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Designing an IoT network with an emphasis on energy efficiency, utilizing a routing protocol

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Abstract—In the last few years, the Internet of Things (IoT) has proved to be an interesting and promising paradigm that aims to contribute to countless applications by connecting more physical "things" to the Internet. Although it emerged as a major enabler for many next generation applications, it also introduced new challenges to already saturated networks. The IoT is already coming to life especially in healthcare and smart environment applications adding a large number of low powered sensors and actuators to improve life style and introduce new services to the community. The Internet Engineering Task Force (IETF) developed RPL as the routing protocol for low power and lossy networks (LLNs) and standardized it in RFC6550 in 2012. RPL quickly gained interest and many research papers were introduced to evaluate and improve its performance in different applications. In this paper, we present a discussion of the main aspects of RPL IoT applications. In recent years, the advances in sensing and communication technologies have led to the rapid development of various applications of the Internet of Things (IoT). The devices in IoT form an autonomous network architecture, in which the device has a limited battery power and the link has a low reliability. This kind of network is called the low-power and lossy network. In this paper, we propose a routing protocol for low-power and lossy networks. The proposed protocol introduces a novel rank value to construct a proper destination-oriented directed acyclic graph for the source node to transmit packets to the destination node. The proposed rank value is mainly derived from the expected transmission count,. Moreover, we consider the residual energy as the metric for a node to select the proper node to relay the packet to the destination node. We conducted simulations for performance evaluation, showing that the proposed routing protocol improves the packet delivery ratio, especially for the environment with a high bit error rate. The result also validated that our approach achieves the balance of energy consumption of nodes, compared to the existing approach
Keywords: internet of things; IoT; RPL routing protocol; network lifetime optimization; energy load balancing; ELB; performance evaluation.

I INTRODUCTION

As an extended architecture of both communication networks and the Internet, the Internet of Things (IoT) is becoming a novel and promising paradigm for many applications in a variety of domains, such as transportation, logistics, public utility, home automation, smart city, and education [1-3]. In IoT applications, many kinds of physical devices perform the sensing, controlling, or identifying task and use wireless network technologies to connect with each other to accomplish the goal of

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specific applications. These devices are constrained by energy supply, processing capability, and memory size. In addition, interconnects of them typically exhibit a high packet loss rate, a low data rate, and an instability due to environmental conditions. We therefore call this kind of network the low-power and lossy network (LLN) [4]. To support the packet transmission in LLNs, the Internet Engineering Task Force (IETF) considers a routing strategy, called route-over routing, which is standardized by the Routing Over Low-power and Lossy networks (ROLL) working group of IETF [5]. The ROLL working group specifies the routing requirements for industrial, building automation, home automation, and urban sensor network applications, and proposes a standard routing protocol for LLNs [6]. This standard routing protocol (hereafter called RPL for simplicity) is carried out on an underlying destination-oriented directed acyclic graph (DODAG), which is a tree-like topological structure rooted at the applicationspecific node (i.e., the destination of sensing packets in wireless sensor networks). Each node in RPL is assigned a rank, which indicates its individual position relative to other nodes with respect to the DODAG root. The node determines the set of its candidate parents and constructs the DODAG according to the rank value. When a node in RPL needs to transmit data packets to the DODAG root, it will select one or numerous nodes from its candidate parents for transmitting packets. In RPL, the node rank significantly dominates the routing performance. It can be derived from different routing metrics according to the application requirement. Existing researchers have proposed many approaches considering various routing metrics, such as hop count, bandwidth, latency, traffic load, mobility, and wakeup duty cycle [7-12]. These routing metrics are generally suitable for the applications with specific requirements. However, they are more unlikely to establish the high-quality routing path for lack of the consideration of link quality. A well-known metric, called the expected transmission count (ETX), is proposed in [13] for reliable routing. The ETX is a measurement to indicate the bidirectional transmission quality of a link and widely used to determine the reliable routing path [14-15]. As an efficient routing metric, many metrics based on ETX have been introduced

RPL Hierarchy-RPL builds a directed acyclic graph (DAG) with no outgoing edges as the base element of the topology, this ensure that no cycles exist in the hierarchy. The sink node starts building the first DAG making itself the ultimate DAG root, other nodes in this DAG start forming their own DAGs which are routed towards the first one making a destination oriented DAG (DODAG). RPL uses a number of control messages to build and maintain its hierarchy. The DODAG information object (DIO) is sent from the root node with information about the rank of the sending node, the instance ID, the version number and the DODAG-ID. This allows nodes to decide whether or not to act upon receiving this message, in addition to keeping valuable information about the network that can contribute to making an informed decision. The destination advertisement object (DAO) is sent from the child node to its parent (the DAG root or the DODAG root) and it contains destination information which practically informs the root that this node is still available. The root node may optionally send a DAOack acknowledgement if required. The DODAG information solicitation is another form of upward control messages that is used to request a DIO from the parent node, this is one of the most relevant and important features that RPL uses to maintain connectivity. Fig 1 shows the direction of RPL control messages.

II RELATED WORK

Internet of things (IoT) refers to a massive increase in the internet and capacity to investigate, collect, and distribute data that can be converted into knowledge or information IoT expands the concept of the internet from a network made up of homogeneous devices such as computers to a network made up of heterogeneous devices like consumer electronics, household appliances, or wireless sensor networks (WSNs) **[17].**

Routing Protocol for Low-Power and Lossy Networks (RPL) is an IPv6 routing protocol that is

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standardized for the Internet of Things (IoT) by Internet-Engineering Task Force (IETF). RPL forms a tree-like topology which is based on different optimizing process called Objective Function (OF). In most cases, IoT has to deal with low power devices and lossy networks. So, the major constraints of the RPL are limited power source, network life time and reliability of the network. OFs depend on different metrics like Expected Transmission Count (ETX), Energy, Received Signal Strength Indicator (RSSI) for route optimization. In this work, the ETX and Energy based OF have been evaluated in terms of energy-efficiency and reliability. For one sink and nine senders, the simulated average power consumption is 1.291 mW and 1.56 mW respectively, for ETX OF and Energy OF. On the other hand, the average hop count for ETX OF is 1.89, which is 3.01 for Energy OF. Thus, ETX OF is more energy-efficient but it is not reliable as it takes fewer hops with long distances. Moreover, it does not take load balancing and link quality into account. However, Energy OF is more reliable due to short hops, but it is not energy efficient and sometimes it might take unnecessary hops. The work in Zhao et al. (2016) proposed a new energy-based routing protocol in the region (ER-RPL), where this protocol achieves the delivery of energy-saving data without sacrificing reliability. In contrast to conventional routing protocols that were dependent on all the nodes to discover the route. [18-19]

III PROPSOED SYSTEM

The proposed study involves MATLAB simulations to evaluate two different scenarios with sender nodes randomly placed in a deployed region. The region is divided into two equal areas, with a sink located at the 0 m line and other sender nodes positioned between the 0 m to 100 m line. The nodes located closer to the sink (0 m to 50 m) are referred to as closer nodes, while those situated between 50 m to 100 m are termed distant nodes.The comparison of average power consumption is conducted for two different routing protocols: ETX (Expected Transmission Count) based OF (Objective Function) and Energy-based OF. The evaluation is performed separately for closer nodes and distant nodes. The power consumption of a node in the RPL (Routing Protocol for Low-Power and Lossy Networks) is analyzed in four sectors:

- Transmit power (Tx power)
- Receive power (Rx power)
- CPU power
- Low Power Mode (LPM) power

The results of the simulations indicate that the average power consumption per node for Energy-based OF is 1.56 mW, while for ETX based OF, it is 1.291 mW. Therefore, it is evident that the ETX-based OF is more energy-efficient compared to the Energy-based OF, making it a preferable option in terms of power consumption for this particular scenario. This article proposed energy-efficient load-balanced RPL (EL-RPL) routing protocol for IoTs networks. In this protocol, a parent selection algorithm is proposed. It selects parent in parent list to be the next hop node toward destination node in networks based that combines between the highest remaining energy and the total number of received packets by the parent. This can balance the load on all parents in the parents’ list. Besides, the EL-RPL protocol improves DODAG construction by preventing DIO packets transmission to the nodes with the lower ranks. This will lead to save energy and hence enhance the networks’ lifetime. Many experiments were performed using the MATLAB simulator to evaluate the efficiency of RPL routing protocol. In comparison with some existing protocol, the results ensure that the proposed RPL protocol can efficiently save energy, decrease the control packets and improve the lifetime of the IoTs networks

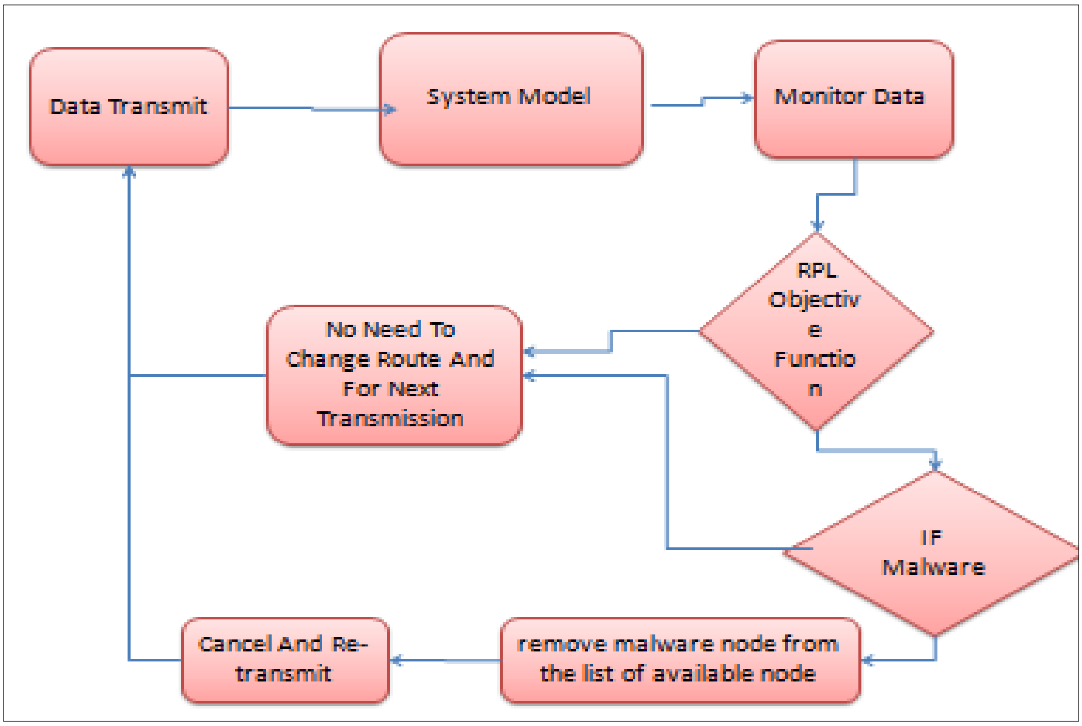

Fig. 2 proposed simulation diagram

IV NETWORK SIMULATION AND SETUP

The Simulation framework for evaluation of Multi DODAGs in RPL .Our proposed method is tested using the MATLAB simulator to study the performance of RPL based sensor networks. The network topology consists of 80 sender nodes and one root node for single DODAG. In Multi DODAGs, we have 80 sender nodes and 2, 3 root nodes. The Network Parameters are explained in Table 1. We have tested the network performance for single and multiple DODAGs for ETX (MRHOF), Hop Count (OF0) and Remaining Node Energy (RE). The obtained results are recorded and compared for network performance and reliability in terms of extended network life time. The nodes in the network topology are arranged randomly in an area of 800 m × 800 m area.
ETX and Energy are two important metrics for OF. Both ETX and Energy based OF have been evaluated with simulations. One sink node and nine sender nodes are used in the simulation. The sender nodes are randomly placed as depicted in Fig. 1 for both the scenarios. For evaluation the deployed region is divided into two equal areas. The sink is located on the 0 m line and nine sender nodes are located on the region from 0 m to 800 m line. The senders which are located in the range of are relatively closer to the sink and termed as closer nodes. The senders which are located in the range of 0 m to 800m are termed as distant nodes. Comparison of the average power consumption for ETX based OF and Energy based OF.

Objective Functions in RPL (OF)

The network layer in this system is divided into two protocols: RPL (Routing Protocol for Low-Power and Lossy Networks) and ICMP (Internet Control Message Protocol). RPL is responsible for handling routing-related issues, while ICMP is used for communication messages.

RPL primarily supports multipoint-to-point (MP2P) traffic, which is well-suited for collection-based applications. However, RPL also supports point-to-multipoint (P2MP) and point-to-point (P2P) traffics. The nodes in RPL organize the network topology using a Destination Oriented Directed Acyclic Graph (DODAG). Each node in the network is assigned a scalar value called "rank," which increases monotonically from the DAG ROOT or sink. The DODAG is identified by a unique identifier called DODAGID. Within one RPL instance, there may be multiple DODAGs or sinks, each optimized based on an Objective Function (OF) identified by an objective Code Point (OCP). The OF specifies constraints or metrics for DODAG construction, such as hop count, latency, expected transmission count, node energy, etc.

To construct and maintain the DODAG, nodes in RPL exchange DODAG Information Object (DIO) messages. The DAG ROOT initiates the process by sending multicast DIO messages to neighboring nodes. The DIO messages contain essential information, including the RPL instance, DODAGID, DAG version number, the chosen OF, and details about the parent rank. Neighboring nodes use this information to update their own rank and forward the DIO messages to other nodes in their vicinity until a route is established from the leaf node to the root node via intermediary hop nodes.

When a new node wants to join the Multi DODAGs in RPL, it can either wait to receive DIO messages from nearby nodes or send a DODAG Information Solicitation (DIS) to neighboring nodes to expedite the process. For point-to-multipoint communication, DODAG Acknowledgement Object (DAO) messages are sent, allowing for the establishment of routes from the root node to leaf nodes. Point-to-point traffic, on the other hand, is used for direct node-to-node communication.

RPL defines two types of routes: upward and downward routes, depending on the direction in which data are transmitted within the DODAG. An upward route provides a path from leaf nodes to the DODAG root, constructed using a node's preferred parent. When a node has data to send to the root, it forwards it immediately to its preferred parent, which further sends it to its parent, and so on until the data reaches the DODAG root. A downward route, on the other hand, provides a path from the DODAG root to leaf nodes, achieved either by appending the source route to the data packet or by simple hop-by-hop routing down to the DODAG leaf node.

Table 1 Simulation parameter

Parameters	Parameters Value
No. of nodes	80
Area	800x800'
Node to CH power Ratio	0.045
Packet Size	2Mb/sec
no of cluster head	Nodes CH=10%
Energy per distance	0.001

V EVALUATION AND DISCUSSION

Reliability in RPL based IoT network for smart cities can be achieved by improved network performance and extended network life. Performance metrics such as convergence time, power consumption, Control traffic overhead and packet delivery ratio are used to measure network performance and node participation metric is used to measure reliability. Our suggested Multi DODAG model attempts to make RPLefficient and reliable for Smart City IoT.

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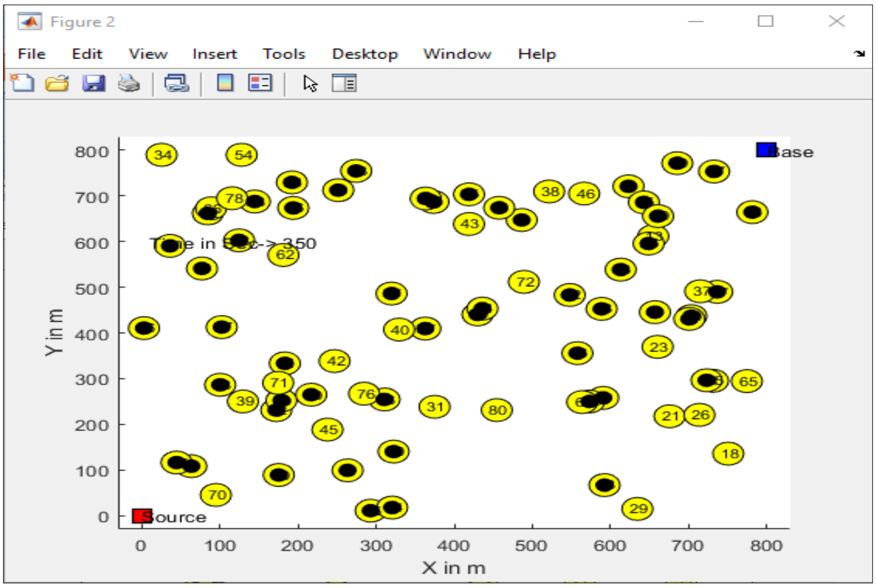

Fig.3 Node deployment

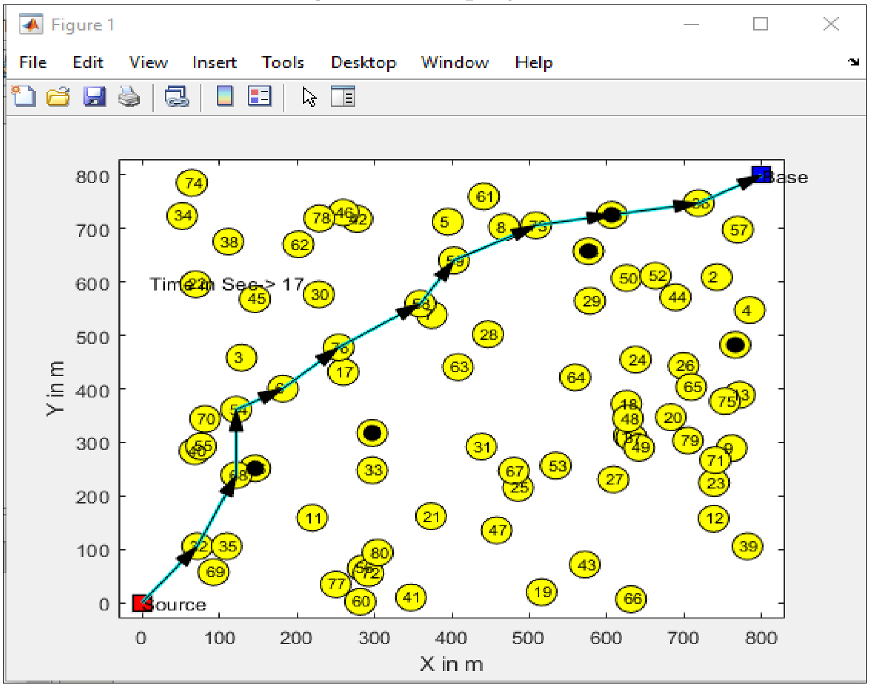

Fig.4 The sink/root initializes

Step 1 The sink/root initialises DODAG information, the root (sink) will broadcast the first control messages DIO that contains the following information: the RPLInstanceID, DODAG identifier, version number, rank, and the OF supported by RPL that has been used to calculate the rank. All nodes within the root communication range will receive a DIO message, and then decide to join the structure or not. The decision to join the node to the graph depends on the node that meets the requirements (if it has enough power to enter the DODAG construction process). When the node meets the conditions, the join depends on the node rank: an incremental value calculated using the predefined target function (OF). Correlation requires that the node rank is not less than or equal to the node rank inside the graph. If the node does not meet the conditions, in this case, the DIO control message is ignored.

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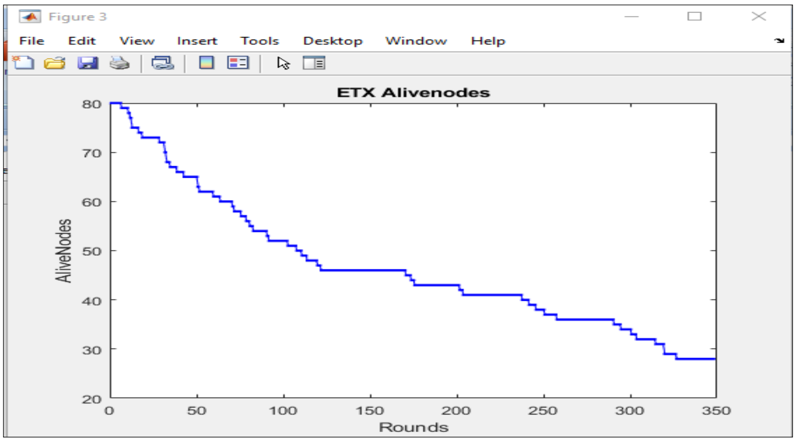

Fig.5 ETX alive node

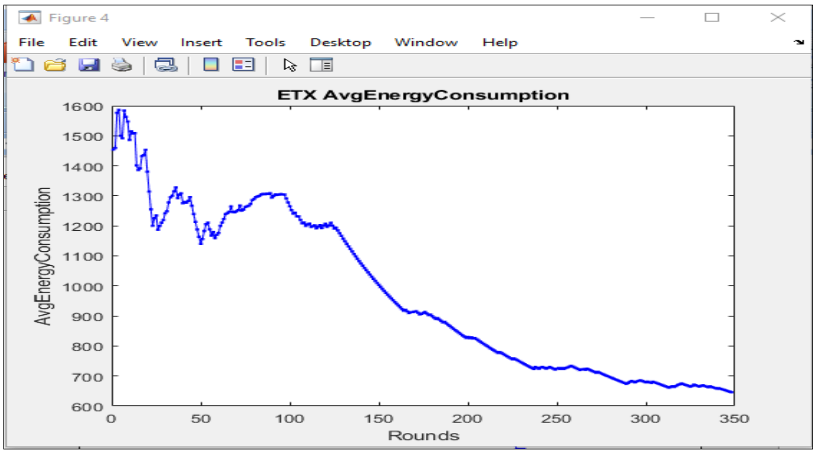

Fig .6 ETX Avg Energy Consumption

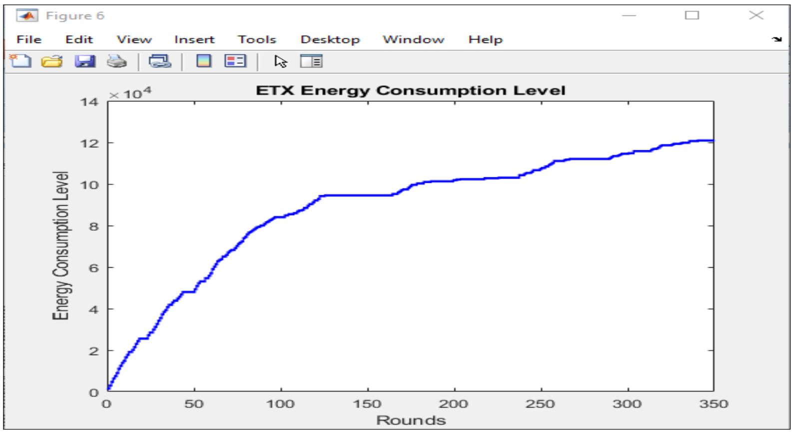

Fig.7 ETX Energy Consumption level

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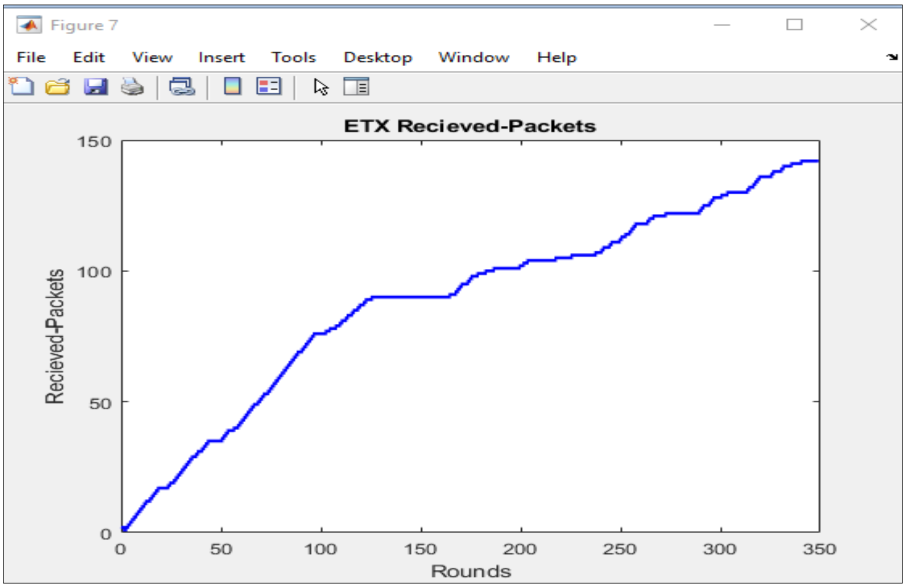

Fig.8 ETX Received-Packets

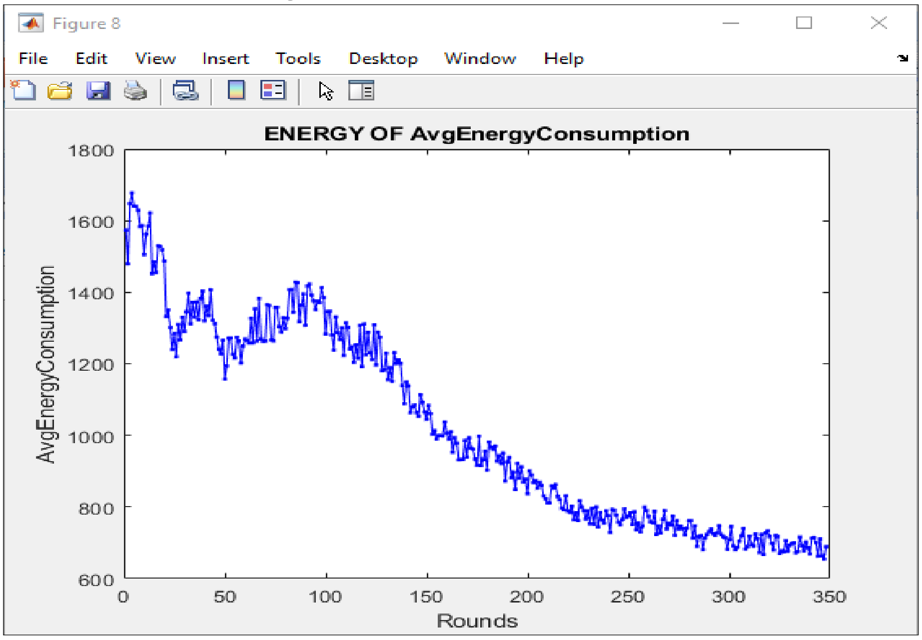

Fig.9 energy OF average energy consumption

Performance metrics:the following metrics to capture the performance of our protocol and to compare it with standard RPL protocol. Energy consumption In order to count the average cumulative energy consumption in the network, it is computed by the following formula:

Table 2 ETX OF and Energy OF Proposed System and Existing System

$$EC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{P} E_i}{n \times P}$$

where EC represents the average value of the energy consumption for each node per period, n

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	Proposed System Results	
	ETX OF	ENERGY OF
TXPower	7.179329	7.179329
RXPower	50.887787	52.688472
LPMPower	14.941470	13.922927
CPUPower	30.573747	33.847660

denotes the 'number of nodes' in the network, P is the number of periods, and Ei represents the total consumed energy of node i.

Energy consumption: The energy consumption has an important impact on the lifetime of nodes. It is mainly related to messages transmission and reception, processing (CPU) and idle state or overhearing. The average energy consumption for each node and each period is computed according to equation (4).

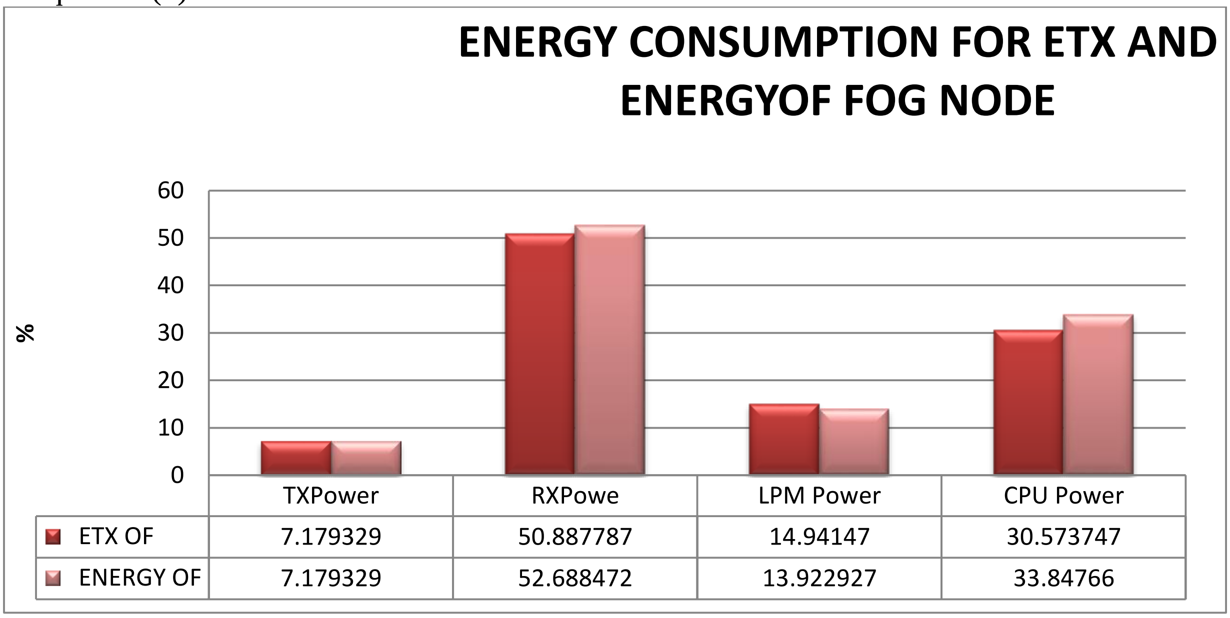

Fig. 10 Proposed System and Existing System

VI CONCLUSIONS

Discussion and Future Scope From the observed results, it is evident that proposed method has improved performance in Packet Delivery Ratio and better performance than Hop Count and ETX in power Consumption and Control Traffic over head. Our general observation is that objective function Hop Count is efficient in smaller networks and ETX is efficient in larger network. Power consumption is low for ETX due to its ability to have reliable links than Hop CountThis article suggests an EL-RPL routing protocol for IoT networks. A PP selection algorithm is suggested to distribute the load among the parents in the list of parents. The DODAG construction is enhanced through preventing sending DIO packets to the nodes with the lower ranks. This will lead to save energy and hence enhance the network lifetime. The proposed protocol provides an energy-efficient routing way in conserving the batteries power of the low power nodes in LLNs. Many experiments were performed using the OMNeT++

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network simulator to evaluate the efficiency of EL-RPL routing protocol compared to two protocols: RPL and IRPL. The results ensure that our proposed protocol can efficiently save energy, decrease the control packets, and improve the lifetime of the IoT network compared to other protocols. In the future, we plan to combine between the different metrics to generate a new OF for selection and persistence of routing paths. The proposed protocol could be improved by considering the reliability of routing. Real experiments would be one of our future objectives to assess the efficiency of the enhanced RPL protocol.

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