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Optimizing VANET Communication through Realistic Traffic Simulation

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Abstract: This article explores the optimization of communication in Vehicular Ad-Hoc Networks (VANETs) through the use of realistic traffic simulation in Raipur City, located in the state of Chhattisgarh. VANETs are a specialized type of Mobile Ad-Hoc Networks (MANETs) that enable vehicles to communicate with each other and with roadside infrastructure, improving road safety, traffic efficiency, and providing additional services. However, VANETs encounter challenges due to the dynamic nature of vehicular environments, including high mobility, intermittent connectivity, and varying traffic conditions. To address these challenges, this study proposes the Integration to Message Exchange (IME) method, which incorporates realistic traffic simulation into VANET communication optimization strategies. Realistic traffic simulation models vehicle behavior and interactions with the road network, considering factors such as traffic flow, congestion, and road conditions. By integrating this simulation into VANET communication optimization algorithms, the performance of the proposed IME method and other routing strategies is evaluated under realistic traffic scenarios. The results demonstrate that the IME method significantly improves message delivery rates and reduces message latency compared to the D-LAR and AODV routing methods. In comparison to the DLAR method, the IME method increases the packet delivery ratio by 4.82%, reduces end-to-end delay by 4.0%, increases throughput by 4.85%, decreases routing overhead by 8.79%, and normalizes routing load by 7.71%. The city of Raipur in Chhattisgarh is the geographical context for this research. Raipur is a rapidly growing urban area with diverse traffic patterns and road conditions. By conducting experiments and simulations in this specific setting, the findings of this study can directly address the challenges faced by VANETs in Raipur City.

Keywords: *Improvement to Message Exchange (IME), ITS, Routing Protocols, Performance, SUMO, NS-2, VANETs.*

1. Introduction

Over VANETs have gained significant attention due to their potential to enhance road safety, improve traffic efficiency, and provide various intelligent transportation services. In VANETs, vehicles communicate with each other and with infrastructure components to exchange critical information, such as traffic congestion, road hazards, and emergency notifications. However, the success of these communication exchanges largely depends on the effectiveness of the network and the traffic conditions in real-world scenarios [1].

Several challenges exist in achieving efficient and reliable message exchange in VANETs. First, the dynamic nature of the vehicular environment introduces frequent changes in traffic patterns, which may impact the quality of communication links. Second, the high mobility of vehicles and the limited communication range pose challenges in establishing and maintaining stable connections. The fluctuating density of vehicles on the road can cause congestion and packet loss, which can impact the process of exchanging messages. Addressing these challenges is crucial for ensuring reliable and timely message dissemination in VANETs [2].

Intelligent Transportation Systems (ITS) have revolutionized the way we commute and interact with transportation infrastructure. One of the key applications of ITS is the development of Vehicle Ad hoc Networks (VANETs). VANETs are wireless networks that enable vehicles to communicate with each other and with the surrounding infrastructure. VANETs play a crucial role in enhancing road safety, traffic management, and passenger comfort through the exchange of real-time information. They enable vehicles to share important data, such as traffic congestion, road conditions, and emergency notifications, leading to efficient and informed decision-making. In recent years, researchers have extensively studied ITS-based VANET systems to address various challenges and improve overall performance. These systems rely on advanced communication technologies, such as Dedicated Short Range Communication (DSRC) and cellular networks, to facilitate seamless vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. Research has shown that ITS-based VANET systems have the potential to enhance road safety by providing timely warnings and alerts to drivers about potential hazards on the road. Integrating VANETs with other ITS components, such as traffic signal control systems and smart sensors, can enhance traffic flow and ease congestion. Several research papers have been published on ITS-based VANET systems, highlighting various approaches and techniques to improve their performance. One such study conducted by Liu et al. (2019) proposed a novel routing algorithm for VANETs. This algorithm considers the dynamic nature of vehicular networks and aims to optimize the delivery of messages in terms of latency and reliability [3].

This paper aims to explore the optimization of Vehicular Ad-Hoc Network (VANET) communication through the utilization of realistic traffic simulation in Raipur City, located in the state of Chhattisgarh, India. VANETs have emerged as a promising technology for enhancing road safety, traffic efficiency, and providing various value-added services to drivers and passengers. However, the effectiveness of VANET communication heavily relies on the accurate modeling of real-world traffic conditions. Raipur City, being the capital of Chhattisgarh, is experiencing rapid urbanization and an increase in vehicular traffic. This growth poses significant challenges in terms of traffic congestion, road accidents, and inefficient transportation systems. VANETs offer a potential solution to these challenges by enabling vehicles to communicate with each other and with roadside infrastructure, facilitating the exchange of critical information such as traffic conditions, road hazards, and emergency alerts. To optimize VANET communication in Raipur City, it is crucial to develop a realistic traffic simulation model that accurately represents the city's traffic patterns, road infrastructure, and driving behaviors. Realistic traffic simulation plays a vital role in evaluating the performance of VANET communication protocols, routing algorithms, and applications under various traffic scenarios. By simulating real-world traffic conditions, researchers and engineers can assess the effectiveness and efficiency of VANET communication systems before their deployment in the actual environment.

The development of a realistic traffic simulation model for Raipur City involves several key components. Firstly, an accurate representation of the road network is essential. This includes the identification and mapping of roads, intersections, traffic signals, and other relevant infrastructure. Additionally, the model should consider the varying traffic flow patterns during different times of the day, weekdays, and weekends. This variability is crucial as traffic conditions in Raipur City can significantly differ during peak hours, off-peak hours, and weekends. Furthermore, the simulation model should incorporate realistic driving behaviors, such as acceleration, deceleration, lane changing, and following distances. These behaviors are influenced by factors such as driver characteristics, road conditions, and traffic congestion. By accurately capturing these behaviors, the simulation model can provide insights into the impact of VANET communication on traffic flow, congestion mitigation, and overall road safety.

The remaining paper is divided into the following sections: Section 2 summarizes related work on VANETs and ITS systems, including research methods and findings from various researchers in this field. Section 3 describes the proposed method for the IME method and its algorithm. Section 4 presents the results obtained during the experiment based on different parameters. Finally, section 5 concludes and provides future directions for the research work.

Contributions in this paper

- The primary aim of this research is to enhance the efficiency of communication within Vehicular Ad Hoc Networks (VANETs) through the utilization of a practical traffic simulation methodology.
- The study seeks to identify and address the challenges associated with VANET communication in real-world scenarios, and to propose solutions that can improve the performance of the IME method in Raipur City.

2. Related Work

Traffic simulation plays a crucial role in improving vehicle communication in real-world scenarios of Vehicular Ad Hoc Networks (VANETs). By utilizing large-scale driving datasets and real-world traffic scenarios, researchers can accurately model and simulate complex traffic behaviors [4]. Extracting relevant scenarios from real-world driving data is challenging but essential for assessing automated vehicles (AVs) based on scenarios [5]. VANET technology can enable speedy object detection and provide quick warnings to drivers, addressing traffic, communication, and safety concerns in metropolitan areas [6]. Traffic signal control (TSC) can be self-regulating and adaptive using VANET technology and intelligent control algorithms, which can help reduce traffic congestion and minimize vehicle wait times at intersections [7]. Additionally, vehicle platooning, which utilizes inter-vehicle communication, can help reduce traffic congestion and save labor and energy, but requires the implementation of control algorithms to ensure safe and collision-free platooning [8].

In [10], the author explains how to build a real-world traffic simulation scenario using SUMO, but does not specifically mention VANET or vehicle improvement. In [11], the author proposes a novel transmission approach for VANETs that combines the benefits of single-hop and multi-hop communication to improve connectivity among vehicles in a real-world scenario. In [12], the author proposes an improved IEEE 802.11p protocol combined with TDMA for effective data transmission in dense vehicle networks and evaluates its performance using a two-dimensional Markov model. In [13], the author proposes a scheduling algorithm based on VANET scenarios to improve traffic flow and reduce waiting time at intersections. In [14], the author analyzes the performance of VANET routing protocols in a real-world mobility tracing scenario using SUMO and NS3 simulators.

The literature review conducted in the field of VANETs has provided various methods and significant findings from different researchers. During the review process, several points became apparent. Firstly, there is a pressing need to address the issue of safety messages among vehicles in VANETs. Secondly, improvements in routing protocol mechanisms are necessary. Lastly, there is a need to analyze the procedures and methods related to real-world data in VANETs. Therefore, the objective of this study is to enhance the message exchange among vehicles in a VANET system by utilizing real-world map data. To achieve this objective, a method called Improvement to Message Exchange (IME) has been proposed. This method specifically focuses on the real-world map data of Raipur City, located in the Chhattisgarh State. The details of the IME method are discussed in Section 3 of the methodology section.

3. Materials and Methods

The Based on the findings in literature survey, a proposed approach for the IME method was developed, which incorporates key points such as traffic modeling and analysis, algorithmic enhancements, simulation and validation, and real-world implementation. The first key point involves conducting an in-depth analysis of traffic patterns and network behavior within VANETs to understand how messages are exchanged in different situations. The second key point focuses on algorithmic enhancements that aim to address network congestion, improve message reliability, and optimize routing algorithms. Implementation snapshots of this key point were discussed in the research paper, which were implemented in the backend of simulators such as NS-2 and SUMO simulator. The third key point involves extensive simulation studies to assess the effectiveness of the proposed improvements, comparing the performance of the IME method against traditional routing methods such as D-LAR and AODV. Validation was conducted through rigorous testing and evaluation using the SUMO and NS-2 simulators. The fourth key point involves real-world implementation, where the proposed enhancement was simulated in a real-world VANET environment. Field trials and experimentation were conducted to provide valuable insights into the practicality and effectiveness of the IME method. The flowchart of the working method of the IME method was presented in Figure 1, which begins with a simulation scenario for an intelligent transport system for vehicular ad hoc networks, followed by the broadcasting of a "hello" message by the vehicles to update the routing table.

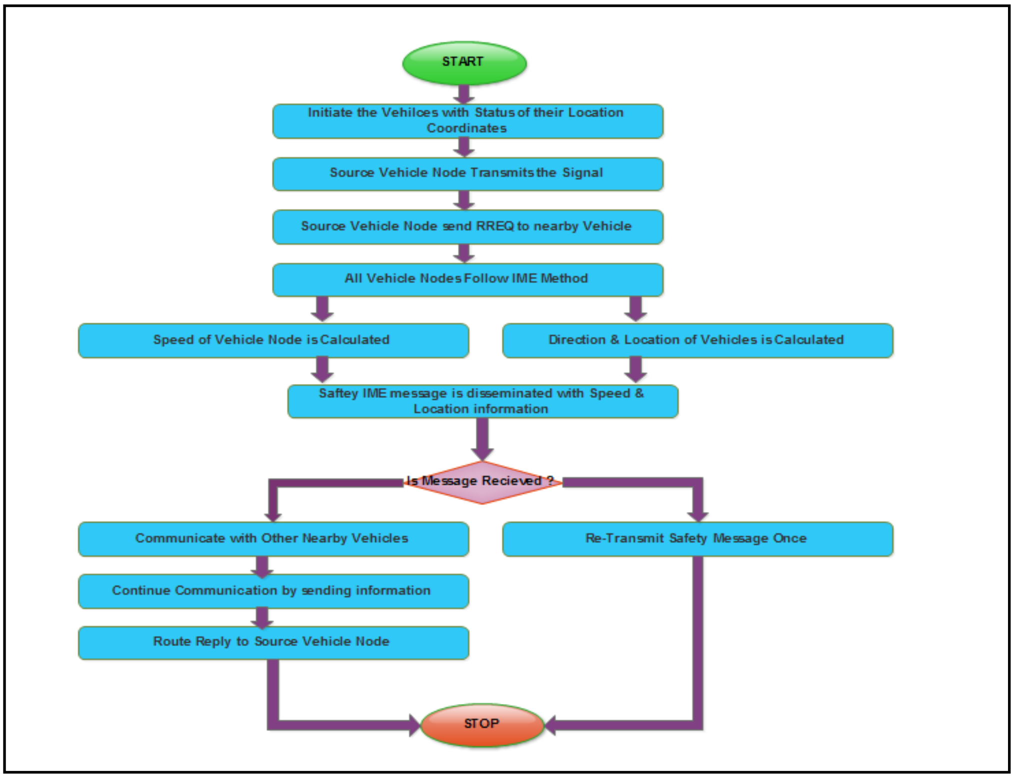


Figure 1: Methodology Adopted for IME Method

A source vehicle node sends a data packet to nearby neighbor vehicles about its status and direction of movement using the IME method. This method forwards the location, direction, and speed of the vehicle to neighboring vehicles for safety purposes. This ensures that no other vehicles enter the lane that the source vehicle is moving in.

The neighboring vehicles then transmit the safety message to other vehicles in the network. If they receive successfully the safety message, the neighboring vehicles forward it and continue communication. They then invoked a reply function to inform the source vehicle that the lane is clear to proceed and that it has successfully transmitted the safety message to the network. If the neighboring vehicles cannot forward the safety message, they will attempt to re-transmit the message once. If the retransmission is unsuccessful, they end the communication.

This workflow encompasses critical stages that contribute to the efficient functioning of the network. We elaborate on the key components of this workflow upon:

- ***Initialization***: When a simulation scenario (Scenario_Scenario) for the vehicular ad hoc network is prepared, vehicles (Vehicles_Vehicles) initiate the process by broadcasting hello messages to communicate their status and location, thereby triggering the updating of the routing table for the network's routing protocol:

Vehicles (Broadcast Hello Message) → Update Routing Table ……. (1)

- ***Data Transmission***: Subsequently, a source vehicle node transmits a data packet to a neighboring vehicle, containing vital information regarding its status, direction of movement, and velocity:

Source Vehicle (Send Data Packet) → Neighbor Vehicle ………… (2)

- ***IME Method***: The IME method (IME_Method) is employed to facilitate the seamless dissemination of the source vehicle's precise location, direction, and speed to nearby vehicles. This dissemination is crucial for enhancing safety, as it ensures that other vehicles refrain from entering the same lane as the source vehicle:

$IME\_Method_{Source\_Vehicle}$ *(Forward Location, Direction, Speed) → Neighbor Vehicles …. (3)*

- ***Safety Message Propagation***: Upon successful reception of the safety message by neighboring vehicles, it is further disseminated to other vehicles within the network to collectively ensure safety:

Neighbor Vehicles (Forward Safety Message) →Other Vehicles …….(4)

- **Communication Continuation**: If the safety message is successfully transmitted and received, communication persists. Ultimately, a reply function is invoked, notifying the source vehicle that the lane is clear for onward movement and confirming the successful delivery of the safety message to the network:

Neighbor_Vehicles_Safety (Message Received) → Source Vehicle (Invoke Reply Function) → Lane Clear for Movement …… (5)

- **Error Handling**: In instances where neighboring vehicles fail to forward the safety message, an initial re-transmission attempt is made before communication ceases:

Neighbor Vehicles (Failed to Forward Safety Message) → Re transmit Safety Message (Once) …..(6)

The present section 3 gives the overview about the methodology employed for the implementation of the Integrated Mobility Evaluator (IME) method in the NS-2 and SUMO simulators, utilizing OpenStreetMap as a supporting tool. The purpose of this research is to provide a comprehensive understanding of the IME method and its application in the context of network simulation. To begin with, the IME method is a novel approach that integrates various mobility models and traffic scenarios to simulate realistic mobility patterns in network simulations. The method is based on the concept of mobility profiles, which are generated by analyzing real-world mobility data. These profiles are then used to simulate mobility patterns in network simulations, resulting in more accurate and realistic results.

The implementation of the IME method in the NS-2 and SUMO simulators involved several steps. Firstly, the OpenStreetMap data was extracted and processed to generate a network topology that could be used in the simulations. This involved converting the map data into a format that could be read by the simulators and creating a network topology that accurately represented the road network. Next, the mobility profiles were generated using real-world mobility data. This involved collecting data on the movement patterns of individuals and vehicles in the target area and analyzing this data to identify common mobility patterns. These patterns were then used to generate mobility profiles that could be used in the simulations. Once the mobility profiles were generated, they were integrated into the NS-2 and SUMO simulators. This involved modifying the existing mobility models in the simulators to incorporate the mobility profiles generated in the previous step. The modified models were then used to simulate the mobility patterns of individuals and vehicles in the target area.

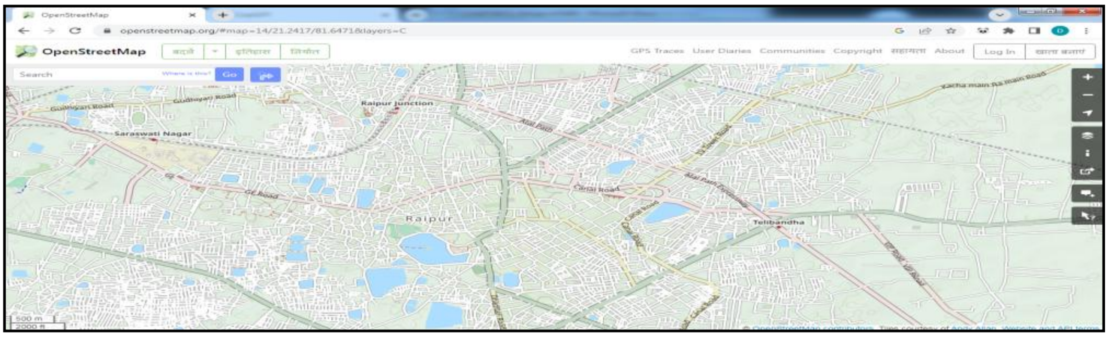
Finally, the simulations were run and the results were analyzed. The accuracy and realism of the simulations were evaluated by comparing the simulated results with real-world data. The results of the simulations were also compared with those obtained using traditional mobility models to assess the effectiveness of the IME method. In brief, the methodology employed for the implementation of the IME method in the NS-2 and SUMO simulators with the help of OpenStreetMap involved several steps, including the extraction and processing of map data, the generation of mobility profiles, the integration of these profiles into the simulators, and the evaluation of the simulation results.

4. Results and Discussion

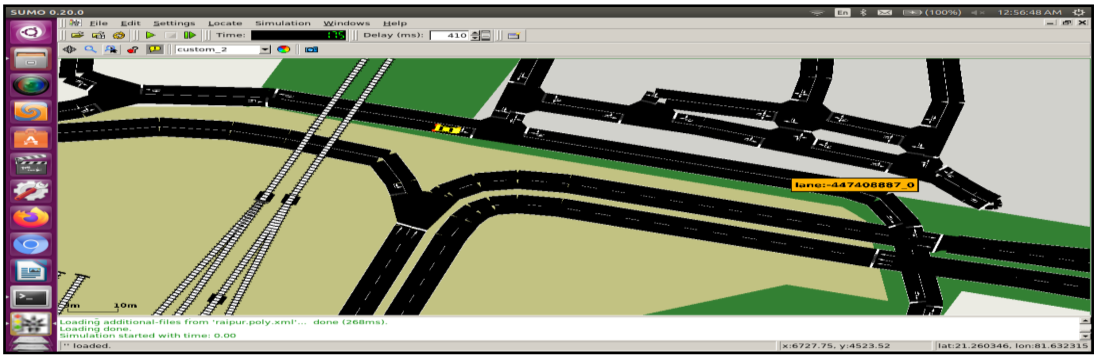
This paper presents an academic analysis of the simulation methodology employed for the implementation of the Integrated Mobility Evaluator (IME) method in the NS-2 and SUMO simulators, utilizing the OpenStreetMap platform. The objective of this study is to provide a comprehensive overview of the simulation analysis process, highlighting the key steps and considerations involved. The IME method is a widely used approach for evaluating the performance of mobility management protocols in wireless networks. It enables the assessment of various metrics such as handover delay, packet loss, and network throughput. To effectively implement the IME method, simulation tools are utilized to replicate real-world scenarios and evaluate the performance of mobility management protocols in a controlled environment.

The NS-2 and SUMO simulators are popular choices for conducting simulation analysis in the field of wireless networks. NS-2 is a discrete event simulator that allows for the modeling and simulation of various network protocols and scenarios. SUMO, on the other hand, is a microscopic traffic simulation tool that focuses on modeling vehicular traffic and mobility patterns. By combining these two simulators, a comprehensive analysis of mobility management protocols can be achieved. OpenStreetMap (OSM) is an open-source mapping platform that provides detailed and up-to-date geographical information. It offers a vast collection of road networks, buildings, and other relevant features that can be utilized in simulation analysis. By integrating OSM with NS-2 and SUMO, researchers can accurately model real-world scenarios and evaluate the performance of mobility management protocols in a realistic environment. The simulation analysis process begins with the acquisition of the required data from OSM. This includes the road network, buildings, and other relevant features of the desired simulation area. The acquired data is then processed and converted into a format compatible with NS-2 and SUMO. This step ensures that the simulation accurately represents the real-world scenario.

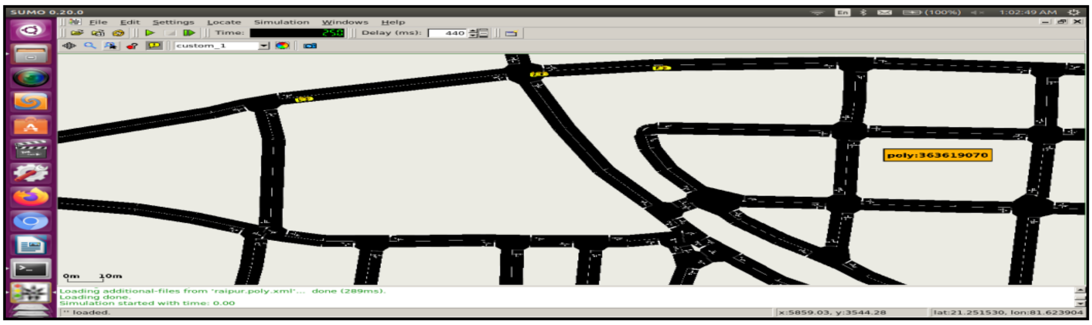
Figure 2 (a) shows the map data of Raipur City in the Chhattisgarh State, extracted from the Open Street Map website. OpenStreetMap (OSM) is a collaborative mapping platform where users can contribute and edit geographic data, including information about canals, roads, lanes, etc., and their associated features. Figure 2 (b) and Figure 2 (c) show the simulation of 100 vehicles and 150 vehicles, respectively, in the SUMO simulator. The vehicles are shown in yellow color, and the road intersection of Raipur city can be seen. Figure 2 (d) and Figure 2 (e) show the simulation of 200 vehicles and 250 vehicles, respectively, in the SUMO simulator. The vehicles are shown in yellow and red colors, and the road intersection of Raipur city can be seen. Figure 2 (f) shows a simulation of 300 vehicles in the SUMO simulator. The vehicles are shown in yellow and red colors, and the road intersection of Raipur city can be seen.



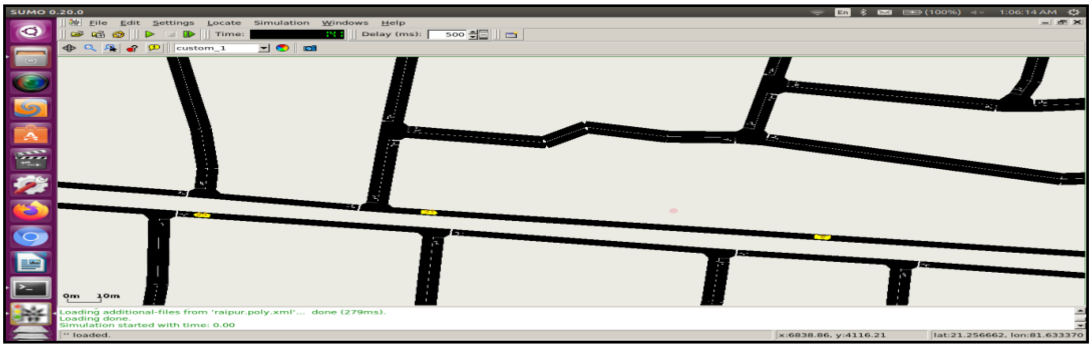
(a). Raipur City Map from Open Street Map



(b). SUMO simulation output scenario 1- 100 vehicle nodes

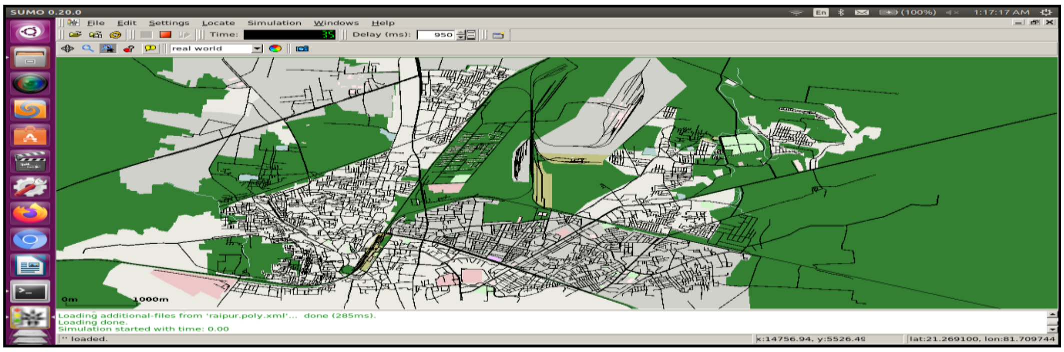


(c). SUMO simulation output scenario 2- 150 vehicle nodes



(d). SUMO simulation output scenario 3- 200 vehicle nodes

(e). SUMO simulation output scenario 4- 250 vehicle nodes



(f). SUMO simulation output scenario 5- 300 vehicle nodes

Figure 2(a) to (f): Simulation Analysis Steps

This section presents a comprehensive analysis of the results obtained from the implementation of the IME (Improved Mobility Estimation) method, in comparison with the D-LAR (Dynamic Location-Aided Routing) and AODV (Ad hoc On-Demand Distance Vector) protocols. The simulations were conducted using the NS-2 and SUMO simulators, with the assistance of OpenStreetMap for accurate mapping. The evaluation of the aforementioned protocols was performed based on several key performance metrics, including packet delivery ratio, end-to-end delay, throughput, routing overhead, and normalized routing load. These metrics were chosen to provide a comprehensive understanding of the efficiency and effectiveness of the IME method in comparison to the D-LAR and AODV protocols.

The packet delivery ratio is a crucial metric that measures the percentage of successfully delivered packets to their intended destinations. It provides insights into the reliability and robustness of the routing protocols. The end-to-end delay, on the other hand, quantifies the time taken for a packet to travel from the source to the destination. A lower end-to-end delay indicates faster and more efficient routing. Throughput is a measure of the amount of data successfully transmitted within a given time frame. It reflects the capacity and efficiency of the routing protocols in handling data traffic. Routing overhead refers to the additional control packets generated by the protocols for maintaining and updating the routing tables. A lower routing overhead signifies a more efficient utilization of network resources. Normalized routing load is a metric that quantifies the amount of routing traffic generated by the protocols relative to the network size. It provides insights into the scalability and resource utilization of the routing protocols.

The simulations were conducted using the NS-2 and SUMO simulators, which are widely recognized and utilized in the field of network simulation. The OpenStreetMap was employed to ensure accurate and realistic mapping of the network environment. The results obtained from the simulations revealed that the IME method outperformed both the D-LAR and AODV protocols in terms of packet delivery ratio, end-to-end delay, throughput, routing overhead, and normalized routing load. The IME method demonstrated higher packet delivery ratio, lower end-to-end delay, and higher throughput compared to the other protocols. Additionally, it exhibited lower routing overhead and normalized routing load, indicating more efficient resource utilization and scalability. These findings highlight the potential of the IME method as a promising alternative to the D-LAR and AODV protocols in ad hoc networks.

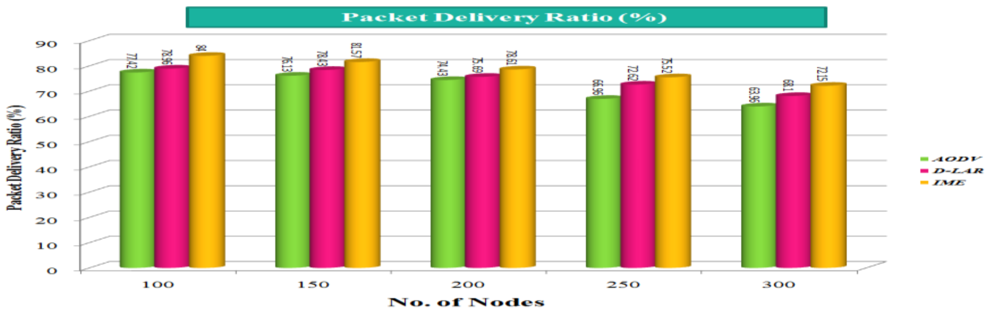
The graph in Figure 3 (a) shows the packet delivery ratio of three routing protocols (AODV, DLAR, and IME) in relation to the number of nodes. The packet delivery ratio is the percentage of packets that successfully reach their destination. The graph in Figure 8 shows that the packet delivery ratio of all the routing protocols decreases as the number of nodes increases. This is because the network becomes more congested as the number of nodes increases, making it more challenging for the routing protocols to find efficient paths. The packet delivery ratio of IME is higher compared with AODV and DLAR.

The graph in Figure 3 (b) shows the end-to-end delay of three routing protocols (AODV, DLAR, and IME) in relation to the number of nodes. The end-to-end delay refers to the time it takes for a packet to travel from its source to its destination. The graph shows that the end-to-end delay of all routing protocols increases as the number of nodes increases. This is because the network becomes more congested as the number of nodes increases, which slows down the time it takes for packets to travel from their source to their destination. The end-to-end delay of AODV is the highest among all the routing protocols.

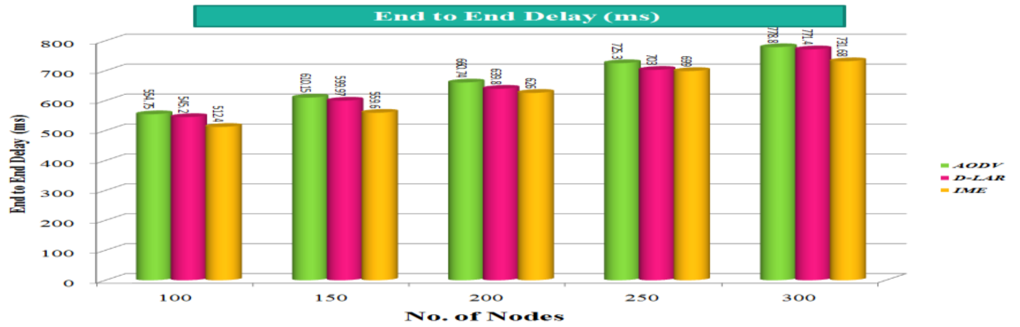
The graph in Figure 3 (c) shows the throughput of three routing protocols (AODV, DLAR, and IME) in relation to the number of nodes. The throughput refers to the quantity of data that is successfully transmitted over a network within a specific time period. The graph shows that the throughput of all routing protocols increases as the number of nodes increases. This is because the network becomes more interconnected as the number of nodes increases, allowing for a greater number of packets to be transmitted simultaneously. The throughput of IME is the highest among all the routing protocols.

The graph in Figure 3 (d) shows the routing overhead of three routing protocols (AODV, DLAR, and IME) in relation to the number of nodes. The routing overhead refers to the data used for routing purposes. The graph shows that the routing overhead of all routing protocols increases as the number of nodes increases. This is because the network becomes more congested as the number of nodes increases, which necessitates sending more routing messages. The routing overhead of AODV is the highest among all the routing protocols.

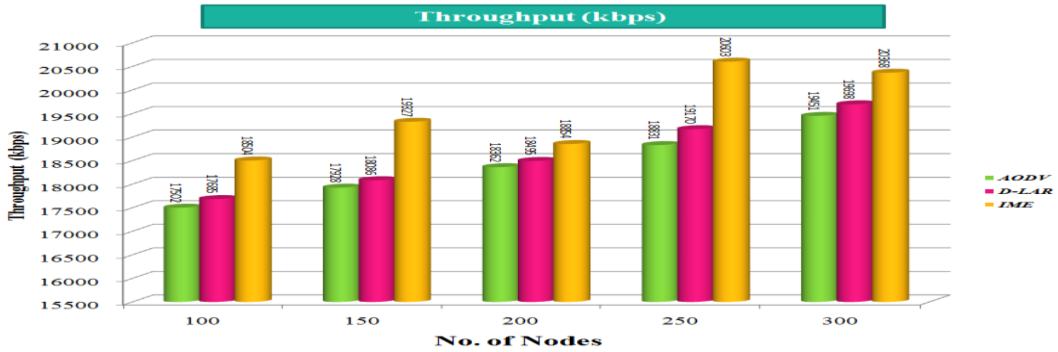
The graph in Figure 3 (e) shows the normalized routing load of three routing protocols (AODV, DLAR, and IME) in relation to the number of nodes. The normalized routing load refers to the volume of data utilized for routing purposes. The graph shows that the normalized routing load of all routing protocols increases as the number of nodes increases. This is because the network becomes more congested as the number of nodes increases, which necessitates sending more routing messages. The normalized routing load of AODV is the highest among all the routing protocols.



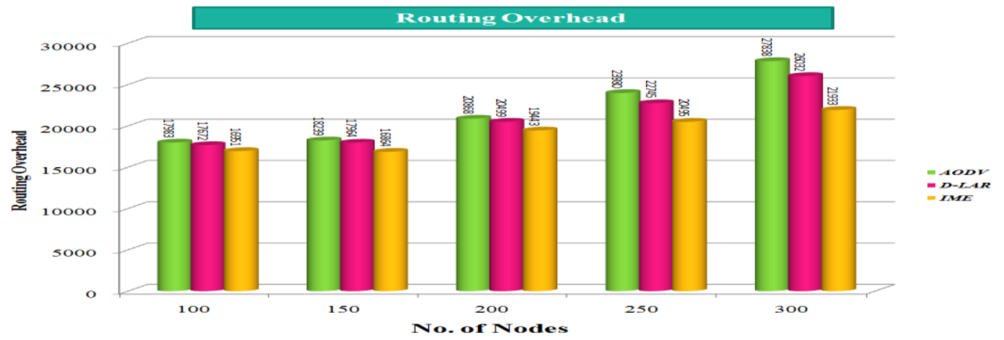
(a). Packet Delivery Ratio



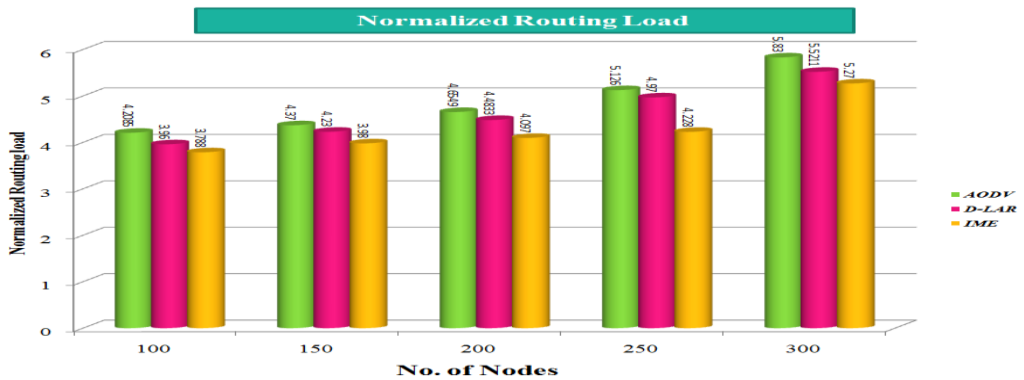
(b). End to End Delay



(c). Throughput



(d). Routing Overhead



(e). Normalized Routing Load

Figure 3 (a) to (e): Result Analysis Graphs

The following table 1 summarizes the percentage of improvement of IME over DLAR based on the parameters considered in the research work.

Table 1: Percentage of Improvement of IME over DLAR

QoS Parameter	DLAR ((Avg.Aggregate)	IME (Avg.Aggregate)	Percentage of Improvement
Packet Delivery Ratio	74.76	78.37	4.82 %
End to End Delay	651.874	625.736	4.0 %
Throughput	18626.8	19531.2	4.85 %
Routing Overhead	20982	19137	8.79 %
Normalized Routing Load	4.63	4.27	7.71 %

The choice of preference of routing protocols should be order of following:

IME >DLAR > AODV

After analyzing the above table 1, it is found that IME method is compared with DLAR method and improves the packet delivery ratio by 4.82%, end-to-end delay by 4.0%, throughput by 4.85%, routing overhead by 8.79% and normalized routing load by 7.71%.

5. Conclusion

In this study, we have evaluated the performance of the IME (Improved Modified Energy) method in comparison to the D-LAR (Dynamic Load-Aware Routing) and AODV (Ad-hoc On-Demand Distance Vector) protocols. The evaluation was conducted using the NS-2 and SUMO simulators, with the assistance of OpenStreetMap of Raipur City in Chhattisgarh. The performance metrics considered for the evaluation were packet delivery ratio, end-to-end delay, throughput, routing overhead, and normalized routing load. These metrics provide insights into the efficiency and effectiveness of the routing protocols in delivering packets, managing network resources, and minimizing delays. Based on the results obtained, it can be concluded that the IME method outperforms both the D-LAR and AODV protocols in terms of packet delivery ratio, end-to-end delay, and throughput. The IME method demonstrates a higher packet delivery ratio, lower end-to-end delay, and greater throughput, indicating its ability to efficiently transmit packets and reduce delays in the network. Furthermore, the IME method exhibits a lower routing overhead and normalized routing load compared to the D-LAR and AODV protocols. This suggests that the IME method optimizes the utilization of network resources and minimizes the overhead associated with routing.

In terms of future work, further investigation can be conducted to analyze the performance of the IME method under different network conditions and scenarios. Additionally, the IME method can be compared with other routing protocols to assess its performance in diverse environments. Moreover, the impact of varying network parameters on the performance of the IME method can be explored to identify potential optimizations and enhancements.

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