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Static to Dynamic transition of RPL protocol from IoT to IoV in static and mobile environments

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Abstract The Routing Protocol for Low power and Lossy networks (RPL) utilises the Objective Function (OF) to form a Destination Oriented Directed Acyclic Graph (DODAG) to reach the destination by selecting the best path. Many works in literature have explored this domain concerning the Internet of Things (IoT) applications. Although, the application of RPL protocol from IoT to the Internet of Vehicles (IoV) in the smart city still presents a big test. Since this gap has not been much traversed, it motivated us to present our findings on this research gap. This paper has realised the transition of RPL protocol from IoT to IoV for the first time. The network performance has been analysed using RPL in a static and mobile environment based on three configurations: Quality of Service (QoS) parameters, network scalability and mobility models. Also, a comprehensive analysis of the RPL performance in both environments has been bestowed in our paper. Finally, we have summarised our inputs and stated potential future directions for researchers. The experiments have been performed using Contiki OS/ Cooja simulator, BonnMotion tool and Wireshark. Simulation results have shown that Self-similar Least Action Walk (SLAW) has outperformed Random Way-Point (RWP) and Nomadic mobility model. High value of Packet Delivery Ratio (PDR) is achieved in mobile/dynamic environment than static. These findings can be directly applied to IoV and IoT applications using RPL protocol like Traffic Monitoring System (TMS), smart corridors, Electronic Toll Collection (ETC), etc. in smart city. Moreover, this article will help the researchers in gaining a better insight of RPL protocol in static and mobile environments for future works.

Keywords Internet of Things · Internet of Vehicles · Low Power · Mobile · RPL · Static

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1. Introduction

Internet of Things (IoT) [1] is an upheaval for the current period, from applications that interface processing devices, advanced and mechanical gadgets, and objects to individuals with unique identifiers. This entwined concept of IoT, Internet of Vehicles (IoV) [2] and smart objects connected through various communication technologies are depicted in Fig. 1. These processing gadgets utilise computing devices called sensors/bits to communicate [3] in realising the smart city concept. These motes utilised in the gadgets/cars have confined assets. They are low power and lossy, creating the generous requirement for a directing convention for Low Power and Lossy Networks (LLNs) [4]. The IETF ROLL working group presented such convention then, RPL [5-6]. RPL protocol permits code changes to manage network traffic [7], energy utilization [8], and so on. A few explorers [9-10] show techniques to extemporise network proficiency utilising RPL protocol for IoT networks [11]. It can be best made out from existing studies that using the RPL protocol can economically build network lifetime and productivity and is the best protocol for LLNs. However, the prime focus is to build a network with a high Packet Delivery Ratio (PDR), quick network convergence and low Expected Transmission Count (ETX). Nonetheless, there still lies a hole in scaling LLNs, for example, security [12-13], mobility [14-15], energy consumption, latency [16], network adaptability [17] and scalability [18]. In addition to mobility in general, many mobility models exist like the Nomadic mobility model, Reference Point mobility model, Gauss-Markov mobility model, Random Walk mobility model, etc., but only a few target human walks and trace other than vehicles.

Since most academicians work only on the use of RPL for IoT networks, we are the first to explore this protocol for IoV networks in smart cities as well. The main contributions of this study can be stated as follows:

- This paper aims to expand the usage of the RPL protocol from IoT networks to IoV networks. First, in this article, we primarily focus on the transition of IoT to IoV in both static and dynamic/mobile environments. The idea behind presenting this novel concept is to widen the scope of using this protocol for the IoV environment other than the IoT network.
- Second, Network scalability, Mobility and Network performance with QoS support are the prime concerns in LLNs. Therefore, this paper covers all these concerns in this article.
- Third, results are organised into three configurations: mobility models (Nomadic, RWP, SLAW), QoS parameters (PDR, ETX, EC, TL, Throughput) and network scalability (10-60 nodes) to infer the findings for both environments.
- Fourth, a comprehensive comparison of the obtained results is discussed for both environments. Findings will be particularly enticing for the researchers working in the LLNs, IoT and IoV in the smart city framework. Hence, this article will be highly expedient and nifty for the scholars seeking a future in this area.

The rest of the paper is systematised as follows: Section II gives an overview of related literature and the scope of this paper. Section III discusses the problem statement for this study and the considered QoS parameters and Mobility Models used for the evaluation of the network. Section IV presents the simulation details and confers the results and findings of this study. Finally, Section V offers the study's conclusion with challenges and future work. Fig. 2 gives the flow of this paper.

2. Literature Study

RPL picked up notoriety in the exploration network as an answer for LLN issues. From that point forward, RPL has been the prime focal point of analysts and thus, has pulled in numerous scientists to propose and examine its enhancements. Despite this fact, to date, just hardly any works have zeroed in that have discussed RPL for IoV networks, which further persuades us to conduct this study.

In papers [19], authors had proposed a Context-Aware Objective Function (CAOF) and had compared the results with the standard OF0. They aimed to reduce power depletion by considering the battery level as a parameter. Their comparable results had shown an effective increase in network lifetime. However, the other standard and default OF of RPL: Minimum Rank with Hysteresis Objective Function (MRHOF), is considered better than Objective Function Zero (OF0) [20-21], which was not considered in their study. The other authors in [22] had also proposed Scalable CAOF (SCAOF), and their results had shown improvement in network lifetime and energy efficiency. They had conducted simulation and real test-bed results but only up to 30 nodes which are relatively less to analyse the efficiency of the proposed method in low-high density scenarios. Consequently, our paper has echoed network scalability up to 60 nodes which can be further scaled to a more significant number of nodes, provided no computational limitation exists.

Authors in the paper [23] evaluated the network performance with four combinations of single and multiple metrics with critical and periodic traffic. The simulation results showed the graph trends for network convergence, PDR and latency. However, no new method/OF was proposed. Similarly, the paper [24] introduced the concept of organising nodes into clusters and then routing those packets using the proposed OF. Although their results had shown an improvement in PDR values, the experiment was only constrained to static nodes. This paper reduces this gap by considering the dynamic/mobile environment too.

In the paper [25], the authors emphasised the need to reduce energy bottlenecks at nodes to ensure higher network lifetime and routing stability. They had proposed an expected lifetime metric with the residual energy of the node as a parameter with promising results. However, the network's reliability was decreased, which can be a significant future direction for the researchers. Likewise, in the paper [26], an energy-aware path selection approach was offered to overcome the issue of node failure in RPL for static nodes and improve PDR and throughput. Authors in [27] discussed strategy to mitigate worst parent attack in RPL. Paper [28] presented effective results targeting latency and packet delivery ratio to support QoS by proposing OFs and comparing their results with the standard OFs. Some authors [29-31] had proposed OFs based on fuzzy logic and context awareness, respectively, intending to improve Data communication and network performance for vehicular

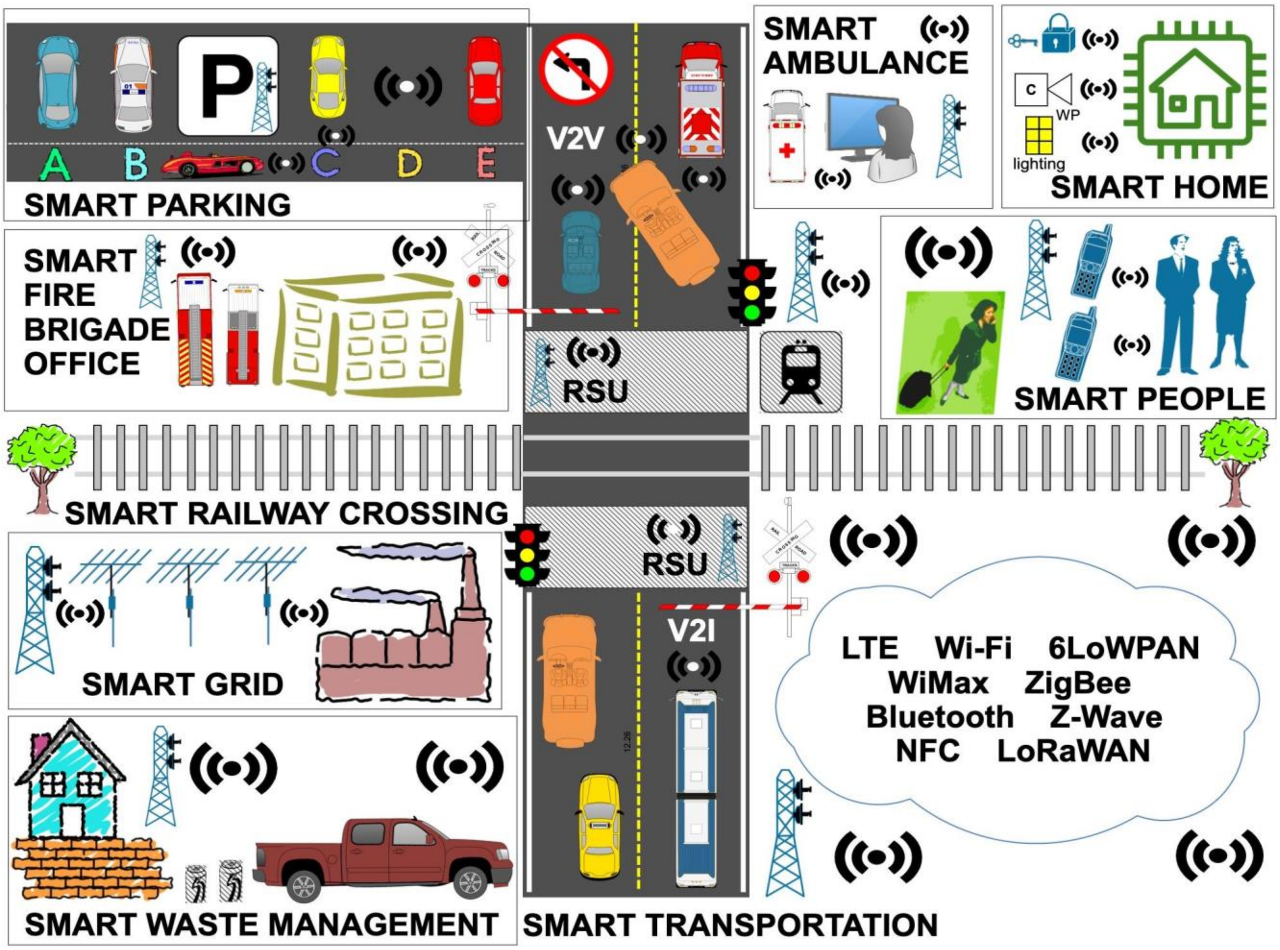


Fig. 1. Communication Technologies in Smart City

networks. However, the above studies were tested for static nodes. They lacked the dynamic nature of the network, which is achieved in this article. In addition to the security and privacy issue of RPL, the authors in the paper [32], had anticipated a self-collected RADAR data-set and a system for detecting routing attacks in RPL called DETONER for static nodes. The data-set can be analysed for privacy and security QoS, but it does not account for mobile nodes.

Paper [33] recommended using a fault-tolerant routing technique for smart grid infrastructure for static nodes. Further studies like papers [35-37] had proposed OF considering the dynamic nodes for the evaluation. Other researches [38-41] reflected mobility in RPL but were restricted to IoT networks only. Authors in [42] proposed a mobility-aware routing metric called REFER, which focused on efficient energy consumption and reliability of the network. However, no prospective derivations for application into IoV could be analysed, which is covered in this study.

Paper [43] presented a new retransmission scheme called IM-RPL. This scheme had considered mobility in nodes to improve data communication in the network, but QoS parameters were not considered, which is covered in this article. In the paper [44], the authors had proposed content-centric OF but with additional mobility features. Their results showed improvements in end-to-end packet reception ratio and transmission delay from the standard OF but at the cost of reduced network lifetime. Authors in [45] had also proposed mobile design in their paper to incorporate mobile nodes. Their work was concentrated on enabling routing/forwarding decisions in mobile nodes for mobility scenarios. Likewise, in [46], the authors worked on reducing network overhead and energy consumption in mobile nodes by proposing a new routing algorithm. Their simulation results had shown improvements but at the cost of PDR and end-to-end delay. These drawbacks are fulfilled in our paper. Paper [47] had considered both environments for analysing the malicious node but the considered dynamic environment was only limited to random mobility, whereas, in this study, both environments are tested for three configurations: QoS parameters (6 parameters), network scalability (10-60 nodes).

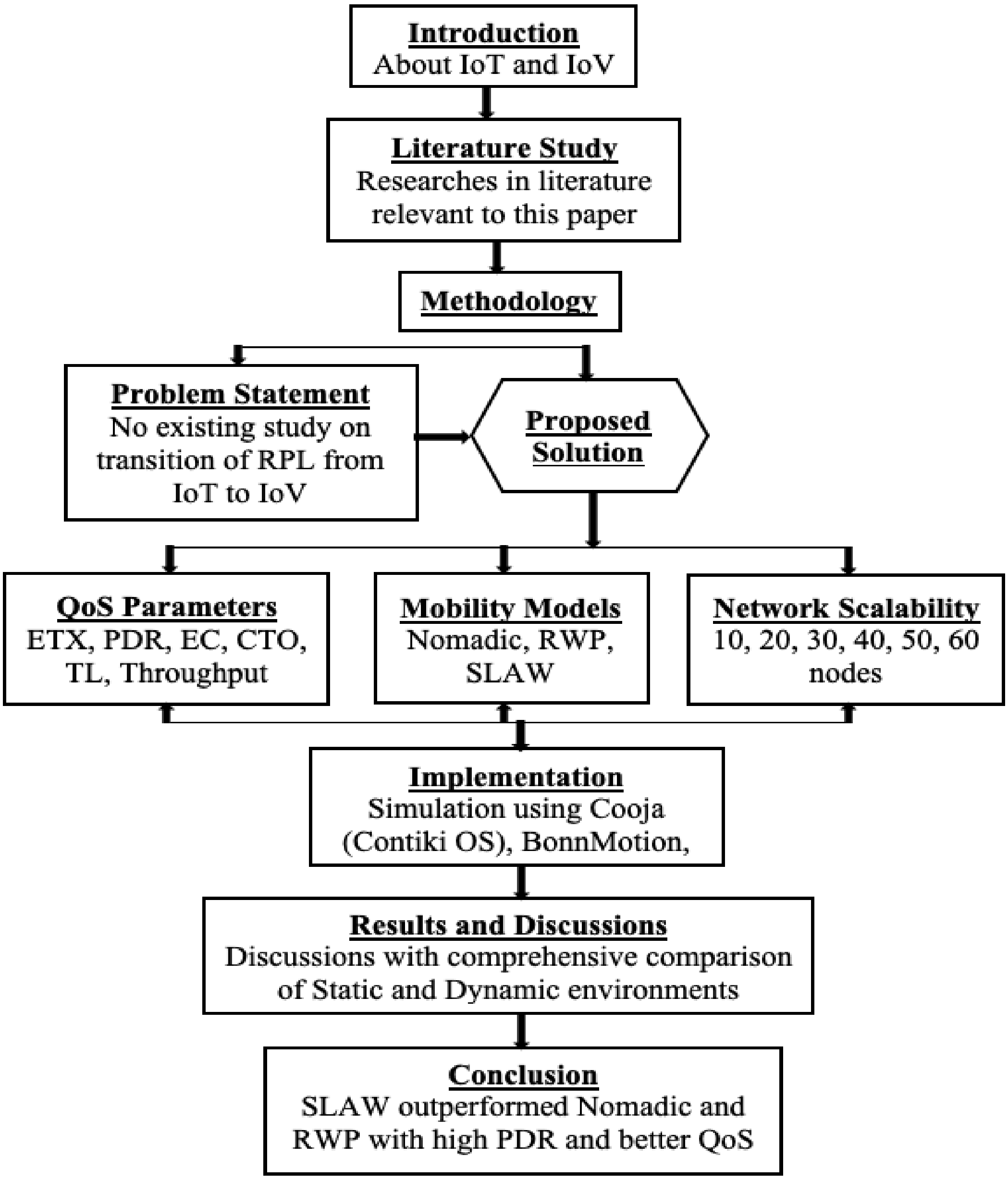


Fig. 2. Summarizing the flow of the paper

and mobility models (3 mobility models).

In paper [48], the authors had proposed a novel mobility-aware routing metric called ARMOR to address the tradeoff between reliability and PDR but yet again for IoT devices only. Likewise, the authors in the paper [49] had proposed a protocol to reduce PDR for IoT-based mobile ad-hoc networks only. The paper [50] suggested evolution strategies for improving RPL performance using swarm optimisation.

Interestingly, it is worth noting that studies from [19-34] had thrived for static nodes in RPL, whereas studies from [35-51] had labored for mobile nodes in RPL but IoT networks. It tends to be gathered that a proactive exploration is needed in the field of RPL considering mobility. This can be analysed from Fig. 3 as well, over the decade. This makes this research neurotic and thought-provoking, where the findings are presented for a) both static and mobile nodes and b) for the vehicular network in IoV. This will give the readers the crux of the transitional overview of the evaluation of RPL from IoT to IoV.

Fig. 3. Rise from Static to Mobile Environment

3. Methodology

3.1. Problem Statement

The routing protocol RPL for LLNs in IoT applications has few failings when deployed and tested for high-density networks, especially for mobile nodes. The growth of mobile nodes for IoT networks and applications is well evident from the literature survey. Though, it is seen that data communication in these types of networks is unreliable and unstable. Consequently, data communication among mobile nodes (e.g., Vehicle-to-Everything (V2X) communications which include Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) and Vehicular Mobile Network (V2C) communication) when combined with vehicular networks, has adversely affected the QoS. Also, accomplishing superior QoS for a mobile environment is much more arduous. Indeed, the vehicular network includes communications for both static and mobile environments(devices like Road Side Units (RSUs), Advanced Metering Infrastructure (AMIs), etc., are static and nodes as vehicles on the road are mobile). Therefore, these issues are explored in this paper for the first time as a transition of RPL from IoT to IoV. Thus, we present the proposed scenario analysis for a static and dynamic environment. First, we state the QoS parameters and then mobility models
used for this study for a network scaled up to 60 nodes:

3.2. QoS Parameters

3.2.1. Expected Transmissions Count (ETX)

ETX is the count of the number of transmissions a packet requires to reach from source to destination successfully. It is a discrete value and computed as:

$$ETX = \frac{1}{(Df * Dr)} \qquad (1)$$

Where Df is the probability measure of the sent packet, which the neighbor successfully receives, and Dr is the probability measure of the successful reception of the acknowledgment packet. The lower the value of ETX, the better the reliability of links/protocol in the network. This value can be obtained from the collect view of Cooja Simulation for every experiment.

3.2.2. Packet Delivery Ratio (PDR)

PDR is the ratio of the total number of packets successfully delivered to the destination to the total number of packets sent to the destination. It is calculated as:

$$PDR = \frac{Total\ number\ of\ received\ packets}{/Total\ number\ of\ sent\ packets} * 100 \qquad (2)$$

The higher the PDR, the better the network performance. This value can be calculated by collecting the value of received packets and sent packets from the collect view of Cooja Simulation for every experiment.

3.2.3. Control Traffic Overhead (CTO)

Control messages are generated to create and maintain Destination Oriented Directed Acyclic Graphs (DODAG). DODAG Information Solicitation (DIS), DODAG Information Object (DIO), and Destination Advertisement Object (DAO) are four types of control messages. CTO is the total sum of these control messages. Lower is the CTO; better is the protocol performance. It is a discrete value and computed as:

$$CTO = \sum\nolimits_{x=1}^{m} DIO(x) + \sum_{x=1}^{n} DIO(x) + \sum\nolimits_{x=1}^{o} DAO(x) \qquad (3)$$

Where x and m are variables, this value can be accounted for in the Wireshark tool by analyzing the .pcap files generated from the Cooja simulation. .pcap file analysis in Wireshark will summarise the total sent packets and the total received packets.

3.2.4. Energy Consumption (EC)

EC is the power/energy consumed by the nodes during the network lifetime. Lower is the power consumption of the acknowledgment packet. The lower the value of ETX, the better the reliability of links/protocol in the network. This value can be obtained from the collect view of Cooja Simulation for every experiment.

$$EC = ((T * 19.5mA\ + L * 21.5mA\ + CPU * 1.8mA\ +\ LPM * 0.0545mA) * 3V)/32768 \qquad (4)$$

Where T is the Transmit Time, L is the Listen Time, CPU (full power mode consumption) is the CPU time, and LPM (low power mode consumption) is the LPM time. T and L are the radio transmit and receive time-related to node communication and can be observed from the collect view during simulation in Cooja.

While CPU is the power parameter representing the level of node processing, LPM is the power parameter representing power used in the sleep state. Values of CPU Time and LPM Time can also be observed from the collect view in Cooja during simulation. These four types of power measurement add up to calculate the total power consumed during the simulation.

3.2.5. Total Latency (TL)

Latency is defined as the total delay in the packet after sending it from the source to successfully receiving it at the destination. The lower the latency, the more efficient the network is. It is computed as:

$$Total\ Latency = \sum_{x=1}^{m} (Received\ Time(x) - Sent\ Time(x)) \qquad (5)$$

Where x and m are variables, this value can calculate by analyzing the .pcap files in Wireshark. Each transmission has a mote ID and time, so the difference between the sending time and receiving time of the node will give the latency for that particular node. The total sum of latency for all nodes is the total latency for the network.

3.2.6. Throughput

Throughput is the ratio of total sent packets to the total simulation time. It is expressed in packets/min. It is dependent on the traffic load on the network. It is computed as:

$$Throughput = \frac{Total\ Sent\ packets}{Total\ Simulation\ Time} \qquad (6)$$

This value can be obtained by analyzing the .pcap file from summary statistics in the Wireshark tool.

It is, therefore, wise and vital to comprehend why only these parameters with QoS support are considered for this study. Thus, Fig. 4 gives the correlation matrix of these QoS parameters to trade off the inter-related effect of these parameters. This will enhance the network performance evaluation.

It can be analysed from the figure that CTO and Throughput are strongly positively correlated, and PDR and Power/EC are strongly negatively correlated. Whereas Power/EC and Total Latency are weakly positively correlated, PDR and Total Latency are negatively correlated. Therefore, we can infer that CTO is expected to increase with the increase of throughput. Similarly, Power/EC is expected to decrease with the increase in PDR and vice versa.

3.3. Mobility Models

3.3.1 Nomadic Mobility Model (NMM)

It is a group mobility model. It is therefore used to determine the movement of nodes that travel together. Each group of nodes has an invisible reference node followed throughout the simulation. Its application can be seen in military movement or a guided city/museum tour. The command to run this model can be referred from [52]. The basic command to obtain data values for 10 nodes in BonnMotion is:

$./bm - fTest1Nomadic - d3600 - x100 - y100$ …(7)

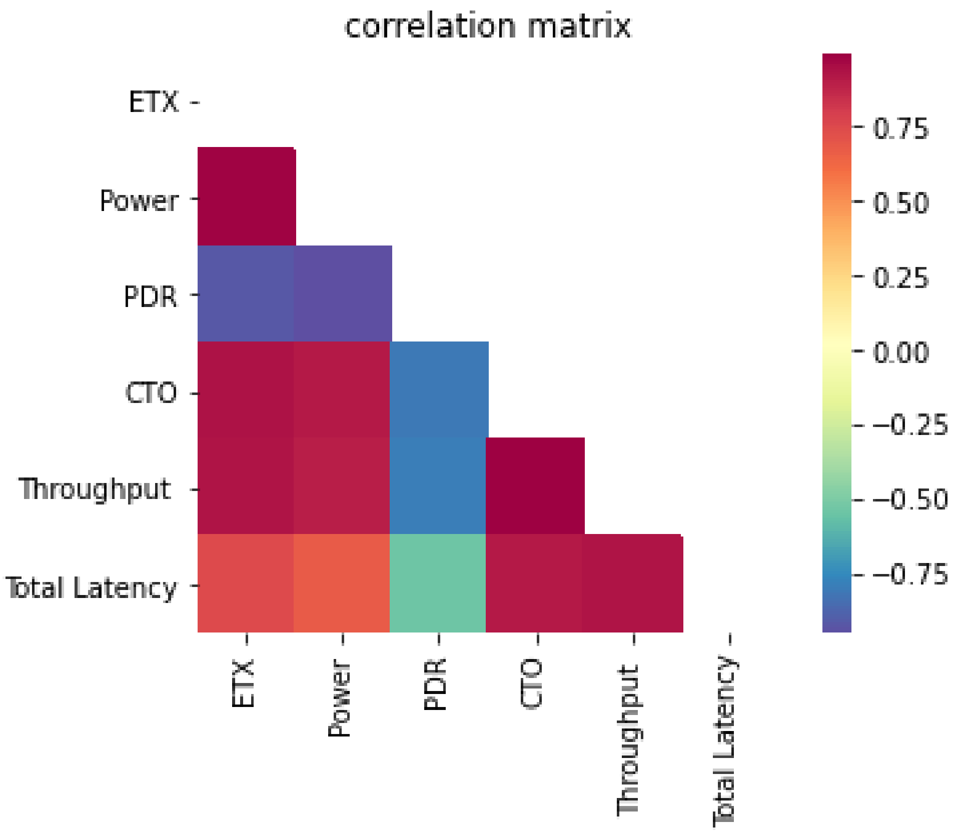


Fig. 4. Correlation Matrix and Data for QoS Parameters

Where f is the filename, d is the duration, x,y are boundaries, n is the number of nodes, and i is the starting delay for mobility. These values in the commands are adjustable as per the requirement. This command represents the use of the Nomadic Mobility Model for 3600s duration, for 10 nodes, with no startup delay and x, y grid of 100 x 100 m^2.

3.3.2 Random Way-Point Mobility Model (RWPMM)

It is an entity mobility model. In this model, nodes randomly select (x,y) position as the destination and move towards the destination with uniform velocity. When that destination is reached, it chooses another destination. A similar process is continued throughout the simulation time. It is the most popular and used model due to its simplicity and availability in research. The command to run this model can be referred from [52]. The basic command to obtain data values for 10 nodes in BonnMotion is:

$$./bm - f\,Test1RandomWaypoint - d3600 - x100 - y100 - n10 \quad \ldots(8)$$

Where f is the filename, d is the duration, x,y are boundaries, n is the number of nodes, and i is the starting delay for mobility. These parameters' values can be modified per the user's settings. Similarly, this command represents the use of the Random Waypoint Mobility Model for 3600s duration, for 10 nodes and x,y grid of 100 x 100 m^2.

3.3.3 Self-similar Least Action Walk Mobility Model (SLAWMM)

Since we talk about the transition of IoT to IoV, it is necessary to consider a variety of models so that we cover all prospects of V2X communications. It is an entity mobility model. It generates synthetic traces of a person's movement. Unlike other models, SLAW can also represent social contexts among humans. The command to run this model can be referred to form [52]. The basic command to obtain data values for 10 nodes in BonnMotion is:

$$./bm - f\,Test1SLAW - d3600 - x100 - y100 - n10 - w6 - r10 \quad \ldots(9)$$

Where f is the filename, d is the duration, p is the minimum pause time, x,y are boundaries, n is the number of nodes, w is the number of way-point to generate, and r is the clustering range. This command's parameter values are changeable per the user's need. Likewise, this command represents the use of the SLAW Mobility Model for 3600s duration, for 10 nodes, minimum pause time of the 20s, number of way-points as 6 and x,y grid of 100 x 100 m^2.

4. Simulation Setup and Details

This section gives the simulation details and set up for the above methodology. Three tools are used to conduct this study. First, Cooja Simulator [53] is used. It provides a simulated platform for the motes to realise the network traffic. Due to computational limitations, up to 60 nodes are considered for this research, where one node acts as a sink and the rest as senders. Table 1 gives the simulation details.

Table 1. Cooja Simulation Details

SETUP DETAILS	INPUT PARAMETERS
Propagation Model	DGM with Distance Loss
Start-up Mode Delay	65 s
Random Seed	123,456
Mote Type	Sky Mote
Number of nodes	10, 20, 30, 40, 50, 60
TX Range	45 m
INT Range	90 m
TX Ratio	100%
RX Ratio	50%
Radio Messages	6LoWPAN with pcap analyser
Total Simulation Time	24 h
Environment	Static and Mobile

Second, the BonnMotion tool [52] is used. It provides the ease to use mobility models in the study. We have incorporated the resulting files from BonnMotion to Cooja simulation to create virtual mobile scenarios. Since the files resulting from BonnMotion cannot be directly used with Cooja, we developed our script to convert those files into Cooja compatible files. Table 2 gives the BonnMotion setup details.

Table 2. BonnMotion Setup Details

SETUP DETAILS	INPUT PARAMETERS
Mobility Model	Nomadic, Random WayPoint, SLAW
Number of nodes	10, 20, 30, 40, 50, 60
Clustering Range	10 m
Number of WayPoint	6
X; Y area	100 m ∀ value of nodes
Pause time	20 s
Simulation Duration	3600 s
Environment	Mobile

Third and last, the Wireshark network analyser tool [54] is used. This tool enhances the research study evaluation by offering the facility to analyse .pcap files generated from the Cooja simulation. Fig. 5 shows a glimpse of experimental test beds for the study.

This proposed concept can be considered replicating V2X communication for a dynamic environment. Since, in real road scenarios, when vehicles are moving on the road, they communicate with each other, and at the same instance, they communicate with us. So, RSU becomes a static unit while the moving vehicle is taken as a mobile unit. This can be further explained by an example of a smart Electronic Toll Collection (ETC) application. In ETC setup, the cars pass through the toll booth and electronically pay their tolls. In that instance, cars simultaneously establish communication between the toll booth and other cars on the roads. Thus, the toll booth acts as an RSU, i.e., static unit, while other cars are mobile units. Such scenarios as Traffic Monitoring systems (TMS) in smart cities, Advanced Metering systems (AMI), etc., directly apply the proposed concept of this article.

Further, the results are categorised into two segments:

1. RPL performance assessment in static and mobile environments
2. RPL performance assessment using mobility models.

These two segments are analysed for network scalability from 10 to 60 nodes. More number of nodes could not be analysed due to computational limitations. The findings from these segments will help us provide an overview of the IoT to IoV transition.

4.1 RPL Performance Assessment in Static and Mobile environment

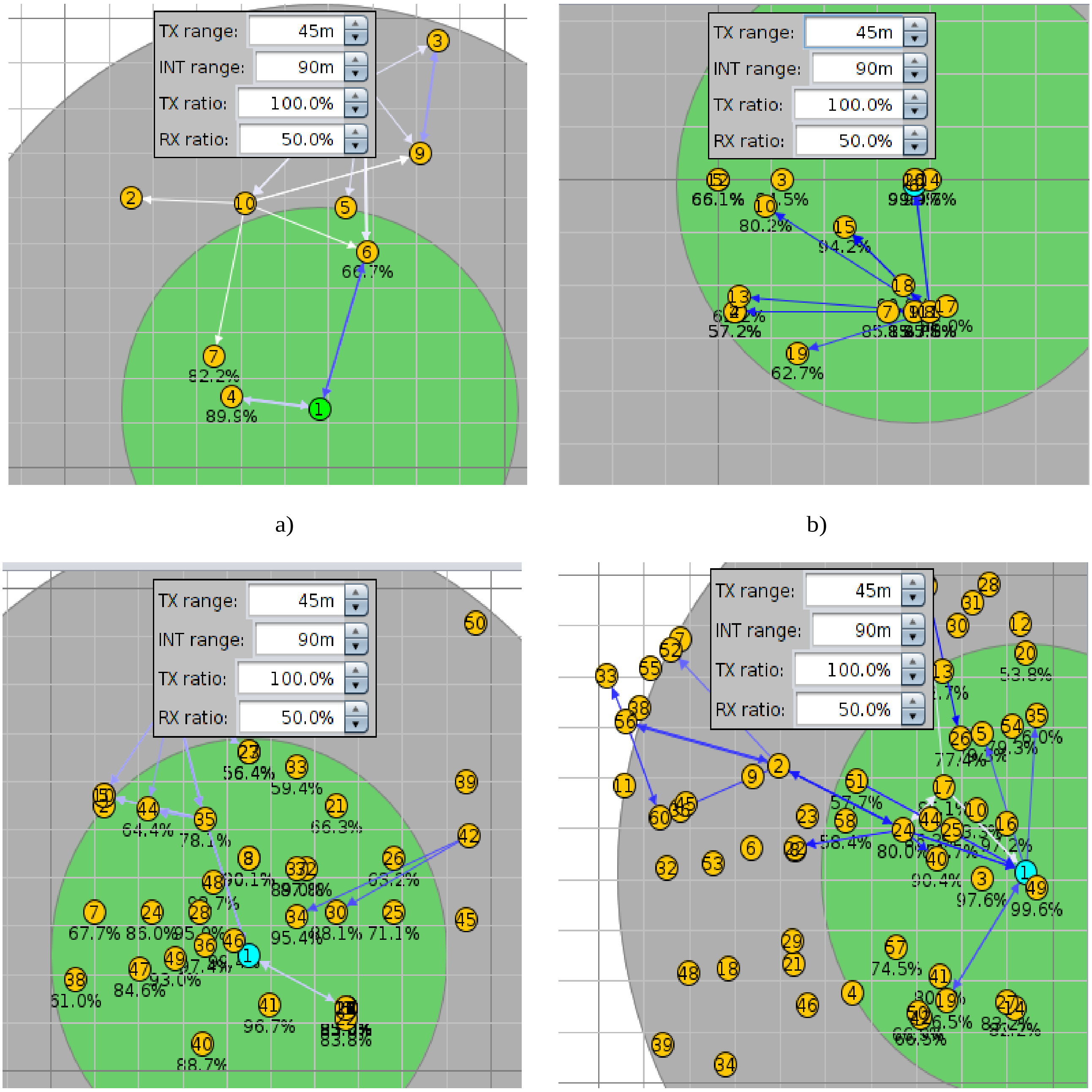
4.2.1 ETX Static vs. Mobile

Fig. 6 shows the Expected Transmission Count for static and mobile/dynamic nodes. It can be seen that ETX increases with the increase in the number of nodes. This can be justified that for a high-density network, a more significant number of packets are sent by the nodes to ensure successful delivery due to increased transmission interference.

But, this is observing that ETX for the static environment is higher than the mobile environment because, in the static environment, the nodes are fixed; hence nodes have the ease of choosing another parent. Therefore, hop count increases which increases the ETX in static. This flexibility is impossible with moving nodes; therefore, we can see a reduced ETX for the mobile environment.

4.2.2 CTO Static vs. Mobile

Fig. 7 manifests the increase in Control Traffic Overhead with the increase in network scalability. This can be explained as for low scalable network with fewer number of control messages are exchanged between the nodes compared to a highly scalable



TX range: 45m
INT range: 90m
TX ratio: 100.0%
RX ratio: 50.0%

a)

TX range: 45m
INT range: 90m
TX ratio: 100.0%
RX ratio: 50.0%

b)

TX range: 45m
INT range: 90m
TX ratio: 100.0%
RX ratio: 50.0%

c)

TX range: 45m
INT range: 90m
TX ratio: 100.0%
RX ratio: 50.0%

d)

Fig. 5. Experimental Test-bed for a) RWP for 10 nodes, b) SLAW for 20 nodes, c) Dynamic for 50 nodes and d) Static for 60 nodes

network. Also, high-density networks face more network congestion, increasing the transmission delay for static and mobile setups.

But, when the nodes are in a mobile state, they send more control messages to other nodes to know and ensure the availability of the network. This consumes additional resources so that we can observe a higher CTO for mobile environments than for static environments.

4.2.3 PDR Static vs. Mobile

Fig. 8 reflects the decrease in Packet Delivery Ratio with the increase in the number of nodes for both environments. It is obvious that in cases of highly dense networks, more packets are lost due to interference, congestion, the collision of packets, etc., than in low-density networks. Therefore, PDR in a mobile/dynamic environment is higher than in a static environment.

We can also read from the Fig. 3 that PDR is inversely proportional to the network size. This is

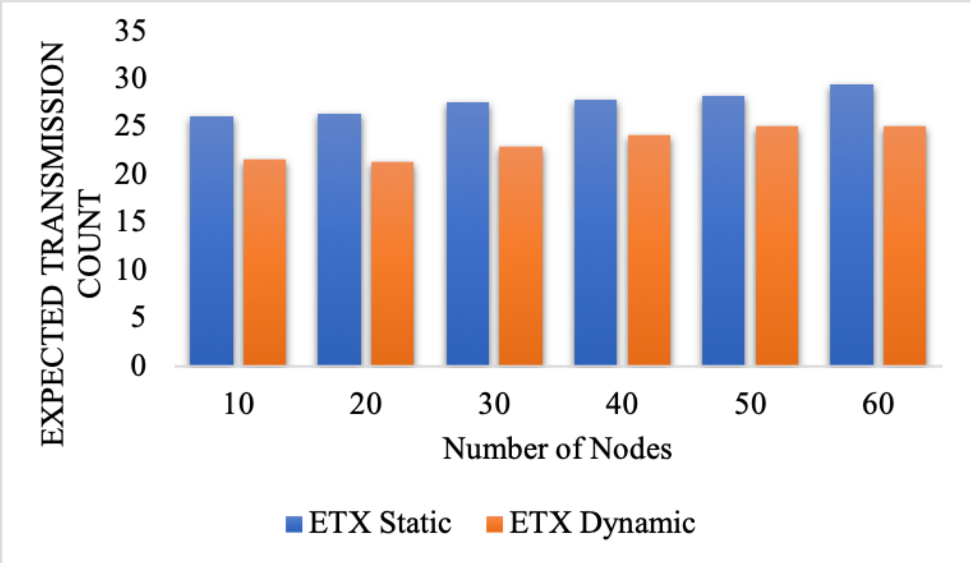


Fig. 6. Static vs. Mobile ETX QoS for scalable network

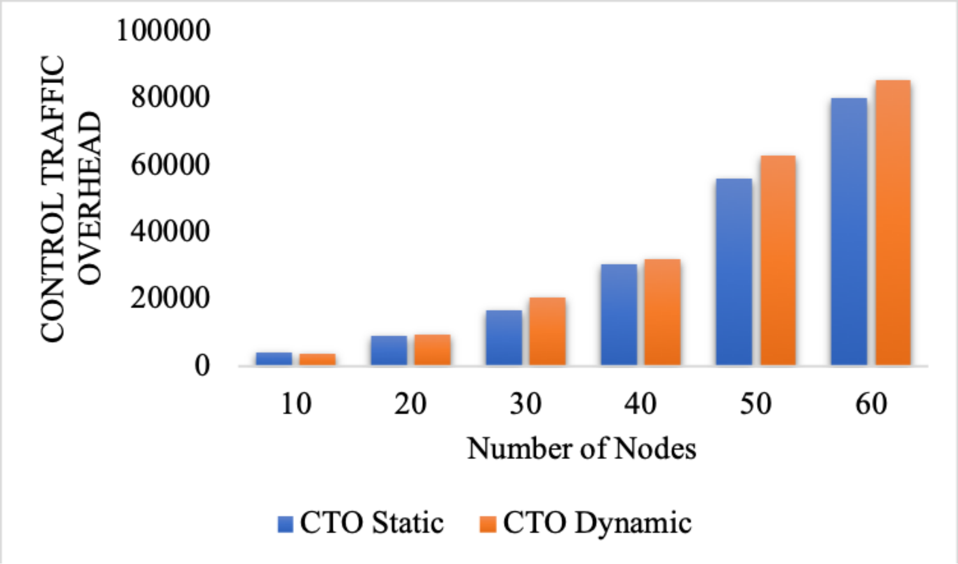


Fig. 7. Static vs. Mobile CTO QoS for scalable network

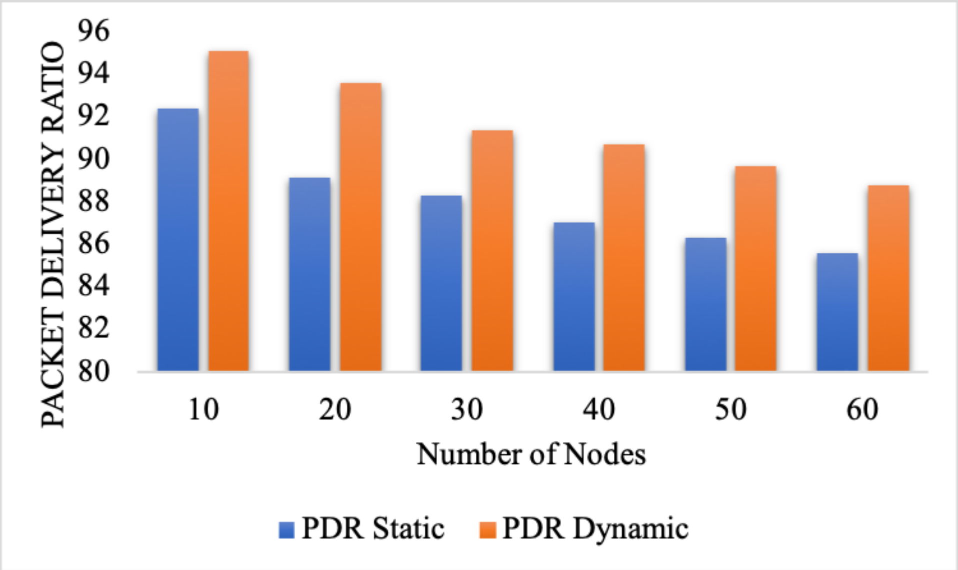


Fig. 8. Static vs. Mobile PDR QoS for scalable network

because, in a dynamic environment, the moving nodes can frequently communicate, so the packet loss is comparatively lesser than the static setup. Thus, PDR is higher in the mobile environment.

4.2.4 EC Static vs. Mobile

Fig. 9 reflects the rise in Power /Energy Consumption with the increase in network size for both environments. When more packets are delivered, the nodes consume more energy. This increases the energy consumption for nodes. This can also be explained from the correlation matrix in Fig. 3 that EC is inversely proportional to PDR. The power is measured in megawatt (mW). Since the nodes are mobile, it takes more effort and resources for the nodes to sustain in the network than in a static environment. That is why consumed energy for nodes in a mobile setupis more than a static one.

4.2.5 Total Latency Static vs. Mobile

Fig. 10 compares the total latency for static and mobile/dynamic environments. We can observe that the total latency increases with the increase in network size. This is measured in seconds.

But, it is interesting to view an exponential rise in total latency on increasing the nodes due to an increase in the number of packets. We could notice a drift of 137% for 10 nodes, 44% for 20 nodes, 40% for 30 nodes, 9% for 40 nodes, 7% for 50 nodes and 2% for 60 nodes from static to dynamic/mobile setup readings. The percentage drift reduced with the increase in nodes due to a relative increase in packets for bothenvironments.

4.2.6 Throughput Static vs. Mobile

Fig. 11 observes an increase in throughput with the increase in the number of nodes for both static and dynamic/mobile environments. This is mainly due to the increase in the number of packets from 10 to 60 nodes for a similar simulation time.

As the network size increases, more packets are sent to ensure that the packet is successfully delivered. This increases the throughput value since the total time of simulation remains the same. This is expressed in packets/min. Also, throughput varies with network load. Since sent packets are higher for dynamic/mobile environments, we can view higher throughput for the mobile environment than static. We can also relate from Fig. 3 that CTO and Throughput are directly proportional. Additionally, the higher the sent packets, the higher the throughput for a network.

From the above studies, we can infer that we need improvisation in the RPL protocol such that it can provide low ETX, low EC and high PDR. This will ensure the highest network lifetime for nodes and an efficient network. Also, low latency and low CTO will enhance the network QoS.

The performance of RPL protocol from static to the dynamic environment should push researchers to work on improvising the OF of RPL for IoV (mobile/dynamic) networks since much work has already been done in favor of static and mobilenodes for IoT networks. This statement can also be well vindicated by our literature study. Therefore, we further discuss using the RPL protocol for IoV networks using mobility models. This will also augment the RPL protocol from IoT to IoV networks.

4.2 RPL Performance Assessment using Mobility Models

4.2.1 ETX Nomadic vs. RWP vs. SLAW

Fig. 12 compares ETX QoS for three mobility models: Nomadic, RWP and SLAW. All three models show a rise in ETX value with the increased number of nodes. ETX increases with the increase in sent packets. Since more packets are sent for high-density networks, ETX also increases. When these three models are compared based on the ETX QoS parameter, we can easily see that RWP shows the highest ETX and SLAW shows the lowest ETX. It is well known that the lower the ETX, the better the proto-col. Thus, this finding suggests the use SLAW mobilitymodel for RPL protocol for IoV networks.

4.2.2 CTO Nomadic vs. RWP vs. SLAW

Fig. 13 reflects the comparison of CTO QoS for Nomadic, RWP and SLAW mobility models. It can be monitored that CTO increases with the increase in network size. This is mainly due to more control messages being exchanged for a higher number of nodes. This is also known that the lower the CTO, the better the network efficiency.

Based on CTO QoS, RWP gives the highest CTO compared to Nomadic and SLAW. At the same time, SLAW gives the lowest CTO for the IoV network. Thus, this concludes SLAW to be the best model among these models for IoV scalable networks.

4.2.3 PDR Nomadic vs. RWP vs. SLAW

Fig. 14 demonstrates the comparison of PDR QoS for Nomadic, RWP and SLAW mobility models. It can be studied from the results that PDR decreases.

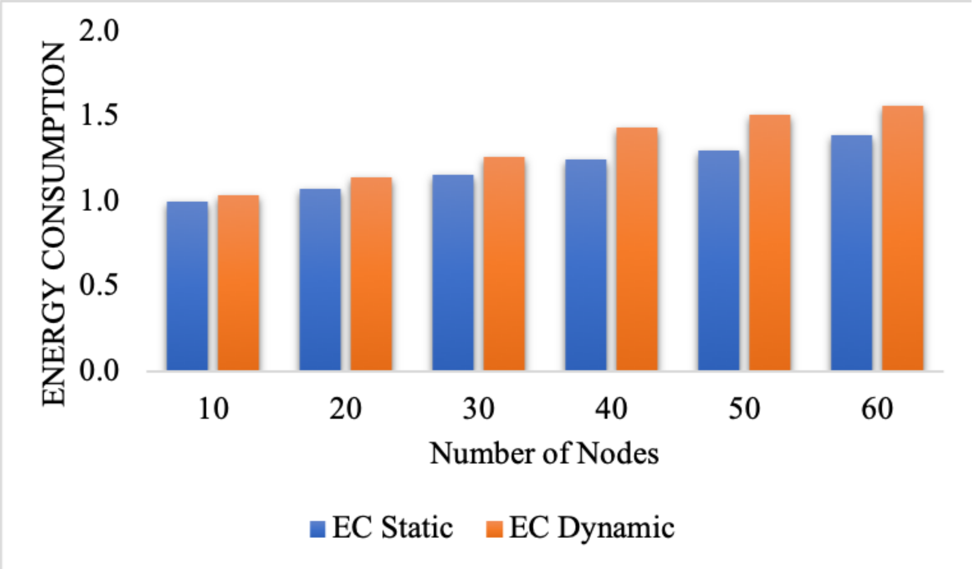


Fig. 9. Static vs. Mobile EC QoS for scalable network

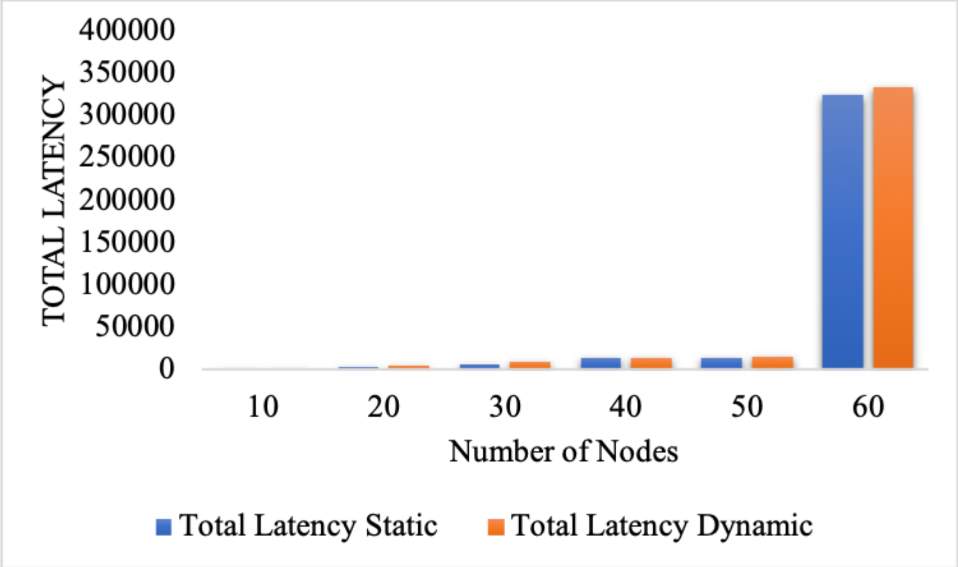


Fig. 10. Static vs. Mobile Total Latency QoS for scalable network

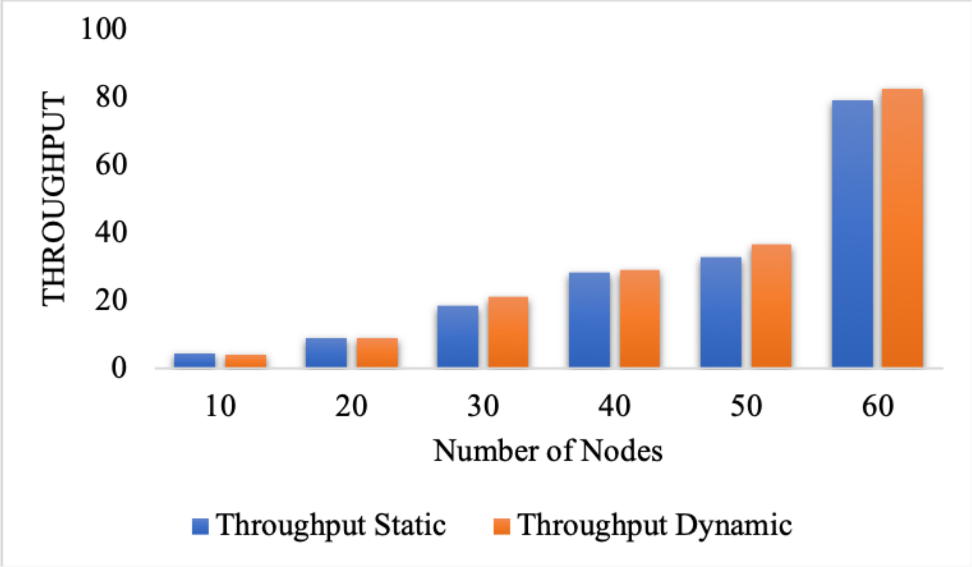


Fig. 11. Static vs. Mobile Throughput QoS for scalable network

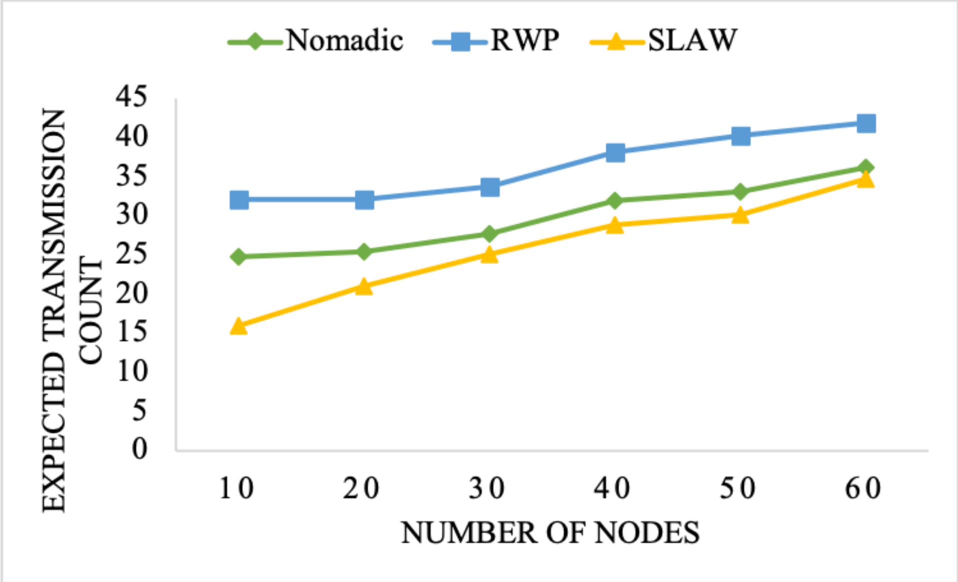


Fig. 12. Nomadic vs. RWP vs. SLAW ETX QoS for scalable network

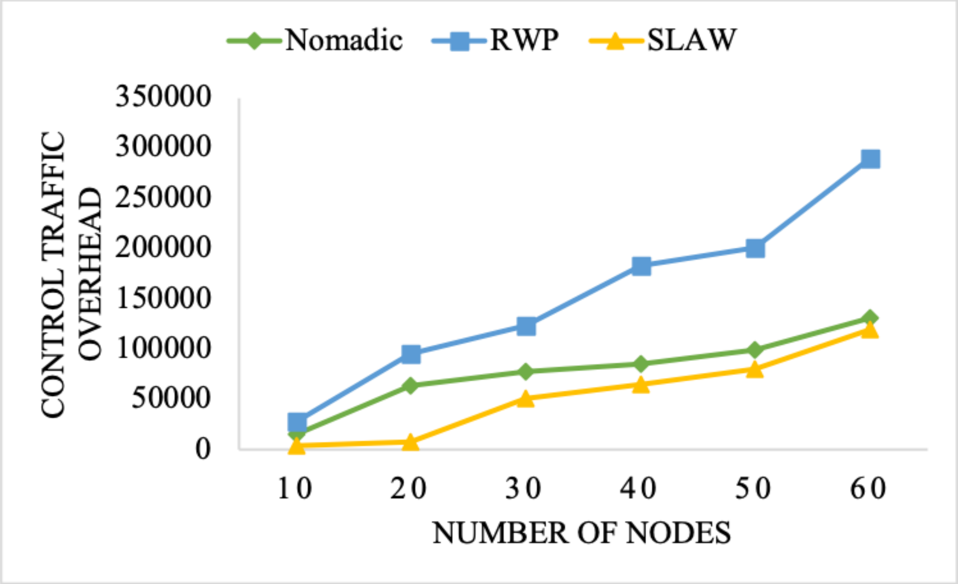


Fig. 13. Nomadic vs. RWP vs. SLAW CTO QoS for scalable network

With the increase in network size. PDR should be high for a better network, even for larger network size. We also know that the higher the PDR value, the better the network efficiency.

Additionally, when these models are compared based on PDR QoS, it can be studied that RWP performs worst with the lowest PDR and SLAW performs the best with the highest PDR for IoV scalable network.

4.2.4 EC Nomadic vs. RWP vs. SLAW

Fig. 15 displays the comparison of EC/power consumption QoS for Nomadic, RWP and SLAW. It is known that the lower the node energy consumption, the better will be the battery life. This will increase the network lifetime. But this can be seen from the figure that EC increases with the increase in scalability of the network for all three models.

Individually, it can be monitored that nodes in the RWP mobility model consumed the most power, while nodes of the SLAW mobility model consumed the least energy among the three models. This infers the use of the SLAW mobility model among these three most widely and popularly used models for the IoV networks.

4.2.5 Total Latency Nomadic vs. RWP vs. SLAW

Fig. 16 displays the comparison of Total Latency QoS

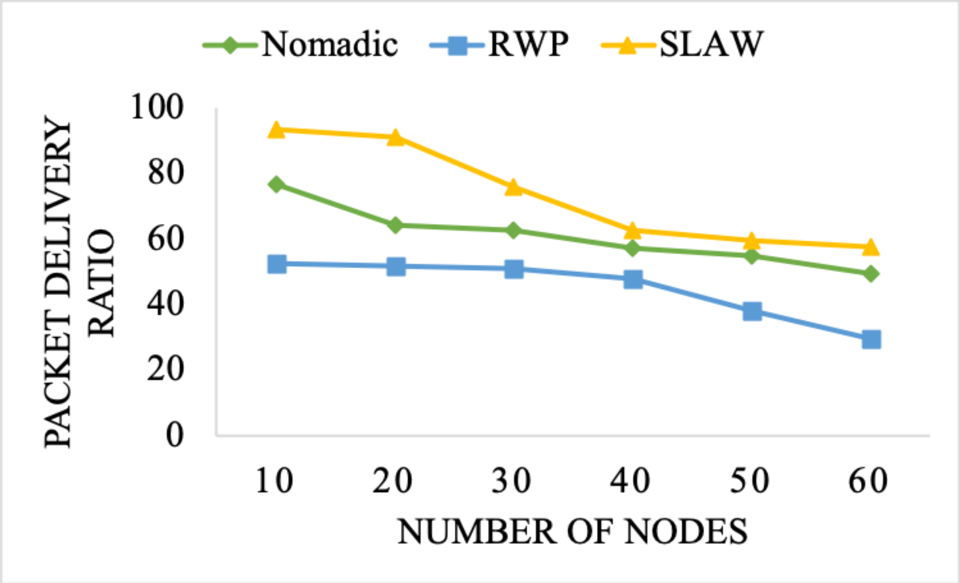


Fig. 14. Nomadic vs. RWP vs. SLAW PDR QoS for scalable network

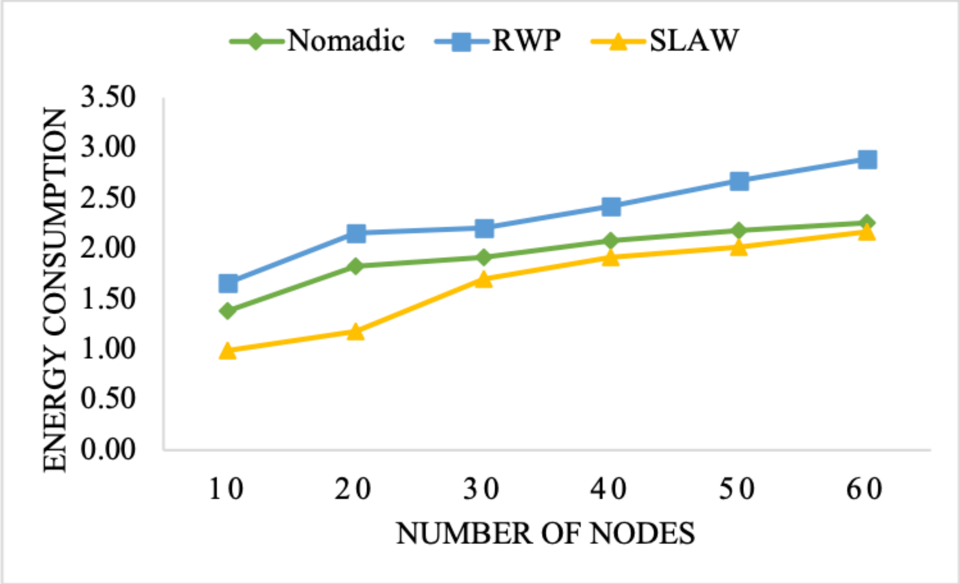


Fig. 15. Nomadic vs. RWP vs. SLAW EC QoS for scalable network

For Nomadic, RWP and SLAW mobility models. It can be studied from the figure that latency increases with the increase in network size. Latency in the network increases with the increase in the number of packets. A higher number of packets are exchanged, creating a high probability of packet collision, network congestion, etc. Ideally, lesser latency in the network will ensure better network efficiency. However, in comparison among the three models, we can see that SLAW shows the lowest latency while RWP shows the highest latency. This infers that nodes face more delay in the RWP mobility model than SLAW. Thus, SLAW proves to be better for IoV networks to ensure the lowest latency and higher network efficiency.

4.2.6 Throughput Nomadic vs. RWP vs. SLAW

Fig. 17 demonstrates the comparison of Throughput QoS for Nomadic, RWP and SLAW mobility models. By throughput, we mean the number of sent packets per minute. So, when the network size increases, a more significant number of packets will be sent, which will increase the throughput value.

It can be seen from the figure that throughput increases with the increase in the network size. Individually, it can be studied that RWP performs worst with the highest sent packets ratio, while SLAW outperforms the other two mobility model s.

We can conclude from the above results and findings that SLAW outperforms the other two mobility models for IoV networks, where RWP performs the worst for the considered QoS parameters and scalable networks. But, this also instantly generates the need for a better model than SLAW that can perform better for

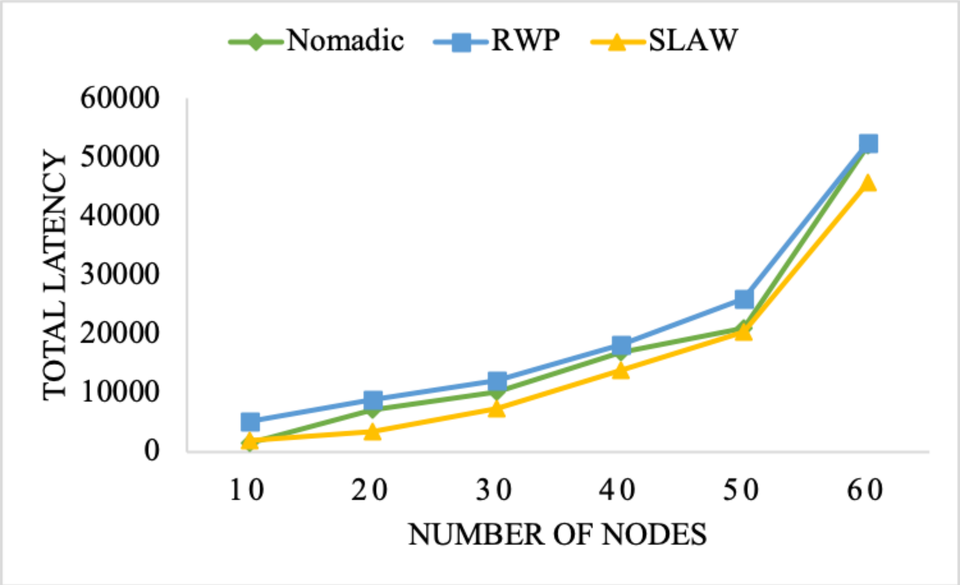


Fig. 16. Nomadic vs. RWP vs. SLAW Total Latency QoS for scalable network

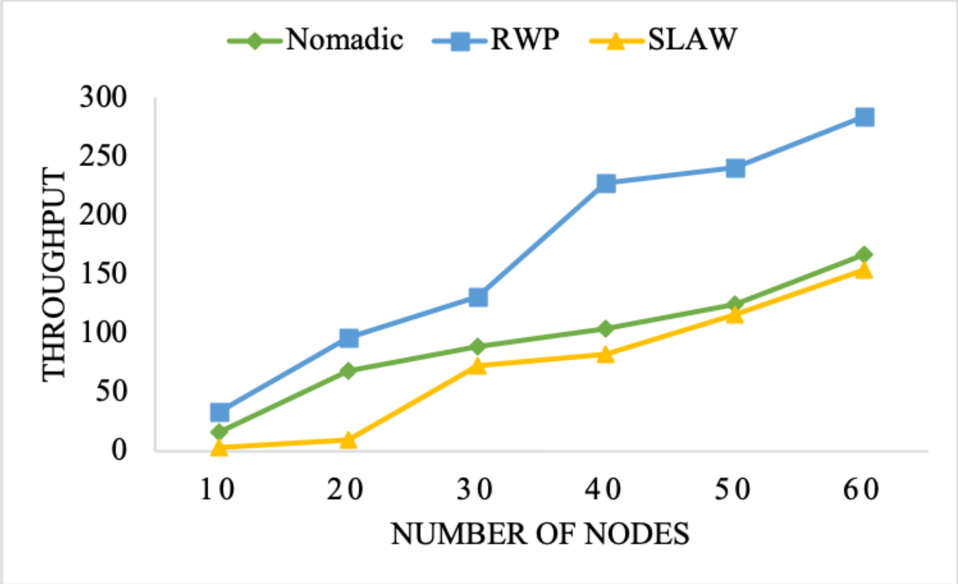


Fig. 17. Nomadic vs. RWP vs. SLAW Throughput QoS for scalable network

High-density IoV network with higher PDR, lower ETX, lower latency and lower EC. This will surely enhance the efficiency of RPL protocol with the use of a mobility model for IoV networks.

5. Conclusion

This paper analyses the transition of RPL performance from IoT to IoV in static and mobile environments. The expected project results define the quality of the network, and QoS guarantees these results significantly. Therefore, we considered QoS parameters (ETX, CTO, PDR, EC, Total Latency and Throughput) for evaluating the RPL protocol in different scenarios. During the literature study, it was pretty prominent that much work has been done in RPL for IoT networks, but IoV networks in context with RPL remain unexplored.

We have then proposed using the RPL protocol for IoV networks by utilizing the mobility models. RPL performance analysis is performed considering network scalability also. QoS parameter correlation showed the inter-effect of these parameters. It was analysed that CTO and Throughput are strongly positively correlated, while PDR and EC are strongly negatively correlated. Likewise, we observed that EC and Total Latency are weakly positively correlated, and PDR and Total Latency are weakly negatively correlated.

In the second scenario, where we compared the static and dynamic environment based on QoS parameters, we noticed high values of EC, CTO and

Latency for mobile/dynamic environment. This generates a substantial need to improvise the RPL protocol for a dynamic environment. Although, high values of PDR in a dynamic environment indicate more stability of the network and fewer packet loss than in a static environment.

Finally, we analysed the RPL protocol for IoV networks using mobility models (Nomadic, RWP and SLAW). The results showed that SLAW outperformed the other two models based on all of the considered QoS parameters. RWP mobility model turned out to be the worst among them. However, high values of EC, latency, ETX, and low PDR for high-density networks in SLAW engender the requirement for improvement in the mobility model. An improved and superior mobility model than SLAW for high-density IoV networks will also ensure higher network performance. The results derived from this study will be enticing and beneficial for the researchers to envisage the network's scalability, reliability, robustness, resilience, stability and other critical qualities.

Our future work will be focused on proposing an improvised composite OF for a scalable IoV network that combines the use of these parameters to guarantee QoS in the network. Developing a mobility model or refining the SLAW model for the highly scalable network is also a potential future direction for researchers.

Declarations

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Conflict of interest: The authors declare no conflict of interest

Availability of data and material: On request

Code availability: Not applicable

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