EGEO-RPL Algorithm for Mobility Management in IoT-WSN

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Abstract
Node mobility may have a substantial impact on the architecture, capabilities, and uses of Internet of Things (IoT) based Wireless Sensor Network (WSN) systems. The change in network topology can affect communication patterns, routing and network coverage. To adapt to these changes and maintain connectivity, efficient routing protocols and algorithms are needed. In this paper, an optimized Routing Protocol for Low Power and Lossy Networks (RPL) algorithm for mobility management in IoT-WSN is proposed. In this algorithm, the optimum parent node is selected from a set of nodes, based on a combined metric. Then a routing cost function computed using this combined metric and RPL rank values. The trade off parameter of the routing cost function can be adaptively optimized in real-time using the Enhanced Golden Eagle Optimization (EGEO) algorithm, keeping the mobility condition as the fitness value. Experimental results show that the proposed EGEO-RPL algorithm achieves lesser delay and packet drop with higher packet delivery ratio and residual energy.

Keywords
Internet of Things (IoT), Wireless Sensor Network (WSN), Mobility management, Routing Protocol for Low Power and Lossy Networks (RPL), Enhanced Golden Eagle Optimization (EGEO).

1. Introduction

IoT refers to a significant regional configuration that is associated with the typical features of a conventional system that has the ability to link and transmit/receive the data. IoT uses a network of computers, sensors, Radio Frequency identification (RFID) and embedded systems to link the digital and physical worlds [1]. IoT can be applied to many different areas, such as smart cities, speedy medical support, smart buildings, and automobile response.

WSN is often made up of several hundred inexpensive, intelligent, multimodal micro-sensor devices that interact wirelessly and essentially use the Internet for various purposes. WSN has been used to monitor and control complex environmental conditions; as a result, dependable and efficient connections between intelligent sensors are required.

In existing IoT systems, a huge quantity of sensors may be replaced by a small number of sensors, and IoT can be centralised on a single platform, thereby spending power. The three primary phases of the detection and control architecture are sensing, data response, and control. Because of IoT-WSN's many uses for automation, control, and tracking in homes, offices, and other rescue areas, scientists have recently become quite interested in it [2].

In WSN and IoT, the ability of sensor nodes or devices to move within a network environment is referred to as mobility. This mobility may have a substantial impact on the architecture, capabilities, and uses of IoT-WSN systems. Mobility causes changes in the network topology as sensor nodes move [3]. This changing topology can affect communication patterns, routing routes, and network coverage. To adapt to these changes and maintain connectivity, efficient routing protocols and algorithms are needed [4].

Energy-saving protocols and techniques are necessary to increase the lifespan of the network and guarantee continuous operation [5]. It may be necessary to combine or fuse the data streams produced by mobile sensor nodes with that of fixed nodes. In spite of node mobility, dynamic data aggregation techniques and algorithms are needed for effective data processing and analysis [6]. To fully realise the promise of mobile IoT-WSN deployments and enable creative applications across a variety of disciplines, effective mobility-related aspect management is essential [7]. Mobile nodes connect to the Internet via wireless networks, which have a number of drawbacks including a greater error rate and a lower bandwidth [8].

Packet loss is frequently caused by network congestion and mobility which significantly degrades QoS overall. [9].

2. Related works

SDMob [10] is a SDN-based mobility management framework that combines an external controller into a conditional IoTs system. SDMob moves the computational burden of resource-constrained filtering techniques from the nodes, to enable seamless mobility. In spite of erratic mobility patterns and shifting network topologies, SDMob allows the network to maintain sub-meter localization precision while providing almost highest packet delivery ratio for a smaller set of nodes.

Based on CoAP, Din et al. [11] have proposed the group mobility management protocol CoMP-G. A single body sensor will serve as a coordinator, communicating with the web-of-things mobility management system (WMMS) on behalf of all other body sensors to exchange control messages. Every WMMS also records the information gathered from the body sensor collection. This technique outperforms the present CoMP protocol in terms of total signalling and handover delay.

A mobility management framework [12] based on energy efficiency and optimisation was proposed with mRPL-based firefly optimisation algorithm in order to offer a stable and reliable protocol. Based on the results, the proposed system (mRPL+firefly optimizer) performed better than the existing systems in terms of power consumption, number of hops, packet delivery ratio, and end-to-end delay. The testing findings showed that the recommended approach improved PDR by an average of 2.31% over the current systems.

The mobility of ED is investigated over many LPWAN technologies [13]. A revolutionary mobility management solution is provided for LPWAN that ensures communication between the Application Server (AS) and the ED in case the link layer technology changes. This system, which is based on IPv6, enables switching between various LPWAN networks and technologies. It shortens the time required for data transmission by streamlining communication route and preserving bandwidth. This technique is verified in scenarios when ED handovers occur between LoRaWAN and NB-IoT.

CoMP is a mobility management technique that effectively extracts moving sensing data from sensor nodes [14]. CoMP uses the CoAP protocol instead of Mobile IP. Therefore, CoMP can provide reliable mobility management, stop packet loss, and eliminate the additional signalling overhead that comes with Mobile IP. To prevent losing crucial data while travelling, a holding mode has been used in place. All of the signalling operations, such as binding, holding, registration, and discovery have been developed by extending CoAP.

2.1 Research Gaps

The existing methods for managing mobility frequently make assumptions about basic patterns of movement or concentrate on particular cases. More dynamic and realistic mobility patterns that take into account a range of environmental factors, user behaviours, and IoT device mobility profiles need to be investigated. For IoT devices, mobility management techniques should put energy efficiency first in order to extend their battery life. Adaptive mobility solutions that minimise energy usage and guarantee dependable communication and smooth changeover across network nodes require further improvement. Mobility management techniques need to be strong and scalable in order to handle a large number of mobile devices as IoT installations continue to grow in size and complexity.

To solve scalability issues and strengthen mobility management techniques' resistance to network outages and disturbances, research is needed. Data integrity, confidentiality, and authentication are among the security and privacy issues that mobility management in IoTs sensor networks brings up. Research is required to create mobility management protocols that are safe, preserve privacy, safeguard sensitive data, and fend off potential security risks and attacks. The integration of mobility management systems with edge and fog nodes has become necessary with the rise of edge and fog computing paradigms. There is a need to examine how IoT sensor network performance, dependability, and efficiency can be improved in dynamic situations through the use of mobility-aware edge and fog computing architectures.

3. Proposed Solution

3.1 Contributions

In this work, an optimized RPL algorithm for mobility management has been proposed. It selects the optimum parent node based on the Expected Transmission count (ETX), Expected Life Time (ELT), Received Signal Strength Indicator (RSSI), and Euclidean distance (D) metrics.

Each IoT device computes a combined metric M for each neighbour, based on these 4 metrics. Then a routing cost function W(x,y) is computed by combing M along with the RPL rank values. The trade off parameter can be adaptively optimized in real-time based on the mobility condition. For this optimization, Enhanced Golden Eagle Optimization algorithm (EGEO) is used, keeping the mobility condition as the fitness value.

3.2 RPL Protocol

The major role of RPL is to admit the IoT devices into the Low Power and Lossy Networks (LLN).

RPL is based on a Destination Oriented Directed Acyclic Graph (DODAG) topology in which the routes are collected by the root node and distributed among various routing protocols. Each node in the DODAG has an associated rank value which denotes its relationship with the root.

A set of parent nodes will be selected by the source nodes from which a preferred parent with highest rank value is selected.

For avoiding the network loop, RPL utilizes the each node's rank metric. The RPL network's nodes choose their selected parent with the help of their rank value. Here, Parent Rank (PR) and Self-Rank (SR) are the two rank calculations involved. The child node's rank value is estimated by SR.

The rank value of node N_i with a one hop neighbor N_j in a DAG m is computed as

$$Rank_i^m = \langle \min \begin{pmatrix} p_{i,j}^m + Rank_j^m \\ Rank_{root}^m \end{pmatrix} \qquad (1)$$

Where $p_{i,j}^m$ is the penalty cost for the link (i,j) in m, $Rank^m_{root}$ is the smallest rank value in m.

A node estimates its SR from the preferred PR as given in equation .

$$SR = PR + Rank_{inc} \qquad (2)$$

The child rank (CR) is calculated by the preferred PR as shown below

$$CR = PR + Rank_{dec} \qquad (3)$$

Where $Rank_{inc}$ and $Rank_{dec}$ are the increment and decrement value of PR.

3.3 Estimation of Combined Metric

The main function of RPL's objective function is to select the path for the parent node to construct a DODAG.

ETX is used for link quality estimation.

The ETX of the parent node at time t is given by

$$ETX_n = \lambda.ETX_{(t-1)}. + (1-\lambda).ETX_t \qquad (4)$$

Where λ is the weighting constant.

Here, ETX_t is given using the following equation:

$$ETX = 1 /(R_{fw}*R_{rv}) \qquad (5)$$

Where, R_{fw} is the probability of receiving a packet at the receiver and R_{rv} is the probability of receiving an acknowledgement (ACK) packet at sender

Note: A link with minimal ETX will results in huge packet drops.

The **expected network lifetime (L_{nw})** is the time required to completely drain the battery energy of a node, during data forwarding.

It is given using the following equation:

$$L_{nw} = \frac{E_{rb}(j)}{H.P_{tx}(j)} \qquad (6)$$

where E_{rb} is the remaining battery energy of a node j , $P_{tx}(j)$ is the transmitting power of node j and H is given by,

$$H = \frac{NP_r . NP_f \, ETX_j}{D_{rate}} \qquad (7)$$

Where NP_r and NP_f are the total number of packets received and forwarded by node j and D_{rate} is the data rate of the nodes.

RSSI is defined by the following equation.

$$\text{RSSI} = 10.\log \frac{P_{rx}}{P_{ref}} \text{ (dBm)} \qquad (8)$$

Where P_{rx} is the ratio of the received power to the reference power (P_{ref})

When P_{rx} increases, RSSI is also increases thereby increasing the link quality.

After computing these metrics, each IoT node of RPL routing, computes a combined metric M for each neighbour as

$$CM_j = w1.\,ETX + w2.ELT + w3.RSSI + w4.\,D \qquad (9)$$

Where D is the Euclidean distance between the mobile node and the parent node, w_i=1 to 4, are the weighting coefficients.

3.4 Computing Routing Cost Function

A routing cost function W(x,y) is computed using CM along with the RPL rank values.

$$CF(i,j) = \theta_i^m .Rank_i^m + (1-\theta_i^m).CM_j \qquad (10)$$

where, $0 \leq \theta_x^m(t) \leq 1$ is trade off parameter.

The trade off parameter θ can be adaptively optimized in real-time using EGEO algorithm with the following fitness function:

$$Fit(x) = Min\ NCR_i(s) \quad (11)$$

Where $NCR_i(s)$ is the Neighbor Changing Rate of node N_i at slot s, which is computed by [16],

$$NCR_i(s) = \frac{1}{\Delta t} . \sum_{T=t-\Delta t}^{t-1} \frac{N_i(s) \cap N_i(s+1)}{\max(|N_i(s) \cup N_i(s+1)|, 1} \quad (12)$$

which monitors the changes of 1-hop neighbors for the node i within the time window $[t - \Delta t, t)$.

3.5 Enhanced Golden Eagle Optimization algorithm (EGEO)

For this optimization EGEO algorithm [19] is used, keeping the fitness function defined in Eq.(11).

GEO is inspired from the intelligence of golden eagles (GEs) in adjusting their speed at various stages of path during hunting. In the beginning stages of hunting, they exhibit more propensity to search for prey and in the final stages, they exhibit more propensity to attack the prey. A GE determines these two stages to fetch the optimum prey in the possible region within short time span. This activity is formed as exploration and exploitation operations for a global optimization technique [19].

The following steps are executed by the algorithm:

1. Initialize the population of GEs.

2. Compute the fitness function given by Eq. (11).
3. Initialize population memory.
4. Initialize o_a and o_c for each iteration t
5. Update o_a and o_c using the following equation

$$o_a = o_a^0+\frac{t}{T}|o_a^T - o_a^0| \tag{13}$$

$$o_c = o_c^0+\frac{t}{T}|o_c^T - o_c^0| \tag{14}$$

Where,

t is the current iteration

T is the max. no. iterations

o_a^0 and o_a^T are initial and final values for attack propensity

o_c^0 and o_c^T are initial and final values for cruise propensity

6. Compute the crowding distance for the current collection of members.
7. For each GE i, choose a prey from the collection using the Roulette wheel selection method , based on crowding distances.
8. Compute the attack vector M as

$$\vec{M}i= \vec{G}b- \overrightarrow{Gi} \tag{15}$$

where M_i is attack vector of GE i

G_i is the current position of GE i

Gb is the best position attained by GE f.

9. If length (M_i) $\neq 0$,

9.1 Compute the cruise vector C

Ci = ($c1$ = random,2 = random,…,ck =(d — Σj;$j \neq kaj$)/ak,…,cn = random)

9.2 Calculate step vector Δx and update the position.

$$x^{t+1} = x^t + \Delta x^{t\,i}$$

10. Estimate the fitness function for the updated position
11. If the updated position is non-dominating to the present members
12. If the exterior collection is not complete
13. Include the updated solution into the collection

    Else

14. Compute the sparsity distances

$$Si = 1 - Ci$$

15. Choose the leaving member using Roulette wheel method based on sparsity distances.
16. Update the leaving solution with the incoming one.

4. Simulation Results

4.1 Simulation Parameters

The proposed EGEO-RPL algorithm was simulated in NS2. The performance is compared with the BRPL[16] and mRPL+ [17] protocols. The performance metrics delay, packet delivery ratio, packet drops, average residual energy and throughput are measured. Table 1 shows the simulation settings.

Number of sensors	10 to 50
Topology dimensions	150m X 150m
Speed of the mobile node	20m/s to 40m/s
MAC protocol	IEEE 802.15.4

Traffic type	Constant Bit Rate
Packet size	512 bytes
Data Rate	50Kb
Initial Energy	12 Joules
Transmission power	0.3 watts
Reception power	0.3 watts
Simulation time	100 seconds

Table 1 Simulation parameters

4.2 Results & Discussion

A. Varying the nodes

The performance evaluations of the techniques are performed by increasing the number of sensors from 10 to 50, keeping the node speed as 20m/s.

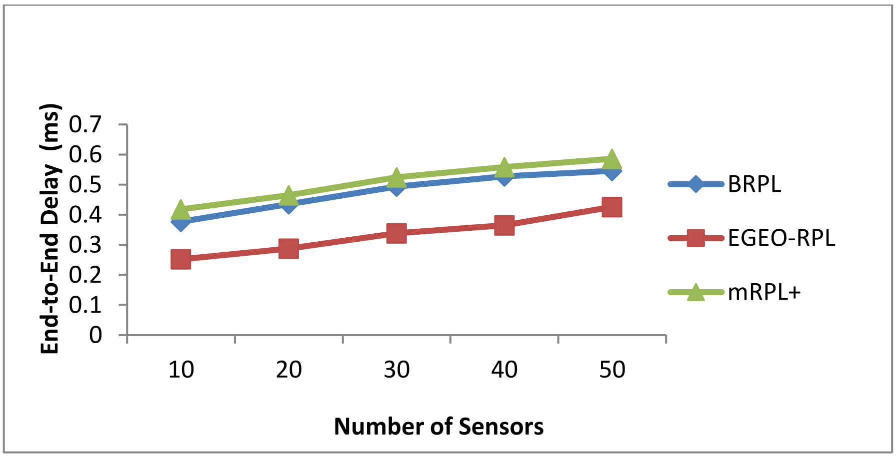

Figure 1 End-to-End Delay for nodes

The end-to-end delays of the techniques are presented in Figure 1. It can be observed that delay of EGEO-RPL is 30% lesser than BRPL and 34% lesser than mRPL+.

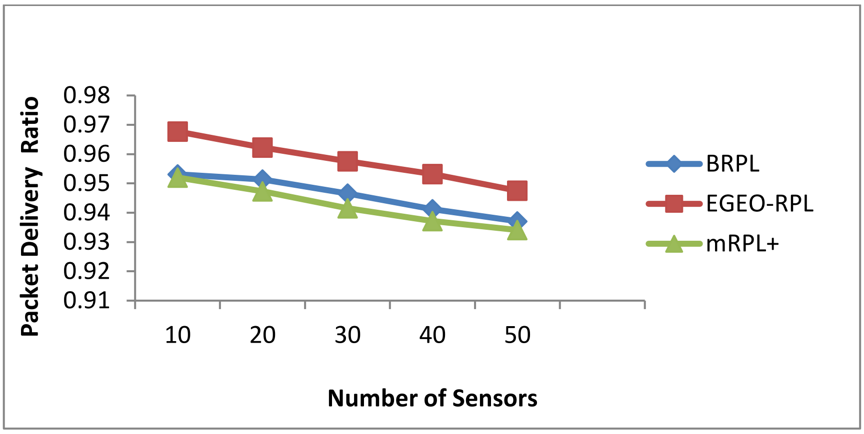

Figure 2 Packet delivery ratio for nodes

The packet delivery ratios of the techniques are presented in Figure 2. It can be observed that EEGO-RPL has 1.2% and 1.6% higher delivery ratio than BRPL and mRPL+, respectively.

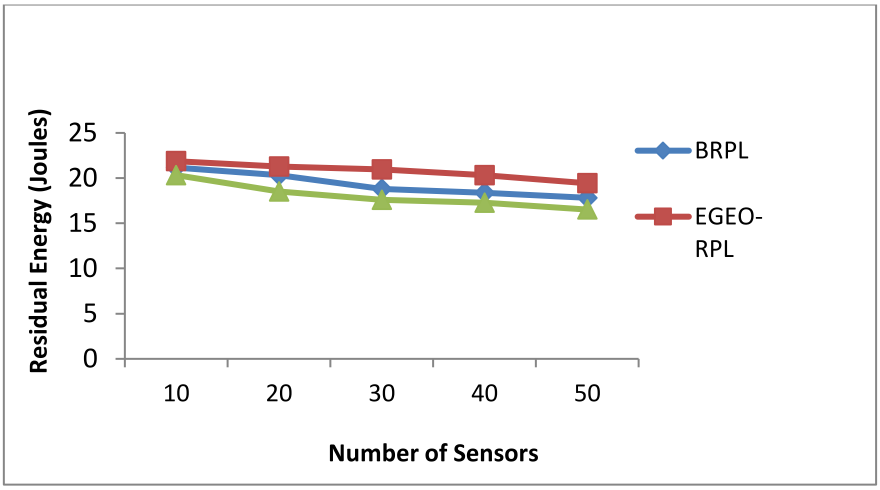

Figure 3 Average Residual Energy for nodes

The average residual energies of the techniques are depicted in Figure 3. We can see that residual energy of EGEO-RPL is 7% higher than BRPL and 13% higher than mRPL+.

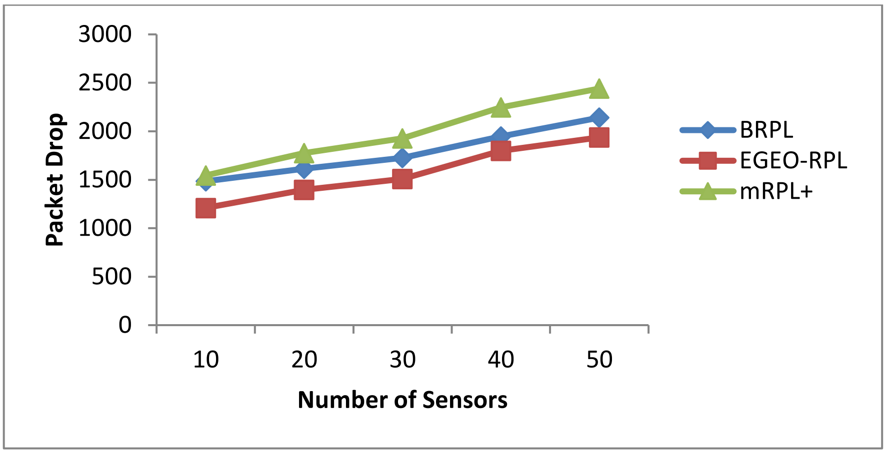

Figure 4 Packet drop for nodes

The average packet drops of the techniques are depicted in Figure 4. We can be see that packet drops of EGEO-RPL is 12% lesser than BRPL and 21% lesser than mRPL+.

B. Varying the Node speed

The performance evaluations of the techniques are performed by increasing the node speed from 20m/s to 40 m/s, keeping the number of nodes as 50.

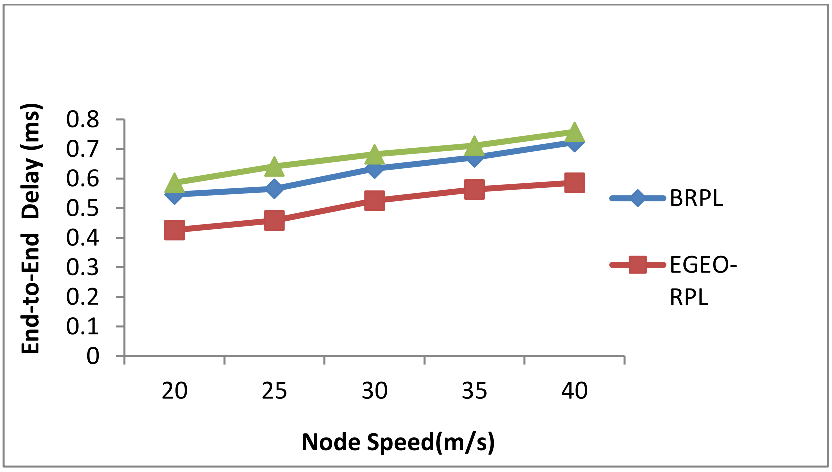

Figure 5 End-to-End Delay for Speed

The end-to-end delays of the techniques are presented in Figure 5. We can be see that delay of EGEO-RPL is 18% and 24% lesser than BRPL and mRPL+, respectively.

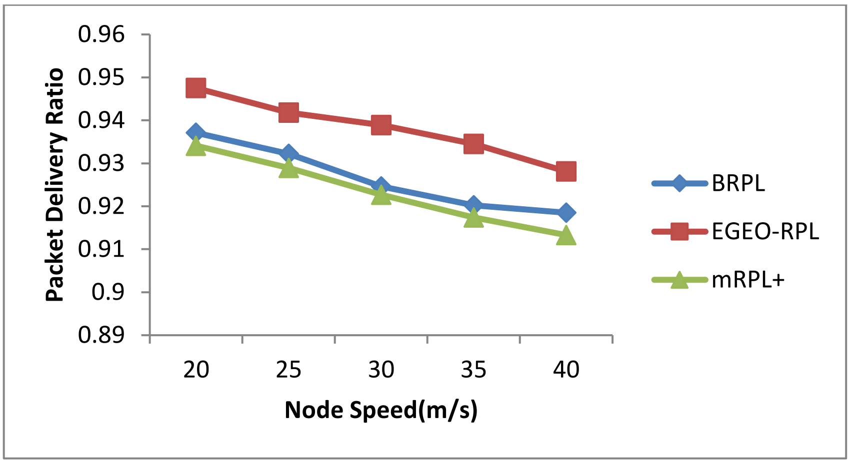

Figure 6 Packet delivery ratio for Speed

The packet delivery ratios of the techniques are depicted in Figure 6. We can be see that EEGO-RPL has 1.2% and 1.5% higher packet delivery ratio than BRPL mRPL+, respectively.

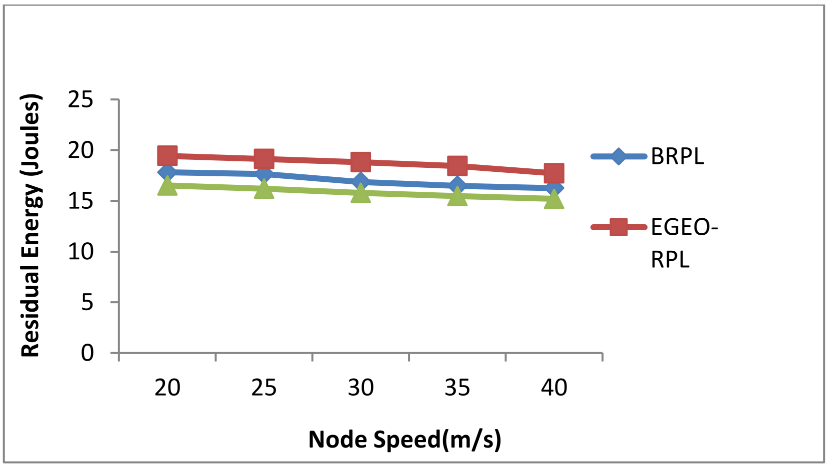

Figure 7 Average residual energy for Speed

The average residual energies of the techniques are depicted in Figure 7. We can be observe that residual energy of EGEO-RPL is 9% and 15% higher than BRPL mRPL+, respectively.

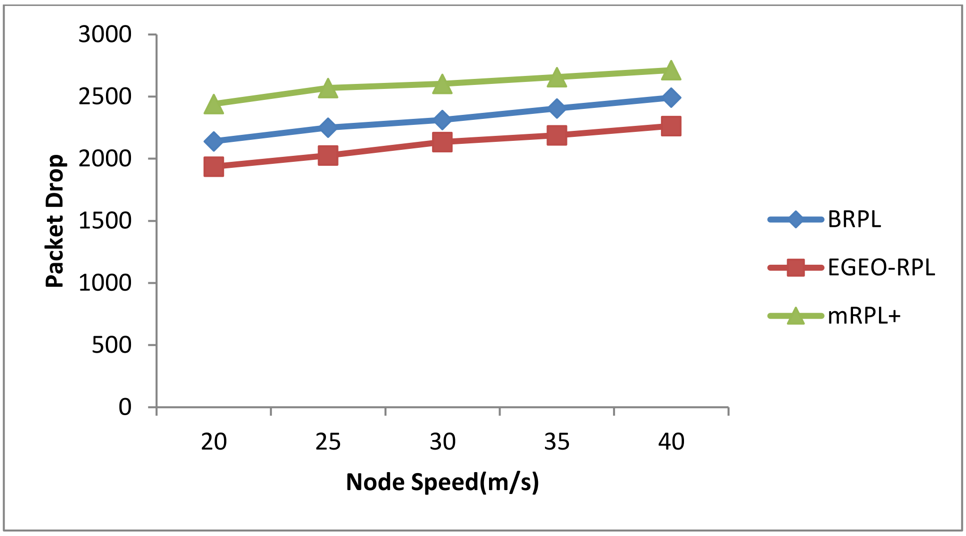

Figure 8 Packet drop for Speed

The average packet drops of the techniques are depicted in Figure 8. We can observe that packet drops of EGEO-RPL is 9% and 18% lesser than BRPL and mRPL+, respectively.

5. Conclusion

In this paper, EGEO-RPL algorithm for mobility management in IoT-WSN is proposed. It selects the best parent from the collection of parents based on a combined metric. Then a routing cost function computed using this combined metric and RPL rank values. The trade off parameter of the routing cost function can be adaptively optimized using the EGEO algorithm. The proposed EGEO-RPL algorithm has been implemented in NS2 and its performance is compared with the BRPL and mRPL+ protocols. Experimental results show that the proposed EGEO-RPL algorithm achieves lesser delay and packet drop with higher packet delivery ratio and residual energy.

Statements and Declarations

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Conflict of Interest: The authors don't have any conflict of Interest.

Competing Interest: The authors don't have any competing interest.

Authors Contribution: In this manuscript preparation author 1 prepared the concept and author 2 prepared the implementation part.

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