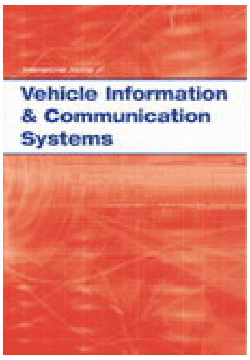

International Journal of Vehicle Information and Communication Systems

ISSN online: 1741-8208 - ISSN print: 1471-0242
https://www.inderscience.com/ijvics

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DOI: 10.1504/IJVICS.2024.10066105

Article History:

Received:	25 January 2024
Last revised:	23 May 2024
Accepted:	07 June 2024
Published online:	27 January 2025

Performance analysis of AODV-based VANETs in Guwahati city: a comparative study of propagation models

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Abstract: As a part of technological advancement, vehicular communication plays a vital role in modern day of urbanisation. The performance of Vehicular Ad-hoc Network (VANET) mainly depends on routing protocols and propagation models. This study looks into how different propagation models affect VANET performance in real time environment. As vehicle environments are dynamic and demanding, selecting an accurate propagation model is essential to create reliable communication. In this work, performance of widely used propagation models, such as Free Space Propagation (FRIIS), ITU-R P.1411 Loss Model and Nakagami fading are assessed and contrasted in Adhoc On-Demand Vector (AODV) routing-based VANET, considering various real-time traffic scenarios of Guwahati city using SUMO and NS3 platform. The results show that ITU-R P.1411 propagation model gives better Average Throughput, End-to-End Delay, End-to-End Jitter Delay and MAC/PHY-Overhead, whereas FRIIS routing protocol gives better Packet Delivery Ratio of Basic Safety Messages, Average Routing Goodput and Packet Delivery Ratio.

Keywords: VANET; AODV; propagation model; FRIIS; ITU-R P.1411; Nakagami.

Reference to this paper should be made as follows: Borah, R.J. and Ganga, D. (2025) ‘Performance analysis of AODV-based VANETs in Guwahati city: a comparative study of propagation models’, *Int. J. Vehicle Information and Communication Systems*, Vol. 10, No. 1, pp.61–84.

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1 Introduction

A specific subset of Mobile Ad-hoc Networks (MANETs) that promote communication between vehicles and infrastructure under dynamic vehicular environment is known as VANETs (Quy et al., 2022; Sohail et al., 2023; Campolo and Molinaro, 2011; Feukeu and Snyman, 2023). The distinct attributes of VANETs, namely their elevated mobility, swift alterations in network topologies and requirement for low-latency communication, provide noteworthy obstacles to dependable and efficient data transfer. When it comes to VANET research, choosing and assessing propagation models is essential to create communication protocols that can adjust to the unique characteristics of vehicle settings. To ensure the public safety in the roads, it is very important to implement Vehicle-to-Vehicle (V2V) communication and Vehicle-to-Infrastructure (V2I) communication (Hbaieb et al., 2022; Vegni and Little, 2021) with proper routing protocol and suitable propagation model so that emergency information can be transferred to targeted destinations within a minimal duration of time.

Propagation models in VANETs (Sharma and Harit, 2021) are essential instruments for forecasting radio signal behaviour in the automotive environment. Selecting the right propagation model has a direct influence on how realistic simulations turn out to be and how communication protocols designed specifically for VANETs are developed. In order to guarantee the reliability and effectiveness of communication protocols implemented in actual automotive contexts, researchers must comprehend the performance consequences of various propagation models in a variety of situations, including urban, suburban and highway environments.

In this work, entire performance evaluation has been executed in VANET using AODV (Sindhwani et al., 2022; Upadhyaya and Shah, 2019; Ali et al., 2020) as routing protocol. Since it can adapt to changing network conditions and handle them well, the AODV routing protocol is frequently regarded as one of the most dependable protocols used in VANETs. By operating on-demand and creating routes only when necessary, AODV minimises costs and conserves bandwidth. Its proactive route maintenance method makes sure that the network architecture is updated on a regular basis, which enables quick adjustments to variations in vehicle movement and network connectivity, hence AODV is a reliable choice for boosting data flow and communication among vehicles in VANETs.

By investigating the nuances of signal propagation in dynamic vehicular scenarios, this analysis seeks to find the impact of different propagation models on the performance of VANETs. The aim of this paper is to provide important insights that can guide the design and optimisation of communication protocols to achieve improved efficiency, safety and reliability in future Intelligent Transportation Systems (ITS) (Mohanta et al., 2022; Gao and Tian, 2022) by assessing and contrasting the effectiveness of various propagation models.

The primary objective of the work is to find the performance of VANET for three major propagation models, namely FRIIS (Erunkulu et al., 2023), ITU-R P.1411 Loss Model (Salous, 2023) and Nakagami fading model (Zhang et al., 2023) by varying the number of vehicles in a real time traffic scenario. The real time traffic scenario is extracted from the open street map and given to Simulation of Urban Mobility (SUMO) (Lim et al., 2017) environment to produce the vehicle movement. Networking between the vehicles are done by Network Simulator version 3 (NS3) (Riley and Henderson, 2010). The considered performance metrics for this investigation are Average Routing Throughput, Average Routing Goodput, End-to-End Delay, End-to-End Jitter Delay, Packet Delivery Ratio, Packet Loss Ratio, MAC/PHY-Overhead and Packet Delivery Ratio of Basic Safety Messages.

The paper is presented in five sections, where Section 2 gives an overview of the related work and Section 3 describes the proposed performance analysis framework with the considered wireless communication standards. In Section 4, comparative result analysis, limitations and future scopes are explained and finally conclusion is covered in Section 5.

2 Literature review

Owing to dynamic nature and behaviour of vehicles, it becomes a challenging task in wireless networking technology to transmit sensitive vehicular information in a short duration of time. So, selection of suitable propagation model along with the routing protocols are most important parameters during the transmission model design process. Numerous researches are going on for the last two decades to find the optimal propagation model under various environments in the VANETs to ensure effective efficiency of transmission channel. Some of the relevant research works are mentioned in Table 1, along with their considered propagation model, performance parameters, simulated platform and results.

The performance of the network is largely dependent on the propagation model applied in VANET simulations. Selection of a propagation model has an effect on connectivity, interference accuracy, reliability and signal strength. The presence of buildings, towers, flyovers, overpasses, tunnels and hills in or near to the road environment can largely impact on the signal transmission in VANETs. Hence simulation of propagation model in VANET should consider the factors such as path loss, shadowing and multipath fading.

Table 1 Overview of related works

Work	*Propagation model*	*Performance parameters*	*Platforms*	*Performance*
Shuhaimi et al. (2021)	Free Space, Two Ray Ground, Nakagami	Average Throughput, Packet Loss, End-to-End Delay	SUMO & NS2	Free Space Model is the most suitable
Malik and Sahu (2019)	Nakagami and Rayleigh	Packet Loss Ratio and Average Delay	SUMO, NetSim & NS2	Rayleigh with DSR protocol is preferable
Angeles et al. (2016)	Free Space, LogNormal Shadowing, Two Ray Ground and Nakagami	Packet Delivery Ratio and End-to-End Delay	SUMO & OMNET++	LogNormal Shadowing and Nakagami are more suitable.
Malik and Sahu (2018)	Rayleigh, Nakagami-m and Rician fading	Throughput and Packet Delivery Ratio	SUMO & NetSim	Nakagami-m with DSR protocol is the most suitable
Poonia and Singh (2012)	Free Space, Two Ray Ground, Shadowing and Nakagami	Throughput, Packet Loss, Transmitted Packet and Received Packet	VanetMobiSim & NS2	Nakagami is more suitable then others
Martinez et al. (2009)	Two Ray Ground, Distance Attenuation Model (DAM), Building Model (BM) and Building and Distance Attenuation Model (BDAM)	Warning Notification Time, Number of Packet Received, % of blind vehicle detected	NS2	BM and BDAM both are preferable
Hota et al. (2022)	Free Space, Two Ray Ground, Log Distance and Nakagami fading	Average Throughput, End-to-End Delay, Packet Delivery Ratio, Average Routing Goodput	SUMO & NS3	Log Distance for min E2E Delay and max PDR, FRIIS and Two ray ground for better Throughput and Goodput.
Iturbe-Olleta et al. (2023)	Two ray interference, Simple path loss, Nakagami and Adjusted Propagation Model	Received Power and Mean squared error	SUMO, OMNET++ & TraCI	Adjusted Model is the most suitable
Qureshi et al. (2016)	Free Space, Two Ray, Proposed RPM, CORNER	Path Loss, Packet Delivery Ratio and Received Signal Strength	Hardware Setup	Proposed Model is the most suitable
Bastani et al. (2016)	Free Space, Simple obstacle model and Measurement Based Model	Packet Reception Rate	OMNET++	Performance of Measurement-Based Model is worse.

Table 1 Overview of related works (continued)

Work	*Propagation model*	*Performance parameters*	*Platforms*	*Performance*
Hussain (2022)	Two-Ray ground and Free Space	Average Throughput, Average Latency and Average Packet Drop	NS2.34	Free Space is suitable in terms of Packet Drop but Two-Ray Ground is most suitable in terms of Avg. Throughput and Avg. Latency.
Hussain and Khan (2021)	Two-Ray Ground, Free Space and Shadowing	Average Throughput, Average Latency and Average Packet Drop	NS2	Free Space performed well in terms of Avg. Throughput and Avg. Packet Drop, but for Avg. latency Two ray Ground is most suitable.
Puttagunta and Agrawal (2020)	Rayleigh and Lee Microcell	Throughput and Packet Dropped	EstiNet	Lee Microcell is the most suitable
Brahmia and Tolba (2020)	OLSR, AODV and DSDV-based fading and No fading Model	Packet Delivery Ratio, End-to-End Delay and Throughput	SUMO & NS3	AODV is most robust under fading
Dessai and Sutar (2019)	Nakagami or Log Normal-Based Existing model, Proposed Radio Propagation Channel	Throughput and Number of Packet Collided	.NET Framework & C#	Throughput of proposed model improved by 40% and Collision rate of proposed system is reduced by 88% as compared to existing model
Boucetta et al. (2019)	Two-Ray Ground and V-PROPAG model	Packet Loss and Rate of discovered routes	Network Simulator with V-MBMM	V-PROPAG model the most suitable
Hafeez et al. (2009)	Probabilistic Propagation Models - Ricean, Nakagami, Rayleigh and Lognormal	Probability Density Function, Time Delay and Success Rate	NS2 & MATLAB	Ricean is the most appropriate model
Eltahir (2007)	Free Space, Two-Ray Ground and Shadowing	Throughput, Packet sent, Packet dropped, Packet Delivery Ratio, Routing overhead	NS2	Free Space is the most suitable

Table 1 Overview of related works (continued)

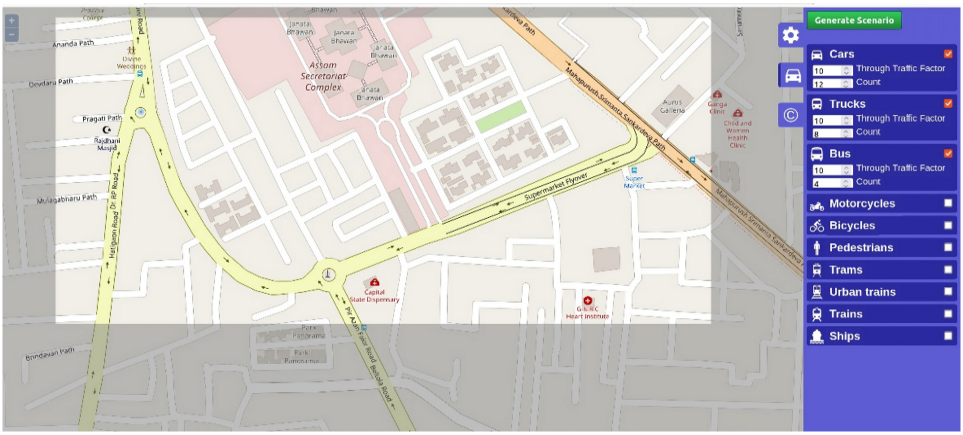
Work	*Propagation model*	*Performance parameters*	*Platforms*	*Performance*
Khan and Qayyum (2009)	AODV and OLSR-based Nakagami Propagation Model	Packet Delivery Ratio, Average End-to-End Delay and Normalised Routing Overhead	NS2, MOVE & SUMO	OLSR-based Nakagami model give better performance
Singh (2012)	Two Ray Ground and Nakagami	Packet Delivery Ratio, Average End-to-End Delay,	NS2, MOVE & SUMO	Nakagami is preferable
Martinez et al. (2010)	Two Ray Ground, Nakagami, BDAM and Proposed RAV	Warning notification time, Percentage of blind vehicle detected and Number of Packet Received	SUMO & NS2	Proposed RAV model gives most suitable performance

In the recent years, numerous studies have explored the impact of propagation models on VANET performance. The FRIIS model facilitates long-range communication in conditions with minimal road obstacles, serving as a baseline in ideal open-space scenarios. It acts as a reference for more complex models, aiding in understanding how additional factors impact results. The Nakagami fading model known for its flexibility, accurately represents diverse fading conditions due to multipath reflections and scattering, making it especially suitable for urban communication scenarios. However, the propagation model recommended by International Telecommunication Union (ITU), the ITU-R P.1411 has not been evaluated in the existing literature, which has the compatibility of both urban and suburban areas and covers a frequency range of 30 MHz to 100 GHz making it applicable to various modern communication systems, including 5G. Moreover ITU-R P.1411 standard takes into consideration 'urban canyon' effects, which enhances accuracy in situations with obstructions and tall buildings. Again, in the existing literature only a few performance metrics have been considered for the evaluation process. This study addresses this gap by considering ITU-R P.1411 as one of the advanced propagation models and by considering all possible performance metrics, which can provide nuanced analysis of how this propagation models influence the performance of VANET. Also, the inclusion of limitations and possible enhancement of the proposed method offers a new perspective to see the possibilities and challenges in the domain of VANET research.

3 Proposed performance evaluation model

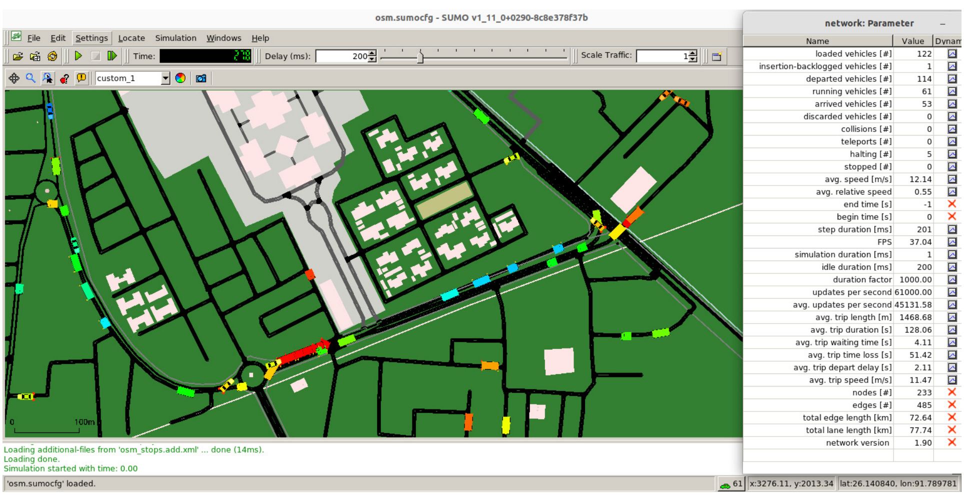
Owing to their highly mobile nature, VANETs require an efficient routing mechanism together with appropriate routing protocols and propagation models for successful data dissemination. In the past, several different routing protocols have been suggested. This article compares, in a real-world VANET context, the performance of VANETs using three alternative propagation models: FRIIS, ITU-R P.1411 and Nakagami fading. A real-time traffic scenario of Guwahati city, hub of Assam in North-East India is obtained from Open Street Map (OSM) as illustrated in Figure 1.

Figure 1 Real traffic scenario generation in OSM (see online version for colours)



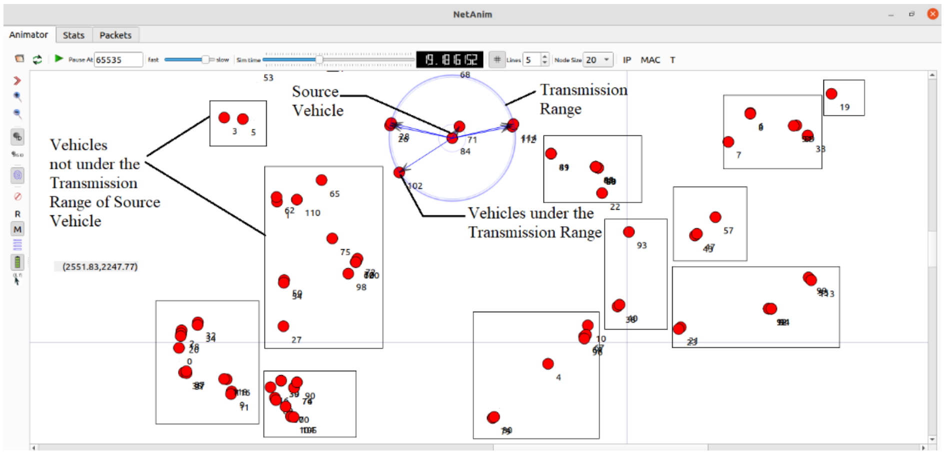
Mobility file for network simulation is created in SUMO platform using the imported OSM as shown in Figure 2, which includes details of each vehicle such as vehicle id, coordinates, speed, position and direction.

Figure 2 Simulated representation of the specified traffic scenario using SUMO (see online version for colours)



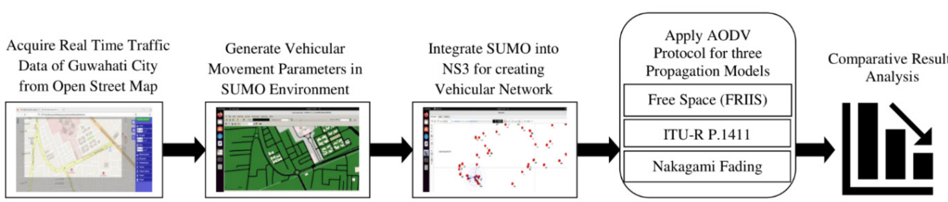
The network simulation of communication in the real time VANET of the chosen area in Guwahati city has been executed in NS-3 network simulator using the SUMO mobility file and network parameter settings. The snippet of simulation is illustrated in Figure 3.

Figure 3 Representation of vehicle information dissemination in NS3 (see online version for colours)



The overall approach adopted to analyse the significance of the propagation models FRIIS, ITU-R P.1411 and Nakagami fading in VANET communication scenarios is depicted in the Figure 4 and detailed flow of processes is shown in Figure 5.

Figure 4 Proposed model for performance evaluation of VANET (see online version for colours)



The proposed methodology analysis the performance of different propagation models in AODV-based vehicular network. The results are compared using network performance metrics to highlight importance of choosing right model for VANET communication.

The effectiveness of the network's routing protocols is assessed by varying the propagation models and vehicle count. Fading, shadowing and path loss are important ideas that affect wireless signal propagation. ITU-R P.1411 helps estimate radio wave propagation, while the FRIIS model provides a baseline for determining signal intensity. Small-scale fading in VANETs is accurately modelled by the versatile Nakagami fading model. The parameters set in NS3 for the simulation of VANET are mentioned in Table 2.

Figure 5 Flowchart of the proposed model (see online version for colours)

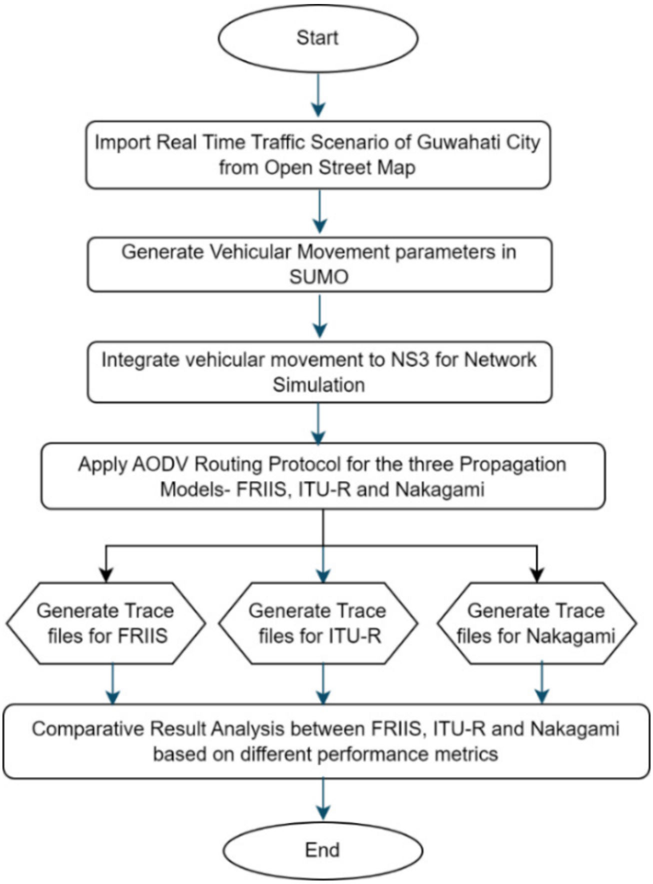


Table 2 Network simulation parameters

Network parameter	*NS-3.35, SUMO*
Radio Range	DSRC
MAC Protocol	802.11p
Frequency	5.9 GHz
Routing Protocol	AODV
Channel Type	Wireless
Propagation Model	FRIIS, ITU-R P.1411 & Nakagami
Vehicle Speed	20 m/s
Transmission power	20 dBm
Data Rate	2048 bps
Packet Size	200 Bytes
Simulation Time	120sec
Vehicle Count	30, 60, 90, 120, 150 & 180

Dedicated Short-Range Communication (DSRC) is a two-way medium range wireless communication designed specifically for ITS. In this communication, in order to monitor the surroundings Basic Safety Messages (BSM) are transmitted in VANET at the frequency band of 5.9 GHz as per IEEE 802.11p MAC/PHY layer standards (Tahir and Katz, 2022). Criteria to choose VANET nodes and boundary conditions considered for the simulation are given below in Tables 3 and 4, respectively.

Table 3 Criteria to choose VANET nodes

Criteria	*Details*
Realistic Distribution	Real Time Traffic Scenario are imported from Open Street Map for Guwahati City
Vehicle Types	Three types – Cars, Buses and Trucks
Behavioural Models	Random Trips are considered for this Simulation in SUMO
Communication	DSRC-IEEE 802.11p, Frequency 5.9 GHz
Positioning and Movement	SUMO allows for dynamic movement and interaction between vehicles for Random Trips

Table 4 Boundary condition for the VANET simulation

Particulars	*Description*
Geographical Area	A portion of Guwahati City (Urban Traffic Scenario) from Open Street Map selected for the study
Road Infrastructure	Road network, including lanes, intersections, traffic signals and road types are extracted from Open street Map for Guwahati City by considering Urban Traffic Scenario
Number of vehicles	For Cars • Through Traffic Factor = 10 • Count = 12 For Buses • Through Traffic Factor = 10 • Count = 4 For Trucks • Through Traffic Factor = 10 • Count = 8
Communication Range	For DSRC, it is in between few hundred meters to few kilometres as per the IEEE 802.11p, but in practical implementation it is typically influenced by various factors line Transmit power, Antenna gain, Propagation Environment and Receiver Sensitivity
Movement Patterns	Uniform distribution

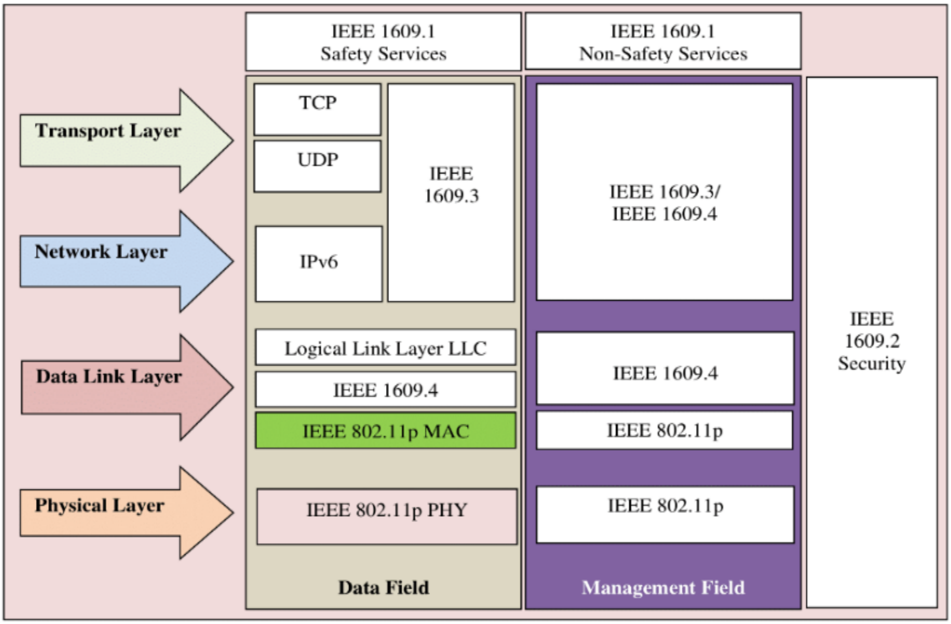
Table 4 Boundary condition for the VANET simulation (continued)

Particulars	*Description*
Obstacles and Environmental Factors	To check the influence of these factors, this research study considers three propagation Models, namely Free Space, ITU-R P.1411 and Nakagami fading Model • The Free Space Propagation Model is used to predict received signal strength when the transmitter and receiver have a clear, unobstructed Line-of-Sight path between them. • The ITU-R P. 1411 Propagation Model is intended for outdoor short-range propagation over the frequency range from 300 MHz to 100 GHz. Short-range propagation over distances less than about 1 km is typically affected more by buildings and trees than by variations in ground elevation. • The Nakagami distribution is being proposed in 1960 by Minoru Nakagami as a mathematical model for small-scale fading in long-distance high-frequency radio wave propagation.

VANETs require IEEE 802.11p because it provides a dependable wireless communication standard in the 5.9 GHz band. For applications where safety is crucial, it guarantees low latency and short-range communication. IEEE 802.11p, which uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and supports both broadcast and geo-cast communication, makes it possible to send safety signals quickly, assisting in the prevention of accidents, emergency notifications and cooperative awareness. Because of its standardised structure, interoperability is improved for efficient traffic management and road safety in dynamic vehicular contexts. IEEE 1609.x standards are the foundation for communication and security in VANET (Hota et al., 2021). Confidentiality, integrity, authentication and privacy are all protected under IEEE 1609.1. Message structure is defined in IEEE 1609.2 to facilitate effective communication in traffic management. In order to improve cooperative awareness, IEEE 1609.3 provides networking services for connections and data sharing amongst vehicles. IEEE 1609.4 promotes efficient information transmission in VANETs by facilitating real-time data flow for applications such as traffic control and driver assistance. The layered architecture of wireless communication standards used in VANET is shown in Figure 6.

The simulations for various vehicle movement scenarios for the vehicle counts of 30, 60, 90, 120, 150 and 180 are performed for the three propagation models namely FRIIS, ITU-R P.1411 Loss and Nakagami fading for a time period of 120 seconds. Several performance indicators that assess communication efficiency and network stability between V2V and V2I are measured in this VANET environment. The details of the metrics and the corresponding values observed for different propagation models and vehicle counts are elaborated in the following section.

Figure 6 Wireless communication standard (Feroz et al., 2021) (see online version for colours)



4 Results and comparative analysis

4.1 *Average routing throughput*

Average routing throughput (see equation (1)) gives the average rate of successful data transmission along a communication channel taking into consideration of factors like packet loss, delay and network congestion.

$$\text{Average Routing Throughput} = \frac{\text{Total number of Successfully Delivered Data}}{\text{Total Time taken for Transmission}} \quad (1)$$

It assesses the efficiency of data transmission since it measures the volume of information successfully transmitted in a given amount of time. Table 5 illustrating the simulation results for Average Routing Throughput shows FRIIS to have highest throughput for less number of nodes. As the number of nodes increases, the throughput decreases. But Nakagami maintains the same performance for all the scenarios with varying number of vehicles. Overall, performance of ITU-R P.1411 propagation model is found to be better than FRIIS and Nakagami.

Table 5 Analysis of average routing throughput (kbps)

Average routing throughput (kbps)			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	74.9798	24.3022	7.22527
60	31.4297	89.3916	9.88257
90	17.6498	54.3041	10.3568
120	16.9802	45.2073	8.1423
150	15.7501	37.3245	9.7591
180	13.8732	35.7205	8.3428

4.2 Average routing goodput

It is well known that goodput denotes to the rate of useful data effectively transmitted across the network without accounting for any protocol or network overheads or retransmissions. Routing protocols in the context of VANETs are responsible for creating paths and delivering data between vehicles and/or Road Side Infrastructure Units (RSU). The Average Routing Goodput refers to the success rate of data delivery for routing protocols as given in equation (2). The FRIIS propagation model shows better Average Routing Goodput than ITU-R P.1411 and Nakagami models (see Table 6).

$$\text{Average Routing Goodput} = \frac{\text{Total Useful data of Successfully Delivered Data}}{\text{Total Time taken for Transmission}} \tag{2}$$

Table 6 Analysis of average routing goodput (kbps)

Average routing goodput (kbps)			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	3.29786	1.43775	1.78332
60	4.42843	3.00348	3.28079
90	2.65365	1.54867	1.79185
120	5.29876	3.02055	2.32514
150	6.09612	3.62048	3.12512
180	7.67543	3.78654	3.78532

4.3 Packet delivery ratio (%)

Packet Delivery Ratio defines the ratio of successfully received packets at the destination to the total number of packets transmitted. Though all the propagation models perform relatively well in terms of Packet Delivery Ratio, FRIIS propagation model has higher value than ITU-R P.1411and Nakagami for all the traffic mobility scenarios. The results are shown in Table 7.

Table 7 Analysis of packet delivery ratio (%)

Packet delivery ratio (%)			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	25	8	25
60	58	29	49
90	69	46	48
120	73	64	50
150	76	67	53
180	79	69	57

4.4 End-to-end delay

This is a vital performance indicator giving the time delay that data packets experience while traveling over the network to reach their destination. The overall time a data packet takes to travel from its source to its destination is measured considering different delays as given in equation (3).

$$\begin{aligned}\text{End-to-End Delay} = {} & \text{Propagation Delay} + \text{Transmission Delay} \\ & + \text{Processing Delay} + \text{Queuing Delay}\end{aligned} \tag{3}$$

While considering the End-to-End Delay, as shown in Table 8**,** ITU-R P.1411 is performing better with less delay than FRIIS and Nakagami models

Table 8 Analysis of analysis of end-to-end delay (ms)

End-to-end delay (ms)			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	2.212	2.898	3.063
60	4.715	1.094	14.18
90	15.76	3.014	23.43
120	25.68	9.008	44.81
150	34.78	13.761	54.54
180	37.86	14.732	57.54

4.5 End-to-end jitter delay

Within VANETs, End-to-End Jitter Delay describes the irregular or variable duration of data packet transit times from the source vehicle to the destination vehicle which is given by equation (4).

$$\text{End-to-End Jitter Delay} = \frac{1}{N-1}\sum_{i=2}^{N}\left|t_i - t_{i-1}\right| \tag{4}$$

where N= total number of received packets

t_i = arrival time of the i-th packet at the destination

t_{i-1} = arrival time of the $i-1$-th packet at the destination

As per the results shown in Table 9, for different traffic mobility scenario with varying number of nodes, ITU-R P.1411 has lower End-to-End Jitter Delay than FRIIS and Nakagami. As the number of vehicles increases, the End-to-End Jitter Delay of FRIIS and Nakagami also increase.

Table 9 Analysis of end-to-end jitter delay (ms)

End-to-end jitter delay (ms)			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	0.9685	0.7727	2.08
60	1.8315	2.6435	8.49
90	8.5332	1.743	13.69
120	20.743	4.389	23.82
150	26.545	4.564	28.23
180	31.657	5.016	32.65

4.6 Packet loss ratio (%)

When data packets are transferred between vehicles or between a vehicle and a roadside device and they fail to arrive at their intended location, it is known as packet loss.

While considering the Packet Loss Ratio, FRIIS has better performance for all the number of nodes than ITU-R P.1411 and Nakagami as shown in Table 10.

Table 10 Analysis of packet loss ratio (%)

Packet loss ratio (%)			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	74	91	74
60	41	70	50
90	30	53	51
120	26	35	49
150	23	32	46
180	20	30	42

4.7 MAC/PHY-Overhead

The extra data and signalling required by the Media Access Control (MAC) and Physical (PHY) layers of the communication stack for tasks like control message exchange, synchronisation, error correction, channel access management, beaconing, header information and handshaking are referred to as 'MAC/PHY-Overhead' (see equation (5)) in VANETs.

$$\text{MAC / PHY-Overhead} = \frac{\text{Total Overhead Data Size}}{\text{Total Data Payload Size}} \times 100\ \% \tag{5}$$

Table 11 shows that, the ITU-R P.1411 outperforms FRIIS and Nakagami in terms of MAC/PHY-Overhead for all the traffic mobility scenarios with varying number of vehicles.

Table 11 Analysis of MAC/PHY-Overhead

MAC/PHY-Overhead			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	0.349409	0.261136	0.343511
60	0.419924	0.334784	0.461327
90	0.432273	0.363483	0.482372
120	0.426198	0.376933	0.512073
150	0.456141	0.384324	0.542133
180	0.475432	0.39483	0.584521

4.8 Packet delivery ratio of basic safety messages (BSM_PDRn)

In VANET, vehicles broadcast BSM signals regularly to other vehicles and infrastructure, which include critical safety-related data like position, speed, acceleration and heading. For the purpose of performance analysis of BSM_PDR, seven covering ranges, i.e., 50, 100, 150, 200, 250, 300 and 350 metres are considered. The basic safety message packet delivery ratio for each of the range is referred to as BSM_PDR1, BSM_PDR2, BSM_PDR3, BSM_PDR4, BSM_PDR5, BSM_PDR6 and BSM_PDR7, respectively.

ITU-R P.1411 and FRIIS perform better than Nakagami in terms of the Packet Delivery Ratio of Basic Safety Messages within the range of 50 m as shown in Table 12. For fewer vehicles in the scenario, FRIIS performs well but for higher numbers of vehicles ITU-R P.1411 is performing well.

Table 12 Analysis of BSM_PDR1

BSM_PDR1			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	0.996531	0.967876	0.867587
60	0.917759	0.930623	0.764572
90	0.834199	0.872699	0.659069
120	0.728586	0.803437	0.566509
150	0.653432	0.762312	0.476931
180	0.617391	0.703952	0.418402

FRIIS performs better then ITU-R P.1411 and Nakagami in terms of BSM_PDR2, BSM_PDR3, BSM_PDR4, BSM_PDR5, BSM_PDR6 and BSM_PDR7 as shown in Tables 13 to 18. But for higher number of vehicles all the propagation models show almost the same performance.

Table 13 Analysis of BSM_PDR2

BSM_PDR2			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	0.851038	0.66948	0.647276
60	0.648982	0.551286	0.500697
90	0.482484	0.46445	0.3899
120	0.348896	0.320711	0.298529
150	0.275934	0.254523	0.214986
180	0.203871	0.194531	0.183621

Table 14 Analysis of BSM_PDR3

BSM_PDR3			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	0.536239	0.318312	0.429249
60	0.378989	0.273899	0.324929
90	0.268967	0.232975	0.243109
120	0.187614	0.191072	0.178679
150	0.112378	0.121913	0.104123
180	0.095643	0.094127	0.0937654

Table 15 Analysis of BSM_PDR4

BSM_PDR4			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	0.352631	0.209322	0.313409
60	0.242193	0.175035	0.227505
90	0.176736	0.153086	0.170513
120	0.121385	0.123622	0.121732
150	0.094287	0.094263	0.095185
180	0.093672	0.0917638	0.090167

Table 16 Analysis of BSM_PDR5

BSM_PDR5			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	0.272049	0.161489	0.248585
60	0.183301	0.132473	0.175847
90	0.132371	0.114658	0.12993
120	0.090599	0.092269	0.0920821
150	0.075296	0.072974	0.076208
180	0.073812	0.071735	0.070451

Table 17 Analysis of BSM_PDR6

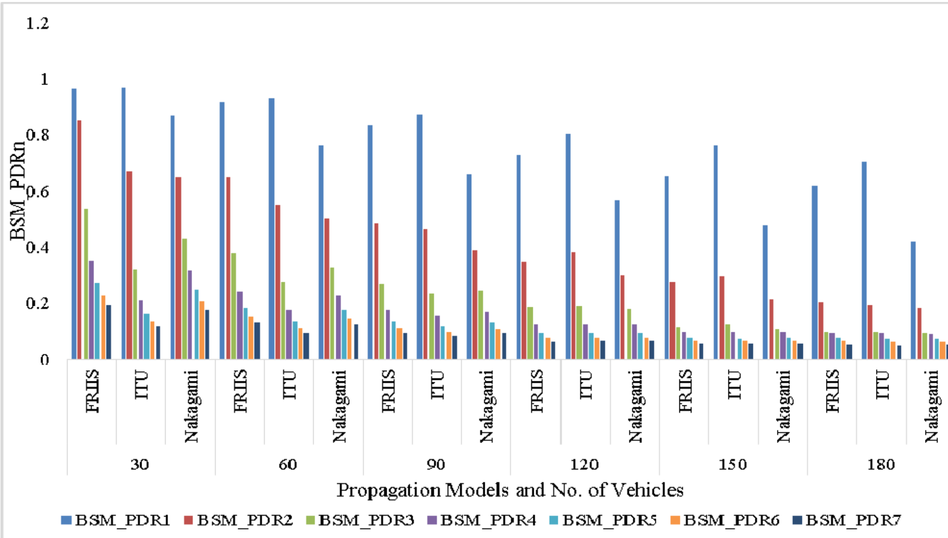
BSM_PDR6			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	0.225483	0.133847	0.207206
60	0.149015	0.107694	0.14367
90	0.108744	0.094193	0.10712
120	0.074251	0.075619	0.0756614
150	0.064975	0.065123	0.063987
180	0.063764	0.061341	0.060543

Table 18 Analysis of BSM_PDR7

BSM_PDR7			
Vehicle count	*FRIIS*	*ITU-R P.1411*	*Nakagami*
30	0.193579	0.114909	0.178101
60	0.128295	0.0927196	0.123791
90	0.093098	0.0806404	0.0917611
120	0.068581	0.0647533	0.0648214
150	0.053782	0.051741	0.052197
180	0.051462	0.049634	0.0513452

Figure 7 shows the overall BSM_PDR analysis for the entire VANET coverage from 50 to 350m, for the three propagation models: FRIIS, ITU-R P.1411 and Nakagami. It is seen that for almost all the ranges, as the number of vehicles increases BSM_PDR decreases. ITU-R P.1411 performs better than FRIIS and Nakagami for the range of 50 m. For the remaining ranges, FRIIS propagation model is dominating the performance. The three-propagation models show almost same performance when vehicle count is high. Though, ITU-R P.1411 is not performing better than FRIIS for the higher ranges, it gives a stability in performance irrespective of the number of vehicles present in the scenario.

Figure 7 Analysis of BSM_PDRn for three propagation models (see online version for colours)



4.9 Highlights of the result analysis

The impact of propagation models in VANETs simulated using SUMO and NS3 with AODV as the routing protocol is investigated with varying number of vehicles in real-time city traffic scenarios. The analysis is also aimed to understand the influence of structural properties on the performance of different propagation models. From the analysis, it is evident that the choice of propagation model has significantly influenced the performance metrics of VANET.

The ITU-R P.1411 propagation model demonstrates strengths in structural properties related to robustness and reliability. It excels in metrics such as Average Throughput, End-to-End Delay, End-to-End Jitter Delay and MAC/PHY-Overhead. These advantages stem from its ability to accurately model real-world urban environments considering factors such as obstacles, line of sight and environmental conditions. Conversely, the FRIIS propagation model exhibits enhanced Average Goodput and Packet Delivery Ratio relative to other models in respect of structural properties. While it may lack the robustness of the ITU-R P.1411 model in certain aspects, its structural properties are well-suited for scenarios requiring efficient data transmission and packet delivery. In contrast, the Nakagami fading model displays limitations in structural properties across all evaluated parameters. Its inability to adapt to sudden changes in channel conditions and dynamic network architectures renders it less effective for VANET applications. This deficiency is particularly pronounced in environments with high-speed mobility, where structural properties related to adaptability and resilience are paramount.

The dissemination of safety messages in VANET underscores the critical importance of structural properties such as Throughput, Packet Delivery Ratio, and End-to-End Delay. However, the analysis reveals that a fixed propagation model may not sufficiently address the structural requirements for effective information dissemination. Hence, there is a pressing need for the auto-shifting of propagation models based on contextual scenarios to optimise structural properties and ensure reliable communication in dynamic VANET environments.

The interpretation of comparative results emphasises the significance of structural properties in determining the suitability of propagation models for VANET applications. By understanding and leveraging these properties, researchers and practitioners can make informed decisions to enhance the performance and reliability of vehicular communication systems.

4.10 Limitations and future scopes

Predictive modelling of vehicle behaviour becomes challenging, given the inability to accurately replicate human driving responses and evolving traffic conditions. Additionally, scalability issues may arise when attempting to simulate large-scale VANET scenarios due to computational constraints. Security also remains a paramount concern in VANETs, with various vulnerabilities that must be addressed. These include privacy risks associated with the transmission of sensitive information, authentication and authorisation to prevent unauthorised access and ensuring data integrity to prevent tampering or manipulation. Denial of Service (DoS) attacks pose a significant threat, as malicious actors may attempt to disrupt communication channels, leading to service disruptions or safety hazards. Developing secure communication protocols, implementing robust cryptographic techniques and establishing trust management mechanisms are essential steps to mitigate these security risks effectively. In VANETs, key distribution in multicast environments is essential for ensuring secure and efficient communication among vehicles and infrastructure (Yadav et al., 2022). By distributing cryptographic keys, VANETs can encrypt multicast messages to safeguard sensitive data such as traffic updates and emergency alerts, thus enhancing confidentiality. Key distribution also enables integrity verification, ensuring that transmitted information remains trustworthy and unaltered.

The presented simulation is performed in offline mode where the messages or commands are not sent to the vehicles from NS3 simulator. Real time communication between the server or network simulator and vehicles can be implemented by Networked Control System (NCS) (Bhatia et al., 2022). The NCS is characterised by the closure of control loops through a communication network to exchange control and feedback signals among its components in the form of information packets transmitted across the network. FPGA controller as NCS provides high flexibility, speed and reconfigurability, making it suitable for dynamic VANET environments where network conditions and communication requirements vary rapidly. FPGA-based implementations enable efficient processing of control algorithms directly at the network edge, reducing latency and enhancing system responsiveness (Gupta et al., 2022). Moreover, FPGA platforms can support hardware-accelerated cryptographic operations, ensuring the security and integrity of communication in VANETs.

By leveraging low power FPGA controller, routing algorithms can be implemented efficiently, allowing for real-time data processing and transmission with minimal energy consumption (Gupta and Kumar, 2023). FPGA-based solutions enable dynamic routing adjustments based on changing traffic conditions, vehicle movements and network topology, ensuring reliable and low-latency communication within smart transportation ecosystems.

Integrating FPGA technology with compatible wireless sensor nodes like IEEE 802.15.4 ZigBee, LIDAR, RFID, CAN, etc., enhances vehicular communication by enabling real-time processing and customisation (Mishra and Kumar, 2022). This integration also ensures low latency, high throughput and power efficiency crucial for safety and efficiency in smart transportation networks. FPGA's parallel execution capabilities optimise communication protocols, routing algorithms, and data processing tasks, enabling rapid decision-making in dynamic vehicular environments.

5 Conclusions

Vehicle-to-Everything (V2X) communication plays a major role in road safety, but emergency information dissemination in short duration of time poses huge challenges due to dynamic nature of vehicular networks. This work has presented detailed performance analysis of AODV based VANET for three propagation models namely FRIIS, ITU-R P.1411 loss model and Nakagami fading for variable vehicle density and ranges using SUMO and NS3 as simulation platforms. The comparative evaluation made using the network parameters reveals the scenarios of best performance of ITU-R P.1411 propagation model and FRIIS propagation model in combination with AODV protocol. The underperformance of Nakagami fading model due to the consideration of wide range of obstacles shows its unsuitability for the chosen geographic area. In terms of practical implementation and information dissemination, the results may be used as insights when the objective is emergency information dissemination for road safety. The methodology for auto shifting of propagation models in accordance to the transportation scenario shall be devised with further analysis using different protocols and machine learning algorithm can be integrated to determine the parameters that affect the performance of the propagation model.

In this work, performance analysis has been made for the VANET of Guwahati city (Assam State) using SUMO and NS3 in offline mode. The network performance of AODV-based VANET and suitability of appropriate propagation model are deduced for enhancing the reliability of communication. As an extension of present analysis, the results deduced shall be implemented in real-time using NCS. The network and structural properties of VANET can be communicated to the NCS for making intelligent decision on selection of propagation model and execute the real-time communication in VANET with high performance.

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