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Reliable Communication for Vehicular Ad Hoc Network (VANET)

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Abstract

Nowadays, VANET's usefulness in the safety of passengers and effective traffic enhancement has become a special area of study and research within the science community. The scientists and researchers have been doing their best to bring about a permanent solution to the reliability issues in VANET considering an increase in the number of vehicles, road congestion, environmental pollution, fuel consumption and traffic accidents that have become global issues in developing and developed countries. As a case study, the performance of vehicular ad-hoc networks in the highway, urban and sub-urban scenarios of Ikeja, Lagos State, Nigeria was evaluated.

1. Introduction

Recently, Vehicular ad hoc networks (VANETs) have been a special area of study and research for scientists and researchers. This is because of the current issues associated with VANETs in terms of reliability, and its usefulness in the safety of passengers and effective traffic enhancement. Due to the continually increasing number of vehicles, road congestion, environmental pollution, fuel consumption

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and traffic accidents that are now global issues, and have become an everyday problem in both developing and developed countries; leading to the loss of many lives and property [1]; the scientists and researchers have been doing their best to bring about a permanent solution to the reliability issues of VANETs so that the aim of creating this technology called VANET can be achieved and maintained. To reduce traffic problems and control the high rate of loss of life and property, the automotive industry came up with Intelligent Transport System (ITS) which allows the moving vehicles to communicate with each other and share traffic flow messages among themselves [2]. These traffic flow messages allow the moving vehicles to know the state of each other and avoid occurrences of traffic accidents. The goal of ITS is to achieve a very high traffic efficiency, provide services for infotainment on the vehicles and control unwanted events that could lead to loss of life and property [2]. For the ITS goal to be achieved, driving conditions, traffic flow messages and driver behaviour should be detected and shared among the vehicles within a location. To circulate this information and promote efficient communication among vehicles to achieve a safer and entertaining journey, ITS introduced VANET [1] & [2]. VANET, which is also known as Wireless Access in Vehicular Environment (WAVE), is responsible for the communication between vehicles and infrastructure in a geographical area called 'environment' [3]. VANET is a wireless technology that ensures secure data transmission for traffic flow messages, acceptable driving conditions and driver behaviour among moving vehicles which eventually aid human lives and properties protection. The main objective of VANET is to create a network among vehicles and monitor the communication among them irrespective of the central base station or any controller [3] & [4]. It is a fact that if the drivers get some warning messages half a second before accident, the accident could still be avoided [3]. VANET is created as a solution to avoid accidents by providing some prior warning information about the close vehicles [3]. There are two main applications of VANET; safety applications, and non-safety applications. Safety VANET applications are used to send safety messages, for instance, various warning messages that help vehicles on the road to take proper actions to prevent accidents and save lives and properties [5]. Safety messages include among others situations such as traffic jam notifications, emergency vehicle warnings, road accident reports and road construction reports [5]. Non-safety applications of VANET is used for entertainment and online connectivity. The non-safety applications provide an efficient and comfortable driving experience [5]. Examples of these efficient and comfortable driving experiences are electronic payments, file sharing, and audio/video streaming. Non-safety applications are in two forms: infotainment and traffic management [5]. Infotainment applications are used for entertainment and information purposes, which provides Internet Access to passengers such as video streaming, data storage, and video calling, and these types of applications, very unlike safety applications, do require high latency and low reliability [5]. Traffic management applications are needed to enhance traffic flow and remove congestion on the road [5]. The VANET comprises several units (Figure 1) namely: On-Board Units (OBUs), Road Side Units (RSUs), and Trusted Authority (TA) [2]. The RSU specifically hosts an application that is being used to communicate with other devices in the network, while the OBU is mounted on each of the vehicles on the road/network to collect some vehicle useful information for safety such as acceleration and speed [2]. These data are then sent to the nearby vehicles through the wireless network. RSUs that are interconnected with each other are also connected to TA through a wired network, and in addition, the TA (Figure 1) is in charge of managing and maintaining the VANET [6].

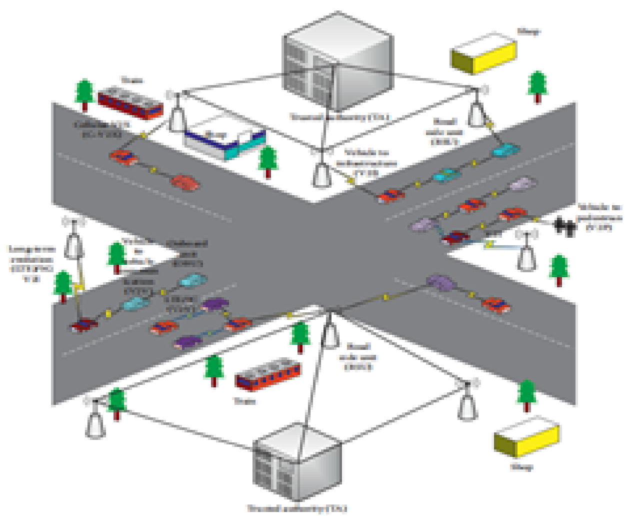

Figure 1: VANET model diagram.

Architecturally, a VANET is made up of moving vehicles communicating with each other as well as with some nearby RSUs [4]. A VANET differs from a MANET in that the vehicles in VANETs do not move randomly as the nodes in MANETs do. Vehicles in VANETs follow some fixed paths such as urban/suburban roads and highways [4]. According to the IEEE1471-2000 and ISO/IEC42010 architecture standard guiding principles, VANET architecture can be categorized into three domains (Figure 2) namely: the mobile domain, the infrastructure domain, and the generic domain (Figure 3) [7] & [8].
The mobile domain is of two parts; the Mobile device domain which encompasses all the portable devices such as smartphones, GPS, laptops, etc., which are moving constantly, and the Vehicle domain which comprises all the vehicles such as cars, trucks, buses, etc. [9] & [5]. The infrastructure domain is also of two

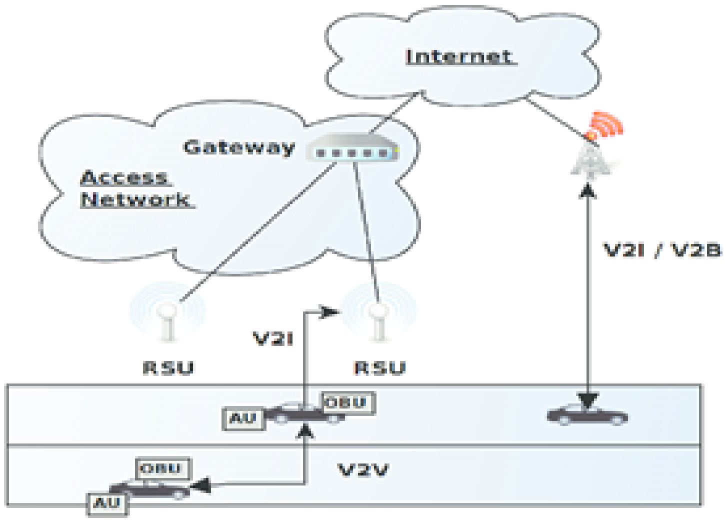

Figure 2: Vanet Architecture.

domains; the Roadside Infrastructure domain and the Central Infrastructure domain [9, 5]. The roadside infrastructure domain consists of roadside unit entities such as traffic lights, poles, etc., while the central infrastructure domain consists of infrastructure management centres such as Traffic Vehicle Management Centers and management centres (TMC) [8] & [10]. Lastly, the Generic domain. It consists of the Private infrastructure and Internet infrastructure; for example, different nodes and servers and other computing resources working directly or indirectly for a VANET are under a generic domain [10].
The mobile domain shares information and communicates to the Infrastructure domain which processes the generated data and does its modulation, while the infrastructure domain, in turn, communicates to the generic domain and shares information with it [8]. This data flow among the immobile and mobile resources results in the professional and successful exploitation of roads by the users [8].
VANET Communication Architecture: Communication types in VANETs can be categorized into four (Figure 4): In-vehicle communication that is is responsible for detecting the vehicle's performance, and determines factors essential for public safety and the driver's safety as well, such as driver's tiredness and sleepiness [7] & [10]. Vehicle-to-vehicle (V2V) communication, that is responsible for providing data sharing medium for the drivers to exchange warning messages and information, in other to enhance driver assistance [7], [10] & [11]. Vehicle-to-road infrastructure (V2I) communication which is taking place between the mobile vehicle and roadside infrastructure, and is responsible for providing environmental sensing and monitoring such as real-time traffic and weather updates for the

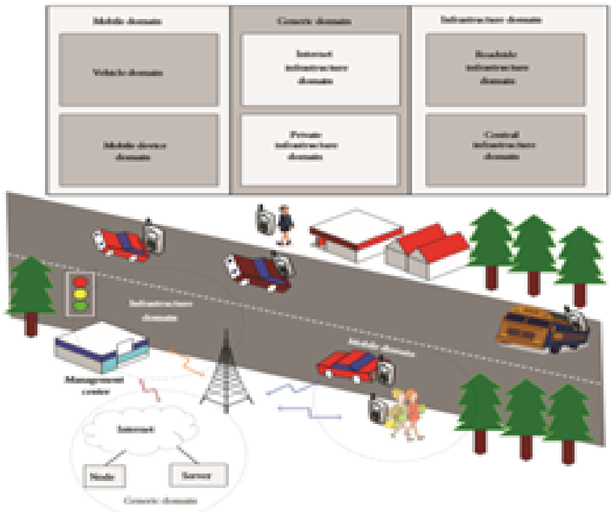

Figure 3: Vanet Main Components Architecture.

drivers [7], [10] & [12]. Vehicle-to-broadband cloud (V2B) communication that is responsible for the communication of vehicles over wireless broadband connections such as 2G/3G/4G/5G, and promotes driver assistance and easy tracking of vehicles as the broadband cloud may contain more traffic information and monitoring data in addition to infotainment, etc. [8] & [10].

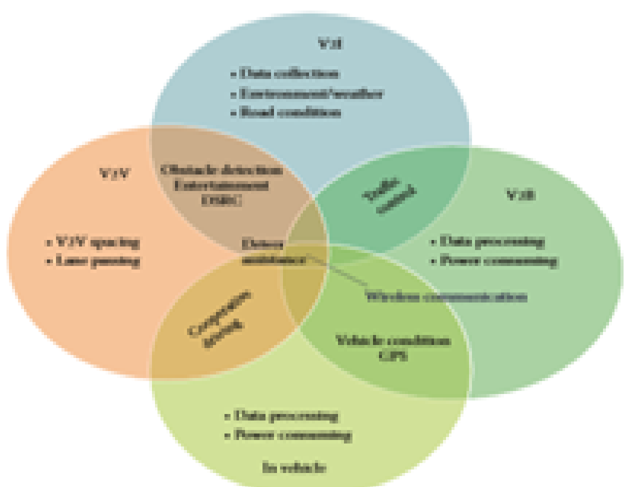

Figure 4: Communication Architecture.

A vehicle that has the capability of computing has a database as well as communication facilities, and can learn (through sensing) from its environment by making decisions appropriately is known as a 'smart' vehicle (a smart vehicle is also called an Intelligent Vehicle) [13]. Thus, the vehicle being used in VANET is a smart vehicle. Despite the attention given to VANET by both the industry and academia, VANET still has a major challenge which is reliability issues. These reliability issues in VANET exist mainly because of the high mobility of the moving vehicles which leads to the constant change in the position of the vehicles (Topology) and then increase in the possibility of disconnection [14], [15] & [9]. Some of the most important reliability challenges of VANETs are: Intermittent connectivity: The management and control of network connections among the vehicles and infrastructure is a key challenge [1]. The Unstable connections in VANET are due to the high mobility of vehicles causing high packet loss in vehicular networks and this has to be avoided [1]. High mobility and location awareness: VANETs require high mobility and location awareness of the communicating vehicles so that each vehicle can have the correct position of the neighbouring vehicles in the network to accommodate an emergency [1]. Heterogeneous vehicle management: The management of heterogeneous vehicles and their irregular intervals connections is another VANET challenge [5]. Considering the above-mentioned VANET's reliability challenges, the requirements for a reliable VANET could be summarized as follows: Low latency and real-time application: Low latency is a fundamental requirement in VANETs regarding real-time applications, therefore, VANETs must support real-time applications, like delivery of safety messages with very low latency [5]. High bandwidth: comfort and infotainment applications such as high-quality video streaming is in high demand, and also, traffic applications such as navigation systems and 3D maps that require frequent automatic updates [5]. Connectivity: To meet the reliable communication requirements, VANETs should support smooth and continuous connectivity among connected vehicles to maintain continuous and highly reliable communication among vehicles and fog devices, and also avoid transmission failures in the communication system [5]. With the above-noted requirements for reliable Vehicular networks, a technology that can support the requirements for reliable communications in VANETs has to be implemented in the Vehicular networks. IEEE 802.11p, though lacking in Vehicle to Infrastructure (V2I) communication, has been considered as the best standard for the Vehicle to Vehicle (V2V) communication in the VANET by some scholars. Some scholars also in their research found out that the integration and overlay of IEEE 802.11 standard (WiFi) and IEEE 802.16 standard (WiMAX - Worldwide Interoperability for Microwave Access) offer reliable and higher network capability than just one of the standards. WiMAX is an International Telecommunication Union (ITU) approved fourth generation (4G) technology for mobile broadband that provides higher probabilities than IEEE 802.11 family [16, 17]. WiMAX, which is IEEE 802.16 advancement technology family is a wireless communication technology that was invented to accommodate a higher number of users and bandwidth than the WiFi which is IEEE802.11 family [16] & [17].

2. Literature Review

In VANET, reliability is the probability that there is no less than one possible connection between two vehicles under a specified condition [18]. Reliability issues appear increasingly essential as advanced networks turn to be increasingly unpredictable and this encouraged the research on the reliability of networks, which drew much attention during previous decades [18]. The increasing population of the world, and also the number of vehicles on the road to aid easy transportation, has brought the need for ITS to minimize (or perhaps avoid) the increasing transportation conflicts, thereby increasing the demand for a well-structured transport system that is capable of handling safely the increasing number of people on vehicle and provide a safe environment. ITS is an information technology application to control transportation to achieve better safety and mobility while reducing the environmental conflicts of transportation [19]. ITS can also be defined as a controlled information and communication upgrade to classical transport and traffic systems, which enables significant improvement in performance, traffic flows, the efficiency of passenger and goods transportation; safety and security of transport, etc [20].

2.1. **WiMAX technology:** WiMAX is a wireless technology characterized under the IEEE 802.16 standard [21] & [22]. The standard was developed in 2001 by the collaboration of Intel and Alvarion companies and approved by the Institute of Electrical and Electronics Engineering (IEEE) under the name IEEE802.16 to specially attend to the specifications for wireless Metropolitan Area Networks (WMAN) [23] & [21]. WiMAX is a broadband wireless access technology that provides reliable, fixed, nomadic and mobile communication across wired and wireless connectivity [21]. WiMAX is gaining more popularity day by day as a technology that delivers carrier-class and high-speed wireless broadband at a much lower cost while covering large distances than Wi-Fi and so, WiMAX is known as an outdoor Wireless Technology [22]. WiMAX is aimed at handling high-quality videos, voice and data services at a very high Quality of Service [23]]. There are two main types of WiMAX: IEEE 802.16-2004, also known as Fixed WiMax: IEEE 802.16-2004. that is designed for transmission to stationary and pedestrian devices i.e. 802.16 and 802.16a [21]. 802.16e or 802.16-2005, also known as Mobile WiMAX: IEEE 802.16e, that is an extension of 802.16-2004, for mobile use in the 2 to 6 GHz band. It allows people to communicate while riding in cars or walking and provides a mobile voice over IP and higher speed data alternative to the cellular networks (GSM, TDMA, CDMA) [21]. To aid mobility, the Institute of Electrical and Electronics of Engineering (IEEE) has developed the IEEE 802.16e amendment, which is, the mobile version of the 802.16 standards, which is also called mobile WiMAX [24]. This new amendment is aimed at sustaining mobile clients connected to a Wide Area Network (WAN) while moving around, and it supports portable devices from mobile smartphones and personal digital assistants to notebook and laptop computers [24]. IEEE 802.16e works in the 2.3 GHz and 2.5 GHz frequency bands [24]. In WiMAX, the central modulation technique is Orthogonal Frequency Division Multiplexing (OFDM), and both systems (that is, IEEE 802.16-2004 and IEEE 802.16-2005) utilize Multiple Inputs Multiple Outputs (MIMO) techniques [21]. IEEE 802.11p IEEE 802.11p is one of the recently developed and approved amendments to the IEEE 802.11 (WiFi) standard to initiate WAVE [25]. It added some enhancements to the latest version of 802.11 that is required to aid applications of ITS and this includes data and file exchange among the high-speed moving vehicles [25]. Although, IEEE 802.11p is not efficient and reliable in the Vehicle to Infrastructure communication in the vehicular environment majorly because of its coverage area (LAN in nature). Based on the standard specification of IEEE 802.11p, the ITS technology 'VANET' employed the method of dedicated short-range communication (DSRC) for the enhancement of driving safety, as well as the comfort of automotive drivers [24]. In WAVE is deployed for ITS on the 5.9 GHz frequency with the IEEE 802.11p and IEEE 1609 standard family, and the OFDM technique is employed on the PHY, which is capable of providing up to a 27 Mb/s data rate with 10 MHz bandwidth and a 300–1000 m communication distance [24].

2.2. **Related Works.** Sourangsu Baneriji and Rahul Singha Chowdhury (2013), in their study titled 'Wi-Fi and WiMAX: A Comparative Study' claimed that Wi-Fi and WiMAX are different in many respects and the two can be integrated, overlay and serve bigger and many more subscribers. They concluded that WiMAX standard goal is not to replace Wi-Fi in its applications but rather to supplement it to form a wireless network web [22]. Zeeshan Hameed Mir and FethiFilali (2014) conducted a study titled 'LTE and IEEE802.11p for Vehicular Networking: A Performance Evaluation' and concluded that a Long Term Evolution (LTE) standard scales better, delivers data reliably and meets the latency requirements posed by several vehicular networking applications, and on the other hand, IEEE 802.11p standard exhibits lower beacon latencies and higher delivery ratio/throughput in places where there are fewer than 50 vehicles [21] & [26]. Rakesh Shrestha, Rojeena Bajracharya and Seung Yeob Nam (2018) in their work titled 'Challenges of Future VANET and Cloud-Based Approaches' claimed that some of the challenges of future VANET are Intermittent connectivity, High mobility and location awareness, Heterogeneous vehicle management, Security, and Support of network intelligence [5]. Shamsul Jamel Elias, MohdNazri Bin

MohdWarip, R Badlishah Ahmad and AznorHanah Abdul Halim conducted research titled 'A Comparative Study of IEEE 802.11 Standards for Non-Safety Applications on Vehicular Ad Hoc Networks: A Congestion Control Perspective' and presented a literature survey on congestion control of VANETs, in which the potential and limitations of congestion control implemented in service control channel (SCH) for VANETs was revealed. The authors concluded that the IEEE 802.11p standard supports most of the requirements of non-safety applications in VANET [27] & [2]. In the study by Lerotholi S. Mojela and Marthinus J. Booysen it was concluded that Wi-Fi (IEEE 802.11n), used for the V2V connection, was found to provide reliable and high bandwidth, while connected. The Wi-Fi connection was unaffected by speed, and the only distinguishable factor seems to be separation which determined whether the connection is made. While WiMAX (IEEE 802.16d) bandwidth, used for V2I connection, is severely affected by even slight mobility [26]. From the above, none of the scholars has considered the integration of mobile WiMAX (IEEE 802.16e) and wifi (IEEE 802.11p) in the vehicular environment. Thus, the integration of IEEE 802.11p for V2V and IEEE 802.16e (mobile WiMAX) for V2I as the technology to offer reliable VANET communication is being proferred as a solution to reliability challenges of VANET. In this study, the causes of the reliability issue in VANET would be identified, and a solution to the reliability issue of a VANET would be established.

3. Methodology

For this research, the areas of study are the architecture of VANET, WiMAX Technology, IEEE 802.11p Technology and Simulation and Performance Test

3.1. **Simulation Procedure.** A structured Simulation was performed to verify the efficiency and performance of both technologies (IEEE 802.11p and IEEE 802.16e) as communication media when integrated and also their performance in different communication environments. To evaluate the performance of both technologies, several simulations were carried out using Open Street Map (OSM), Simulation of Urban Mobility (SUMO) and Network Simulator 3 (NS3), which are free simulation tools that run best on Linux (Ubuntu) System Software. The reason behind the decision to use this three software is that they provide reproducible, real-time and traceable results.

3.2. **Simulation Parameters.** Table 1 shows the simulation parameters that were used in the simulation.
Table 1: Simulation Parameters STANDARD INTEGRATED NETWORK Frequency 3.5GHz (IEEE 802.11) and 5.9GHz (WiMAX) Channel Bandwidth 10MHz RSU Transmission Power 43dBm RSU Antenna Height 32 m Mobile Station (MS) Transmission Power 38 dBm MS Antenna Height 1.5 m Distance between RSU's 5 km

Throughput and packet loss rate were the main focus as the metrics of performance evaluation during the simulation from the source node to the receptor node. Throughput is the average rate of data packets transmitted successfully over the IEEE 802.11p/IEEE 802.16e communication channels' capacities; while the Packet Drop Fraction is the ratio of the number of packets transmitted unsuccessfully (that is, as a result of packet drops) to the total number of packets sent from the VANET sources. That is, Packetdropfraction=Unsuccessfultransmittedpackets/Totalpacketssent
Simulations were performed to verify if 802.11p and mobile WiMAX (IEEE 802.16e) integrated network can ensure acceptable performance for reliable and real-time vehicular communication. These metrics aimed to quantitatively determine the packet loss average during the overall communication session and the average throughput obtained for the overall communication process. These simulations were performed in the following scenarios:

Figure 5: Highway Scenario.

3.3. **Procedure for Data Collection.** The Simulation was done using Open Street Map (OSM) for environment generation, Simulation of Urban Mobility (SUMO) for network interface generation, and Network Simulator 3 (NS-3) for processing of the simulation and generating the needed result with the help of Network Animation (NetAnim) and Gnuplot for plotting graphs. All data relevant for this research were collected through the simulators mentioned above. NS-3 was the main simulation tool for the collection of the required data for processing the performance analysis, while OSM and SUMO were only used to generate the interfaces required in this study.

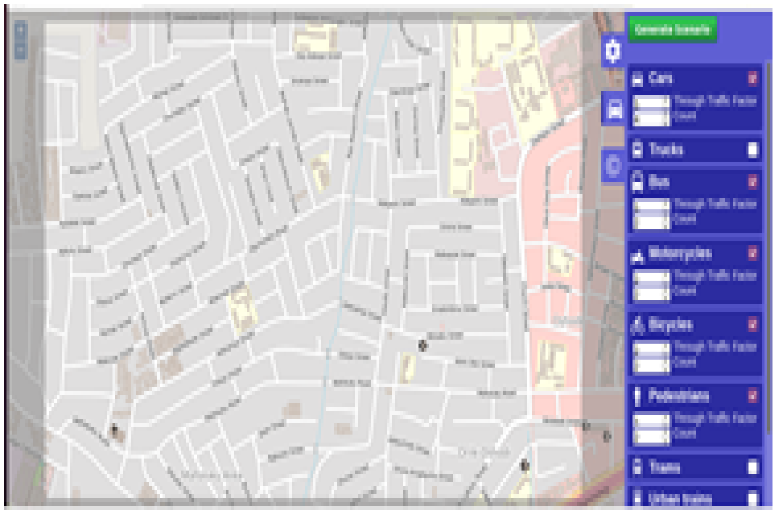

Figure 6: Urban Scenario.

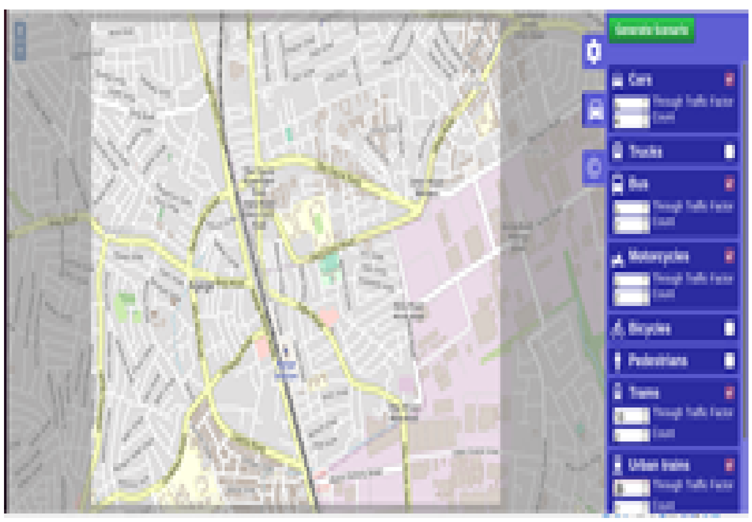

Figure 7: Sub Urban Scenario.

3.4. **Performance Analysis.** To examine the performance of integrated 802.11p and 802.16e technologies in a vehicular environment, a highway, suburban, and urban zone of Ikeja, Lagos, Nigeria was mapped out from the OSM that was fully under the coverage of base stations as generated by the simulator according to the area. The vehicles in the network were equipped with a wireless communication interface known as OBU of 802.11p for V2V communication. The

Road Side Unit (Antennas) in the generated environment was equipped with a wireless communication interface, IEEE 802.16e (WiMax) for V2I communication. The movement and part to the destination of all the vehicles on the road were randomly generated by the simulator used for the network interface, the SUMO. In SUMO, each vehicle was monitored independently and all parameters were observed such as speed, route, data transmitted and dropped etc, traffic controllers were also added and removed manually in the network, and junctions were also added and removed. Driving behaviour was also observed on the car profile. The sumo output file was passed through the NS3. NS3 was used to install the routing statistics on the outputted sumo file as defined in this study. These routing statistics includes the communication modes (which was integrated IEEE 802.11p for the V2V communication and IEEE 802.16e (mobile WiMax) for the V2I communication), and the communication parameters (which includes the antenna height and parameters for radiation, antenna clustering for reliable V2I communication, the maximum speed of the moving vehicles, frequency of communication and data exchange rate).

3.5. **Highway Scenario:** The total number of vehicles generated in the highway-scenario through the SUMO was 96 vehicles. The highway scenario was configured to run with continuous access to a 10 MHz Control Channel (CH) for all traffic. All vehicles (known as nodes) transmit a 200-byte safety message 10 times per second (which was a 0.1-second interval) at a 6Mbps rate. The GPS was configured with a synchronization accuracy of 40ns (nanoseconds). Transmission maximum delay time is set at 10ms. 10 nodes were selected as sink nodes. Though optional, all nodes did try to continuously route 64-byte packets at an application rate of 2.048 Kbps to one of 10 special nodes, selected as sink nodes for BSM (Basic Saft Messages). The routing protocol used in this scenario is Optimized Link State Routing (OLSR) and the Two-Ray Ground loss model for the propagation loss model. The transmission range for safety message packet delivery was 145m and the transmit power was set to 43 dBm. The nodes speed was set at 50m/s with a no-stop time. The vehicles communicated with the RSU (V2I) at the frequency of 5.9GHz and with each other at the frequency of 2.4GHz (V2V). The result of the simulation is shown in Figure 8.

Packetdropfraction=Unsuccessfultransmittedpackets/Totalpacketssent

Packetdropfraction=2/110 Packet drop fraction (for the Highway Scenario) = 0.01818.

3.6. **Performance Output of the Highway Scenario:** The generated Network Animator (NetAnim) file is shown in Figure 9.

3.7. **Urban Scenario:** The total number of vehicles generated in the urban-scenario through the SUMO was 191 vehicles. The urban scenario was configured to run with continuous access to a 10 MHz CH for all traffic. All vehicles (nodes)

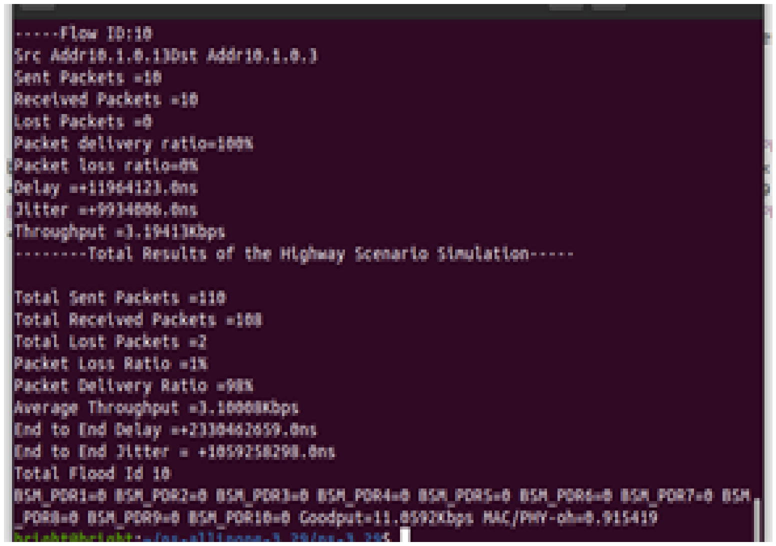

Figure 8: Performance Output of the Highway Scenario.

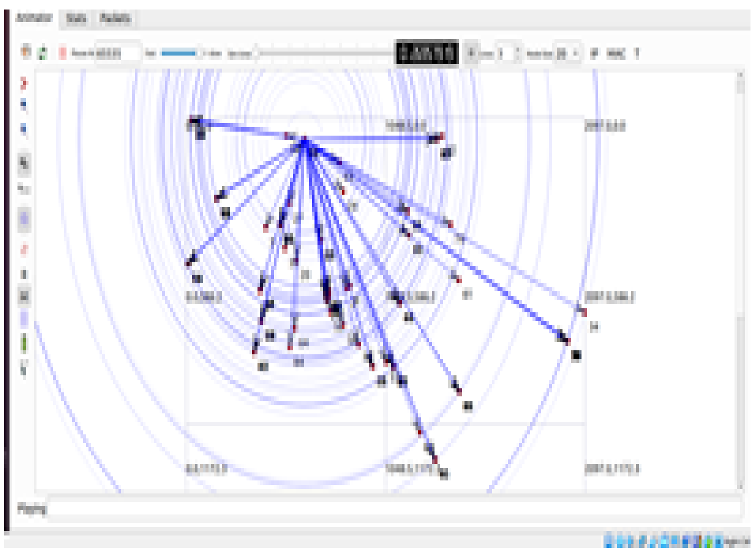

Figure 9: NetAnim Interface of Highway Scenario.

transmitted a 200-byte safety message 20 times per second (which was 0.05-second interval) at a 6Mbps rate. The GPS was configured with a synchronization accuracy of 40ns. Transmission maximum delay time was set at 5ms. 10 nodes were selected as sink nodes. Though optional, all nodes did try to continuously route 64-byte packets at an application rate of 2.048 Kbps to one of 10 special nodes, selected as sink nodes for BSM. The routing protocol used in this scenario is OLSR and the Two-Ray Ground loss model for the propagation loss model. The transmission range for safety message packet delivery was 145m and the transmit power was set to 38 dBm. The node speed was set at 20m/s with a no-stop time. The vehicles communicate with the RSU (V2I) at the frequency of 5.9GHz and with each other at the frequency of 2.4GHz (V2V). The result of the simulation is shown in Figure 10.

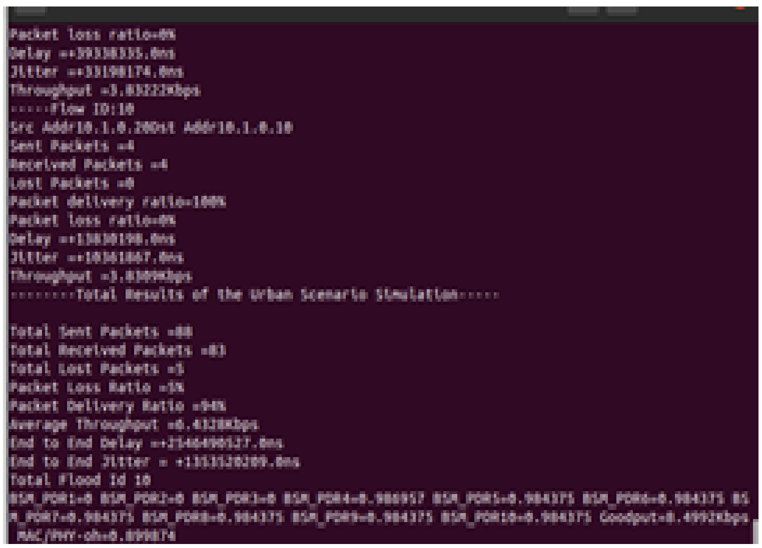

Figure 10: Performance Output of Urban Scenario.

Packetdropfraction=Unsuccessfultransmittedpackets/Totalpacketssent Packetdropfraction=5/88 Packet drop fraction (for the Urban Scenario) = 0.05682.
The generated NetAnim file is shown in Figure 11.

3.8. **Sub-urban Scenario:** The total number of vehicles generated in the Suburbanscenario through the SUMO was 201 vehicles. The sub-urban scenario was configured to run with continuous access to a 10 MHz CH for all traffic. All vehicles (nodes) transmitted a 200-byte safety message 10 times per second (which was a 0.1-second interval) at a 6Mbps rate. The GPS was configured with a synchronization accuracy of 40ns. Transmission maximum delay time was set at 5ms. 10 nodes were selected as sink nodes. Though optional, all nodes did try to continuously route 64-byte packets at an application rate of 2.048 Kbps to one of 10 special nodes, selected as sink nodes for BSM. The routing protocol used in this scenario was OLSR and the Two-Ray Ground loss model for the propagation loss model. The transmission range for safety message packet delivery was 145m and the transmit power was set to 38 dBm. The nodes speed was set at 30m/s with a 0 stop time. The vehicles communicated with the RSU (V2I) at the frequency of

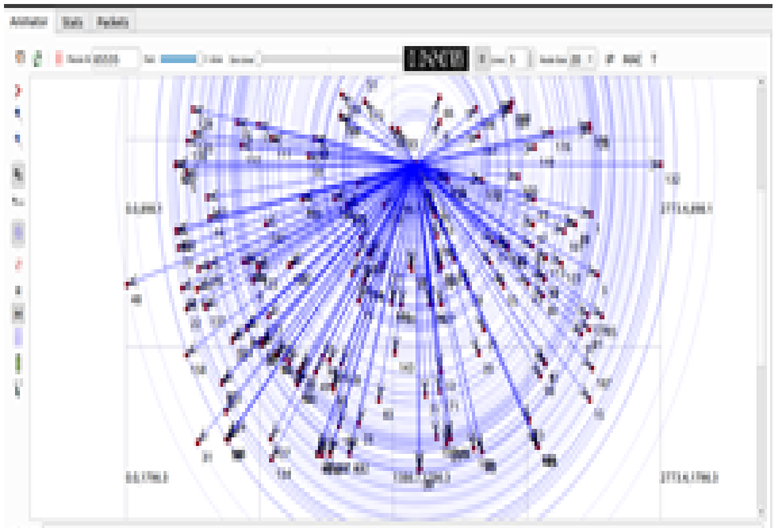

Figure 11: NetAnim Interface of Urban Scenario.

5.9GHz and with each other at the frequency of 2.4GHz (V2V). The simulation result is shown in Figure 12.

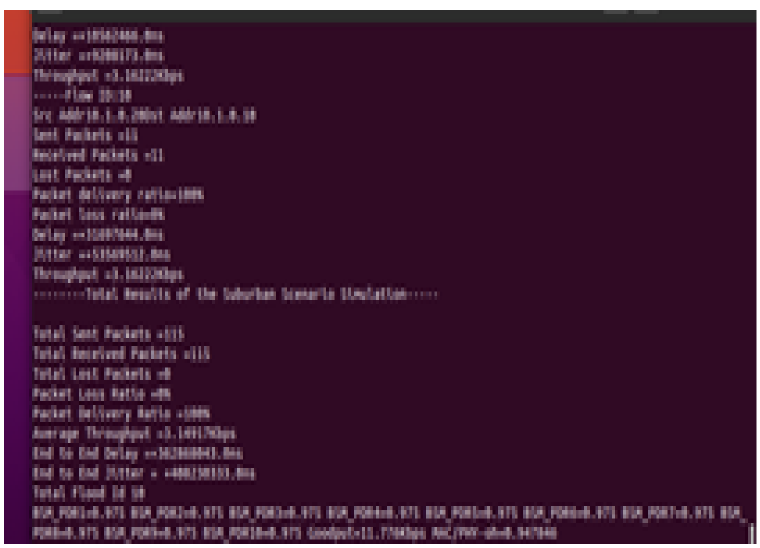

Figure 12: Performance Output of Sub-Urban Scenario.

Packetdropfraction=Unsuccessfultransmittedpackets/Totalpacketssent Packet-dropfraction=0/115 Packet drop fraction (for the Urban Scenario) = 0.00.
The generated NetAnim file is shown in Figure 13.

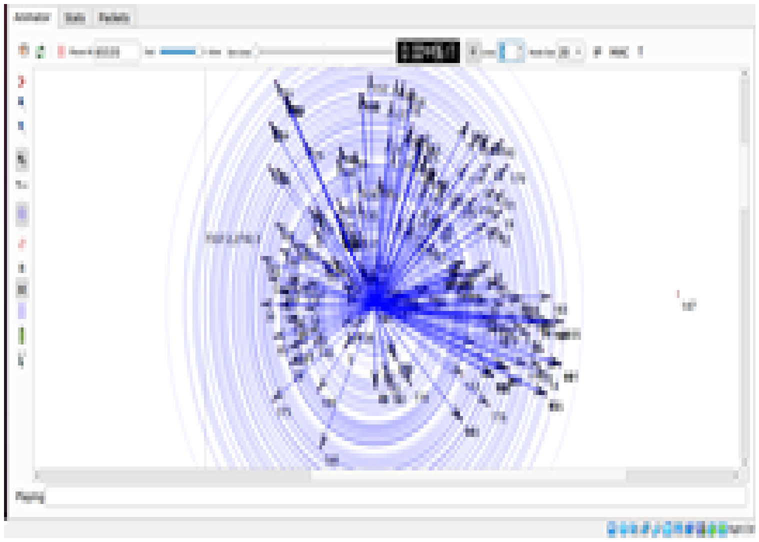

Figure 13: NetAnim Interface of Suburban Scenario.

4. Result Analysis and Discussion

Table 2 shows the result generated from the case studies.

Table 2: Results analysis and discussion Highway Sub-urban Urban Total Sent Packets 110 115 88 Total Received Packets 108 115 83 Total Lost Packets 2 0 5 Packet Loss Ratio (Packet Delivery Ratio (Average Throughput (Kbps) 3.10008 3.14917 6.4328 End to End Delay (ns) +2330462656 +362868043 +2546490527 End to End Jitter (ns) +1059258298 +408230333 +1353520209 Goodput (Kbps) 11.0592 11.776 8.4992 MAC/PHY 0.915419 0.947846 0.899874 Discussion The purpose of this studying is to develop a reliable VANET. That is, to develop a VANET with a minimal packet loss ratio. Figures 14 and 15 show the relationship between the number of packets sent, the number of packets received and the number of packets lost in three defined scenarios.

From the chats (Figures 14 and 15), it is obvious that the rate of successful transmission is extremely close to the transmitted packets in the defined scenarios. While the rate of packet loss is very far below the transmitted packets (2 out of 110 in Highway, 0 out of 115 in Suburban and 5 out 88 in Urban). This implies that the packet would be delivered in all the defined scenarios and methods.

Conclusions: It was observed in the study that the probability that a packet will be lost is between 0 to 0.06 in all the defined scenarios. Thus, it can be further deduced that with the integration of mobile WiMAX (IEEE 802.16e) and wifi (IEEE 802.11p), the VANET system is reliable as the reliability problems in VANET is greatly minimized.

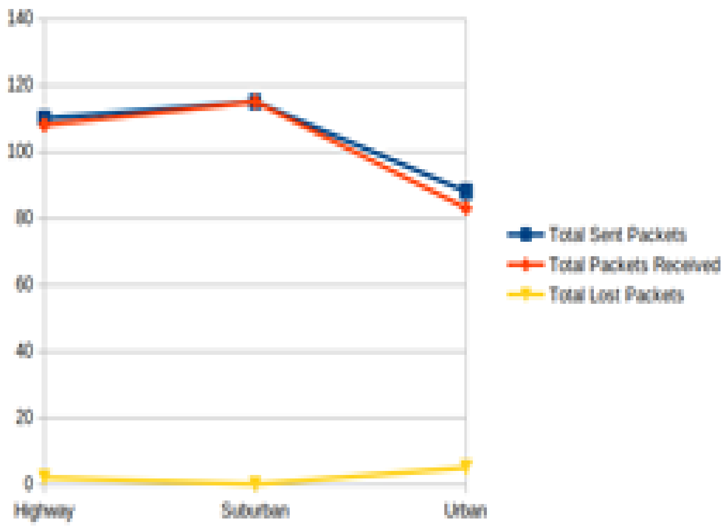

Figure 14: Chart showing Sent, Received and Lost Packets.

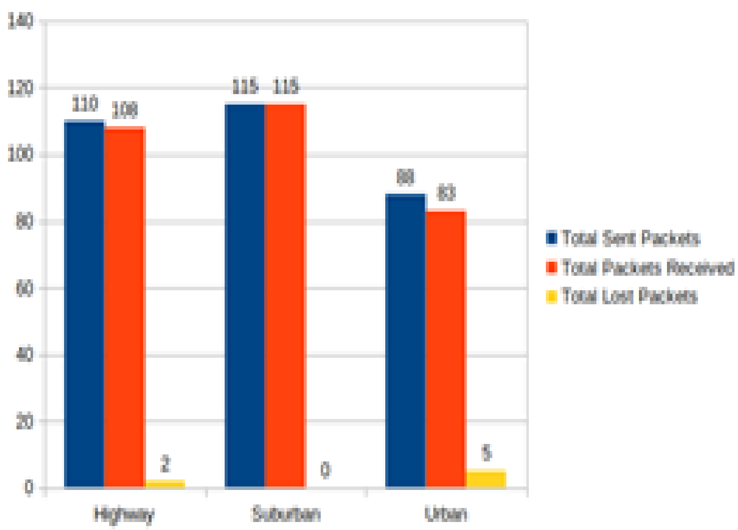

Figure 15: BarChart showing Sent, Received and Lost Packets.

Recommendations. Future research should be made on the integration of WiMax and WiFi VANET systems to evaluate the threats to the reliability of the system with the solutions proffered.

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References

[1] Rakesh Shrestha, Rojeena Bajracharya, and Seung Yeob Nam "Challenges of future VANET and Cloud Base Approaches," Wireless Communications and Mobile Computing, vol. 2018, p. 15, 2 May 2018.

[2] Muhammad Sameer Sheikh and Jun Liang "A Comprehensive Survey on VANET Security Services in Traffic Management System," Wireless Communications and Mobile Computing, vol. 2019, p. 23, 15 September 2019.

[3] Taskeen Zaidi and Syed Faisal "An Overview: Various Attacks in VANET," in 4th International Conference on Computing Communication and Automation (ICCCA), Noida, 2018.

[4] Sabih ur Rehman, M. Arif Khan, Tanveer A. Zia, Li h o ng Zhe ng "Vehicular Ad-Hoc Networks (VANETs) - An Overview and Challenges," Wireless Networking and Communications, vol. 3, pp. 29-38, 2013.

[5] Rakesh Shrestha, Rojeena Bajracharya, and Seung Yeob Nam "Challenges of Future VANET and Cloud-Based Approaches," Wireless Communications and Mobile Computing, vol. 2018, pp. 1-15, 2 May 2018.

[6] M. Azees, L. Jegatha Deborah, and P. Vijayakumar IET Intelligent Transport Systems, vol. 10, no. 6, p. 379–388, 2016.

[7] T. Kosch, C. Schroth, M. Strassberger, and M. Bechler "Automotive Internet working," 2012.

[8] Ravi Tomar, Manish Prateek, G. H. Sastry "Vehicular Ad hoc Network (VANET) - An Introduction.," International Journal of Control of Theory and Applications, pp. 8883-8888, 2016.

[9] M. Ghosh, A. Varghese, A. A. Kherani, and A. Gupta "Distributed misbehavior detection in VANETs," Proceedings of the IIEEE Wireless Communications and Networking Conference (WCNC), April 2019.

[10] Wenshuang Liang, Zhuorong Li, Hongyang Zhang, Shenling Wang, and Rongfang Bie "Vehicular Ad Hoc Networks: Architectures, Research Issues, Methodologies, Challenges, and Trends," International Journal of Distributed Sensors Networks, vol. 2015, p. 11, 6 November 2014.

[11] Muhammad Rizwan Arshad, Shahid Mehmood, Salman Afsar, Muhammad Azam Zia and Umar Farooq 2012. An Evaluation study of WiMAX and WiFi on Vehicular Ad-Hoc Networks (VANETs). *International Journal of Scientific & Engineering Research.* **3** (12).

[12] N. B. Truong, G. M. Lee, and Y. Ghamri-Doudane "Software defined networking-based vehicular adhoc network with fog computing," in Proceedings of the IEEE conference on Integrated Network Management, p. 1202–1207, 2015.

[13] Salm Shangguang Wang, Manzoor Ahmed, and Muhammad Rizwan Anwar "A Survey on Vehicular Edge Computing: Architecture, Applications, Technical Issues, and Future Directions," Wireless Communications and Mobile Computing, pp. 1-20, 24 February 2019.

[14] H. Moustafa and Y. Zhang "Vehicular Networks: Techniques, Standards, and Applications," BocaRaton,Fla,USA, 2009.

[15] H. Hartenstein and K. Laberteaux 2010. it VANET-Vehicular Applications and Inter-Networking Technologies. John Wiley & Sons.

[16] D. T. staff "4G explained: A guide to LTE, LTE-A, WiMax, HSPA+, and more," 2 June 2017. [Online]. Available: https://www.digitaltrends.com/mobile/what-is-4g-the-ultimate-guide-to-4g-wireless-networks-phones-coverage-and-more/.

[17] O. A. Tiamiyu (2012).Analysis of IP Routing Protocols for Trusted Routing in the Global Data Networks. *Science Journal VESTNIK ENGEC: Technical Science Series.* **59** (8), 157-160.

[18] Saajid Hussain Di Wu, Wang Xin, Sheeba Memon, Naadiya Khudar Bux and Arshad Saleem, "Reliability and Connectivity Analysis of Vehicluar Ad Hoc Networks for a Highway Tunnel," International Journal of Advanced Computer Science and Applications, pp. 1-6, 2019.

[19] Sumit Mallik "Intelligent Transportation System," International Journal of Civil Engineering Research, pp. 367-372, 2014.

[20] Prof. Sadko Mandžuka, PhD INTELLIGENT TRANSPORT SYSTEMS, Zagreb: Intelligent Transport Systems Department Faculty of Transport and Traffic Sciences University of Zagreb, 2015.

[21] Divya Garg and Prof. Hari Om Tyagi Wi-Fi & WiMAX: Wireless Technology, International Journal of Computer Science and Information Technologies, Vol. 8 (5), pp. 548-551, 2017.

[22] Sourangsu Banerji and Rahul Singha Chowdhury "Wi-Fi & WiMAX: A Comparative Study," Indian Journal of Engineering, 2013.

[23] Felician ALECU "The WiMAX Technology," Oeconomics of Knowledge, vol. 2, no. 2, pp. 2-8, 2010.

[24] V. Devarajan, Dr. R. Gunasundari, T. Karthik and V. Rajasekaran "Integration of VANET-WiMAX Networks," Devarajan 2013 integration of VANET, pp. 695-700, 2013.

[25] Abdeldime M.S. Abdelgader and Wu Lenan "The Physical Layer of the IEEE 802.11p WAVE Communication Standard: The Specifications and Challenges," Proceedings of the World Congress on Engineering and Computer Science, pp. 1-5, 2014.

[26] Lerotholi S. Mojela and Marthinus J. Booysen "On the use of WiMAX and Wi-Fi to provide in-vehicle connectivity and media distribution," Research Gate, pp. 1-7, February 2013.

[27] Hammad Shafiq, Rana Asif Rehman , and Byung-Seo Kim "Services and Security Threats in SDN Based VANETs: A Survey," Wireless communications and mobile computing, vol. 2018, pp. 1-14, 23 April 2018.

APPENDIX

```
#include ¡fstream¿
#include ¡iostream¿
#include ”ns3/core-module.h”
#include ”ns3/network-module.h”
#include ”ns3/internet-module.h”
#include ”ns3/mobility-module.h”
#include ”ns3/aodv-module.h”
#include ”ns3/olsr-module.h”
#include ”ns3/dsdv-module.h”
#include ”ns3/dsr-module.h”
#include ”ns3/applications-module.h”
#include ”ns3/itu-r-1411-los-propagation-lossOmodel.h”
#include ”ns3/ocb-wifi-mac.h”
#include ”ns3/wimax-module.h”
#include ”ns3/wifi-80211p-helper.h”
#include ”ns3/wave-mac-helper.h”
#include ”ns3/flow-monitor-module.h”
#include ”ns3/config-store-module.h”
#include ”ns3/integer.h”
#include ”ns3/wave-bsm-helper.h”
#include ”ns3/wave-helper.h”
#include ”ns3/yans-wifi-helper.h”
#include ”ns3/netanim-module.h”
using namespace ns3;
using namespace dsr
NS_LOG_COMPONENT_DEFINE (”vanet-routingocOmpare”);
class RoutingStats
public:
RoutingStats ();
uint32_t GetRxBytes ();
uint32_t GetCumulativeRxBytes ();
uint32_t GetRxPkts ();
uint32_t GetCumulativeRxPkts ();
void IncRxBytes (uint32_t rxBytes);
void IncRxPkts ();
void SetRxBytes (uint32_t rxBytes);
void SetRxPkts (uint32_t rxPkts)
uint32_t GetTxBytes ();
uint32_t GetCumulativeTxBytes ();
uint32_t GetTxPkts ();
```

```
uint32_t GetCumulativeTxPkts ();
void IncTxBytes (uint32_t txBytes);
void IncTxPkts ();
void SetTxBytes (uint32_t txBytes);
void SetTxPkts (uint32_t txPkts);
private:
uint32_t m_RxBytes;
uint32_t m_cumulativeRxBytes;
uint32_t m_RxPkts;
uint32_t m_cumulativeRxPkts;
uint32_t m_TxBytes;
uint32_t m_cumulativeTxBytes;
uint32_t m_TxPkts;
uint32_t m_cumulativeTxPkts;
RoutingStats::RoutingStats ()
: m_RxBytes (0),
m_cumulativeRxBytes (0),
m_RxPkts (0),
m_cumulativeRxPkts (0),
m_TxBytes (0),
m_cumulativeTxBytes (0),
m_TxPkts (0),
m_cumulativeTxPkts (0)
uint32_t
RoutingStats::GetRxBytes ()
.....
......
.........
m_mobility = 1;
m_nNodes = 96;
m_TotalSimTime = 10.01;
m_nodeSpeed = 50;
m_nodePause = 0;
m_CSVfileName = "/home/bright/highwayOscenario/highway.csv";
m_CSVfileName = "/home/bright/highwayOscenario/highway2.csv";
```