network connecting" stuff "uniquely recognizable to the Internet. The "things" have capacities for sensing or actuating and potential programmability. By exploiting unique identification and sensing, it is possible to collect information about the "thing" and the state of the "thing" can be changed from anywhere, anytime, by anything [3].

An IoT device is any inter-connected stand-alone device that can be monitored or controlled remotely. Nowadays IoT device is smaller with more powerful chips which can be used in almost all products. All the components that enable consumers, governments, and businesses to connect to their IoT devices, including dashboards, remotes, gateways, gateways, data storage, analytics, and security, are part of the IoT system.

According to a survey of BI (Business Intelligence) premium research service, there will be over 24 billion IoT devices on earth by 2020. That means for every human, and there will be approximately four devices on the planet. An amount of $6 billion was invested into IoT solutions which includes device hardware, data storage, system integration, connectivity, application development, and security. It is estimated that the profit for the invested amount will be around $13 trillion by 2025.

The major stakeholders for IoT systems are consumers, governments, and businesses. IoT affects every industry in many ways. IoT contributes major benefits to three groups as consumers, governments, and ecosystems with several environments. The major benefits are connected homes and smart buildings, agriculture, manufacturing, defense, infrastructure, banks, transportation, smart cities, hospitality and health care, logistics, etc.

In IoT, system routing plays a major role. Routing is nothing but transferring data from one node to another node through some intermediate node across inter-network. Basically, it is the selection of a path from source to destination and occurs at the network layer.

Implementation of appropriate Routing techniques in IoT based networks can be very challenging because of the below reasons

- Variation in the sensor types
- Variation in the implementation of network stacks
- Connectivity problems because of vast heterogeneity
- Change in the topology because of mobility
- There can be multiple hops in the end to end connectivity
- The device should have a unique address for connectivity
- The problem of energy because the mobile device may drain the battery quickly

II. RELATED WORK

In [4], an optimized ND protocol has been used for the performance evaluation of routing protocol. The protocol was implemented on Contiki OS v2.6, and the Cooja simulator is considered for results evaluation. The method increases the energy efficiency in 6LoWPAN networks and allows host nodes to start direct communication with routers. The node reachability affects the ND protocol behavior. In this node, retransmission of RS messages is required for finding a new default router.

By using the IEEE 802.15.4 radios, Routing Protocol for Low power and Lossy Networks (RPL) can be analyzed by simulating sensor devices [5]. For simulation, ContikiOS and Cooja were used. This RPL reduces the energy consumption of the network and increases the network lifetime. It also reduces the transmission and reception of multicast packets and delays.

RPL focuses on energy balancing by prolonging network lifetime. It uses a new metric to load the balance of the network and its lifetime [6].

The RPL routing protocol behavior simulated and compared its performance with other routing protocols. In [7], it is concluded that RPL is better in its performance than other protocols for small networks. It is better because of its fast establishment. The work can be enhanced by considering a large number of nodes.

The packet overhead, throughput, and average end-to-end delay of IoT routing protocol were compared subjected to change in mobile nodes. The work has to be extended to consider location information and the variable speed of nodes in the network. So, the appropriate IoT routing protocol has to be selected for better improvement in network performance [8].

The RPL routing protocol performance can be increased for dense networks. The comparison has been made for different metrics [9]. The performance metrics were increased proportionally with an increase in the number of nodes. It also considers the power consumption of the network related to the availability of the number of sink nodes. The mobility affects directly on received packets. If the number of sinks was increased, then the power consumption is less in the network.

The two multipath ELB and FLR protocol has a minimal end-to-end delay, packet delivery rate, overhead, and faster local repair mechanism compared with RPL [10]. The combination of ELB and FLR also maintains a well-balanced network and improves performance.

The metrics such as sent, received, lost packets, duplicate packets received, and throughput was used to compare different routing protocols. Based on the number of nodes, these metrics can be increased. The type of mobility model directly affects the data transmission. Compared to entity mobility models, the group models have the lowest throughput [11].

The protocol used in WSN and ad hoc networks for energy-efficient is not enough for IoT. [12]A special protocol designed by IETF is named RPL for various application requirements in LLNs to provide IPv6 communication. For RPL, metrics such as link reliability, hop count have been proposed to capture a link-level characteristic performance.

RPL adopted larger in IoT because of today's IoT market, heterogeneity, application requirements, and hardware constraints. [13] RPL could be a standard framework for interrelated standards, which focus on specific application profiles and communication technologies. To support a broad range of efficiency features required for application, a standard framework has to be used. The framework should provide the interoperable capability, which is an alternative for the composing network stack.

III. RPL (ROUTING PROTOCOL FOR LOW POWER AND LOSSY NETWORKS)

A distance vector routing protocol has been developed to meet the requirements of Low-power and Loss Networks (LLNs) by the ROLL working group and named it RPL. For several reasons, including the specification and complexity of execution, RPL has been commonly criticized. It reduces the implementation complexity and makes it more suitable for resource-constrained node deployment. The design of RPL should operate on top of several mechanisms, including the MAC layer and IEEE 802.15.4 PHY layers. The primary target of RPL is collection-based networks where nodes send readings to a collection point regularly.

RPL represents the alternative for low power and loss network routing. The main purpose of this design is to provide alternative routes when routes are inaccessible by default for highly adaptive network conditions. To disseminate information, RPL provides a mechanism to form network topology dynamically.

A. RPL Topology

RPL topology organizes into Destination-Oriented-Directed-Acyclic Graphs (DODAG) for destinations. DODAG is a single destination rooted in DAG. There are no outgoing edges of the DODAG root [14]. The DODAG graph of RPL is uniquely identified by combining the RPL instance and DODAG id. Figure 1 shows the construction of RPL DODAG using DODAG ID and RPL instance.

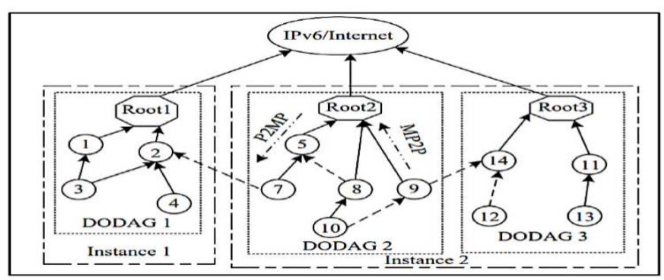

Figure 1: RPL DODAG Construction [14]

Each RPL instance has one or more DODAG and is identified by a DODAG ID. Every node in the DODAG has a rank value. The rank value reflects the position of the node in relation to the DODAG root node. Rank values increase strictly downward and decrease upward as it approaches the root node. DODAG Root is liable for aggregating paths and building DODAG.

B. FEATURES OF RPL

Loop avoidance and detection: The rank of any node in RPL is higher than its parent node. In RPL, a node rank value to be greater than its parent node, which results in the acyclic nature of the DODAG. Furthermore, RPL provides recovery mechanisms in local and global to detect the loop and recover the topology.

Self-configuration - Dynamically discovers the network paths with the help of IPv6 neighbor discovery mechanisms.
Communication paradigms - supports Point-to-point (P2P); Point-to-multipoint (P2MP) and Multipoint-to-point (MP2P)
Target networks - used for Low-Power and Lossy Networks (LLNs), 6LowPAN networks, and other IPv6 networks.
Identifiers - It can use RPL Instance ID, DODAG ID. DODAG Version, Rank.
Security mode - Supports different security mechanisms
Mode of operation (MOP) - It can operate in MOP (0) for no downward routes, MOP (1) for Non-storing, MOP (2) for Storing, and MOP (3) for Storing with multicast.

C. TYPES OF RPL

There are many types of RPL. Table 1 gives the protocol classification and their characteristics.

Table 1: Protocol classification

Sl. No	**Protocols Classification**	**Energy Efficiency**	**Data Aggregation**	**Load Balance**	**Multipath**
1	RPL standard	No	Yes	No	No
2	RPL-BMARK	No	No	Yes	No
3	P2P RPL	Yes	Yes	No	No
4	CO-RPL	No	Yes	Yes	No
5	Qu-RPL	Yes	Yes	No	Yes
6	Ec-RPL	Yes	Yes	No	Yes
7	ENHANCED-RPL	Yes	Yes	No	Yes
8	ER-RPL	No	No	Yes	Yes
9	C-RPL	Yes	No	No	No
10	ME-RPL	No	Yes	Yes	No
11	GI-RPL	Yes	No	No	Yes
12	MoMoRo	No	No	No	Yes

IV. SIMULATION ENVIRONMENT

To measure the performance of the RPL protocol in a large-scale network, a Cooja simulation environment has to be used. It is used to emulate the Sky motes. Nodes are dispersed randomly over an area of 100x100 m^2. Each node in the network sends a data packet of size 140 bytes every 30 seconds towards the sink node. The simulation was repeated for 20 to 50 nodes with 1 to 3 sinks for 5 minutes.

A. CONTIKI OPERATING SYSTEM

The operating system plays a major role in the simulation of the experiments. So, Contiki Operating System is used for simulating applications of IoT. It is an open-source operating system generally designed for wireless sensor networks but can be used for IoT. It is implemented using the C programming language and supports multitasking operations. It is a UNIX-based operating system. It consists of a set of lightweight networking protocols known as Rime stack, the IPv4 networking protocols µIP TCP/IP stack, and µIPv6 stack for tiny and embedded sensor devices, which offers Contiki MAC layer which packages radio packets into IEEE 802.15.4 frames.

B. COOJA SIMULATOR

Cooja simulator is a Java-based simulator supported by Contiki operating system. Using this simulator, the RPL protocol is simulated. Nodes are programmed using C language, even though the simulator is Java-based. The sensor hardware is emulated using the Cooja emulator. Using external plugins such as simulation visualizer, timeline, and radio logger, it interacts with the simulated nodes. It can simulate independent networks based on some defined parameters and run real data files from testbeds.

In this paper, the RPL metrics that are considered to measure the performance of the RPL protocol are:
Average power: It is the amount of energy or work done per unit of time. To measure the average power of a continuous light beam, fiber optic power meters are used. These are used to test signal power in fiber-optic networks.
Radio Duty Cycle: Contiki provides three types of duty cycling mechanisms. X-MAC mechanism is generally used for low power listening. ContikiMAC is similar to X-MAC but enhanced to power consumption reduction. Contiki's LPP mechanism is Low Power Probing (LPP) protocol but enhanced to reduce the power consumption and to provide the mechanism for sending broadcast data.

In the radio duty cycle, we can discuss the radio on, radio Transmit (Tx), radio Listen (Rx). It's the time when the radio chip hardware is turned on, i.e., it is in a ready-to-receive state, Receiving (Rx) or Transmitting (Tx).
Transmit (Tx) Duty Cycle: It is the percentage of the duty cycle used to transmit to the radio in-network as shown in equation (1)
Listen to (Rx) Duty Cycle: the percentage of the duty cycle used to listen to the radio in-network as shown in equation (2)

$$Rx = \frac{Rx\_time}{CPU\_time + LPM\_time} \tag{1}$$

$$Tx = \frac{Tx\_time}{CPU\_time + LPM\_time} \qquad (2)$$

Radio Tx Time: It is the time taken to transmit PHY-layer packets
Radio Rx Time: It is the time taken to receive PHY-layer packets.

The energy consumption of the radio chip is almost the same as in the receive mode when the node is neither transmitting nor receiving even the radio chip is on. Some amount of energy is consumed to keep the receive machinery active, and sampling the medium continues to detect the start of a packet.

V. SIMULATION RESULT AND DISCUSSION

A. SIMULATION

In this paper, we have considered a maximum of 50 nodes and a maximum of 3 sinks for simulation purposes and to measure the performance of RPL. Figure 2 shows the Radio Environment view for 50 nodes. We use radio Environment view for node sink.

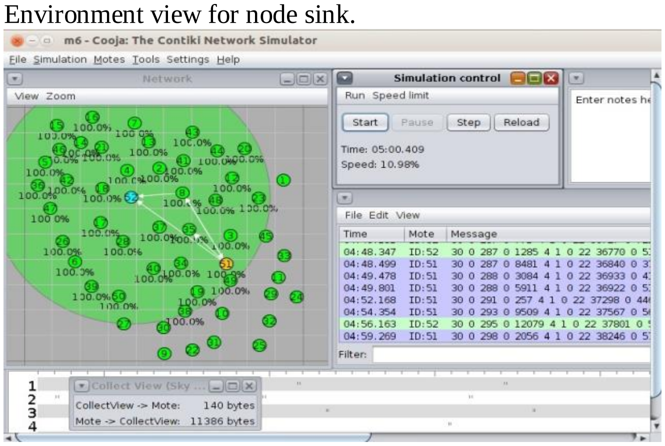

Figure 2: Radio-environment for 50 nodes

In this paper, the network has stimulated for 20, 30, 40, and 50 nodes with 1, 2, and 3 sinks. The nodes and sinks are distributed using the random topology in a squared area. In this work, RPL average power and average listen and transmit duty cycle has to be measured for 20, 30, 40, and 50 nodes with 1, 2, and 3 sinks. The main RPL parameters used in the simulation are listed in table 2.

Table 2: RPL Simulation parameters

Parameter	Value
No. of nodes	20, 30, 40, 50
No. of sink nodes	1, 2, 3
Topology	Random
Tx range	50 m
Tx Ratio	100%
Rx Ratio	100%
Square area	1000 m
Simulation time	05 inutes

B. RESULTS AND DISCUSSION

This section explains the experimental evaluation study of RPL using the data collected from the Cooja simulator. In this RPL, average power consumption, average listen, and duty cycle has to be measured using the Cooja simulator. The average power has to be measured for 20, 30, 40, and 50 nodes with 1 sink, 2 sinks, and 3 sinks. Figure 3 shows the comparison of average power consumption for 20, 30, 40, and 50 nodes with 1 sink, 2 sinks, and 3 sinks.

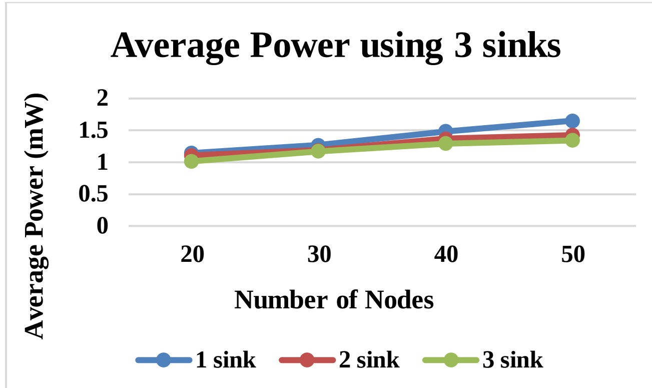

Figure 3: Average power comparison of nodes with sinks

Figure 3 shows average power for 20 nodes with 1 sink, 2 sink, and 3 sinks, 30 nodes with 1 sink, 2 sinks, and 3 sinks, and similarly for 40 and 50 nodes. In all the cases, the average power is decreased if the number of sinks increased, so to reduce power consumption, sinks are used optimally.

The average duty cycle has to be calculated by measuring the average listen and transmit duty cycle. Figure 4 shows the average listen to the duty cycle for nodes 20, 30, 40, and 50 with 1 sink, 2 sinks, and 3 sinks.

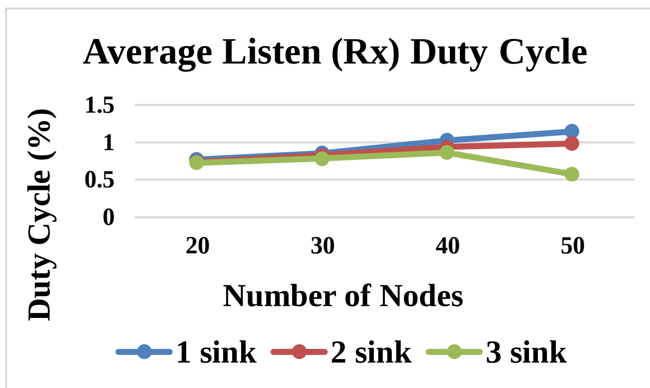

Figure 4: Comparison of average listen to (Rx) duty cycle for different nodes

Figure 4 shows the average listen to the duty cycle for nodes 20 with 1 sink, 2sink, and 3 sinks, nodes 30 with 1 sink, 2 sinks, and 3 sinks similarly for nodes 40 and 50. In all the cases average listen duty cycle decreased as nodes and sank increased. Similarly, the transmit duty cycle also decreased as nodes and sank increased.

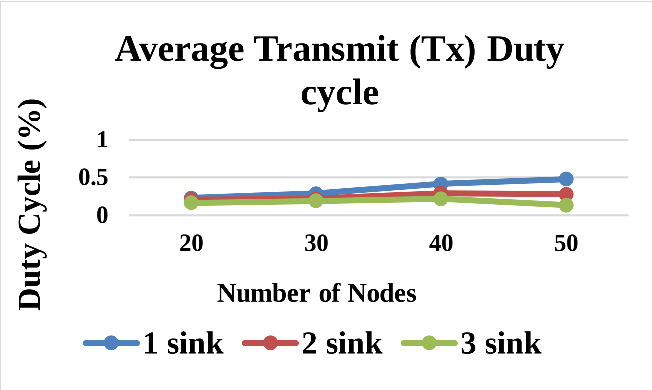

Figure 5: Shows the transmit duty cycle for nodes 20, 30, 40, and 50 with 1 sink, 2 sinks, and 3 sinks.

VI. CONCLUSIONS

Internet of Things is a highly scalable environment which finds its applications in almost every aspect of our life. RPL is a robust networking technology, and we have investigated the behavior of the RPL routing protocol by varying the number of nodes and the number of sinks. This study provides insight into the applicability of the RPL routing protocol for the Internet of Things. In the scalability architecture of the Internet of Things, Routing has a prominent role. The low power and lossy network is the basic requirement for routing data in real-time for IoT networks. We have studied the RPL under different parameters using the Cooja simulator. The parameters evaluated are duty cycle and power consumption. The power consumption is studied by varying the number of nodes for 1, 2, and 3 sink nodes. Our simulated study indicates that RPL is suitable for Internet of Things devices as it is reliable and reduces the overall energy consumption of the network efficiently. This study serves as the foundation to apply RPL for industrial IoT applications.

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