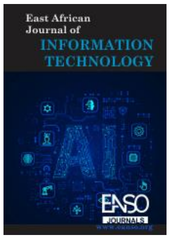

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Original Article

Performance Evaluation of IEEE 802.11p Enhanced Distributed Channel Access based on Vehicular Ad-hoc Network Characteristics

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VANET- Vehicular Ad-hoc Network,
ITS – Intelligent Transport System,
V2V- Vehicle to Vehicle,
EDCA – Enhanced Distributed Channel Access,
MAC – Medium Access Control

ABSTRACT

Kenyan road accidents increased by 20% between January 2015 to January 2020 with fatalities from road traffic accidents (RTAs) rising to 1.3 million per year. More than 93% of these accidents occur in low-income and middle-income countries like Kenya. Vehicular Ad-hoc Network (VANET) is a subclass of Mobile Ad-hoc Network (MANET) that constitute mobile nodes deployed on all road networks. Network performance is affected by VANET characteristics, i.e., dynamic topology, high-speed nodes, varying vehicle density, and frequently switched links. This research focused on performance evaluation of the IEEE 802.11p Enhanced Distributed Channel Access (EDCA) mechanism using: node speed and node density. The methodology used two scenarios, the highway and rural roads. To demonstrate these scenarios, we used various tools such as OpenStreetMap and SUMO to generate a real mobility model that gives aspects of real-life traffic. The generated scenarios were exported to a Network Simulator (NS 3.31) in order to evaluate the performance of 802.11p. To evaluate the effectiveness of 802.11p, we compared its performance with 802.11a. Performance metrics used were throughput, packet delivery ratio and end-to-end delay. The results obtained showed that 802.11p is better and more effective than 802.11a in both highway and rural scenarios.

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INTRODUCTION

Kenyan road accidents increased by 20 % between January 2015 and January 2020. Injuries in users, i.e., pedestrians, passengers, and motorcyclists have increased compared to 2015 data. Policies to protect vulnerable road users and rogue driver behaviour is needed. Fine-tuning data collection for accidents are useful in modelling and data analysis for future planning. Research shows that injuries in pedestrians, passengers, and motorcyclists have doubled compared to 2015 data (Muguro et al., 2020).

The global status report by World Health Organization (WHO) on road safety shows injuries from road traffic accidents increased to 1.3 million per year. Low-income and middle-income countries contribute to more than 93% of these accidents. Road traffic demises (RTDs) are the number one cause of death for ages 5-29. The economically productive years in human life are 15-49 years and research on RTA estimates more than 50% of injuries/fatalities occur in this group (Macharia et al., 2009).

Research estimates that the financial implications of road traffic injuries in a country range between 1.3% and 3.0% of gross domestic product (GDP) (Manyara, 2016). Over the last decade, Kenya has realised an increase in RTAs. This is because of urbanisation and increasing motorisation in the country. Being a low income-economy, road infrastructural development and policy challenges are slow in adopting international safety standards. NTSA tends to adopt a dead-on-the-spot for death report and little or no follow-up is done with hospitals to determine which injuries led to death which is contrary to the international recommended standardised way of reporting, which considers RTDs within a 30-day window (Toroyan et al., 2013).

Vehicular Ad-hoc Network (VANET) is a research area where much is being done to facilitate an Intelligent Transport System (ITS). This is used in a number of applications such as traffic safety, traffic management, and entertainment, among others. Communication in VANET is classified from vehicle to vehicle, where On-Board Units (OBU) in each vehicle are used to communicate independently. The other is vehicle to the infrastructure where Road Side Units (RSU) is the central communication station where data is stored periodically and used for decision making (Al-Absi et al., 2018). This is shown in fig 1.

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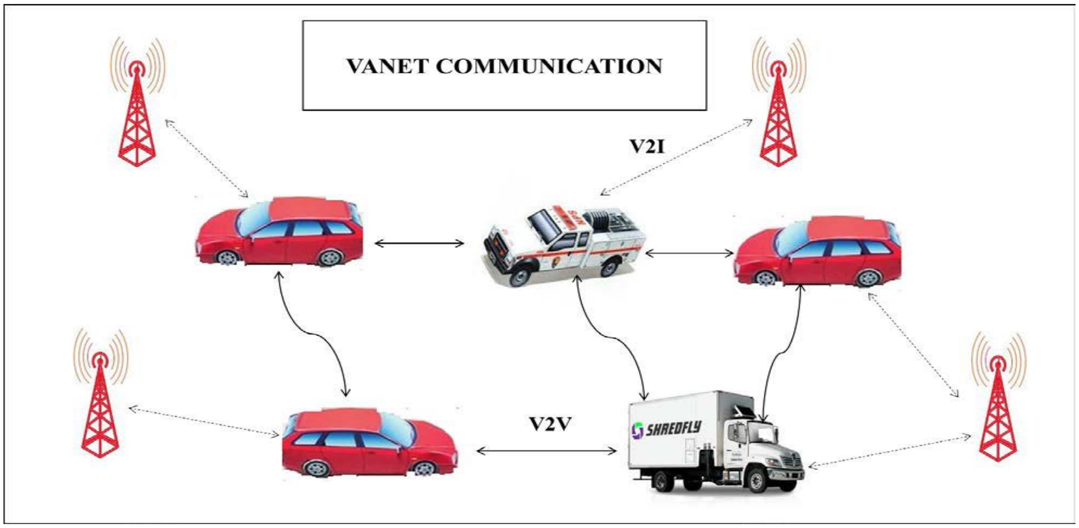
Figure 1: VANET Communication Architecture



VANET is characterised by high-speed nodes, varying vehicle density, frequent disconnection and a dynamic topology (Meneguette et al., 2018).

Statement of the Problem

Network performance is affected by vehicular ad-hoc network characteristics such as dynamic topology, high-speed nodes, varying vehicle density, frequently switched links and short duration of communication link, especially in the Medium Access Control (MAC) sublayer. IEEE 802.11p standards ability to provide efficient and reliable services required by VANET that are handled by its MAC protocol is questionable. Its concerns include appropriate performance metrics to be used to measure the performance of the MAC protocol for different applications, such as packet delivery ratio, throughput and delay. The focus was on performance evaluation which was to determine the performance of the IEEE 802.11p Enhanced Distributed Channel Access mechanism using VANET characteristics: node speed and node density and also its ability to guarantee QoS for priority-based applications in VANET.

Justification

Traffic efficiency is achieved by using an effective traffic management system. With the upsurge in traffic jams, accidents, and infotainment, among others, there is a need for traffic data collection, analysation, interpretation, and transmission in real-time to help drivers and intelligent devices make good and informed decisions on the state of the road network ahead. Reduced fuel consumption and improved monetary flow are some of the benefits of ITS when there is efficiency and reliability. ITS contributes to social and economic development worldwide (I. Meneguette et al., 2018).

Contribution to the Existing Body of Knowledge

Data was collected in real-time by using GIS and through simulation using NS3. The main contribution to the research is that we used two road environments; highway and rural. The objective was to measure the performance of the network in these two distinct road environments. The results obtained were to enable us to come up with a framework that can be optimised for the Kenyan road environment.

The study measured the parameters in the form of equations which were operationalised as follows;

- Packet Delivery Ratio (PDR) in a highway environment
- Packet Delivery Ratio (PDR) in a rural environment
- Throughput in a highway environment
- Throughput in a rural environment
- Delay in a highway environment

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- Delay in a rural environment

The study contributes significantly to the management of transport in Kenya, which contributes to 60% of the commuter services. This will help the department in making strategic investment decisions. The Government of Kenya (GoK) has invested heavily in the road sector and therefore, the study is of great importance to the government policy-making on ITS such as the Bus Rapid Transit (BRT) system. It will also serve as a benchmark to be used by future studies on ITS since we don't have any studies done that compare the same parameters on different road environments in Kenya and the rest of the world. Most of the studies done focused on reducing road accidents without the aspect of ITS. The findings therefore, contribute to the professional extension of existing knowledge in the role of ICT in corporate operations of the road sector.

Objectives

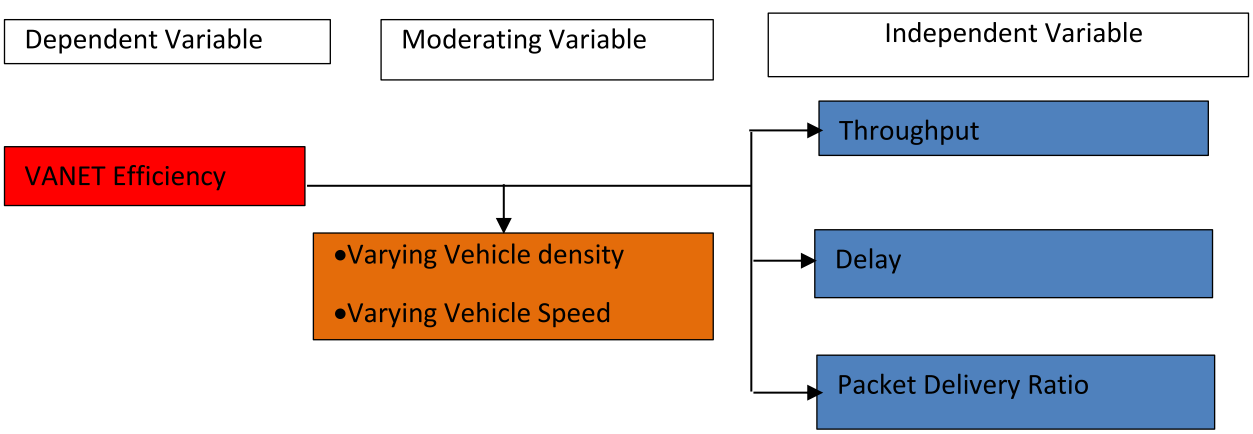
To carry out a performance evaluation of IEEE 802.11p Enhanced Distributed Channel Access mechanism using specific vehicular ad-hoc network characteristics: node speed and node density in a traffic scenario. The specific objectives of the study were:

- Develop a highway network schema that was used as the simulation environment for vehicular ad-hoc network characteristics.
- Evaluate the performance of IEEE 802.11p Enhanced Distributed Channel Access mechanism with varying node speed in the simulated highway and rural environment.
- Evaluate the performance of IEEE 802.11p Enhanced Distributed Channel Access mechanism with varying node/vehicle density in the simulated highway and rural environment.
- Verify the effectiveness of the IEEE 802.11p Enhanced Distributed Channel Access mechanism in vehicular ad-hoc networks by comparing the different parameters in the two environments.

Conceptual Framework Diagram

Figure 2 below describes the inter-relationship between the dependent and independent variables that were used.

Figure 2: Diagrammatic illustration of the inter-relationship between the dependent and independent variable



(**Source**: Alice2021)

Scope

This study used unidirectional traffic, where signals were generated for vehicles moving in one direction. Vehicle to vehicle communication mode was used in the two scenarios where VANET characteristics were varied: node density and node speed in different road environments; highway and rural roads, to evaluate the performance of IEEE 802.11p Enhanced Distributed Channel Access

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mechanism using QoS metrics: packet delivery ratio, throughput and end to end delay.

The Ruiru- Thika section has more features like speed bumps, a toll station, and bus stops, markets and there are also different speed signs along the highway section thus giving us a real-life scenario. The Thika- Garissa highway is single-lane and has features like bumps, markets, bus stops, and shopping centres that depicts a real-life scenario but in a rural environment. Both stretches are 19 km. In both scenarios, the simulation time is 100s.

LITERATURE REVIEW

Traffic Situation in Kenya

Preceding research has pointed out various transportation and traffic situation as identifiers for accident frequency. The identifiers include traffic jams, human behaviours, road types, vehicle conditions, policing, and weather, among others (Zheng et al., 2020). In this section, we surveyed some of the situations that carry the day, which increases RTAs in the country and some measures and policies being taken by the relevant stakeholders.

Public Service Vehicles and Motorbikes

Kenya relies on public service vehicles (PSVs) to meet the commuter needs of various groups of people. Reports indicate that the mode of public transport in Kenya is very effective when it comes to issues of safety (Manyara, 2016; Mogambi & Nyakeri, 2015). Literature shows that growth in the usage of motorised two/three-wheeled vehicles has been reported to increase injuries and deaths among users (Mogambi & Nyakeri, 2015). The situation has worsened due to the rise in registered vehicles in the country.

Disaster Preparedness

First aid and emergency centres availability has been identified as a challenge in many different developing countries like Kenya. Reports indicate that only 16% of road accident casualties received first aid, 76.5% of the injured persons were transported to hospitals by well-wishers, while Police and ambulance vehicles transported 6.1% and 1.4%, respectively (Mogambi & Nyakeri, 2015).

Policing

Reports indicate that 85% of the accidents are caused by driver error in Kenya, which includes over speeding, intoxication, and/or plain recklessness, among others (Mogambi & Nyakeri, 2015). NTSA, in conjunction with the Kenya police traffic department, has been enforcing adherence to traffic rules in the country. The problem of drunk driving still persists, but there has been no published information on its reintroduction since then. The Kenya police department still monitors reckless driving, speeding, and other malpractices that can cause road accidents. They perform random “Crack-down” on vehicles that do not conform to the road safety standards laid out by the laws (Manyara, 2016).

Research and Public Awareness in RTAs

There are few research works related to RTAs in the period 2015–2020 in relation to the prevalence of the menace (Muguro et al., 2020). Authors have focused on different aspects of RTAs in the country ranging from road and infrastructure, impacts of RTAs, access to hospital and emergency centres, and trauma in accidents, among others, in the reviewed literature. This is heightened by over-reliance on media stations for accident reporting. Mogambi and Nyakeri (2015) have pointed out the tendency of media stations to prime and depend on eyewitnesses. This is a major shortcoming in the publicly availed data source (*National Transport and Safety Authority*, n.d.).

Zusha Campaign

Zusha campaign is one of the most successful awareness campaigns in the country, a nationwide awareness effort to combat RTAs. “*Zusha*” -the Kiswahili word for “protest” or “speak up” is meant to encourage passengers in PSV to speak up against reckless driving (*Zusha! - The Life You Can Save*, n.d.). Stickers were distributed on PSVs with graphics and messages encouraging passengers to speak directly to the drivers against dangerous driving. From the campaign, the cost-effectiveness ratio of the intervention is estimated to lie between US$6.50 and $11.70 per disability-adjusted life year

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(*Zusha! - The Life You Can Save*, n.d.). The campaign gives the passenger the mandate of supervision. Some of the campaign challenges include laxity from passengers when they allow recklessness to gain a minute or two in the middle of a traffic jam and hostility from other passengers who are late or partisans in the transport industry, among others.

ITS Overview

Intelligent Transport System (ITS) comprises information processes and a set of technologies which aim to improve the transport system safety, mobility, quality, and functioning as well as increasing productivity and reducing the harmful effects of traffic. In the 20th century, researchers in the United States proposed the ITS concept, but the research has now been embraced worldwide by the industry as well as academia. ITS is integrated with ICT and then applied in the transport sector. The equipment installed in vehicles are referred to as On-Board Units (OBU), roadside infrastructure is referred to as Roadside Units (RSU), and sensors are used to collect data, analyse, store, and facilitate informed decisions in the transport sector. The application of ITS reduces fuel consumption, carbon monoxide emission, and monetary losses through eased traffic jams. (Meneguette et al., 2018).

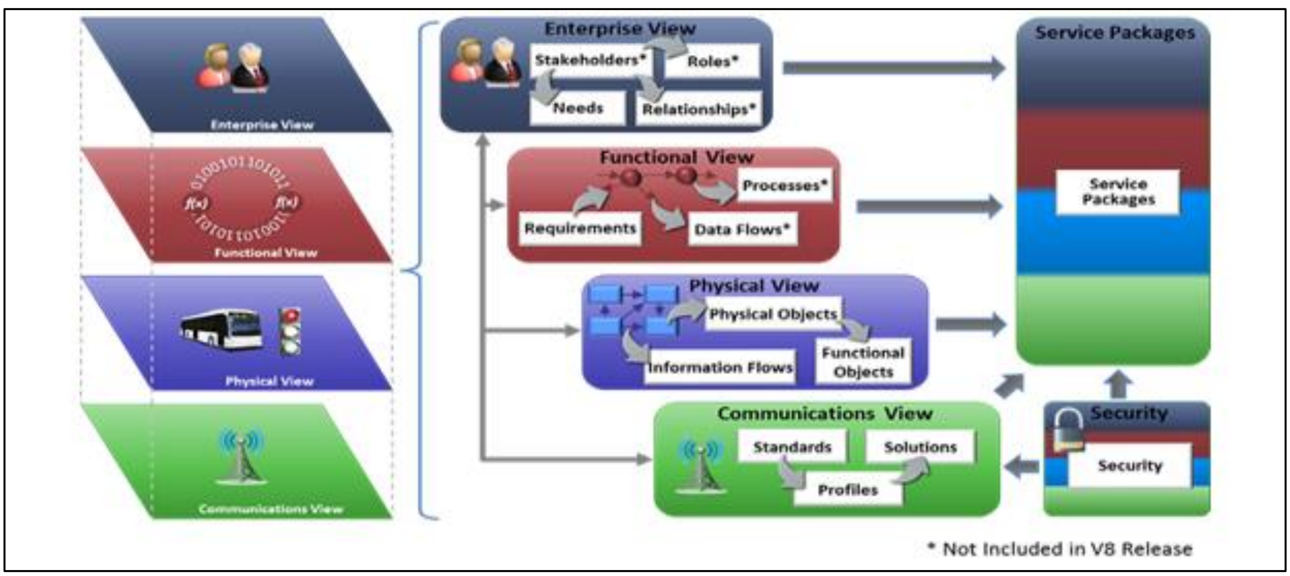
ITS Architecture

The interaction of devices and components in ITS must be defined by a general method because of the high diversity of factors, thus the need for standardisation. In this research, we describe the architecture adopted by the United States.

United States ITS Architecture

It was developed by the United States Department of Transportation and is referred to as the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT). Its design focuses on assisting urban mobility by use of a cooperative system and is organised into four views, as we can see in *Figure 3* (Meneguette et al., 2018). The views are described as follows;

Figure 3: United States ITS Architecture



Source: (I. Meneguette et al., 2018)

a) Enterprise View

It focuses on the relationship between organisations and users, coming up with rules that such organisations will abide by within the cooperative ITS environment. Enterprise View consists of the following set of objects. *Enterprise Object* includes an organisation or individual that interacts with an object (I. Meneguette et al., 2018). *Resource* may be a physical or virtual element that supports the execution of some object with limited dispersion. *Roles* are functions, actions or rules that an object participating in a relationship abides to.

b) Functional View

It deals with the interaction of logical and abstract elements, which defines the functional requirements that support the needs of ITS users. The functional model only includes collections of processes and their data flows (I. Meneguette et al., 2018). Some structural artefacts used in the Functional View include; *Process* consists of an activity required to perform actions and achieve an objective or support actions of another process. *Process Specification* is the textual definition of the most detailed processes. *Data Flow* is the flow of information among processes and an object within a process. *The terminator* shows an external device that belongs to the architecture, such as a sink for information.

c) Physical View

It focuses on the physical elements that provide functionality in ITS, such as devices and systems. Delivery of user services, respective capabilities of such elements, and connections between them are some roles of elements contained in this functionality. The Physical View, therefore, outlines the transport system and the information exchanges supported by ITS. According to (Joseph, 2006) physical View consists of the following objects;

Physical Objects constitute people, objects, or places that are involved in ITS. The objects are demonstrated according to their processing, application, and their interfaces with other objects. *Functional Objects* constitute the building blocks of the physical objects in the physical view. *Information Flow* consists of exchanging information between a view and a physical object. The information should meet the requirements the interface provides. *Triple* is used to define an interface which is the junction of a Physical Object source and destination with the Information Flow and Physical Object destination. *A subsystem* constitutes a Physical Object with a specified functionality inside the ARC-IT system boundary. *Terminator* means a Physical Object without a specified functionality outside the ARC-IT system boundary. *Service Package Diagram* shows all Physical Objects diagrams.

d) Communication View

It defines communication between Physical Objects by outlining the communication protocols for effective communication between Physical Objects in the Physical View. System requirements with the constraints for physical connectivity are mapped by the protocols.

Technologies Used in ITS

ITS is supported by three technologies which include data collection, communication, and database technologies (Zear et al., 2016). They are discussed as follows;

Data Collection Technology - Accurate and comprehensible data is one of the functional requirements for ITS. For better data collection methods, various techniques have been proposed and implemented in recent years. They are classified into vehicle-based technology, which includes GPS, floating car technology, and cell-based and infrastructure-based technology, which includes sensors, CCTVs, and induction loops.

Communication Technology - There are many technologies that can be applied in ITS depending on price, working environment, and capacity. The technologies vary from telephone lines to advanced technologies in mobile computing such as Long-Term Evolution (LTE), High-Speed Packet Access (HSPA) and finally, various Ad-hoc wireless communication technologies. Wireless communication for intelligent vehicle-to-vehicle communication has also become very popular in VANET.

Database Technology - Information related to traffic and a review of the network based on information received is managed using a database.

ITS Application

Vehicular networks provide many applications and services for users because there is the ease of communication between vehicles and with road

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infrastructure (Meneguette et al., 2018; Zear et al., 2016). The main applications of ITS are as follows;

Safety Applications - For drivers to make a quick decision in order to avoid a collision or an obstacle ahead, an alert is sent to the driver.

Traffic Control - This helps to improve the travel time for road users and the traffic flow of vehicles. In return, huge economic and environmental benefits are realised.

Entertainment - This intends to make road users engaged and entertained in their travel time by promoting social benefits.

VANET Overview

Vehicular Ad-hoc Network (VANET) is a subclass of Mobile Ad-hoc Networks (MANET). It is a research area that has been growingly drawing attention from both the industry and academia. It is one of the key contributors to intelligent transport systems that seek to have a transport management system that will help in reducing the number of accidents, traffic jams, sending alerts, and entertainment, among others (Hamdi et al., 2020).

According to Al-Absi et al. (2018), a vehicle is referred to as a node and is equipped with a chipset which is referred to as an Onboard Unit (OBU) for communication with other vehicles and stationary units along the road network, referred to as Road Side Unit (RSU).

VANET Characteristics

Some of the VANET characteristics are as follows;

Varying vehicle density - VANET is composed of an enormous number of vehicles, especially during peak hours than off-peak hours (Hamdi et al., 2020). Vehicle density also varies from urban, highway, or rural types of road networks.

Dynamic topology - This is attributed to the high movement of vehicles; thus, communication is for a very limited time. However, such network topologies are also very insecure (Hamdi et al., 2020). For example, mobile vehicles travelling at a speed of 50km/h in the opposite direction. Assuming that the transmission range is 500m, communication between the two vehicles will last for (0.5km/100km/h), 0.005 h * 3600 = 18s.

High-speed nodes - There is high movement of vehicles at high velocities. It can be zero when the vehicles are in traffic jams to a maximum of 110 kilometres per hour.

Frequently disconnected nodes - This is attributed to the high movement of vehicles and obstacles nearby the road, which leads to periods of network disintegration. In rural areas where vehicle density is low, frequent disconnection of the network will occur (Al-Absi et al., 2018).

Mobility Modelling and Prediction - It is easy for us to show the knowledge of the positions and movements of the vehicles but hard and complicated to predict where the vehicle can move randomly.

Communication Environment - There are different environments that can be used in the analysis of vehicular networks. These vary from city, highway, and rural environments. Accordingly, mobility modelling is important because it will show us the varied number of vehicles and their mobility.

Hard Delay Constraints - The sudden break and connection and emergency calls are some of the safety features of the application. These rely heavily on the delivery time of data. Therefore, in VANET, the hard delay limitation is very important than the high data rate. Interaction with On-board Sensors - The interaction between the sensors of the various vehicles are used for effective communication between the vehicles and shows the vehicle location, vehicle speed and vehicle pattern movement.

VANET Applications

VANET provide an opportunity for improving the intelligent transport system (Hamdi et al., 2020). It is classified into three categories; road safety, road efficiency and infotainment

Road Safety Applications

They aim at giving fore warnings in order to reduce the likelihood of an accident occurring. In this instance, alerts are given through a vehicle OBU

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from nearby vehicles about road events. Road safety applications are classified into three categories;

Collision Avoidance **-** The RSU detects the risk of a collision between two vehicles and sends a warning to the drivers through the OBU. They include warning of intersection collisions, pre-collision warnings, line change warnings, and dangerous location alarms.

Traffic Sign Notification - It sends warning to drivers about road signs and provides assistance during the route. They include curve Speed Warning and Traffic Signal Violation Warning.

Incident Management - They are used in emergencies in the event of a traffic accident. They include Emergency Vehicle Alarm and Post-Collision / Shock Warning.

Road Efficiency Applications

Monitoring and managing road conditions and vehicle traffic helps to improve traffic conditions. This function can be classified into;

Traffic management - They process information about the traffic flow and control from the RSU elements of the transportation system, such as traffic lights and tolls. Some of the applications include Intelligent traffic control, Traffic-free tolls, Speed control, Route guidance and improved navigation.

Traffic monitoring - These applications monitor vehicles and road conditions. In case of irregularities, notify drivers and traffic authorities. Some of these applications include Monitor of Road Conditions and Vehicle Tracking and Tracking Agent.

Infotainment

They aim to provide entertainment and information services to road users. It can be classified into;

Entertainment - They offer the occupants of the vehicles the possibility of using the VANET resources for recreational purposes; through stationary access points arranged on the road. The services may include surfing the internet, online games, movies etc.

Background information - They provide drivers with location-based services. They include Update and Download Maps, Location and Parking Reservation and Information on Sites of Interest.

VANET Challenges

VANET characteristics include varying vehicle density, high-speed nodes, varying topology, frequent disconnection and short communication links. These characteristics have an important impact on the design of response in these networks therefore, the many challenges must be addressed for communication to be effective (Hamdi et al., 2020).

Security - Trust is a big issue in vehicle-to-vehicle communication, which is why it is important to verify the content of the received message within a short time to be able to use the information as soon as possible. The validation of the messages is to prevent the spread of incorrect information.

Vehicle Density - Vehicles will increase from zero to thousands in the mutual radio range.

Vehicle Speed - For VANET mobility, the vehicle speed is an important component. It can range from 0 when the vehicles are trapped in traffic jams to 100 km per hour. These two extremes present an exceptional challenge for the VANET communication system. For example, mobile vehicles travelling at a speed of 50km/h in the opposite direction. Assuming that the transmission range is 500m, communication between the two vehicles will last for (0.5km/100km/h), 0.005 h * 3600 = 18s.

Mobility Patterns - VANET is characterised by mobile nodes. This high mobility can be relatively essential for the type of roads, which can either be city, highway or rural roads. The vehicles move in two directions; unidirectional or bidirectional. Irregular changes in vehicle direction occur only at crossroads and traffic lights are used to regulate the movement.

Privacy - This service provides confidentiality of the communication channel. It should guarantee the privacy of drivers against unauthorised observers.

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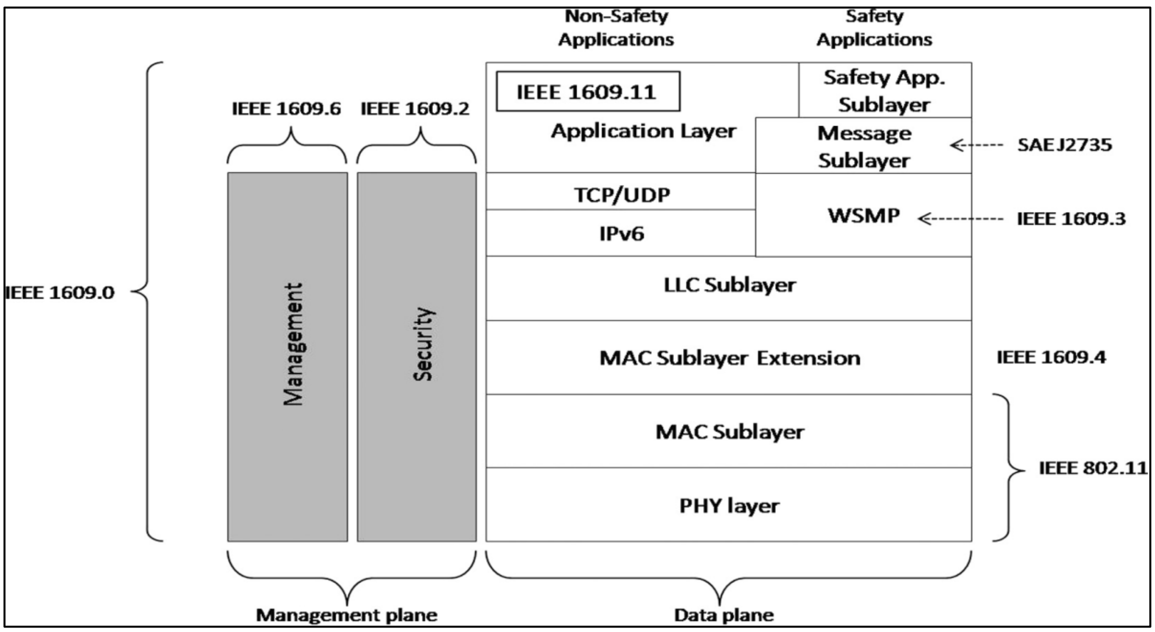
Data Dissemination - This service provides stability during the streaming of data. It should assure that messages are received as sent without relays, modification, reordering or insertions.

IEEE 802.11p Overview

IEEE 802.11p is an amendment of IEEE 802.11 family approved especially for vehicular networks to define enhancements required to support ITS applications. It operates in the 5.9 GHz band higher than 5GHz accorded to Wi-Fi protocols over a total bandwidth of 75MHz and provides Wireless Access in Vehicular Environments (WAVE) at a distance up to 1000m. The spectrum is divided into seven channels of 10MHz and a guard band of 5MHz. The Control Channel (CCH), channel 78, is reserved for safety applications such as accidents and collision warning applications, while the other channels, commonly referred to as Service Channels (SCH), are used for non-safety applications such as infotainment and information service applications in order to make technology available and cost-friendly. WAVE covers the entire OSI layer by merging IEEE 802.11p and 1609.x, as shown in *Figure 4* (Akkari Sallum et al., 2018).

Figure 4: WAVE Communication Stack



Source: (Campolo et al., 2015)

In its communication stack, IEEE 802.11p has physical (PHY) and Medium Access Control (MAC) layers that use one control channel (CCH) and six Service Channel (SCH) of 10MHz each for different operations using the Dedicated Short-Range Communication (DSRC) spectrum. High priority messages such as position, speed and direction fall under safety applications that require periodic updates and their transmission should never be impacted by low priority messages such as infotainment which fall under non-safety applications (Zulfiker Ali et al., 2018; Benabdallah et al., 2018).

The PHY layer features Orthogonal Frequency Division Multiplexing (OFDM) to provide support for different data rates depending on modulation and coding rates. The MAC sublayer features Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), where Enhanced Distributed Channel Access (EDCA) is based to support different levels of Quality of Service (QoS). IEEE 802.11e standard provides QoS support in Wireless Fidelity (Wi-Fi) (Zulfiker Ali et al., 2018).

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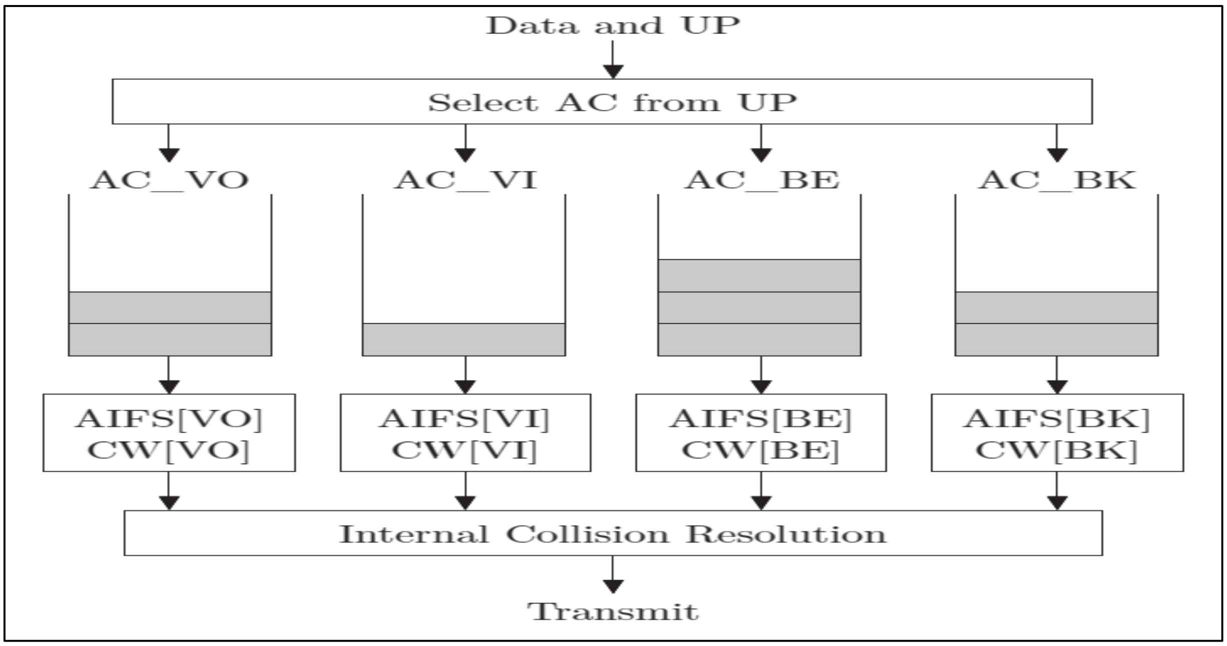
EDCA Mechanism

EDCA is a medium access mechanism that is used to provide priority levels to four access categories (AC) which constitute AC_VO (voice), AC_VI (video), AC_BE (best effort), and AC_BK (background). IEEE 802.11p uses the EDCA access control mechanism that was proposed in IEEE 802.11e standard to introduce service differentiation when accessing the channel using the four access categories. The four ACs have different priority levels with video and voice having higher priority than best effort and background (Janevski, 2019).

Figure 5: EDCA Mechanism



Source: (Finansów & Vistula -Warszawa, 2018)

Each AC consist of the following parameters:

- **Arbitration Inter-Frame Space (AIFS)**

It is a technique used by the 802.11e wireless local area network (WLAN) standard to prevent collisions by prioritising ACs and determining a time interval to wait before sending a request frame. AC with higher priority is assigned shorter AIFS.

AIFS=AIFSN ∗ slot time + SIFS (Equation 1)

Where AIFSN is a positive integer in different AC queues (default values in *Table 1*), slot time is the maximum time for a frame to transmit between two nodes. Short inter-frame space (SIFS) is the period between data and an ACK frame. AIFS is decremented in parallel for each AC queue, Slot time is defined as 13µs and SIFS is defined as 32µs in DSRC (Janevski, 2019).

- **Minimum contention window (CW min) and Maximum contention window (CW max**)

It is the size of the contention window used for backoff that varies from one AC to the other. AC with higher priority has smaller CW min and CW max values compared to lower priority ACs (Campolo et al., 2015). Default values are presented in *Table 1.*

- **Transmission Opportunity (TXOP)**

It is the time duration to be used to transmit once the AC win the access medium.

Table 1: Default EDCA parameters for Access Category

AC Name	AC Description	CW min	CW max	AIFSN	TXOP limit
AC_BK	Background	15	1023	7	0
AC_BE	Best Effort	15	1023	3	0
AC_VI	Video	7	15	2	3.008ms
AC_VO	Voice	3	7	2	1.504ms
DCF	Legacy station	15	1023	2	0

In IEEE 802.11p, only one packet is sent per channel by all ACs because the transmission opportunity (TXOP) is always set to 0. When all the ACs happen to access the medium at the same time, they first check if it is busy and when it is, they delay the transmission. Operation mode known as Outside Context of BSS (OCB) in IEEE 802.11p allows vehicles to communicate without registering in the nearest ad-hoc network due to the latency requirements and short-lived connectivity in most applications, especially those used for safety (Campolo et al., 2015).

Related Work

Sarvade and Kulkarni (2017) have compared IEEE 802.11ac with previous MAC protocols IEEE 802.11p and IEEE 802.11 n in an urban scenario where they used Simulation of Urban Mobility (SUMO) and Network Simulator 3 (NS3). The parameters used to measure the performance were throughput, jitter, and end-to-end delay using Ad-hoc On-Demand Distance Vector (AODV) as the routing protocol. IEEE 802.11ac and IEEE 802.11n had better throughput, jitter, and end-to-end delay than IEEE 802.11p thus suitable for non-safety applications. IEEE 802.11p is suitable for safety applications.

Alwan et al. (2019) have concentrated on IEEE 802.11 and IEEE 802.11p in a highway environment where vehicle speed was used to evaluate communication performance using the metrics throughput, delay, and packet delivery ratio. Destination-Sequenced Distance-Vector (DSDV) was used as the routing protocol. Their simulation showed that IEEE 802.11p provided better performance with the evaluation metrics.

Performance analysis between IEEE 802.11p and IEEE 802.11a using the performance parameters Packet Delivery Ratio (PDR), End to End delay (E2E), and throughput have been done by Fitah et al. (2018). Open Street Map (OSM), SUMO and Network Simulator 2 (NS2) were the traffic and network simulators used, respectively. A highway scenario was used where scenario i) Had the highway and trunk roads with 64 nodes and scenario ii) had the primary, secondary, tertiary and residential nodes with 97 nodes. File Transfer Protocol (FTP) was used as the traffic type, and AODV as the routing protocol.

According to (Muschik, 2016), a performance analysis of throughput, e2e delay and packet loss in different highway scenarios with varying vehicle density and simulation time was made. Cloud computing technology is embedded in the experiment to minimise accidents, and congestion, among others. The simulation results concluded that moderate simulation time enhances good VANET performance while many nodes in a network produce more throughput and packet loss. OPNET was used as the simulation tool in a highway scenario to evaluate the performance of AODV, OLSR and GRP using the performance metrics routing traffic sent and received, end-to-end delay and throughput. A single node with voice traffic was used with varying speed

Tomar and Patreek (2017) provide an analysis of the performance of IEEE 802.11p using beacons when only the control channel is used for beaconing. SUMO is used as the traffic simulator, while OMNET++ and VEINS framework are used as network simulators. They observed that each node generates a message as per the frequency allotted.

Ribeiro and Becker (2019) did a performance comparison between IEEE 802.11p EDCA and IEEE 802.11n 2.4GHz and 5GHz using DCF and EDCA coordination functions depending on the reliability and survivability of Unmanned Aerial Vehicles (UAV). SUMO and NS3 were the tools used for simulation. Their evaluation showed that

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IEEE 802.11p is more effective in terms of performance adaptation of traffic flow, while IEEE 802.11n is effective in terms of prioritised video streaming.

Harkat (2018) has concentrated on performance analysis of IEEE 802.11p EDCA-based VANETs using a manual schema where vehicles are in a circumference and NS2 network simulator. They observed that even in critical situations, IEEE 802.11p EDCA could be adapted for ITS applications.

METHODOLOGY

Simulation Environment

This section consists of the simulation environment and the tools used to carry out the simulation. Implementing a real test bed for VANET is very expensive due to cost constraints. To address this limitation, computer simulation based on real-world data was adopted for this research.

Simulation of Urban Mobility (SUMO)

SUMO is an open source; a microscopic and continuous road traffic simulator was used to carry out these tasks because it has a set of tools that help in traffic simulation. NETCONVERT command-line tool creates the SUMO network used to import the highway network from different data sources such as open street map (OSM) (*OpenStreetMap*, n.d.). It was used in refining any missing network data in order to achieve the necessary level of detail for microscopic simulation. NETEDIT is another tool used as a graphical network editor which is used to create, analyse and edit network files. The files generated in SUMO are in Extensible Markup Language (XML) format and python was required to generate the scenario. A complete configuration file which includes the type of vehicle trips details per vehicle, additional features and routes, is created according to the map generated (Lopez et al., 2018; Zaidi et al., 2018).

Network Simulator (NS3)

It is a series of discrete-event network simulators used in research and development (*Ns-3 | a Discrete-Event Network Simulator for Internet Systems*, n.d.). NS3 completely abandoned backward compatibility with NS2. It obtains data from the SUMO trace file and translates it to NS2mobility and configuration files. The script in NS3 is written in C++ or python language (Anupriya et al., 2020). In our case, we will use a python script. The four categories of NS3 are node, net device, channel and application.

Traffic Control Interface (TraCI)

It is used to couple SUMO and NS3 simulators for them to communicate and evaluate their simulation outcome. It uses TCP-based architecture for its communication for both client and server. Simulated object values are retrieved, and their behaviour is manipulated online from the running road traffic simulation accessed. A python script is used in the interface.

Traffic Data

Some important elements are required when defining a scenario to simulate traffic. They include;

- Network data such as the highway section.
- Additional traffic infrastructure such as speed bumps and signs.
- Traffic demand such as the route, O/D matrix.
- Simulation objects such as the nodes are required for qualitative analysis.

SUMO GUI (Graphical User Interface) allows observing the simulation for different node densities and at different node speeds, among others (*Eclipse SUMO - Simulation of Urban MObility*, n.d.).

Wireshark

Wireshark is open-source software that is used as a network protocol analyser that displays data in a human-readable format. It has the potential to analyse the periodic packets exchanged between nodes in a VANET (Shakeel et al., 2015). It was used to capture packets from the wireless network. Ad-hoc On-Distance Vector (AODV) routing protocol was filtered in order to get all the details of the total packets sent, total packets delivered, total packets dropped and time taken to deliver the packets from source to destination node. QoS

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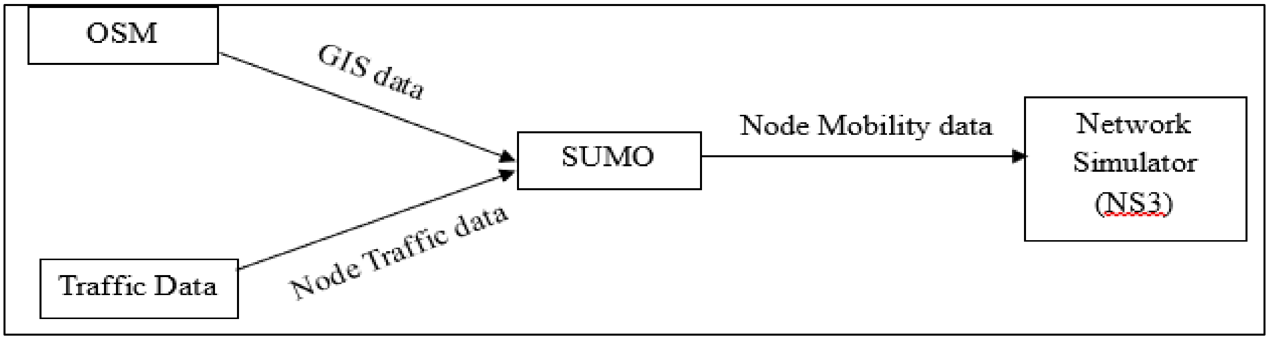
metrics PDR, throughput and end-to-end delay are then measured.

Figure 6: Simulation Structure



Simulation Scenario

Scenario generation with OSM

OSMWebWizard, which is part of python tools in SUMO used to generate a simulation scenario from the browser-based interface. A set of parameters with traffic modes allows a user to select an area of interest to import network data from an open street map. In this research, the area of interest was the Ruiru-Thika section of the Thika Superhighway and Gatitu- Kilimambogo section of the Garissa Road because they will produce a real traffic and mobility pattern (Fonseca & Vazão, 2013).To populate the network, random traffic is generated, which includes cars, trucks and buses.

Figure 7: Ruiru- Thika Section of the Highway Environment

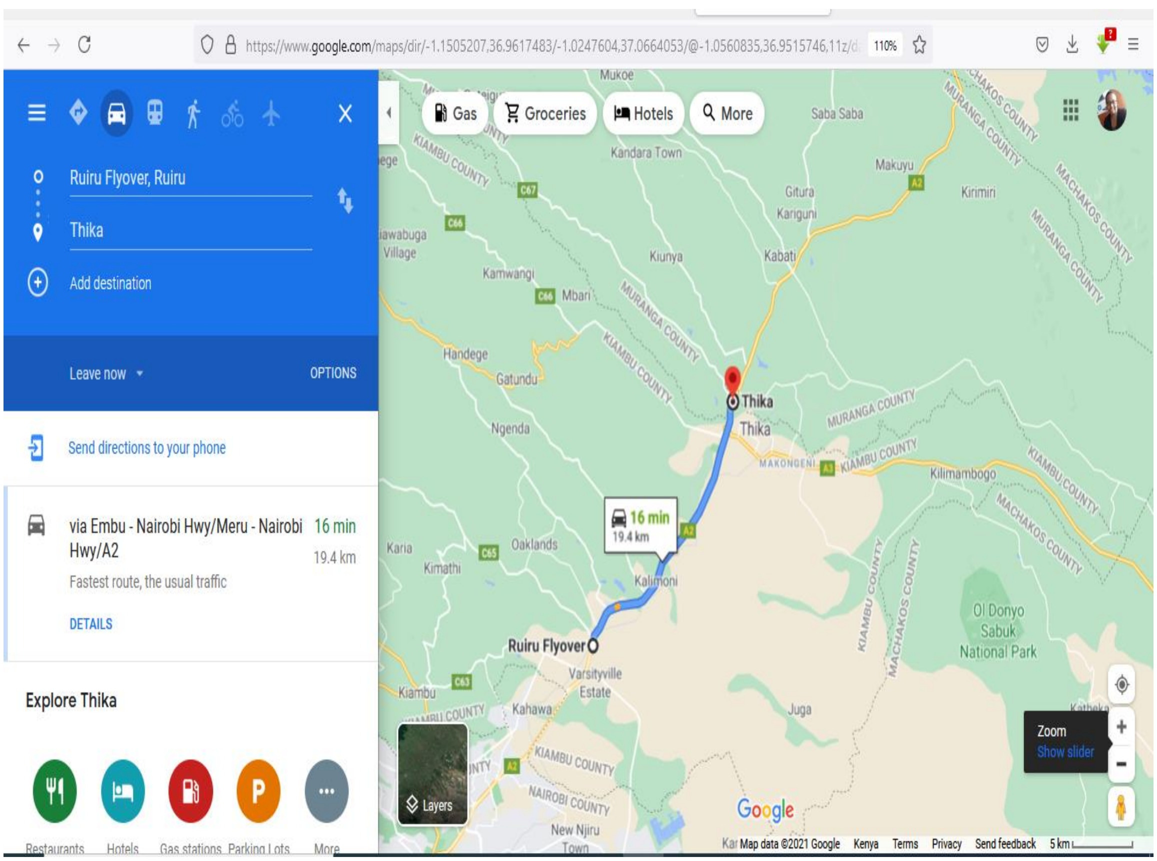


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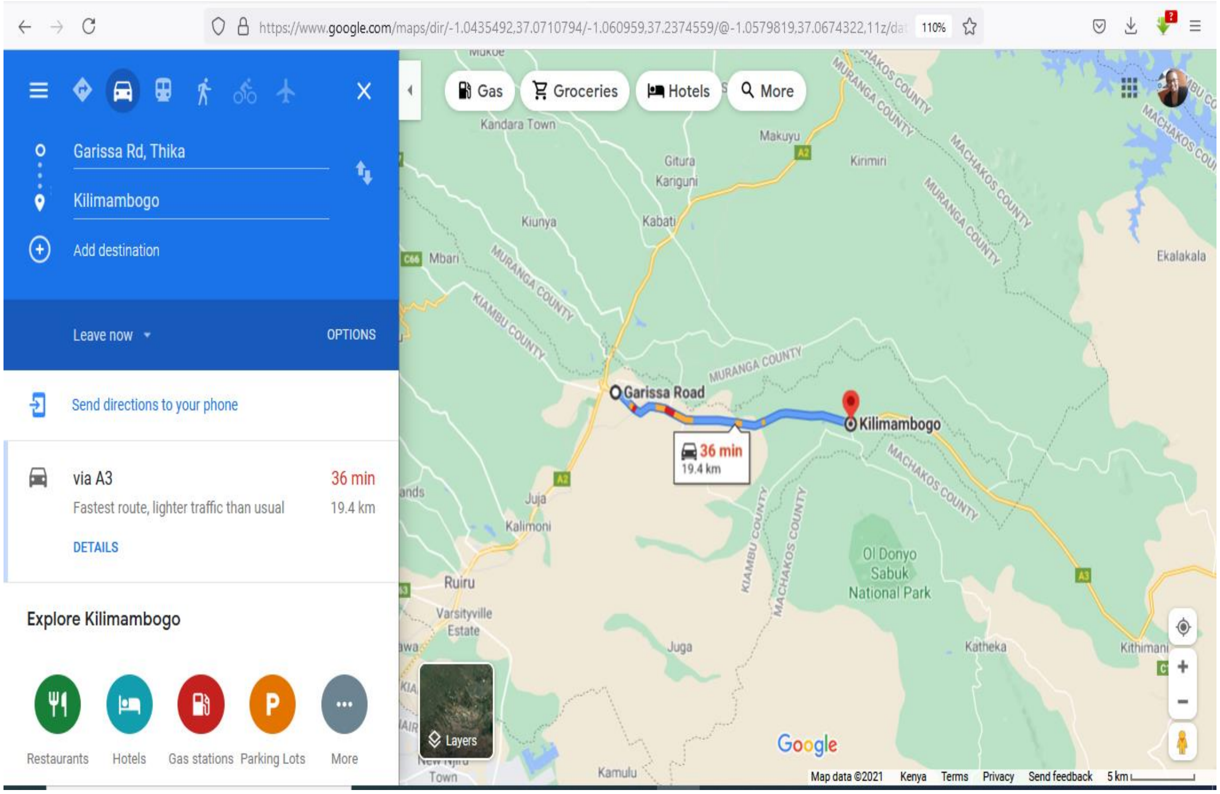
Figure 8: Gatitu- Kilimambogo section of the Rural Environment



Ruiru- Thika and Gatitu- Kilimambogo scenario development

Attributes such as lanes are defined.

Route definition

Each node has a route defined by creating a trip file with attributes such as route id and departure id. A route file contains the node information for the trip in the rou.xml file.

Configuration file

The simulation scenario showing the highway network includes the network and route file in sumo.cfg file.

i. Simulation input/output in SUMO and NS3

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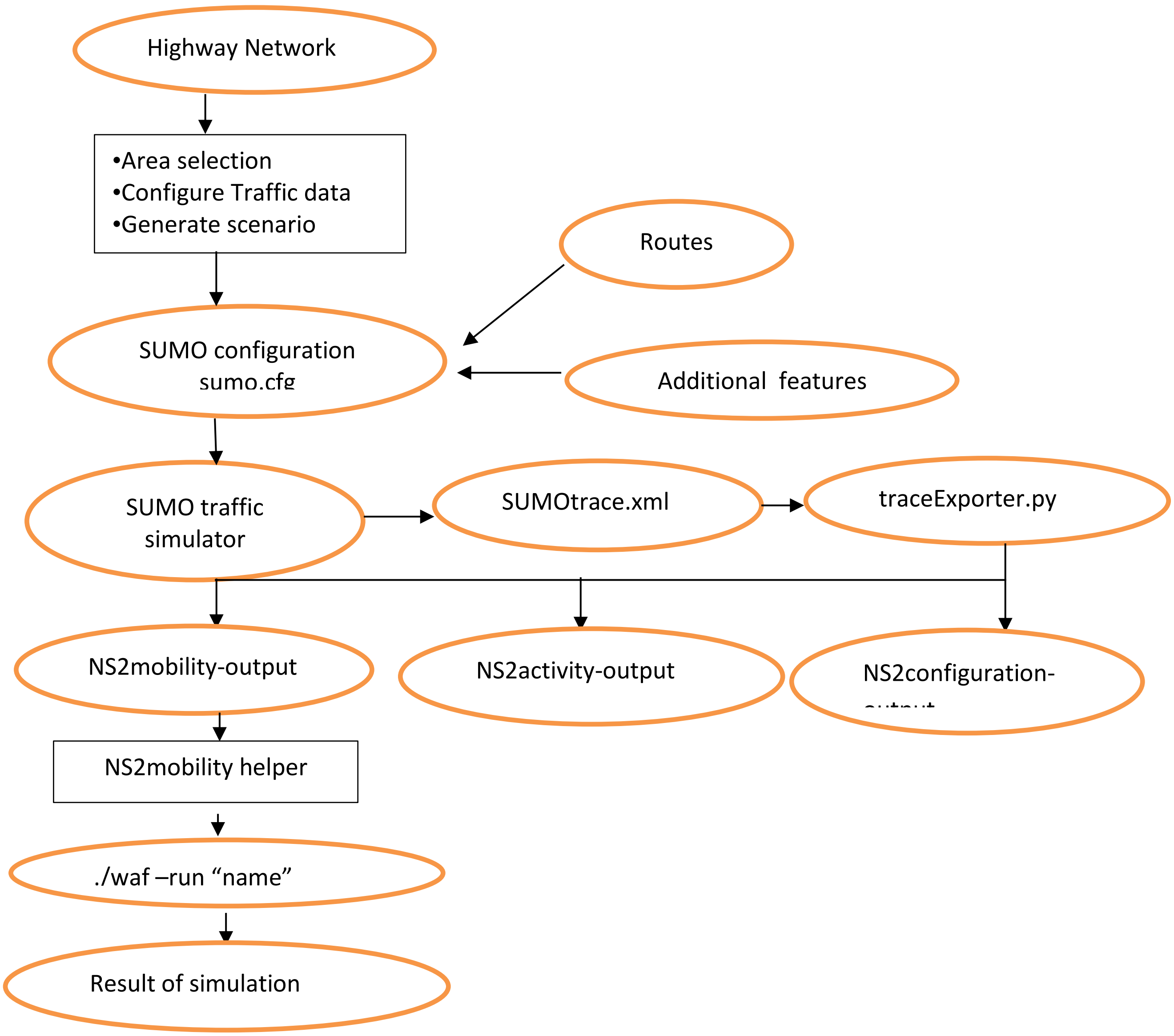
Figure 9: Simulation input/output in SUMO and NS3



Simulation Implementation

In order to conduct simulation on performance evaluation of VANET characteristics, there is a need to build a simulation scenario that mimics reality because it gives an inexpensive and quick understanding. In this case, our simulation adopted a real-life highway scenario of the Ruiru - Thika section on the Thika Superhighway for the highway environment and the Gatitu- Kilimambogo section on Thika, Garissa Road for the rural environment; one-directional segment for our two simulation scenarios.

OSMWebWizard, which is part of python tools in SUMO is used to generate the scenario of both the highway and rural section. The traffic scenario created is then shown using SUMO graphical user interface (Lim et al., 2017). SUMO simulation file is then translated using a python script in NS2 mobility and configuration file in NS3 network simulator while Wireshark sniffs packets in order to carry out the research. The analysis of all the parameters was carried out on every node using the AODV routing protocol and the results were viewed using Wireshark to analyse and compare the outputs.

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This research employs vehicle-to-vehicle communication. This means that vehicles were equipped with On-Board Units which feature storage, computational, and sensing capabilities. The research evaluated the effect on the performance of the IEEE 802.11p standard Enhanced Distributed Channel Access mechanism by varying VANET characteristics: node density and node speed using QoS metrics packet delivery ratio, throughput and end-to-end delay. IEEE 802.11p defines the maximum transmission range up to 1000m; thus, the distance between the three lanes in the highway environment was neglected. Implementation of IEEE 802.11e Enhanced Distributed Channel Access mechanism is adopted in NS3 where some few parts of the source code will be modified according to IEEE 802.11p Enhanced Distributed Channel Access mechanism. A File Transfer Protocol (FTP) transmission is used between vehicles. Simulation scenarios and parameters required are discussed in section 3.3. Data obtained was then analysed and plotted using a gnu plot.

Simulation Parameters

To conduct our simulation, low-integrated simulators were used where SUMO was used as the traffic simulator and Network Simulator-3 (NS3.30) as the network simulator.

Table 2 below shows the performance metrics notations. They include;

Table 2: Performance Metric Notations

Variable	Definition
T_P	Throughput
N_R	Number of packets successfully received at the destination
T_S	Total Simulation Time
P_S	Packet Size
D_L	Delay
T_R	Time a packet is sent from the source node
T_D	Time a packet is received at the destination node
N_S	Total number of packets sent
N_V	Number of Vehicles
PDR	Packet Delivery Ratio
S_P	Speed

***Scenario 1*: Impact of node density on Enhanced Distributed Channel Access Mechanism**

Node density varies from 10 to 40 and the communication range is set as 500 meters. The maximum node speed is 80km/h which is the speed limit for public service vehicles and trucks in Kenya (Muchene, 2015). In our study, nodes were only captured if their speed was less than 80km/h. The parameters below were tested in both rural and highway road environments.

- **Packet Delivery Ratio (PDR)**

It is the ratio of successfully delivered packets at the destination node to the total packets that were sent from the source node to the destination node. High values of PDR indicate good performance.

$$\text{PDR} = \frac{\text{NR}}{\text{NS}} \quad \text{(Equation 2)}$$

- **Throughput**

It is the average number of successfully delivered packets over a communication channel for a specific time. High values of throughput denote enhanced performance. It is gotten by;

$$\text{Tp} = \frac{\text{NR}}{\text{TS}} * P_S \quad \text{(Equation 3)}$$

- **End to End delay (E2E)**

It is the amount of time consumed to deliver a packet from source to destination. Small values of delay denote better performance. It is gotten by;

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$$D_L = \frac{(TR - TS)}{NS} \quad \text{(Equation 4)}$$

The parameters above were also used to test the varying speed in Scenario 2 below.

Scenario 2: Effect of node speed on Enhanced Distributed Channel Access Mechanism

Node speed varies from 40km/h to 100km/h, which is an agreeable speed for both highway and rural environments while maintaining a constant node density at 40.

MAC layer parameters remain the standard default settings as described in *Table 1*. Additional parameters used in the simulation are listed in *Table 3* below;

Table 3: Simulation Parameters

Parameters	**Values**	
	Scenario 1	**Scenario 2**
Traffic simulator	SUMO	SUMO
Map model	Open Street Map	Open Street Map
PHY	802.11 p	802.11 p
Propagation Loss model	Log-Distance	Log-Distance
Routing protocol	AODV	AODV
Simulation time	60s	60s
Number of vehicles	10,20,30,40	40
Speed	80 km/h	40,60,80,100 km/h
Traffic Type	CBR	CBR
Data Rate	6 Mbps	
Slot time	13 µs	
SIFS	32 µs	
OFDM symbol duration	8 µs	
Header duration	40 µs	

Assumptions of Our study

- The varying vehicle density was randomly selected within the stretch.
- For equations (2,3,4), the vehicle speed remained constant at 80km/h when vehicle density was being varied since we were working with one variable at a time.
- For equations (5,6,7), the vehicle density was at a constant of 40 when vehicle speed was being varied since we were working with one variable at a time.

Simulation Algorithm

The protocols are implemented in NS3 using the following algorithm:

i. Obtain the real map using OSMWebWizard

ii. Network schema development using SUMO.

iii. Develop movements file using NS2 Mobility Trace Exporter.

iv. Initialise simulation of the nodes.
   - Varying nodes
   - A constant node (10)

v. Configure the speed
   - Constant speed (80)
   - Varying speed

vi. Configure nodes with IEEE 802.11p Enhanced Distributed Channel Access values.

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vii. Read mobility pattern from movements file.

viii. Generate CBR (Constant Bit Rate) Traffic between any two random pairs of nodes.

ix. Generate data file for PDR, throughput and end-to-end delay evaluation metrics

x. Analyse and present data in graphs using gnu plot

RESEARCH RESULTS AND DISCUSSION

Node Speed

In this scenario, the node density remained constant at 40 while the speed was varied in intervals of 20km/h, which are 40, 60, 80, and 100.

Throughput

Table 4: Throughput in Highway and Rural against Node Speed

Variables	40	60	80	100
802.11p- Highway	20.71	20.71	20.71	20.71
802.11p- Rural	7.26	7.26	7.26	7.26
802.11a- Highway	0	0	0	0
802.11a- Rural	0	0	0	0

Figure 10: Throughput against varying Node Spefed

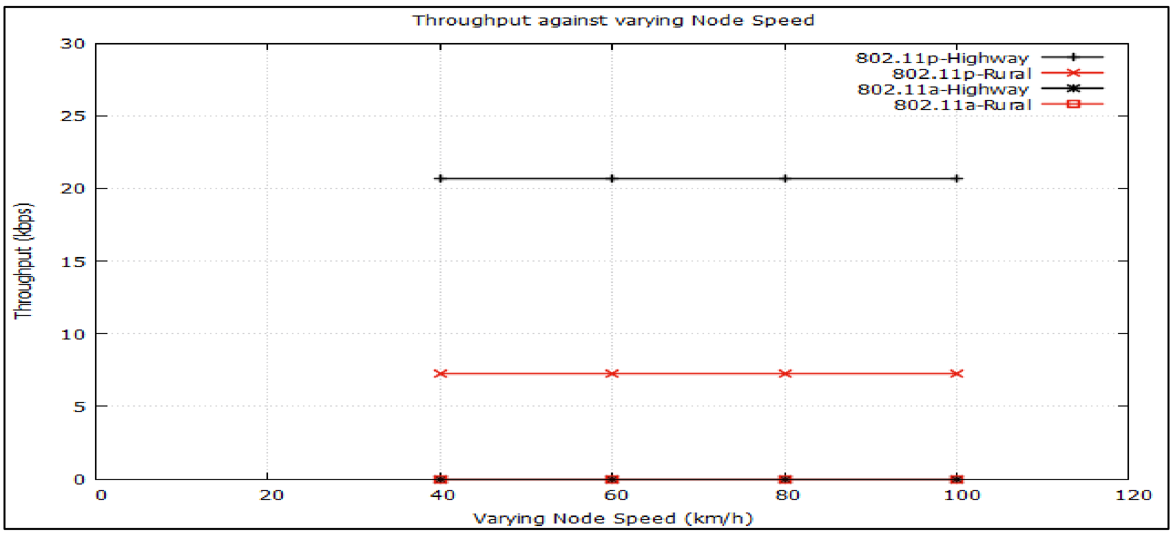

Figure 10 indicates uniformly distributed data for 802.11p. Likewise, the same values of the standard error of Kurtosis were observed.

The mean average throughput on a highway is higher than in rural. This can be attributed to the vehicles being sparsely distributed in the rural scenario, unlike in the highway scenario and there are more lanes in the highway setting in the rural one.

Identical values of throughput for different speeds in both scenarios were observed. This could be attributed to the nodes being obtained from a real scenario where the speeds could not be altered in a simulator.

There are also higher values of throughput in both scenarios in 802.11p than 802.11a, where no packet was received.

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End-to-End Delay

Table 5: Delay in Highway and Rural against Node Speed

Variables	40	60	80	100
802.11p- Highway	+2.689s	+2.689s	+2.689s	+2.689s
802.11p- Rural	+1.247s	+1.247s	+1.247s	+1.247s
802.11a- Highway	0	0	0	0
802.11a- Rural	0	0	0	0

Figure 11: Delay against varying Node Speed

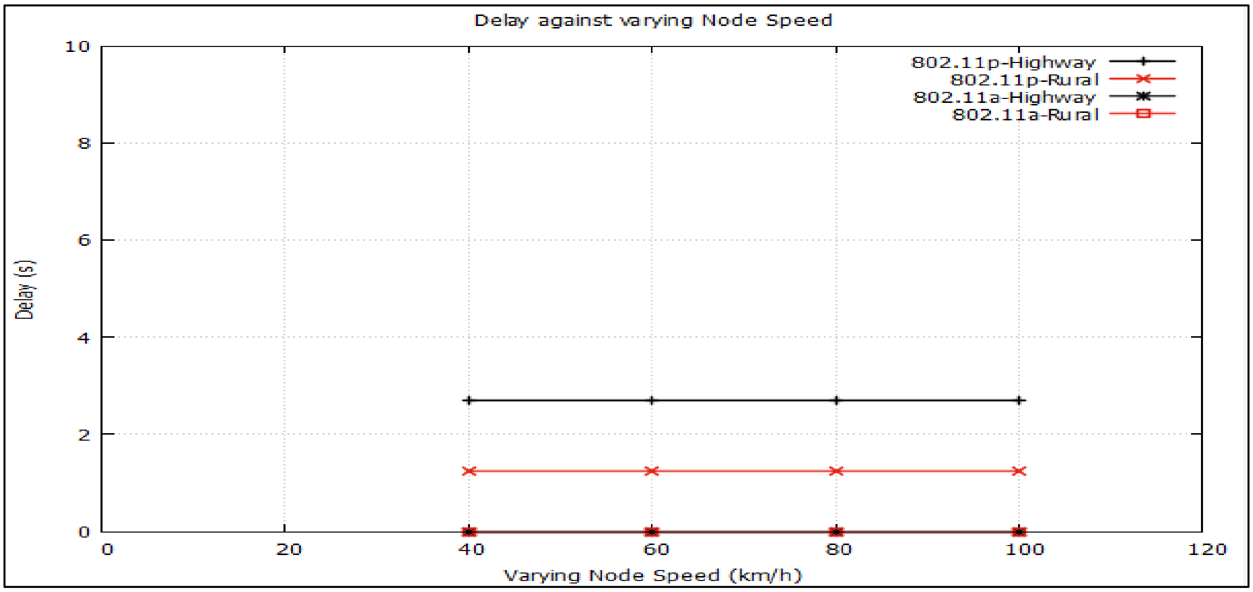

Table 4 observed that the standard deviation is 0 and the standard error of skewness of 1.014 for 802.11p. This is an indication of uniformly distributed data. Likewise, the same values of the standard error of Kurtosis were observed. This reflects relatively normal distribution data. There was a higher value of delay in a highway setting than in a rural setting. This can be attributed to the vehicles being close to each other.

Higher values of delay were observed in 802.11p than in 802.11a.

Packet Delivery Ratio

Table 6: PDR in Highway and Rural against Node Speed

Variables	40	60	80	100
802.11p- Highway	0.11	0.11	0.11	0.11
802.11p- Rural	0.10	0.10	0.10	0.10
802.11a- Highway	0	0	0	0
802.11a- Rural	0	0	0	0

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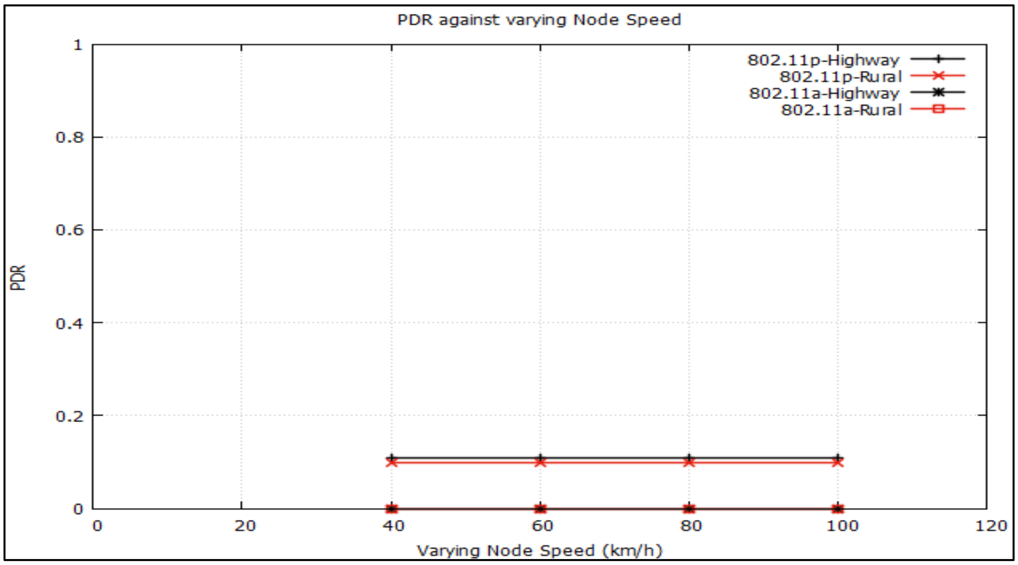
Figure 12: PDR against varying Node Speed



From *Table 6*, Packet Delivery Ratio is higher on highways than in a rural scenario for 802.11p. This is attributed to the higher numbers of nodes. Higher values of PDR were observed in 802.11p than in 802.11a.

Node Density

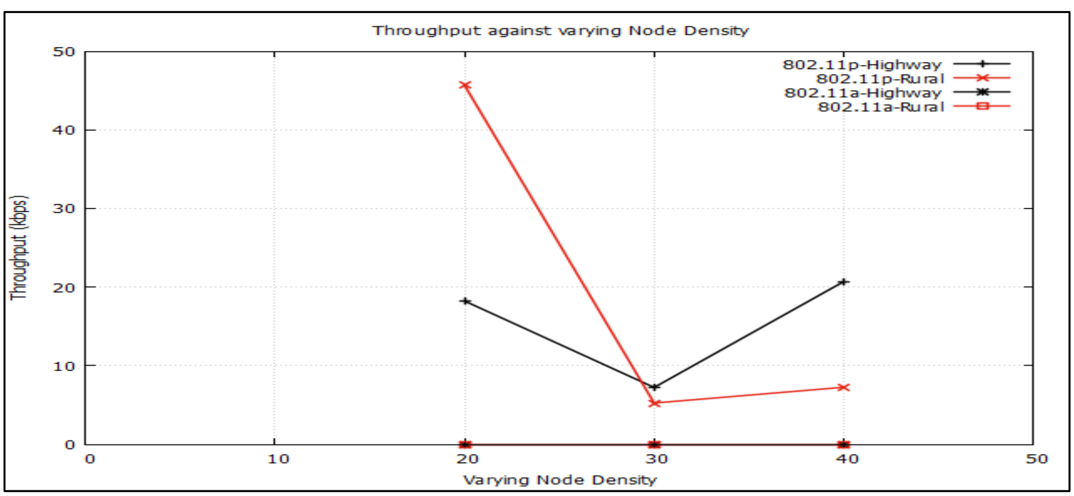
In this scenario, the node speed remained constant at 80km/h while the speed was varied in intervals of 10 nodes which are 10, 20, 30, and 40.

Throughput

Table 7: Throughput in Highway and Rural against Node Density

Variables	10	20	30	40
802.11p-Highway		18.23	7.23	20.71
802.11p- Rural		45.67	5.26	7.26
802.11a- Highway		0	0	0
802.11a- Rural		0	0	0

Figure 13: Throughput against varying Node Density



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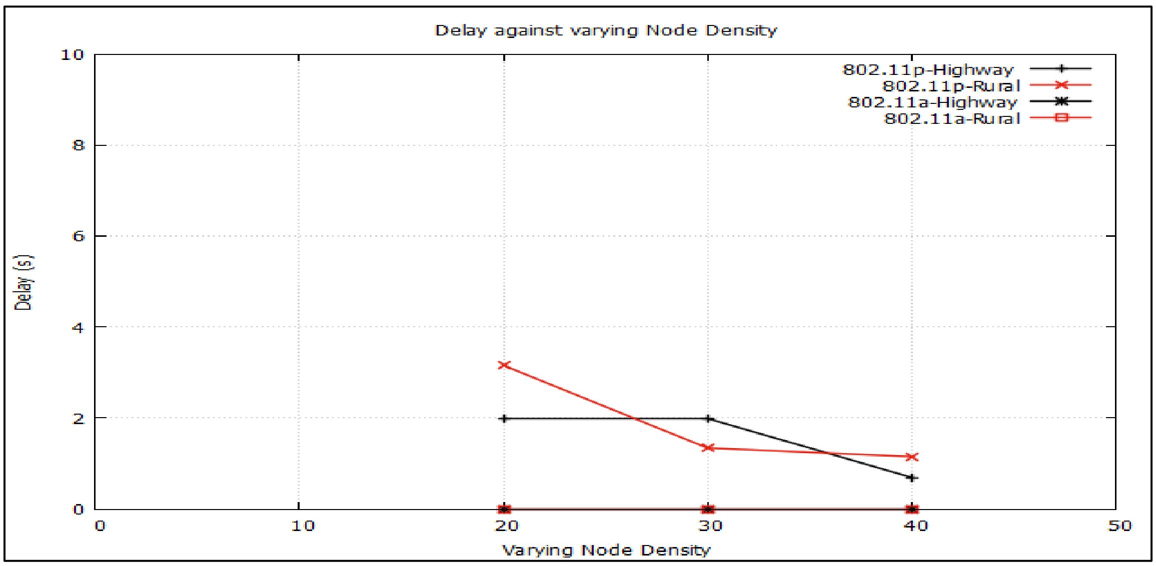
Here we are analysing a different number of nodes but at the same speed. Again, we don't have control of the number of nodes and their distribution along the sampled stretch. The standard deviation is higher in rural than on the highway for 802.11p. This is because the nodes are likely to be closer than in the rural since this takes a random distribution. Higher values of throughput were observed in 802.11p than in 802.11a.

End-to-End Delay

Table 8: Delay in Highway and Rural against Node Density

Variables	10	20	30	40
802.11p- Highway		+1.986s	+1.987s	+0.689s
802.11p- Rural		+3.152s	+1.336s	+1.147s
802.11a- Highway		0	0	0
802.11a- Rural		0	0	0

Figure 14: Delay against varying Node Density



The delay is lower in the rural setting than on the highway since the less collision and distance between the nodes in 802.11p. There are higher values of PDR in 802.11p than in 802.11a.

Packet Delivery Ratio

Table 9: PDR in Highway and Rural against Node Density

Variables	10	20	30	40
802.11p-Highway		0.07	0.08	0.11
802.11p-Rural		0.10	0.10	0.10
802.11a- Highway		0	0	0
802.11a-Rural		0	0	0

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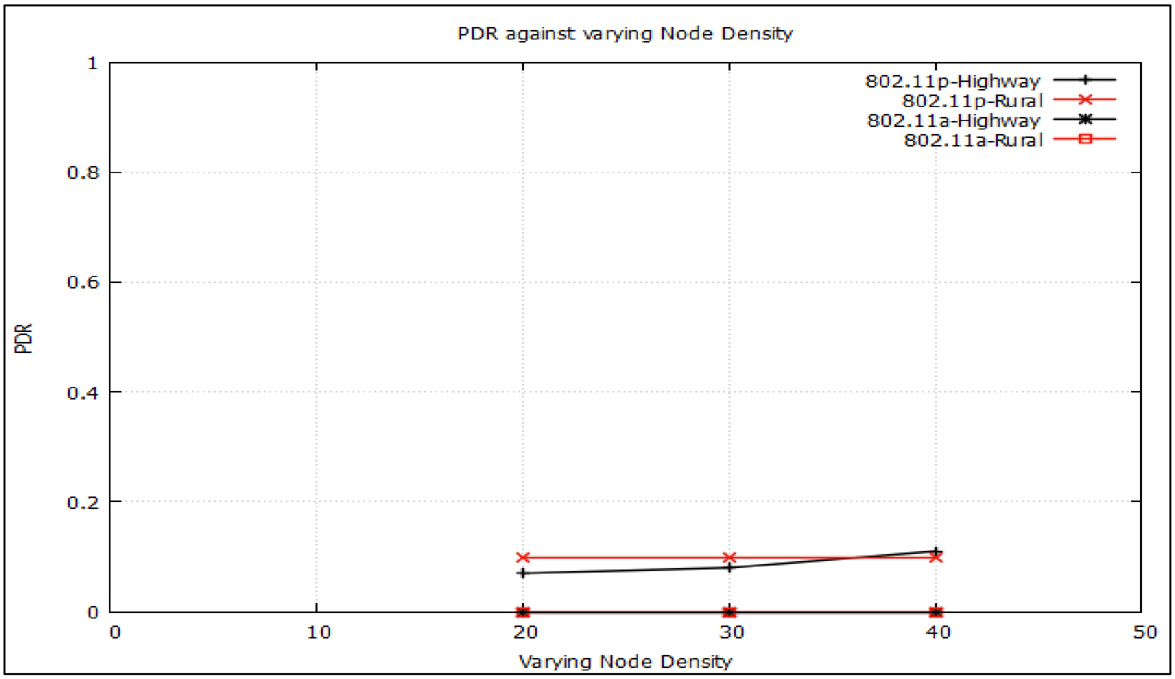
Figure 15: PDR against varying Node Density



The PDR in the highway increases as the nodes increases in 802.11p. This is due to the fact the distance between the nodes is significantly reduced. There are higher values of PDR in 802.11p than in 802.11a.

CONCLUSION AND FUTURE WORK

The project focus was to evaluate the performance of the IEEE 802.11p Enhanced Distributed Channel Access (EDCA) mechanism using VANET characteristics, i.e., node speed and node density. In this paper, we analysed the performance of safety messages broadcasted in a real traffic model. The results of the simulations showed that 802.11p is better than 802.11a in both scenarios. 802.11a did not deliver any packet successfully. This indicates that 802.11p is more effective to be used in VANET than 802.11a. For future studies, we intend to compare the performance of 802.11p with other standards, such as Long-Term Evolution.

Limitation of study

Implementation of VANET in a real test bed is very expensive due to cost constraints of the vehicles herein referred to as nodes, software and manpower required. To address this limitation, computer simulation is widely adopted for research to make improvements in VANETs (Mallissery et al., 2019).

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