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Energy and Bandwidth-Aware Parent Selection Mechanism to Mitigate Congestion in RPL-Based IoT Networks

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Abstract: The Internet of Things (IoT) refers to a network of unified devices equipped with sensors, software, and communication capabilities, facilitating the seamless exchange of data to enhance automation, efficiency and convenience across diverse applications. Routing in IoT involves the establishment and optimization of communication paths among interconnected devices, ensuring efficient data transfer and effective network management in diverse IoT applications. RPL (Routing Protocol for Low-Power and Lossy Networks) is a specialized routing protocol designed for low-power and lossy networks in IoT. Congestion in RPL can occur when there is a heightened demand for network resources that exceeds the network's capacity to handle the traffic efficiently.Issues related to congestion in RPL include limited bandwidth, variations in link quality, energy constraints, adaptability to network changes, security implications, and the need for effective congestion management mechanisms. Addressing these issues is crucial to maintaining the performance and reliability of low-power and lossy networks in IoT environments. In this paper, an Energy and Bandwidth-aware Parent Selection mechanism is proposed to avoid congestion in RPL for IoT Networks. The proposed mechanism focuses on the Received Signal Strength Indicator (RSSI) for identifying node positions. The energy of the node is identified from the DIO message and the bandwidth of the link is also considered for selecting the node with a high bandwidth link. The energy and bandwidth of the links are calculated for all neighboring nodes. This proposed work enhances throughput from 87.9% to 89% for 50 nodes than the existing protocol.

Keywords: *Internet of things, RPL, Congestion, and Throughput.*

1. Introduction

A huge number of sensor nodes are distributed spatially and are organized in order to form the WSN networks which are useful for monitoring the surrounding environmental and physical conditions like light, sound, pressure, temperature and vibration. WSNs link to the Internet using IPv6 over Low-Power Wireless Personal Area Networks (i.e., 6LoWPAN) to build the Internet of Things (IoT). Nowadays, the applications of WSNs are growing rapidly and the sensor nodes are deployed almost everywhere like smartphones, buildings, forests, seas, factories and vehicles. But these sensor nodes possess limited number of resources like power supply, memory, bandwidth and computation capabilities. Because of this limitation, the conventional congestion control techniques employed for Internet could not be implemented to the WSNs. Hence developing a new congestion control method is necessary and is very challenging [1].

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Congestion takes place when numerous nodes begin to transmit the packets at the same time at a higher data rate and when a node receives many such flows coming from different networks. It makes a greater impact on the Quality of Service (QoS) parameters and on the energy efficiency of sensor nodes [2]. Moreover, various parameters like packet loss, throughput and end to end delay also get affected due to congestion in the networks.

2. Related works

Some of the works existing in the literature related to congestion in RPL based network are presented in this section. An enhanced RPL technique named DT-RPL was implemented in the research work [3], for updating the wireless link quality and decreased the traffic in the network. In [4], an innovative method namely M-RPL was proposed to offer temporary multipath routing at the time of congestion in the network.

In [5], a new technique known as Objective Function model was developed for mapping the congested node by using the packet queue. This routing model was compared with the existing technique M-RPL through the Contiki OS and Cooja environment.

A new RPL routing measure known as Buffer Occupancy was proposed for reducing the number of lost packets which caused buffer overflow during the congestion [13]. Moreover, a new RPL Objective Function known as Congestion-Aware Objective Function (CA-OF) was also developed by the author.

In RPL, a node in the network runs on multiple RPL instances in parallel. Each instance together to form a RPL instance. RPL instance can be identified by RPL instance ID. Network congestion occurs when a network is unable to handle the volume of data flowing across it. Normally, network congestion is a transitory condition that exists in the network rather than a permanent one. Due to the presence of the malicious node in the network, the network remains in a congested state. This indicates presence of the attacker node in the network.

According to Chansook Lim, congestion is one of the major issues in resource constrained network. Congestion affects the lifetime of the node present in the network. [6], have surveyed on the issue congestion and briefly explained about few mechanisms to avoid congestion. Many mechanisms were introduced to avoid the issue congestion in the RPL. This mechanism helped in identifying the congested node or congested path in the network. Selecting too many parent nodes also lead to congestion.

Most of the mechanism forward packet or distribute traffic through less congested route using the metrics based on the degree of congestion. Some of the congestion detection mechanisms are Game Theory based Congestion Control (GTCC), Queue Utilization- RPL (QU-RPL), Power Controlled- RPL (PC-RPL), Optimization based Hybrid Congestion Alleviation (OHCA) and Congestion-aware Objective Function (CA-OF).

A mechanism to detect the congested node in the network was proposed [7]. The GTCC [7] mechanism identified congested node by monitoring the packet flow. Positive value denotes high possibility of the congestion. Once a node is identified as the congested node then the DIO message is broadcasted to the neighbor nodes. Alternative parent node is identified by the potential game theory. DIO message carries the node information like children information, parent list, transmission rate and link quality indicator to select the parent node. Result shows small variation when compared with the proposed work.

A mechanism was proposed to improve the performance of the RPL protocols [8]. The issue addressed in this work is congestion. A new mechanism is introduced named as QU-RPL to identify congestion node, QU-RPL use QU factor [8]. Queue is calculated by number of packets in queue of node k divide by the total queue size of node. The queue is calculated based on the node queue to identify whether it is malicious node (or) not malicious node. Based on the QU factor parent node were selected. Considering the other metrics, the proposed method can be improved.

Author have introduced an energy and congestion aware routing protocol for smart grid [9]. In this work author considered node energy, ETX and queue utilization factor for identifying the neighbor node. The parent change scheme is initialized when the nodes residual energy and queue utilization is not met with the threshold. Metrics considered for this work is average power consumption and packet delivery ratio.

Proposed a work to address load imbalance. The load imbalance lead to increase in traffic load and high packet loss. The parent nodes were identified by hop distance, ETX and RSSI. Only few nodes were used for evaluating the performance of the proposed work. This proposed work is compared with RPL and Q-RPL. Metrics used for analysis of the performance of the proposed work are PRR, hop count, end to end ETX, parent change frequency, routing overhead and total transmission count[10].

Congestion aware objective Functions developed to identify the congested nodes by routing metrics ETX and buffer occupancy [11]. Based on the degree of traffic the buffer occupancy is weighed. This proposed work is compared with OF0, ETX-OF and energy-OF metric considered for the evaluation are PDR, energy consumptions and throughput.

A new strategy is introduced to control the traffic in the network. Gray Relational Analysis (GRA) use Multi-Attributes Decision Making mechanism (MADM) for parent selection. GRA procedure uses a different characteristic of the metrics [12]. This work is compared with existing work QU-RPL, DCCC6. Metrics used for the evaluation are throughput, energy consumption, end to end and packet loss rate.

Motivation

The proposed technique is capable of selecting more than one node for a transaction which results in increased consumption of energy and congestion of networks. Hence in order to avoid the congestion in the RPL networks, an Energy & Bandwidth based Parent Selection technique (EPS) is proposed. The proposed technique not only reduces the delay and also to avoid choosing the congested path to route the packet. It also calculates the RSSI value and energy based on which the parent node is selected.

Objective

The primary objective of this work is to propose an Energy & Bandwidth based Parent Selection technique (EPS) to avoid congestion in RPL network. Congestion is one of the major factors responsible for decreasing the throughput of a network. The basic idea of the proposed work is to select the best parent node based on the RSSI value, energy and the bandwidth of the neighboring nodes which in turn will contribute to avoid congestion in RPL networks. Thus, the proposed mechanism provides a solution to select the parent node in order to improve the throughput in RPL.

Hence the objectives are framed as follows,

✓ To identify the node with minimum RSSI value.

✓ To obtain maximum node energy and bandwidthof link.

✓ To avoid congestion and to improve the throughput during the routing process in an IoT environment.

Effects of Network Congestion

Network congestion may leads to some of the drawbacks like

i. Routing time increase

ii. Decay the energy of the node

iii. Reduce the lifetime of the node present in the network

iv. Reduce the packet delivery ratio

v. Increase the packet loss

Delay

The delay is the amount of time it takes for a packet transmitted by a sender to reach its destination. For instance, the length of time it takes for the packets from the web server to reach the client determines how long it takes for a webpage to load. When watching a video, buffering is another indication of latency. For eg, YouTube.

Packet Loss

While packets may take some time to arrive at their destination (delay), packet loss is a more serious consequence of network congestion. This is especially worrisome for applications such as Voice over IP (VoIP), which do not handle delay and packet loss well, resulting in dropped calls and Call Detail Records, slowness, robotic voices, and other issues.

Timeouts

Timeouts in many apps can also be caused by network congestion. Because most connections will not remain active continuously while waiting for packets, this can result in lost connections.

3. Proposed Work

Energy and bandwidth-based path selection (EPS) mechanism is to avoid congestion in RPL network for IoT. In this work, the DODAG is constructed by using the existing objective function. When a node is present in a dedicated path is committed to route to many packets from the neighbor node. Parent node present in the network send the packet to the neighbor node without monitoring the current status of node transaction. This approach leads to congestion. Due to congestion many issues seem to be occur. It increases delay in sending the packets, increases packet loss and decreases the packet delivery ratio. This proposed work is used to avoid the congestion in the path and reconstruct the path to avoid congestion in the routing path.

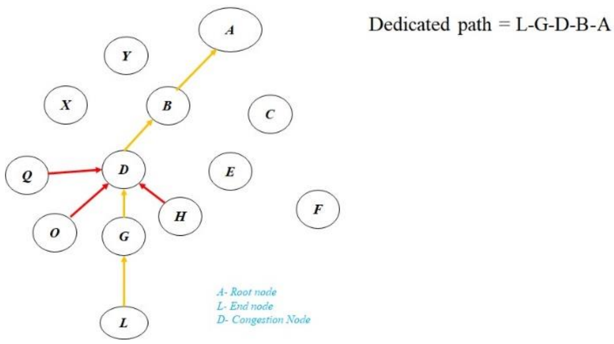

Fig 1.1 Node Failure due to congestion Parent Selection Procedure

This proposed mechanism, to improve the performance of the RPL protocol by following three important steps as:

- Finding the RSSI value
- Computing the node energy
- Calculating the bandwidth of link

Henceforth, to select the best parent node based on above steps. These three steps are the backbone of our proposed mechanism, which is indicated via the below figure.

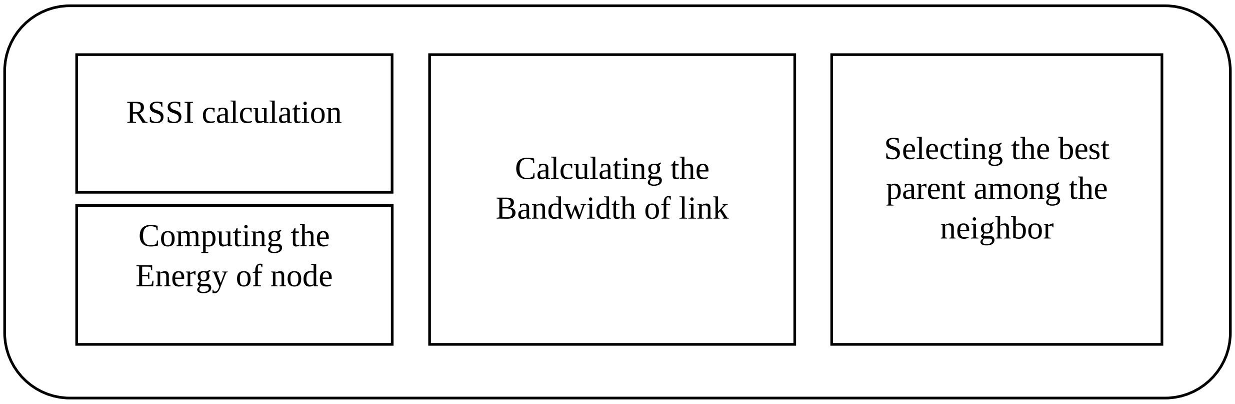

Fig 1.2 Working Procedure of Proposed Mechanism (EPS)

Figure 1.2 depicts the working procedure of the proposed mechanism. It shows that how the parent node is being selected to route packet towards the root node. The first step in the parent selection processis to identify the adjacent nodes based on the RSSI value of the DIO messages received. Then, the energy of every neighboring node is fetched from the DIO message received from every neighboring node. The third step is to identify the nodes that havegreater energy than the threshold energy. Such neighboring nodes with energy greater than the threshold energy are identified as qualified nodes. Next for every qualified node, the bandwidth of the link connecting the node to the source node is calculated using the following equation 1.1.

$Bi = RF/L$ ` ... (1.1)

where,

Bi = bandwidth of link

RF = Required size

L = Actual size of link

Now, the bandwidth required for transmitting the current packet is calculated using the following equation 1.2.

$BR = PS \geq AB$ ... (1.2)

where,

BR = Bandwidth Required

PS = Packet size

AB = Actual Bandwidth

Finally, qualifying nodes whose bandwidth exceeds the needed bandwidth are discovered. From these eligible nodes, the node with the most bandwidth is chosen as the new parent node. The newly identified parent node is then used to rebuild the new path, and the packet is routed down it.

Working Procedure

The following are the working procedure to enhance the Quality of Service based on energy and bandwidth in the effort to avoid congestion in RPL network for IoT:

Step 1: *Construct DODAG*
Step 2: *Compute Ei for DP* *//Energy of node Ei, Dedicated Parent DP*
Step 3: *Check Ei with Thi* *//Threshold of node Thi*
If Ei > Thi then proceed with DP
If Ei < Thi then Initialize the parent selection process based on RSSI and Energy
Step 4: *Compute Bw for DP* *//bandwidth of node Ei, Dedicated Parent DP*
Step 5: *Check bandwidth link*
If bw ≥ available bandwidth then proceed with DP
If bw ≤ available bandwidth then initialize the parent selection process based on RSSI, Energy and bandwidth of link
Step 6: *Reconstruct the path with Min-RSSI, Max-Energy and bandwidth of link.*

Illustration of the proposed EPS

In this suggested work, EPS, RSSI, energy values of neighbouring nodes, and connection bandwidth are utilized to choose the optimum node for routing the packet to the root node. The actions outlined above are designed to prevent node failure owing to the existence of a node with low energy and to avoid congestion during routing in RPL.

Table 1.1 displays the rank of the nodes in the DODAG used for demonstration. The rank values are determined using the distance values, which are derived from the RSSI data. The neighbour node with the shortest distance receives a lower rank. The rank values allocated to neighbour nodes depending on distance are shown in table 1.1.

Table 1.1 Rank of neighbour nodes in DODAG based on distance

Node	Distance (m)	Energy (%)	Rank
P	1.2	95	1
C	2.5	80	6
G	1.2	83	1
H	1.4	92	3
O	1.3	83	2
K	2	81	5
L	1.5	85	4

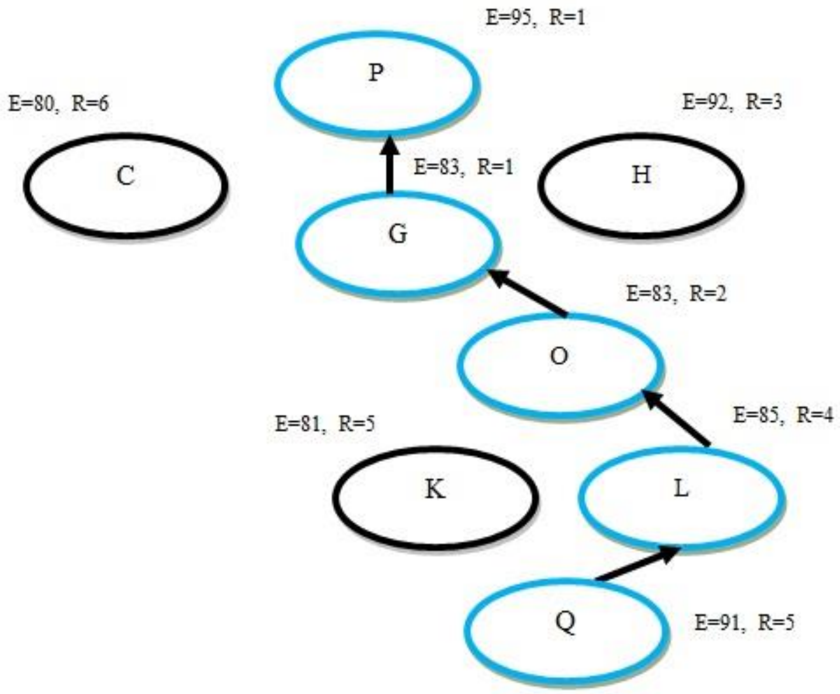

Fig 1.3 DODAG constructed based on energy and distance

Now, to find the path from source node Q to the root node P, first examines the rank values of its neighbour nodes K and L. According to the table 1.1, K's rank is 5 and L's rank is 4 which is L's rank is lesser than k. So, Q selects L as its parent node. Next, L has to select its parent and so it examines the ranks of its neighbour node K and O. Node K has the rank 5 and node O has the rank 2 which is lesser than node K. Hence, node O is selected as the parent node of node L. Similarly, node O and node G select their parents as G and P respectively. Thus, path Q-L-O-G-P is selected for routing the packet. This is depicted in figure 1.3.

The existing method of selecting the parent without considering the energy is not efficient because the nodes tend to select a parent node with lesser remaining energy while there may be another neighbour node with greater energy. Selecting a weaker node that is, a node with lesser energy may lead to node failure which subsequently decreases the packet delivery ratio and thereby the throughput is decreased.

To overcome this and to select a robust node from among the neighbour nodes it is necessary to consider the remaining energy of the nodes, rank values and along with their bandwidth of the link. Hence, the proposed mechanism takes into account the minimum rank, maximum energy and link capacity as the Objective Functions to select the parent node. This is illustrated in figure 1.4. The energy and rank values of nodes taken for illustration are presented in the following table 1.1.

The proposed parent selection mechanism first identifies the neighbour nodes based on the distance computed from the RSSI values and assigns ranks to the nodes. The rank is awarded to the node with the shortest distance, which is assigned the lowest rank. Figure 1.3 depicts node Q receiving DAO from its neighbours K and L. Node Q computes the distance of K and L is based on the RSSI of DAO messages received from K and L using the equation 3.2. Let the distance calculated be 4 meters and 2.9 meters for K and L respectively. Here, though L has lesser distance value its remaining energy and size of the link must also be checked before it is selected as parent. In this scenario, L has lesser rank value, greater energy value and packet size is lesser than the link size so, L is selected as the parent.

If L had lesser energy than K, then the proposed mechanism will select K as the parent and will not select L as the parent though its distance is lesser than K. This process can be illustrated more clearly by the parent selection by O. The parent selection process from O proceeds by considering O's neighbours node K, G and H. According to the rankings awarded based on the distance value estimated using RSSI, the neighbour nodes of O namely K, G and H have their ranks assigned as 5, 1 and 3 respectively as displayed in Figure 1.3.

Even though G has the lowest rank, the suggested technique will not choose it as the parent node since it lacks maximum energy. Only H is selected as the parent node since it has maximum energy of 92% and High link when compared with packet size among the three neighbour's node K with energy 81% and node G with energy 83%. This is done to ensure that a robust node is selected as the parent to minimize the possibility of node failure and avoid the packet send via the congested parent. Similarly, every child node ensures that a robust node with maximum energy is select as the parent node. Thus, the path Q-L-O-G-P is selected as shown in figure 1.3.

Node O chose Node H as the parent using the current goal function, which considers energy as the major parameter. When the current objective function energy is chosen, node O selects node H as the parent. Hence, the Q-L-O-G-P route is chosen. However, when the proposed goal function specifies Energy as the principal restriction, the node's distance and bandwidth are also fixed. Node Gis was selected by Node O. So, the path Q-L-O-H-P is chosen as the best way.

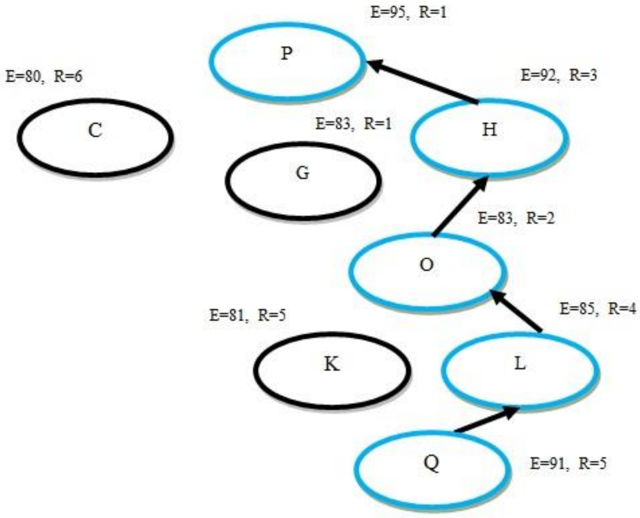

Fig 1.4 DODAG created based on the suggested work EPS

Figure 1.4 shows the DODAG created based on the suggested work EPS and explains how the path Q-L-O-H-P is selected to route the packet. Node L selects Node O as a parent. Parent Node O has two parents Node G and Node H. The Node G's rank and energy are 1, 83, and it has a high bandwidth link. The rank and energy of Node H are 3, with 92 poor connection bandwidth links. Node G is the parent based on its rank, energy, and bandwidth.The energy-based rank calculation approach selects Path Q-L-O-H-P to deliver the packet. Similarly, these procedures are continued until the route has been created. Figure 1.4 depicts the DODAG created based on the suggested work. The packet is routed along the path Q-L-O-G-P.

4. Simulation Environment

The proposed Energy and Bandwidth based Parent Selection technique (EPS) was simulated using Cooja simulator to avoid the congestion in the RPL network. Contiki is an open source and lightweight operating system that is designed especially for dealing with the Internet of Things (IoT) related applications. The evaluation was performed using the QoS metric, throughput. The suggested system employs sky mote nodes, and testing was conducted with varying numbers of nodes, including 10 nodes, 20 nodes, and 50 nodes. The simulation setup used for the simulation of the proposed technique is presented in the following table 1.2.

Table 1.2 Network simulation parameters for the Experimental set-up

Parameters	**Description**
No. of nodes	10, 20, 50
Simulation Area	1000 x 1000 m
Data Rate	250kbps
Node Arrangement	Random
Radio Medium	UDGM
Operating System	Contiki
Simulator	Cooja
Types of sensor node	Sky mote
Technique	EPS, RPL

The screenshot of the simulation window in the Graphical User Interface of the Cooja simulator is shown in the following figure 1.5.

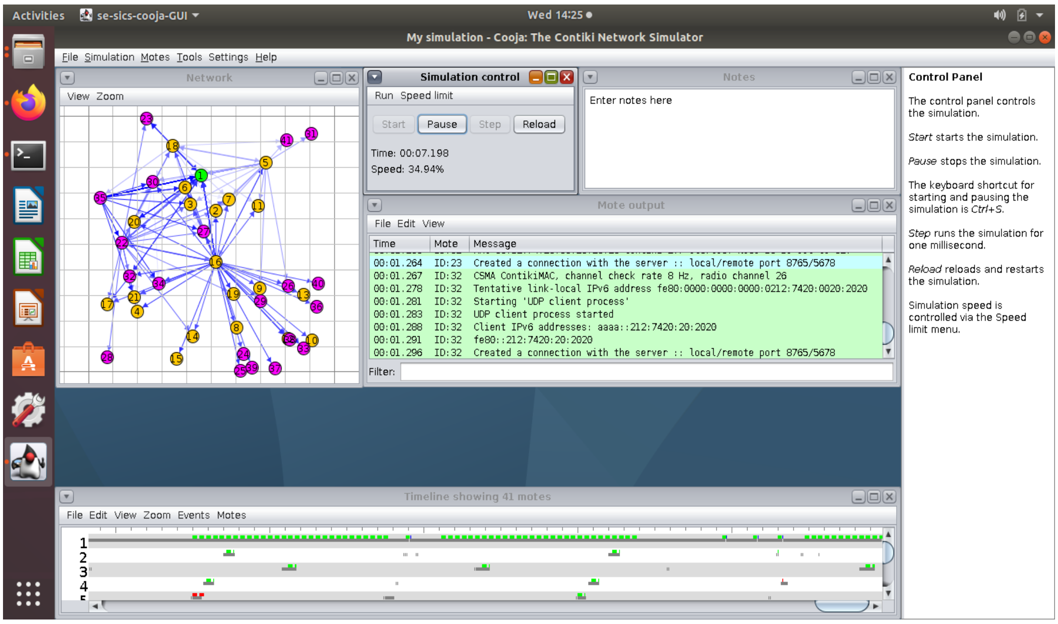

Fig 1.5 Screenshots of Simulation Window

The simulation of the proposed approach is performed for three distinct scenarios by altering the number of nodes. That is, the testing is done for 10 nodes, 20 nodes, and 50 nodes. Screenshots of simulation windows, sensor mappings and settings panels are depicted in the figure 1.6, figure 1.7 and figure 1.8.

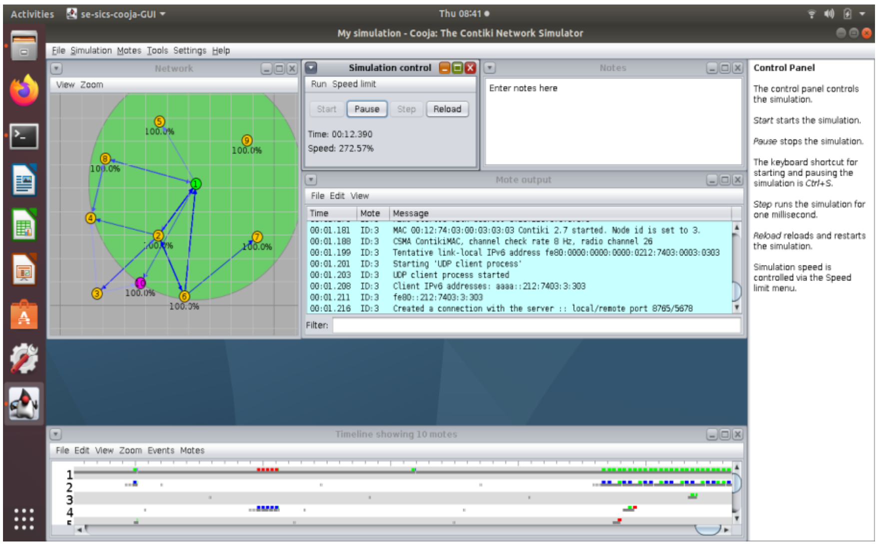

Fig 1.6 (a) Simulation window for 10 nodes

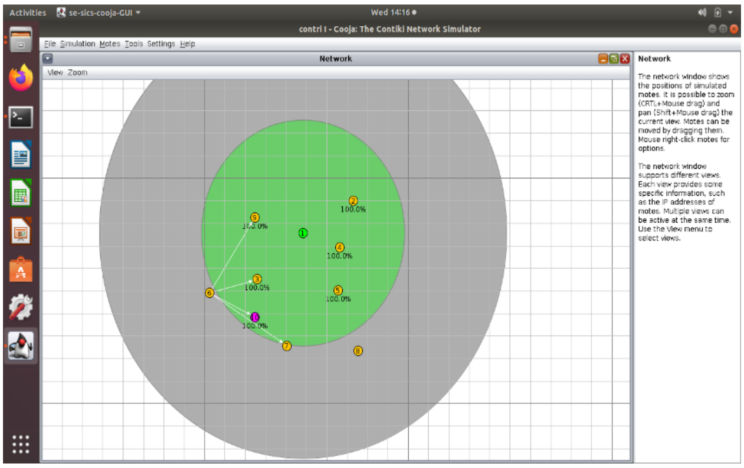

Fig 1.6 (b) Zoomed Simulation window for 10 nodes

Fig 1.6 Simulation screenshots of node deployed with 10nodes

For 10 number of nodes, the screenshots of simulation window for 10 nodes and zoomed simulation window for 10 nodes is depicted in the above figure 1.6.

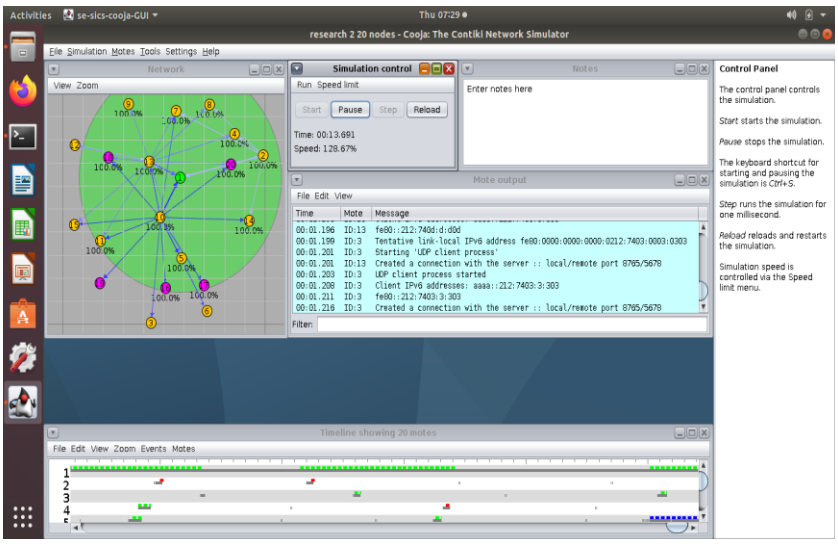

Fig 1.7(a) Simulation window for 20 nodes

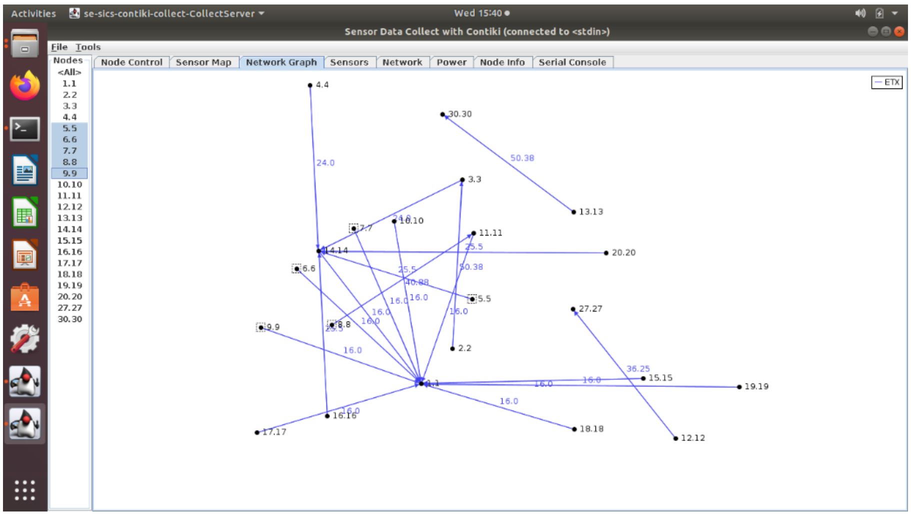

Fig 1.7 (b) Simulation sensor mapping for 20 nodes

Fig 1.7 Simulation screenshots of node deployed with 20nodes

Similarly, the screenshots of simulation window for 20 nodes and simulation sensor mapping for 20 nodes are represented in the above figure 1.7.

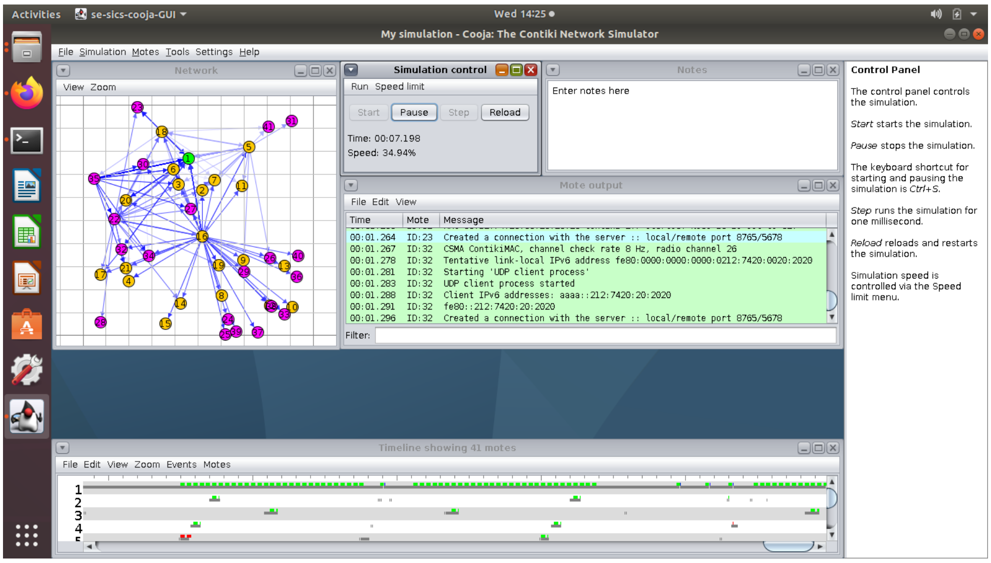

Figure 1.8 (a) Simulation window for 50 nodes

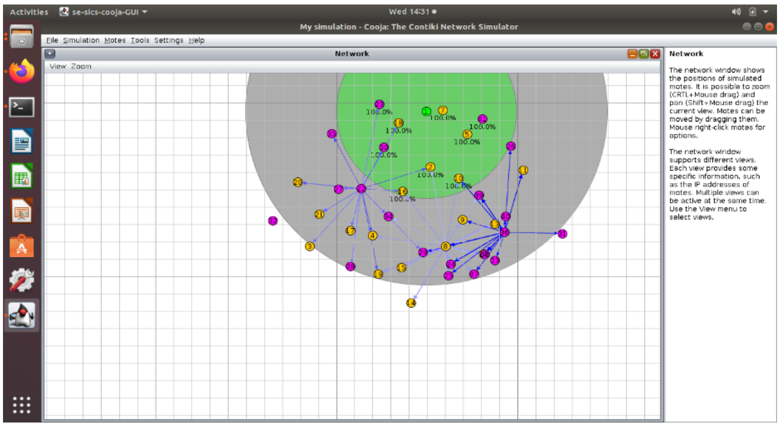

Fig 1.8 (b) Settings panel of simulation done for 50 nodes

Fig 1.8 Simulation screenshots of node deployed with 50nodes

Finally, simulation for 50 nodes is performed. The screenshots of simulation window and settings panel of simulation for 50 nodes are shown in the above figure 1.8.

Simulation Results

The throughput results of the proposed efficient parent selection technique are compared with that of the existing Routing protocol for low power and Lossy network (RPL).

The following table 1.3 shows throughput values for Energy & Bandwidth based Parent Selection Technique to Avoid Congestion in RPL Network (EPS) along with the existing method of RPL for three different number of nodes like 10, 20 and 50.

Table 1.3 Performance of proposed EPSbased on Throughput (bits per second)

Techniques/ Node	**10 Nodes**	**20 Nodes**	**50 Nodes**
Routing protocol for low power and Lossy network (RPL)	90.8	89.1	87.9
Energy & Bandwidth based Parent Selection Technique to Avoid Congestion in RPL Network (EPS)	**92**	**90.5**	**89**

From the table, it is observed that the proposed EPS method provides improved throughput for all the three cases which is highlighted in table 1.3. The same values are plotted in the following figure 1.9 as well by taking the nodes in the x-axis and throughput values in the y-axis respectively.

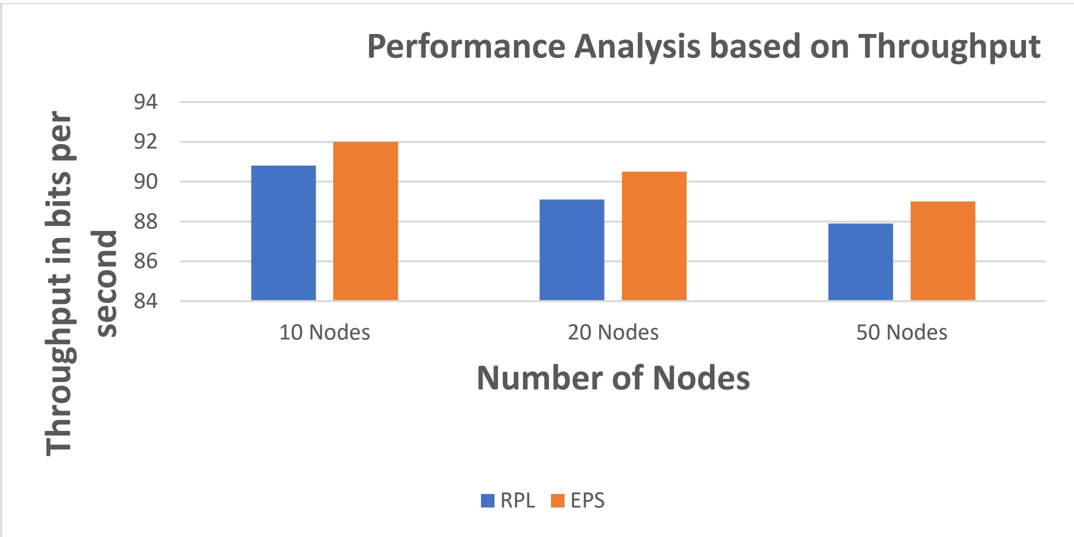

Fig 1.9 Throughput comparison of proposed EPS with existing RPL

The throughput values of existing RPL technique and the proposed EPS method are compared with each other in the above figure 1.9. It is seen that the proposed EPS technique gives higher throughput values for all the cases, than the existing RPL technique.

5. Summary

Energy & Bandwidth based Parent Selection technique (EPS) is proposedto avoid the congestion occurring in RPL networks. In this proposed work, RSSI value, node energy and bandwidth of link are considered as the criteria for selecting the best possible parent. The concept of maximum RSSI value, maximum node energy and bandwidth of link is considered to avoid congestion in RPL networks. The parent node selection is not only taken place based on the energy and bandwidth to avoid congestion, but also it is found to be efficient in terms of throughput as per the objective.

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