International Journal For Advanced Research In Science & Technology
A peer reviewed international journal
www.ijarst.in
ISSN: 2457-0362
IJARST

Energy and Delay Aware Routing Algorithm For Fiber Wireless Network

[1]Mr.A.SanyasiRao, [2]Rehana,Reddy [3]Devender, [4]Akula Sandhya Rani
[1]Associate Professor
[2,3,4]UG Scholar
Balaji Institute of Technology & Science

Abstract: Energy conservation is one of the most critical problems in Internet of Things (IoT). It can be achieved in several ways, one of which is to select the optimal route for data transfer. IPv6 Routing Protocol for Low Power and Lossy Networks (RPL) is a standardized routing protocol for IoT. The RPL changes its path frequently while transmitting the data from source to the destination,due to high data tra_c in dense networks. Hence, it creates data tra_c across the nodes in the networks. To solve this issue, we propose Energy and Delay Aware Data aggregation in Routing Protocol (EDADA-RPL) for IoT. It has two processes, namely parent selection and data aggregation. The process of parent selection uses routing metric residual energy (RER) to choose the best possible parent for data transmission. The data aggregation process uses the compressed sensing (CS) theory in the parent node to combine data packets from the child nodes. Finally, the aggregated data transmits from a downward parent to the sink. The sink node collects all the aggregated data and it performs the reconstruction operation to get the original data of the participant node. The simulation is carried out using the Contiki COOJA simulator. EDADA-RPL's performance is compared to RPL and LA-RPL. The EDADA-RPL o_ers good performance in terms of network lifetime, delay, and packet delivery ratio.
Keywords: Internet of Things; data aggregation; compressed sensing theory; residual energy

1. Introduction

IoT is an emerging technology in Information and Technology (IT) [1]. It is a collection of internet-connected embedded devices that are capable of sensing and transmitting data from one
location to another location without human support [2]. The name IoT indicates that things are
connected tothe internet via communication technologies such as wireless sensor networks, near field communication, radio frequency identification, and Bluetooth [3]. IoT provides a lot of potential benefits in all aspects of human life [4]. IoT applications include smart homes, industrial Internet, smart supply chains, smart cities, wearables, smart grids, connected health, connected cars, smart farming, smart retail, etc. [5]. LLN is a type of IoT network which consists of routers and nodes restricted by resources [6]. The Routing Protocol for Low Power and Lossy Networks (RPL) has been standardized by IETF [7]. RPL forms the Destination Oriented Directed Acyclic Graph (DODAG) to transfer the data from the source to the Sink. The DODAG consists of a DODAG root and DODAG nodes. The top of a DODAG node is called DODAG's root and the rest of the nodes are called

DODAG nodes. The direction of the participant node towards the root of DODAG is called up routing, and vice versa is called down routing [8]. It supports trc patterns, including point to multipoint, multipoint to point, and point to point [9]. The participant node chooses the best parent based on the objective function, which can decide on the application requirements [10].

2. RelatedWorks

In this section, we discuss energy-aware data aggregation techniques in RPL to increase the packet delivery ratio, decrease the delay, and improve the lifetime of the network in IoT. Mohammad Hossein Homaei et al. [20] proposed an enhanced data aggregation method for IoT. It proposed a distributed method to balance the child node and reduce the congestion among the nodes in the network. Also, a learning automata-based dynamic data aggregation technique is proposed to aggregate the data in RPL (LA-RPL). Each node has a learning automaton to perform the data aggregation and transmission from one node to another node. The simulation has been done using a Contiki Cooja simulator. The LA-RPL's performance is compared to RPL, BD-RPL, m-RPL, and A-RPL. However, LA-RPL causes congestion, as it doesn't consider the trickle timer. Ainaz Bahramlou and Reza Javidan [21] proposed a data aggregation based RPL (A-RPL) protocol for IoT. In IoT, the routing protocol changes its path frequently due to its resource-constrained nature. It proposed a dynamic method to reconstruct the DODAG quickly, which finds a suitable objective function among the number of objective functions. In this dynamic method, the sink node collects the aggregated data from the downstream nodes. A-RPL selects the parent node based on the environmental changes and control overhead in the network. The performance of A-RPL is compared with RPL and A-RPL. A-RPL provides substantial packet delivery consistency and increases the lifespan of the network. However, it causes congestion in a particular situation, as it does not consider the dynamic trickle timer.

S. Sankar and P. Srinivasan [27] proposed a fuzzy set based cluster routing (FC-RPL) protocol for IoT. The FC-RPL consists of three phases, namely cluster formation, CH selection, and CH parent selection. The cluster is formed from the Euclidean distance. The CH selection is performed by considering the fuzzy logic over the routing metrics residual energy, centrality, and nearest neighbor node. The CH parent node is selected from the CH parent rank. The simulation has been conducted using the Contiki COOJA simulator. The performance of FC-RPL is compared to RPL. The proposed FC-RPL extends the network lifetime. However, it forms an excess number of clusters in the network. Yaarob Al-Nidavi et al. [28] proposed a cluster-based routing (MUCBR-RPL) protocol for LLN. The MUCBR protocol divides the entire network into multiple clusters. In each cluster, the MUCBR selects the cluster head based on the residual energy. The CH node collects the data packets from cluster members and

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performs the data aggregation. Finally, the aggregated data is forwarded to the Sink node. The simulation has been conducted using the COOJA simulator. The performance of MUCBR-RPL provides better performance in terms of network lifetime and reliability. However, initially, it takes time to form the cluster. The literature review of Data aggregation on routing protocols is given in Table 1.

Table 1. Literature review of Data aggregation on Routing Protocol for Low Power and Lossy Networks (RPL).

S.No	Protocol	Author's	Proposed Technique	Improvement	Limitations
1	LA-RPL	Mohammad HosseinHomaei et al.	learning automata-based dynamic data aggregation	Extends the network lifetime	It does not consider the trickle timer
2	A-RPL	Ainaz Bahramlou and Reza Javidan	data aggregation based RPL	Increased the network lifetime	congestion occurs in a particular situation
3	RECOUP-RPL	Mauro Conti et al.	cluster-based multicast routing	Increased the packet delivery ratio	It takes more energy consumption, as it checks each data packets in each node.
4	CCR-RPL	YichaoJin et al.	content-centric routing	better performance in terms of latency, energy efficiency and reliability	Create the congestion due to dynamic network conditions.
5	C-RPL	Ming Zhao et al.	Cluster parent routing	Increased the reliability	It takes more time to choose the cluster parent
6	FLWP	Madan Mohan Agarwal et al.	fuzzy-based data fusion technique	It provides superior performance than the AODV	It takes a longer time to predict the parent node
7	C-RPL	Marc Barcode et al.	cooperative interaction	Increased the network lifetime	It takes additional time to choose the parent node present in the multiple DODAG
8	FC-RPL	S. Sankar and P. Srinivasan	cluster routing	Extended the network lifetime	It forms the more number of clusters in the network.
9	MUCBR-RPL	Yaarob Al-Nidavi et al.	cluster routing	Improved the network lifetime and packet delivery ratio	Initially, it takes time to form the cluster.

3. Network Model

The IoT network consists of 'N' number of nodes and one DODAG root. The nodes are randomly deployed in the network. The EDADA-RPL follows the tree-based approach. The sensor node generates the data and transmits it to the parent node. Each parent node collects the data packets and performs the data aggregation using compressed sensing (CS) theory [29]. Likewise, the data aggregation operation performs from a downward parent to the root of the DODAG. Finally, the DODAG root obtains the compressed data and it performs the data recovery using the matching pursuit algorithm. Figure 1 shows the network model of EDADA-RPL.

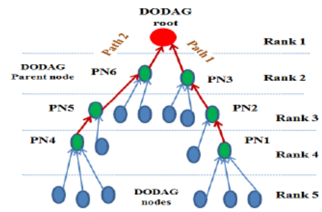

Figure 1. Energy and Delay Aware Data aggregation in Routing Protocol (EDADA-RPL) Network Model.

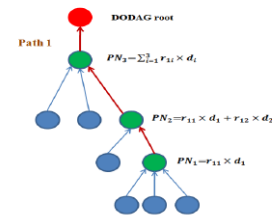

Figure 2. Data collection and aggregation from node PN1 to Destination Oriented Directed Acyclic Graph (DODAG) root using compressed sensing (CS) theory.

4. Data Aggregation Using Compressed Sensing Theory

4.1. Data Aggregation

Data aggregation is an essential process in wireless routing for collecting the data from various sources in the network [15]. It aggregates the sensor's data, which removes the data redundancy and reduces the number of data transmissions. Thus, it saves the energy on the network nodes in IoT. Data fusion clubs the sensor's data and removes the noise from various sources. Finally, it generates accurate data for data transmission. The data aggregation process is shown in Figure 3.

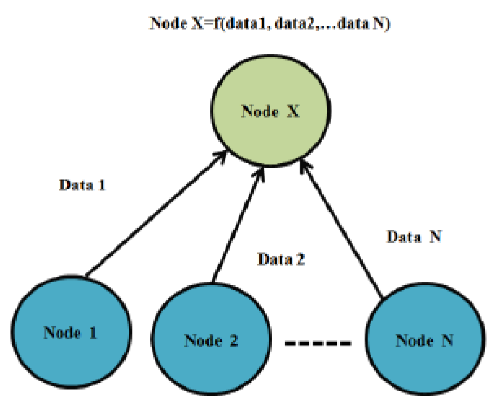

Figure 3. Data aggregation process.

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4.2. Compressed Sensing Theory

A sensor data or signal can be converted from lower dimensional space to higher-dimensional space is called sparse. Generally, the data is converted into a sparse matrix. Later, it converts the sparse matrix into the observation matrix. Finally, the data recoveries will perform from the observation matrix [30]. Figure 4 shows the overall process of the compressed sensing theory.

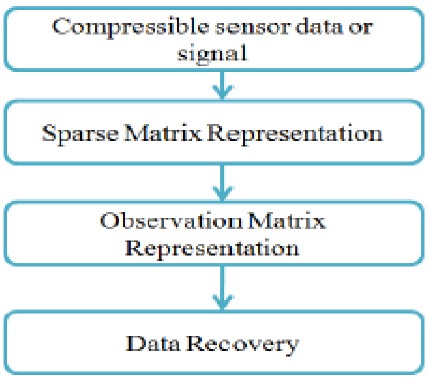

Figure 4. Compressed sensing theory.

5. Energy and Delay Aware Data Aggregation in RPL

The Proposed Energy and Delay Aware Data aggregation in RPL (EDADA-RPL) has two processes, namely parent selection and data aggregation. The process of parent selection uses routing metric residual energy (RER) to choose the best possible parent for data transmission. The data aggregation process uses the compressed sensing (CS) theory in the parental node to combine data packets from the child nodes. Finally, the aggregated data transmits from a downward parent to the DODAG root or sink. The DODAG root gathers aggregated data and conducts the reconciliation process to recover the original data.

5.1. Parent Selection

In EDADA-RPL, the DODAG root node broadcasts the DODAG Information Object (DIO) to the neighbor nodes in the network. The DODAG Advertisement Object (DAO) message is sent to the parent or DODAG root by the participant node. The DODAG root or parent node sends the signal of the DODAG Advertisement Object-Acknowledgement (DAO-ACK) to the child node within the trickle interval. The participant node choses the parent node depended on the DODAG node-level routing remaining metric energy (RER).

Algorithm 1: EDADA-RPL parent selection

Input: DIO, DAO, DAO-ACK, DIO_RER
Output: Optimal Parent
1:**For** preferred_ParentNodeparentNode-list **do**
2: compute RER
$$RER(Ni) = \frac{E_{Initial} - E_{Depleted}}{E_{Initial}}$$
3:compute the Rank(N)
$$Rank(x) = Rank(parentNode(x)) + Rank\_Increase\_Value$$
4:Calculate the Rank_Increase_Value
Rank_Increase_value = RER + MinHop_RankIncrease
5:**If**Best_ParentNode>= Preferred_ParentNode**Then**
Best_ParentNode=Preferred_ParentNode
6:**End**
7:**While**preferred_ParentNode==Best_ParentNode**do**
SourceNode=Preferred_ParentNode
8:**End**
9:**End**
10:Return Optimal Parent

Algorithm 2: Data Aggregation Using Compressed Sensing Theory

Input: Sensor data $d = \{d1, d2, \ldots, dn\}$
Output: Compressed data y
1:Compute the data aggregation fromPN1 to DODAG root
$$y_1 = \sum_{i=1}^{k} r_{1i} \times d_i$$
2:Compute the data aggregation in DODAG root from the M paths
$$\begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ y_M \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & .. & .. & r_{1N} \\ r_{21} & r_{22} & .. & .. & r_{2N} \\ . & . & .. & .. & . \\ . & . & .. & .. & . \\ r_{M1} & r_{M2} & .. & .. & r_{MN} \end{bmatrix} \begin{bmatrix} d_1 \\ d_2 \\ . \\ . \\ d_N \end{bmatrix}$$
3: Return the aggregated data y.

6. Result and Discussions

In our simulation, all the nodes have equal energy, which is deployed randomly in the network. The network contains 120 RPL routers and one DODAG root. The data transfer interval is 60 s. We have taken the sky mote for our simulations [37]. The simulation has been conducted in the COOJA simulator [38]. The data transfer rate is one packet per minute. All results presented in the figures below are averaged over 10 simulation runs and error bars show the 95% confidence intervals. The

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ISSN: 2457-0362

simulation parameters are given in the Table 2.

Table 2. Simulation parameters.

Parameter	Value
Operating System	Contiki 2.7
Simulator	COOJA
Initial Energy	1500 mA
Routing Protocol	RPL
Simulation Time	1 h
Network area	300 m × 300 m
Topology	Random
Node Type	Skymote
Number of Nodes	120
MAC Layer	802.15.4
Data Transmission Interval	60 s
Physical Layer	Two Ray Ground Propagation Model
RPL Parameter	MinHopRankIncrease = 256

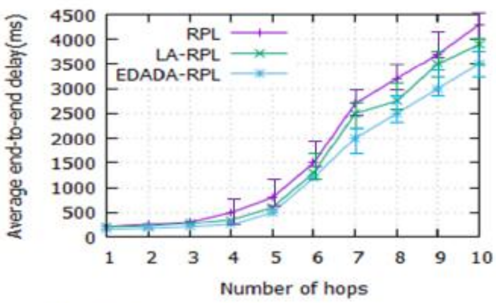

Figure 5. Average end-to-end delay vs. number of hops.

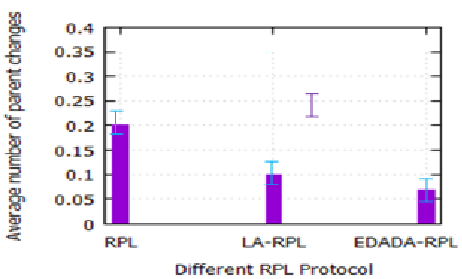

Figure 6. Average number of parent change vs. various RPLs.

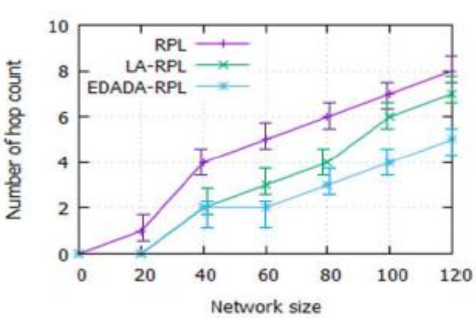

Figure 7. Number of hop count vs. Network size.

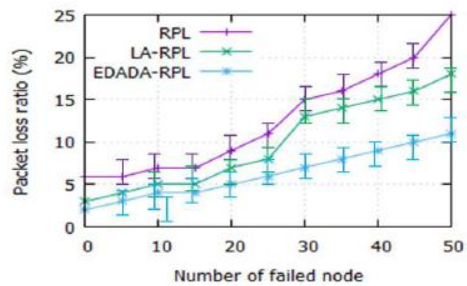

Figure 8. Packet loss ratio vs. number of failed nodes.

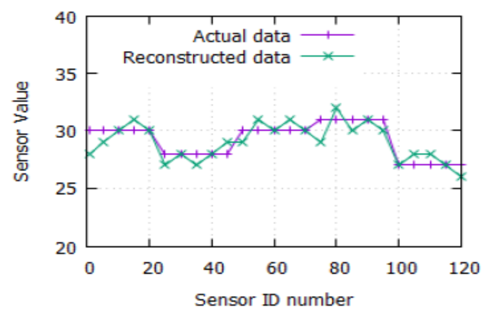

Figure 9. Sensor value vs. sensor ID number.

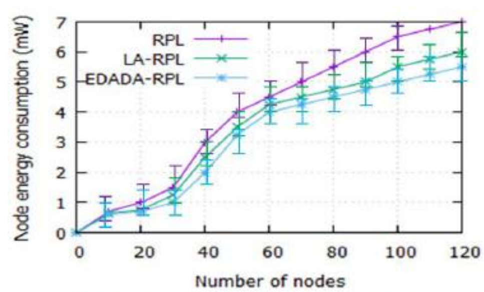

Figure 10. Node energy consumption vs. number of nodes.

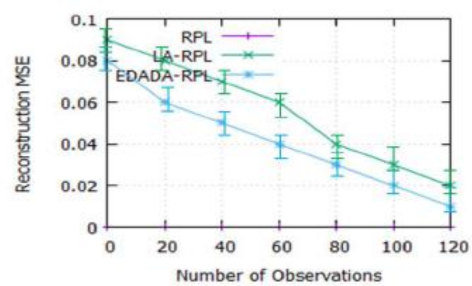

Figure 11. Number of observations vs. reconstruction MSE.

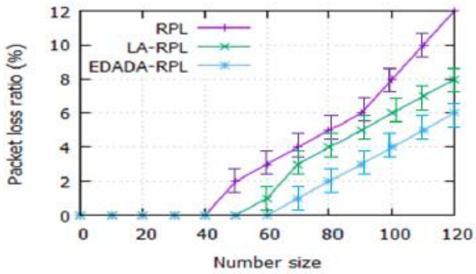

Figure 12. Packet loss ratio vs. network size.

7. Conclusions and Future Works

Energy conservation is important role in Internet of Things (IoT). Therefore, routing plays an essential role in IoT. We proposed Energy and Delay Aware Data aggregation in Routing Protocol (EDADA-RPL) for IoT. It has two processes, namely parent selection and data aggregation. The parent selection process uses the routing metric residual energy (RER) to select the optimal parent for data transfer. The data aggregation process uses the compressed sensing (CS) theory in the parent node to combine data packets from the child nodes. Then, the aggregated data is transmitted to the DODAG root from the downward parent. The DODAG root node collects all the aggregated data and performs the reconstruction operation to get original data. The performance of EDADA-RPL is compared with RPL and LA-RPL. The EDADA-RPL decreases the delay and packet loss ratio by 8–15 s and 6–10%, respectively.

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