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Vehicular Communication Framework to Reduce Congestion and Improve Efficiency in Smart Cities

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***Abstract* - This paper explores the role of wireless network technologies in enhancing the efficiency, safety, and traffic management of smart cities. The primary goal is to ensure that smart cities operate with the utmost efficiency and minimal transportation congestion, even in the presence of self-driving cars, which currently exhibit instability and susceptibility to errors. Existing research gaps in the domain of Vehicular Ad-Hoc Networks and Vehicle-to-Everything studies revolve around concerns related to privacy and security, signal interference, message propagation, and mobility management. To address these gaps, our project conducts a comprehensive investigation using wireless sensor networks, vehicle-to-vehicle networks, and vehicle-to-infrastructure networks. This study sheds light on issues pertaining to privacy and security, signal interference, the dynamics of message propagation, and challenges related to mobility management that currently impede V2X-based systems from realizing their full potential. By seamlessly integrating state-of-the-art wireless technology, notably Visible Light Communication, this framework aims to mitigate traffic congestion, minimize accidents, and streamline traffic-related operations. VLC technology plays a crucial role in facilitating communication between vehicles and infrastructure, enabling real-time data transmission and enhancing traffic management, accident prevention, and congestion alleviation. The paper serves as a roadmap for the development of smarter, safer, and more resilient smart cities, set to revolutionize urban mobility through the utilization of cutting-edge wireless technology, particularly VLC technology.**

Keywords: VANET, V2X Communications, Congestion, Efficiency, VLC.

I. INTRODUCTION

The concept of a Smart City is evolving. Being “smart” refers to using technology as “a tool” to address the challenges that cities face [1]. Traffic congestion is a common problem in cities, which results in delays, increased fuel costs, and environmental pollution. Congestion can be made worse by traffic accidents, lengthening wait times and raising the chance of fatalities. Intelligent Traffic Systems (ITS) and connected vehicles are two solutions that have been used as a result of the advent of "smart cities" to address this issue. The objective of this project is to provide a framework for vehicle communication in smart cities to reduce traffic caused by accidents and boost productivity.

A major problem in urban areas is motor accidents. According to the National Council for Road Safety report for 2021, nearly 22000 motor accidents have occurred in Sri Lanka, resulting in over 2500 deaths. It has been identified that most of these accidents occur on expressways and Grade A and B main roads [2]. Accidents and fatalities have increased with the increase of vehicles on the road.

Vehicular Ad-Hoc Networks (VANETs) are an important field of research for intelligent transportation systems. Due to the large number of vehicles on the road, on-road wireless communication technology is essential to make the trip safe and enjoyable. VANETs provide wireless communication between moving cars by using nearby roadside equipment. Through VANET connectivity, the ITS improves various things, including lowering traffic congestion, reducing fuel and harmful emissions, speeding up the response time of emergency vehicles, improving road safety, and delivering entertainment services. VANET communication notifies drivers of their travel environment at the appropriate moment. It is a new mobile ad hoc networking architecture that enables Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication.

Because large-scale studies on real roads are challenging, simulation is critical in VANET research. To bring the simulation closer to reality, precise and realistic models of vehicle behaviour under varied road conditions are needed. Because modelling of vehicle behaviour and communication behaviour are distinct jobs, they should be performed independently for improved modularity while being smoothly integrable. This thesis study investigated the online and

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seamless integration of vehicle behaviour and network simulators.

II. RELATEDWORK

VANETs has garnered a lot of interest in recent years as a technology with great potential for enhancing active and preventative road safety as well as trip comfort. Road networks frequently encounter a variety of potentially disastrous situations, many of which could result in traffic congestion. If drivers are informed in advance of accidents or traffic conditions, driving quality may be significantly improved in terms of time, distance, and safety. V2V, V2I, and V2X communications all help to solve a number of issues that both vehicles and pedestrians encounter. Wireless data exchanges between cars, which enable them to broadcast their position and speed, are one of the main characteristics of V2V technology. The interaction of the cars with physical elements like traffic signals, RSUs, streetlights, etc. is made possible through V2I communication [3].

The use of VANET simulators helps to study and analyze the phenomenon before the real-time implementation because of the high cost and complexity of implementing new protocols and scenarios for large testbeds. Vehicle mobility generator, network simulator, and VANET simulator are the three different types of simulators. Network simulators simulate source, destination, and traffic transmissions at the packet level in great detail. The network simulator needs accurate vehicle motion traces from the vehicular mobility generators. The vehicle's mobility patterns will be the output, and two examples of the input parameters are maximum vehicle speeds and vehicle arrival rates.

The vehicular mobility generator used here is called SUMO (Simulation of Urban Mobility). It allows users to simulate the behaviour of particular types of traffic on a given road network. Additionally, you may import a road network produced from Open Street Map and indicate the traffic demand that corresponds with it, or you can design unique traffic networks at your own discretion. The distinctive identification, departure and arrival times, and routes taken by each vehicle in the simulation allow for a precise definition of each one. More detailed information on vehicles is available, such as the lanes to be used, their speed, and their exact placement on the edge [4].

The network simulator which is used in this study is OMNeT++. This discrete network simulator is C++-based software which is used for creating and running simulations. Modules are the fundamental building components of OMNeT++. Modules can send messages to one another in order to communicate with one another directly or through a pre-established method. Comparing OMNeT++ to other network simulator software, performance metrics for memory use and execution time reveal that OMNeT++ is significantly more scalable. More consumers are drawn to it because of its excellent functionality, lively graphical user interface, and simplicity of use [5].

Veins plays a pivotal role in seamlessly combining mobility and network simulation in Vehicular Ad-Hoc Networks (VANETs) [6]. Through the establishment of a bidirectional connection between these two simulators, this open-source middleware framework effectively oversees the interaction between OMNeT++ and SUMO simulators [7]. Veins enhances the capabilities of the OMNeT++ network simulator by offering an extensive vehicular communication stack rooted in IEEE 802.11p standards, along with tailor-made channel models. Furthermore, it facilitates the realistic modeling of node mobility by leveraging the road traffic simulator SUMO [8][9]. The aforementioned VANET simulators' design is depicted in Fig. 1 [10].

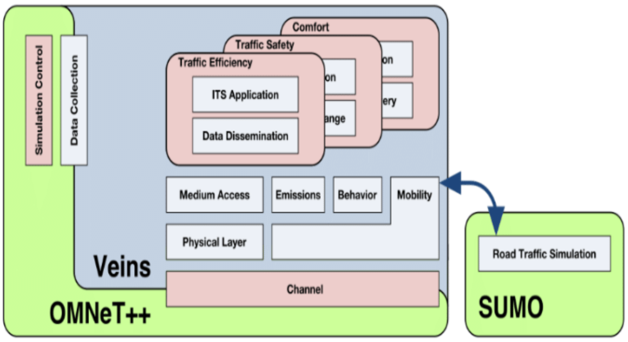

Figure 1: VANET Simulation Architecture

Visible Light Communication (VLC) is an advanced communication system that uses visible light as a medium for signal transmission. Unlike other well-established communication technologies such as Ethernet, wireless cellular communication, or IrDA, VLC technology has a relatively brief history. By exploiting the fast-switching capability of LEDs compared to conventional lighting, data signals can be modulated onto the LED light, allowing LED illumination to serve as a communication source. Given the ubiquity of illumination sources, LED illumination devices are anticipated to soon function as lighting and communication transmitters in virtually every setting [11]. VLC is superior to other wireless communication methods in several ways, including data speeds, interference, Privacy, and security [12]. Integrating LED-equipped lighting modules with transportation infrastructure allows for the implementation of Vehicular Visible Light Communication (V-VLC) applications. V-VLC's Line-of-Sight (LOS) property, directionality, and reduced collision domain significantly reduce interference. Moreover, the visible light spectrum's broad bandwidth offers substantial potential data rates [13].

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V-VLC, on the other hand, necessitates an unobstructed LOS, which may not always be achievable in outdoor circumstances owing to mobility or environmental conditions such as thick snow. Nonetheless, V-VLC requires significant research to ensure stable network operation, complementing RF-based alternatives. [13].

Several studies that examined the use of VLC in Vehicular Communication networks (VCN) have focused on the IEEE 802.15.7 protocol, a standard for VLC communication [14]. It specifies the media access control (MAC) and physical (PHY) layer standards for VLC. The protocol supports data rates of up to 96 Mbps [15] and includes a variety of modulation methods, such as pulse position modulation (PPM) and on-off keying (OOK). Numerous VLC applications, such as indoor location, wireless local area networks (WLANs), and intelligent transportation systems (ITS), are supported by the standard.

III. METHODOLOGY

The objective of this project is to develop an effective V2X (Vehicle-to-Everything) platform designed to improve traffic efficiency and safety in smart cities, including Visible Light Communication (VLC) as a fundamental technology. This project adopts an integrated strategy that blends theoretical investigation with practical application. Because real-world implementation may not be practical, we rely on simulation tools to demonstrate the feasibility of our suggested method. The major goal is to develop a vehicular communication network that optimizes traffic flow, reduces congestion, and provides effective reaction in the case of an accident, with a special focus on deployment in smart city contexts. VLC, with its high-speed data transfer capabilities utilizing visible light, plays a critical role in accomplishing these goals.

In this study, Veins, a unified experiment platform, is used to create a V2X-enabled traffic control system. Veins is an excellent simulation platform that combines SUMO and OMNET++, two well-known simulators. The Veins-VLC protocol architecture, based on IEEE 802.15.7, is used to specify the specifics of V2X communication using VLC. Real-time simulations may be run online in Veins with two bi-directionally linked simulators, unlike other traffic micro simulation tools. Additionally, Veins can enable a wide range of ITS and traffic safety applications (such as emergency alerts) that improve traffic efficiency [16].

In this study, OpenStreetMap will load a map of a chosen region of Sri Lanka, and SUMO will be used to setup and control vehicle movements and traffic flow. Veins and OMNET++ are largely used for setting up the network infrastructure, gathering and processing data, creating accidents, and rerouting vehicles. Figure 2 provides a schematic representation of the unified simulation platform.

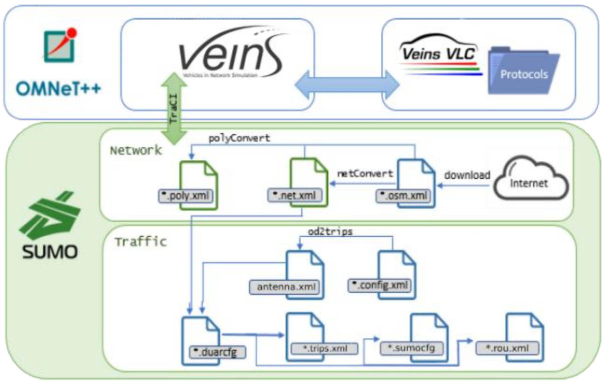

Figure 2: Simulation Platform

Several assumptions and conditions must be considered within the simulation framework.

- In the simulation, every vehicle has an onboard data processing and networking unit.
- Each vehicle's initial trajectory is predetermined before the simulation's execution. In the OMNET++ simulator, it is assumed that every vehicle has the same specified communication range.
- Receivers and Transmitters are placed at the exterior of the vehicle (Headlights and Taillights for V2V communication and at the bottom of the front and back windshields for V2I communication)
- RSUs are located on the light poles and have VLC receivers as well as RF Transceivers and the RSUs communicate with each other using cellular networks (4G/5G)
- The effect of ambient light on VLC is already mitigated using some technology.

The integrated simulation platform and underlying assumptions are then used to create an event-driven traffic algorithm for vehicle rerouting. When a car accident or breakdown happens, the broadcasting system awakens, and it begins to operate. Immediately after that, alerts are created and sent to nearby cars in the form of periodic beacons, which are continually and repeatedly broadcast until the vehicle breakdown has been cleared. Following the proactive activation of the dynamic re-routing system to avoid the vehicle breakdown site, the approaching cars that have received the warning signals through V2V first transmit them to the nearby vehicles. The same destination is used while recalculating the new route with the changed parameters. In the absence of alternate routes, approaching cars move slowly to prevent crashes.

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IV. RESULTS & DISCUSSION

The simulation data obtained in the study reveals a significant impact of the Vehicular Communication Framework on mitigating congestion and enhancing transportation efficiency within smart cities. In a standard scenario, prior to the adoption of the proposed solution, vehicles experienced an average delay of 15 minutes, a figure derived from empirical observations of traffic patterns in Sri Lanka, resulting in a typical travel time of 40 minutes to reach their destinations.

However, with the incorporation of the novel framework, leveraging Visible Light Communication (VLC) for real-time vehicle-to-vehicle communication, the results indicate a marked reduction in travel times. On average, vehicles were able to reach their destinations in approximately 33 minutes, representing a significant improvement compared to the 40-minute baseline scenario.

When contrasted with an ideal scenario in which vehicles traverse uncongested routes, taking an average of 28 minutes, the solution demonstrates a notable reduction in travel time. While not entirely replicating travel times in the absence of congestion, the framework effectively mitigates the adverse effects of traffic congestion, resulting in a nearly 7-minute decrease in travel time and an overall enhancement of transportation efficiency.

In addition to the noteworthy reduction in travel times, the adoption of the Vehicular Communication Framework also demonstrates its eco-friendliness by significantly mitigating fuel consumption. One key finding is that the excess fuel consumption incurred when vehicles opt for a detour is negligible in comparison to the fuel consumed while waiting in the traffic queue.

On average, the difference in fuel consumption between vehicles taking the detour and those queued in traffic was approximately 17%. This significant reduction in fuel consumption not only contributes to cost savings for individual vehicle owners but also aligns with sustainability objectives, making urban transportation more environmentally friendly.

There are some functional and non-functional requirements that must be considered when deploying this architecture. The system should always be accessible and must have 100% uptime, it must be easily scalable and should protect the privacy of the users and the data. The system must have monitoring and auditing capabilities.

V. CONCLUSION

In comparison with the studies and research conducted regarding integrating VLC with vehicular network systems, this study focuses on the following novelties.

- First ever solution for a vehicular network with being focused to be deployed in a smart city.
- First study in Sri Lanka regarding vehicular networks based on VLC based vehicular communication technology.

Future smart cities gain greatly from the Internet of Vehicles, which also offers ease, road safety, and a number of other advantages. As a result, finding safety assurance is important when using integrated technologies in intelligent transportation systems. In order to reduce accidents and the associated congestion in smart cities, this study aimed to identify the different kinds of blockchain and cloud computing, as well as their purposes, contexts, and operation in the environment. In order to categorize the many usage scenarios, whether they involve technology for communication, support, security, application, consensus, or intelligent decision-making, it was necessary to take into account both the advantages and disadvantages of each proposal. In summary, this research is aimed to initialize a smart mobility system with the latest wireless technologies for smart cities in the future.

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