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Using VANET as mechanism for monitoring compliance of speed and mobility restrictions: a Quito-Ecuador case study

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ABSTRACT

Quito city in Ecuador is well know for its traffic issues. This is mostly generated because the geography of the capital city. It is a narrow but long territory that makes transportation to be difficult and generates traffic jams, specially in rush hours. For a long time this problem has been the center of attention of the municipality of Quito, some programs have been adopted in the urban area of the city. One of the most important was "Pico y placa", now called "Hoy no circula" because its implementation changed to have more impact in the mobility of Quito. Other program adopted by the municipality is speed control, done by fixed radars in the main highways, or by the transit agents found in strategic locations. The main purpose of this work is the analysis of the implementation of Vehicular Ad Hoc Networks(VANET) to solve some problems arising from the application of this programs in the city of Quito. VANET allows all the network to be aware of every car connected to it by the use of communication units, making it easier to control traffic flow and even controlling what cars are inside the network and what cars should not be in the network at a specific time. The simulation was done in Omnett++ and with help of SUMO and Veins to obtain the desired simulation process where data was obtained for prior analysis. At the end the paper the main results found during the research are presented, and some recommendations for the adaptation of this project to the city of Quito and what advantages will it bring. This information could be used by the municipality to adopt this project or a similar idea to solve the mobility problems found in Quito.

Keywords: Quito, Intelligent Transport System, "Hoy no Circula" program, Speed Control, Sustainable mobility.

Article originality and practical implications: The article explores the potential of VANET to improve traffic management in Quito, Ecuador, addressing issues from "Hoy no Circula" and speed control. It offers practical insights for implementing intelligent transportation systems to enhance urban sustainable mobility and reduce congestion. The implications of the article can guide public policies of sustainable development to improve mobility in the city.

INTRODUCTION

Quito is Ecuador's capital city, located on the western slopes of the Pichincha volcano it is well known for its traffic issues. It is the most populated city in Ecuador with over 3 million inhabitants and with over 450 thousand vehicles registered in 2019(Informa, 2020). The traffic problems in the urban area are mainly caused by its geography and the amount of vehicles transiting in the city. Due to the shape of the land, Quito is a very long but narrow city, it has grown mostly from north to south with an extension of 80 km long and only 5 km wide(FLACSO, 2015). Figure 1 shows the map of the Metropolitan District of Quito (canton) and its parishes at the left and the urban area (city) of Quito at the right. Throughout this work we will refer to the urban area (right) and its road policies.

The municipality of this city had to implement new programs and measures to solve the problems of mobility and transportation that were becoming a daily annoyance for citizens and visitors. One of the biggest projects implemented was called, at that time, "Pico y placa"; now called "Hoy no circula" due to the variation in the daily duration of the measure. Another implementation adopted regarding transportation and mobility was the speed control in the city, this is done mainly by transit agents or fixed radars in the road side.

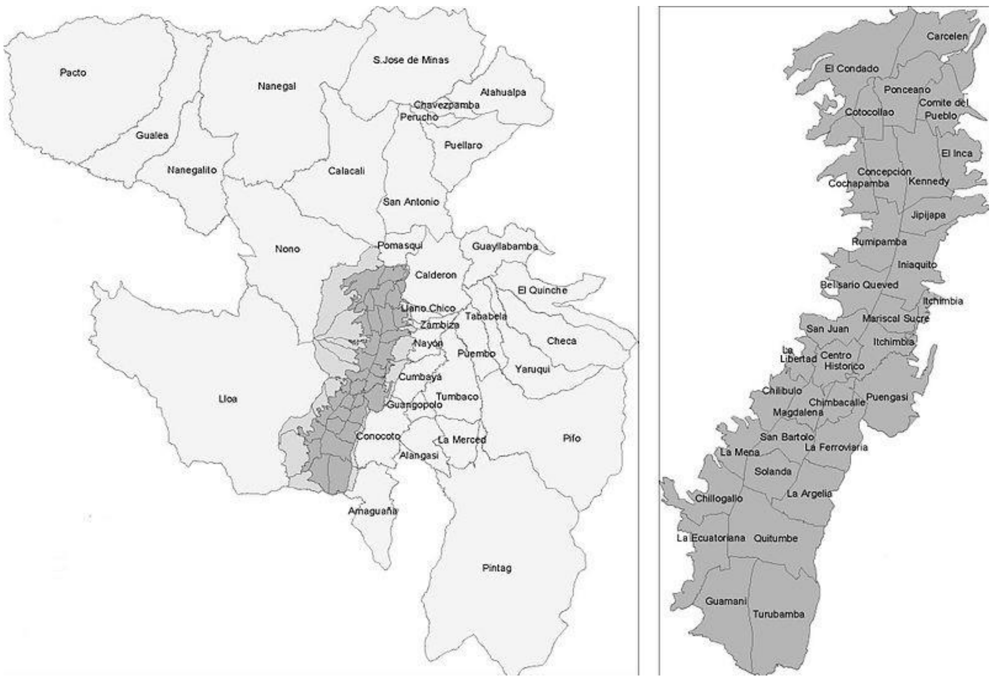
Both of these alternatives need some kind of control where transit agents and police officers have to get involved and some problems may arise from this. For example, a police officer may not recognize the last digit of a license plate or some police officer may let the transgressor leaves with a warning or by paying a bribe. Another kind of control is with video cameras that take a video or photographs of the offending car, the problem here is that sometimes the numbers in the license plates are not legible or it is hard to spot the offending car among others.

This research introduces Vehicular Ad-hoc Networks (VANETs) to solve the problems arising from the control needed for the conversion to a safer and less-congested city environment. The automotive industry acknowledges the significance of integrating cars with IT systems for improved communication, leading to enhanced traffic flow and safety. Key factors such as driver behavior, driving conditions, and traffic patterns are observed and shared among vehicles. Vehicular Ad Hoc Networks (VANETs) have been implemented to facilitate the exchange of this information, thereby increasing communication efficiency among vehicles (Karabulut et al., 2023). This work proposes VANETs as a solution to speed and mobility restrictions("Hoy no circula") control, the proposed idea is to identify the on-board units (OBUs, explained in detail in the next section) of every car with a code according to the license plate’s last number so the network knows who can and cannot be driving at that time making easier to control "Hoy no circula". The second idea is to control cars speed by measuring and sending the current speed of the OBUs and programming the streets’ speed limits so they are aware when they are infringing the speed limit in a certain street of Quito.

At the end of this work, the simulation results give some insights of how to proceed for the implementation of this system in the city of Quito as well as the problems that may arise while applying it, also some changes that can be applied for a better coupling of the proposed system to the city

The remaining of this paper is structured as follows: Section II describes the conceptual information and theory needed to understand this work. The problem to be addressed is described in section III. Section IV shows similar researches and how the proposed solution is different. In section V the proposed solution is presented, with its component, architecture and functioning. Section VI presents how the simulation was performed while section VII gathers the simulation main results and discussion. Finally, the concluding remarks as well as future work are drawn in the last section.

Figure 1. Map of Metropolitan District of Quito and its parishes



Source: authors' development

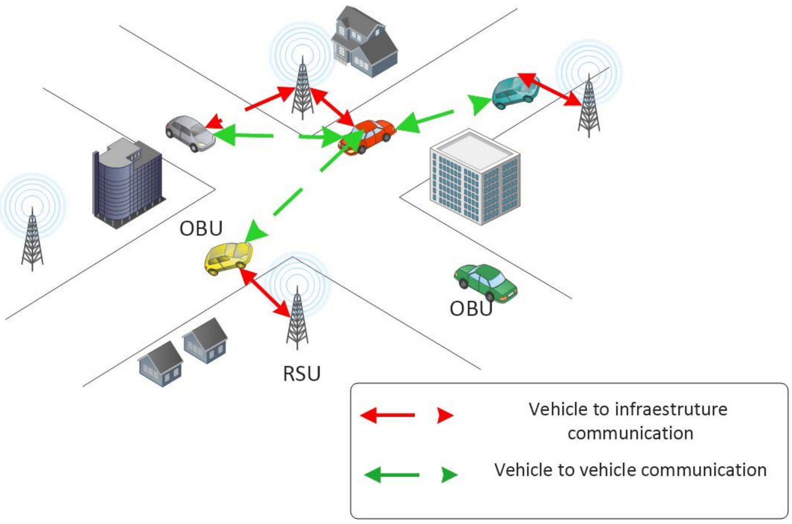
VANET

The principles of Mobile Ad-hoc Networks (MANETs) of spontaneously creating a wireless network of mobile devices were used to create VANETs when applied to the vehicular domain. In VANETs, vehicles are considered communication nodes that can be part of a self-organizing network without previous screening or information about the presence of other nodes. The dynamic network architecture, influenced by high car speeds, supports the development of Intelligent Transportation Systems (ITS)(Agrawal et al., 2023).

Figure 2 presents the components and the different types of communication existing in VANETs, here it can be observed that there exists 2 different kinds of nodes: On-Board Units (OBUs) and Road Side Units (RSUs). OBUs are installed radio devices in vehicles that move in the network, on the other hand, RSUs compose the network infrastructure and are placed near the road (Hozouri et al., 2023). OBUs can link the car to RSUs using Dedicated Short Range Communication (DSRC) devices (Engoulou et al., 2014). Figure 2 also shows the existing types of communication as: vehicle to vehicle (V2V) communication, vehicle to infrastructure (V2I) communication and infrastructure to vehicle (I2V) communication.

VANETs have been used widely to improve the transportation world, it allows all the network to be aware of every car connected to it. They were first introduced by Toh in the book 'Ad hoc mobile wireless networks: protocols and systems' in 2001 (Toh, 2001) and have been extensively studied since then. Part of the work done with VANET is to transform a city into a smart city (Khatoun and Zeadally, 2016; Laouiti et al., 2016) through different mechanisms. For example, environmental sustainability(Joshua et al., 2023), detection of driver behaviour (Hernafi et al., 2016) or ITS (Chehri et al., 2020; Raut and Devane, 2017) to improve the life's quality of the citizens, by making everything easier, safer and having a better control of the transport system.

Figure 2. Vehicular Ad-hoc Networks' components and types of communication



Source: authors' development

"Hoy no circula" (Today no traffic)

The municipality of Quito has implemented actions to reduce pollution and traffic issues. One of the most important is the program "Hoy no circula" (Today no traffic), which determines a perimeter and an application schedule (Uyaguari Guachisaca, 2020) showed in Table 1. This program tries to solve the traffic jams at peek hours by restricting the movement of certain cars during a certain time of the day inside the city of Quito. Each weekday from Monday to Friday some cars cannot move inside a delimited area from 6:00 to 9:30 and from 16:00 to 20:00, according to the last digit of its license plate. License plates ending with 1 or 2 are restricted to mobilize on Mondays, license plates ending with 3 or 4 cannot move on Tuesdays and so on. If a restricted car is found in motion it will be retained until the owner of the car pays a fine. Since 2010 when this program was implemented there has been some improvement in the traffic circulation and air quality in the city.

Table 1. "Hoy no circula" application schedule

HOY NO CIRCULA	
Schedule	
Day	Number
MON	1-2
TUE	3-4
WED	5-6
THU	7-8
FRI	9-0

Source: Quito Metropolitan Transit Agency
Available from: https://www.amt.gob.ec/index.php/informacion/pico-y-placa

Speed limits and control

This measure applied in most of the countries intend to have more control over the vehicles circulating and increase safeness of drivers and pedestrians. Police operatives and fixed speed radars in the main highways and streets are in charge of controlling the car's speed and fining the offenders. There are different speed limits in Quito, they can go from 50 km/h to 90 km/h depending on the street the vehicle is on, as well as the type of vehicle(heavy, light, public transportation). Streets in urban areas have a speed limit of 50 km/h while on the peripheral highways the speed limit is 90 km/h. Eventhough, extensive research has been conducted on the application of VANET technology for controlling vehicle speeding, this technology has not been completely introduced to Ecuador.

Problem description

Since the introduction of "Hoy no circula" program in the city of Quito, it has faced many problems, mainly in the control of this measure inside the city. Vehicles avoid transit agents for not being fined, other illegally modify their license plate so it seems like it is a legal car circulating when it is not. Not only that, when caught offenders may try to bribe the officer so they do not pay the complete value and avoid their car being taken away. There is also a human factor when talking about the transit agents, so they are not 100% reliable, sometimes they cannot see the last digit of the license plate due to high speed of the vehicles or heavy traffic flow. There are also some problems when controlling the speed, for example with fixed speed radars, drivers already know where the radars are and they reduce the speed when passing them and then continue at high speed.

Another problem with fixed radars is the vehicle identification trough photos or video, due to high speed and other vehicles nearby it is hard to identify the offender car. When talking about police speed controls, again some of the problems described before may arise as bribing or avoiding the streets where these speed controls are been executed or reducing the speed while passing them. Thus, the main challenges of "Hoy no circula" and speed controls are the permanent control of the vehicles inside the designated area and to avoid a human factor in any of the steps of these measures so the offenders may not get away with their infraction.

PREVIOUS RESEARCH

This research not only intend to give the first step to transform Quito into a smart city, but also propose a way to fine the offender cars circulating in the city. There are several studies regarding automated fining systems or similar approaches in automated systems for toll collection that would be discussed in this section.

Ahmed et al. (2015) and Ahmed et al. (2016) highlight the importance of using smart traffic violation ticketing systems for cop vehicles, enabling traffic agents to identify violating vehicles without putting lives in danger by chasing them. In this implementation, vehicles record infractions committed by the drivers in a table, then traffic monitoring vehicles named as cop vehicles request this table from their neighbors and issue tickets to the offender vehicle. Vehicles store this tickets until they reach an tollbooth were an automatic payment of the fine is performed, to then move the already paid ticket to a new table to keep record of the infractions. For this purpose it is assumed that every vehicle have a bank account associated to it. Isong et al. (2017) suggest an approach to monitor and detect automatically drink-driving and over-speed offenders with minimum or even none intervention of traffic agents in South Africa. The system operates in real-time to detect drunk drives and speeding offences with the help of sensors and IoT. The offenders get identified and traffic officers get notified to take the corresponding actions to avoid putting lives at risk. An application was developed to make it easier to the officers to identify offenders and their location.

Abbas et al. (2019b) and Abbas et al. (2019a) proposed an automated speeding fining system. In their work the authors introduce a system capable of using RSUs and OBUs to analyze the vehicles' current speed and take actions according to it. In this research the authors capture the vehicle's speed and check if it is over the speed limit. If a speeding offence occurs, a warning will be sent to the vehicle by the RSU with the hope that the driver reduces the speed. If the driver is still over the speed limit a fine would be issued to the owner.

According to Sathyapriya et al. (2021), ITS are crucial for future smart cities, particularly in enhancing road safety. The authors propose using VANET technology to control vehicle speeds automatically. By transmitting speed limit data to the vehicle's Engine Control Unit (ECU) via VANET, the system ensures vehicles adhere to speed limits. This data is broadcasted from a central location and relayed through V2V communication, creating a chain of information dissemination. Once a vehicle receives this data, its ECU compares the current speed with the prescribed limit and adjusts the speed of the car accordingly to maintain safe speeds. VANET offers a more reliable solution compared to traditional methods like GPS transceiver systems, which are prone to signal loss at high speeds.

Parveen et al. (2022) highlight the severe issue of road crashes in a developing country similar to Ecuador, India. This road crashes are caused due to factors like high-speed driving, driver fatigue, distractions, drunk driving, and traffic rule violations. To prevent this, they propose an intelligent system that continuously monitors parameters such as accurate location, route information, vehicle speed, and alcohol consumption levels. The system integrates an alcometer, smoke detector, camera, GPS tracker, automatic braking system, IR eye blink sensor, and pressure sensor to record these measurements. Utilizing machine learning algorithms, the system classifies vehicles in real-time as either risky (crash-prone) or non-risky (non-crash- prone). For vehicles deemed risky, safety alarms are sent, and in worst-case scenarios, an ambulance is dispatched while the driver and relevant contacts are notified immediately. By employing VANETs for fleet tracking, the system enhances real-time monitoring and response, thereby improving road safety.

Mohamed (2019) also discuss the increasing number of road accidents and their associated problems in Saudi Arabia. These accidents are primarily caused by traffic rule violations, such as speeding, running red lights, tailgating, and driving in the wrong direction. Given the extensive network of roads and the impracticality of continuous monitoring by traffic patrols or cameras, the authors propose an autonomous system to detect and record traffic violations without human intervention. They propose an autonomous system with an onboard unit (OBU) to detect and record traffic violations in real-time. Speeding is one of the traffic violations considered in this work. The OBU accurately measures vehicle speed and compares it to speed limits from digital maps. It logs details such as speed, violation duration, peak speed, average speed, location, and time of the violation. An automatic reporting system then sends these violations to traffic authorities, enhancing enforcement and improving road safety.

As it has been shown the study of VANET in the context of smart cities and automated fining systems is an extensive topic due to its importance in the fields of vehicular security and mobility in the cities. The main difference in this research with respect to the reviewed literature is the control of the mobility restriction based on the vehicle's license plate. Another difference with the proposed system is there is no need of a bank account associated to the vehicle, the payment will be done in the usual way fines are handled in the transit system in Quito; while annually registering the vehicle to be able to drive it

PROPOSED SOLUTION

In this section the proposed system is presented in terms of its components, architecture and functioning.

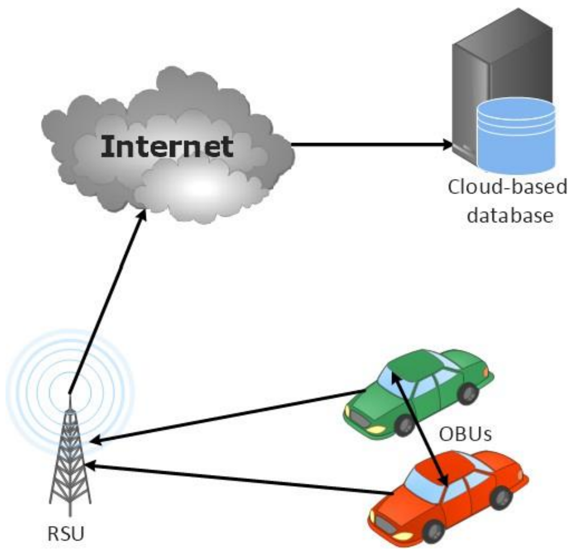
System Overview

This system allows the permanent control over all the vehicles with an OBU. This will be accomplished by a self-control, meaning the OBU register its own infractions; and neighbors control, as all the neighbors will also register the nearby offenders. Both, speed infractions and "Hoy no Circula" restriction depends on the street the car is, the OBU has a list of roads to recognize the speed limit of each road and a list of roads where there are no mobility restrictions. In this way the OBU recognize if it is committing an infraction, depending on the street it is driving and the OBU conditions(speed, license plate). As mentioned before, the infractions will be kept in the OBU of the vehicle and in its neighbors infraction lists which will later be sent to the RSU. The RSU purge the data and saves relevant entries in its own infraction lists, and finally all RSUs send their offender's lists to the cloud to be analyzed.

System Architecture

The architecture proposed for this solution is presented visually and explained in this section. Figure 3, shows the components of the system and how are they distributed and connected. This system's components are: the vehicle system(OBU), the RSU and a cloud-based database.

Figure 3. Proposed system architecture



Source: authors' development

1) Vehicle system (OBU): It is made up of all the hardware components integrated into each vehicle which will sense and collect the required data as position(road ID) via GPS, current speed via speed sensor, it also contains a memory unit where the ID of the car will be programmed and where infraction lists will be stored to be transmitted to the RSU.

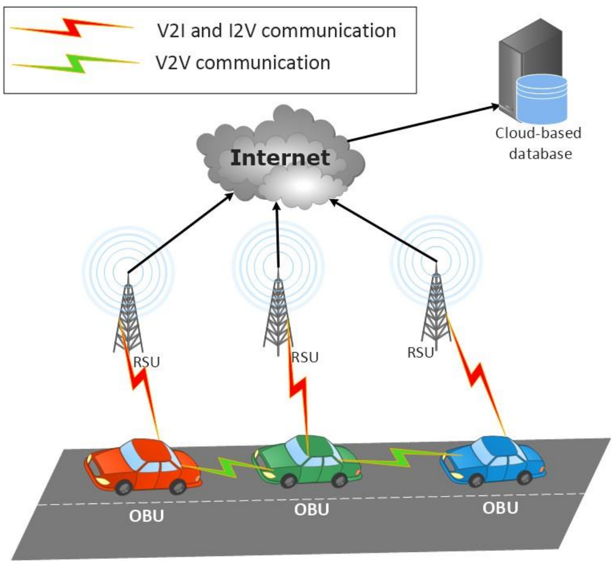
2) The Roadside Unit (RSU): The RSU acts like an intermediary between the data generation(in the OBU) and the data final collection (in the cloud-based database). Each RSU collects the information from nearby OBUs and upload this information to the database.

3) Cloud-based Database: This is the end point of the system. All the infractions and offenders data stored in the RSUs are passed via Internet to a central unit where they will be analyzed to avoid redundancy. This database will contain all the offenders to be fined according to the type of infraction.

Network Architecture

Given the conditions of the network, the proposed system employs VANET in its operation. As shown in Figure 4 the types of communication supported by the network are V2V, V2I and I2V communication, the proposed architecture maintains strong connectivity between the OBUs and the RSUs in the network. The OBUs read the vehicle's conditions and process the information to generate and inform the infractions to other nodes, they send this data to their neighbors(V2V and V2I) as a WAVE Short Message(WSM). When an OBU receives a Basic Safety Message(BSM) from a RSU it sends the content of its infraction list as a WSM to the RSU. Finally the RSUs upload this information to the database via Internet.

Figure 4. Network architecture

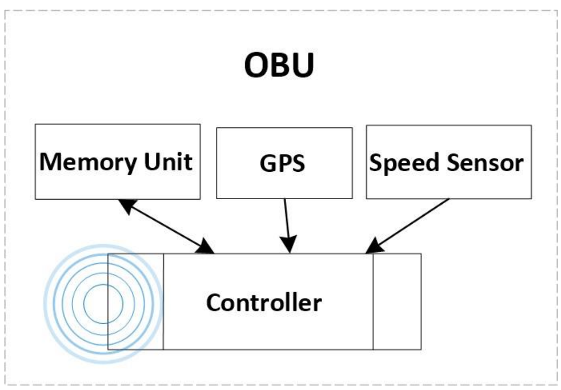


Source: authors' development

Vehicular System Architecture

In this section the design details and key components of the vehicular system necessary to achieve the goal are discussed. As shown in Figure5, the vehicular system is made up of a GPS, a speed sensor, memory unit and a controller unit.

Figure 5. Vehicular system architecture and components



Source: authors' development

1) GPS: This device is capable of receiving information about its position, this information is then used to know the road where the vehicle is.

2) Speed sensor: This device senses the vehicle's current speed and sends this data to the controller.

3) Controller: It is the processing unit of the vehicular system, it analyze and process the information received from the speed sensor, GPS and other OBUs. The controller stores relevant data(infractions' list) in the memory unit and also retrieve data from it like the vehicle ID(license plate) and information of the streets (street's speed limit, street with restriction).

4) Memory Unit: It is the unit where information is stored and from where information is retrieved. It stores the infractions' list, the streets' list with restrictions, the information about the speed limits, and the ID of the vehicle according to its license plate.

Ideally, this vehicular system cannot be hacked or altered in any way to guarantee the correct operation of the proposed system.

Algorithmic Design

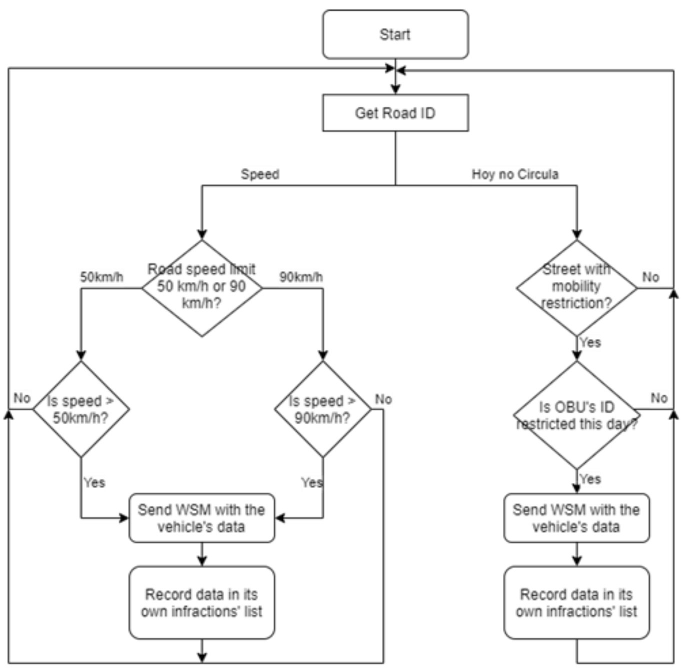
In this section, the algorithm that describes the overall operations of the system is presented. First the controller operation is discussed and then the overall system operation is described.

1) Controller Operation: The controller operates continuously obtaining information from the speed sensor and GPS to perform the processing and checking if an infraction was committed. Data will only be recorded and transmitted if the driver is over the speed limit or if the vehicle is in a mobility restricted area and its license plate has a restricted number for that day. The process of checking whether data should be recorded and transmitted as an infraction is shown in the algorithm represented by the flowchart in Figure 6. Assumptions:

- All the vehicles have and OBU integrated to their system.
- There are only two speed limits in the city 90km/h and 50km/h.
- All the vehicles have the same restrictions whatever its type is (heavy, light, transport).

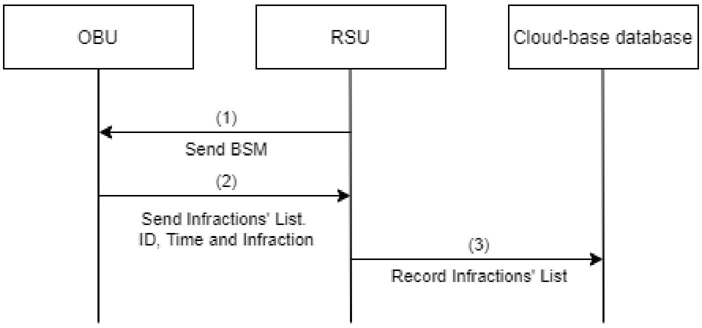
2) System overall operation: Once the OBU performs it operation, if it or one of its neighbors commit and infraction the OBU will record the offender data as well as the infraction type. When the OBU knows it is in connection range with a RSU (when receiving a BSM from an RSU), the stored data(infractions' list) will be transmitted to the RSU which then will transmit the data to the cloud-based database for a centralized and distributed data storage coming from all RSUs. Each vehicle has an unique ID that identifies it, this ID is generated according to the vehicles license plate, specifically according to its last number of the license plate. The data transmitted will include the vehicles ID, the type of infraction and the time when the infraction occurs. A high-level sequence of interaction is shown in Figure 7.

Figure 6. Flowchart describing the controller's operation



Source: authors' development

Figure 7. High-level system interaction process



Source: authors' development

EXPERIMENTAL WORK

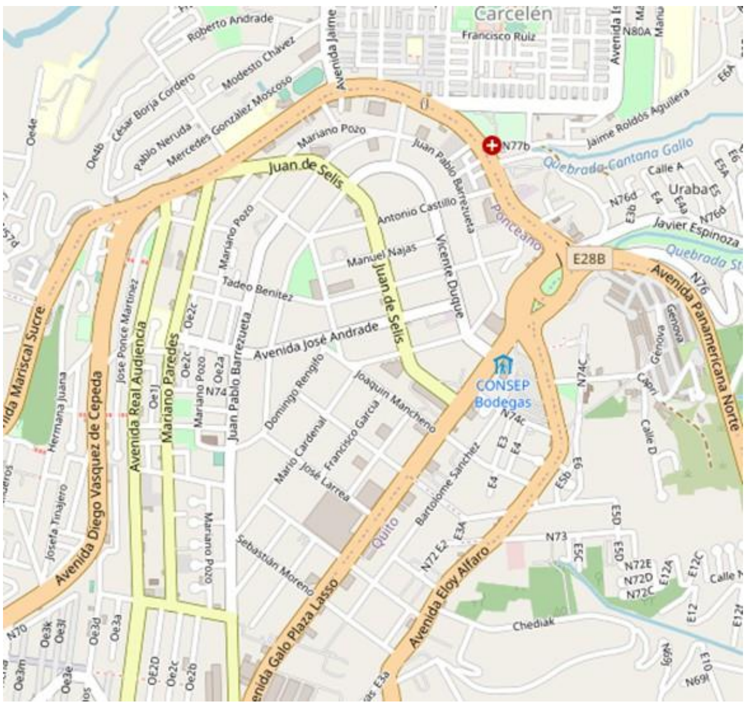
Simulation overview

The presented solution was simulated on Omnett++ 5.6.1 (Varga, 2010) and SUMO 1.2.0 (Behrisch et al., 2011). Veins 5.0 (Sommer et al., 2010) was also used, Veins is based on the two simulators discussed before. This framework enhance them to offer a complete suite of models for Inter-Vehicle Communication simulation. The Veins' example was modified to obtain the solution for the previously described problem. The vehicles' device was programmed to check if the vehicle has committed any infraction depending on the street it is on, if it has, a WSM is sent to the neighbors. It was also programmed to respond based on the incoming messages. If a WSM coming from other vehicles is detected it record the information of the infraction in its own infractions' list, on the other hand, if a BSM coming from a RSU is detected it sends the stored infractions' list. The RSUs' device was programmed to respond incoming messages as well, they handle the information of the offenders contained in the messages to record this data in its own infractions' list. Later on, the RSUs upload this infractions' list to the cloud-based database.

Experimental Scenario

In this sections, first it is important to mention that the selected area for the research contains: streets with mobility restriction, streets without mobility restriction, streets with speed limit of 90km/h and 50km/h. Figure 8 shows the selected area corresponding to the north of Quito in the limits of "Hoy no Circula" application perimeter.

Figure 8. Map of the selected area of Quito used for simulation



Source: The map was obtained from OpenStreetMap (www.openstreetmap.org)

The simulation was performed in 6 different scenarios. In each scenario the number of RSUs and the traffic density varied, three different traffic densities and two different number of RSUs were utilized. The traffic densities were Low Density(LD) with 10 *vehicles/km*^{2}, Medium Density(MD) with 50 *vehicles/km*^{2} and High Density(HD) with 100 *vehicles/km*^{2}. The number of RSUs could be 9 RSUs equally distributed around the map or 16 RSUs equally distributed as well. The different combination of this 2 variables lead us to the 6 simulation scenarios used to evaluate the proposed system.

RESULTS AND ANALYSIS

In this section the results obtained from the simulation of the proposed system are presented and analyzed. It is important to mention that the 6 scenarios were named depending on the number of used RSUs and the vehicular density. The scenarios are "9LD", "16LD", "9MD", "16MD", "9HD", "16HD", for example, "9LD" means 9 RSUs were used in this scenario with low traffic density(10 vehicles/km2).

The final result of the simulation is a list containing all the offenders registered by the all the RSUs in the scenario. Table 2 presents an example of this list and the information contained in every record, the infraction types are "HNC" (Hoy no Circula), "UAS" (Urban Area Speeding) and "HWS" (High Way Speeding).

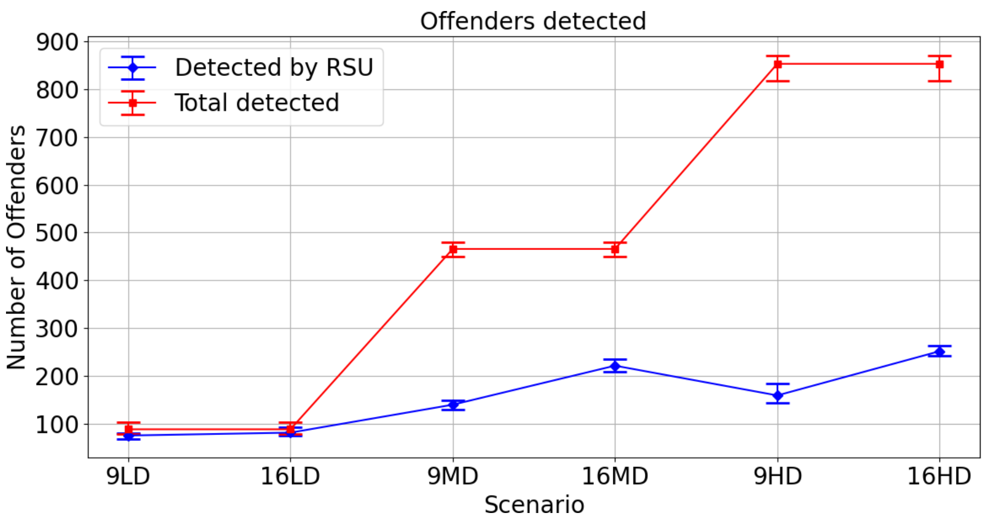
Table 2. Example of Infractions' List stored in the cloud-based database

Infractions' List		
Monday		
ID	**Time**	**Type**
2	13	UAS
2	14	HNC
7	43	HWS
11	37	HNC
13	36	UAS

Source: authors' development with the simulation data

The limitation of this implementation is the capacity of the RSUs of having all the vehicles within their range. If a vehicle committed an infraction but never established a connection to an RSU, the infraction will not appear in the infractions' list in the cloud-based database unless another vehicle registered the infraction and at any time that vehicle established connection with an RSU and pass it infractions' list. Figure 9 shows this limitation, the red line shows the total infractions detected during the simulation, while the blue line shows the total of infractions registered in the cloud-based database.

Figure 9. Total offender vehicles vs Offenders vehicles detected by RSUs



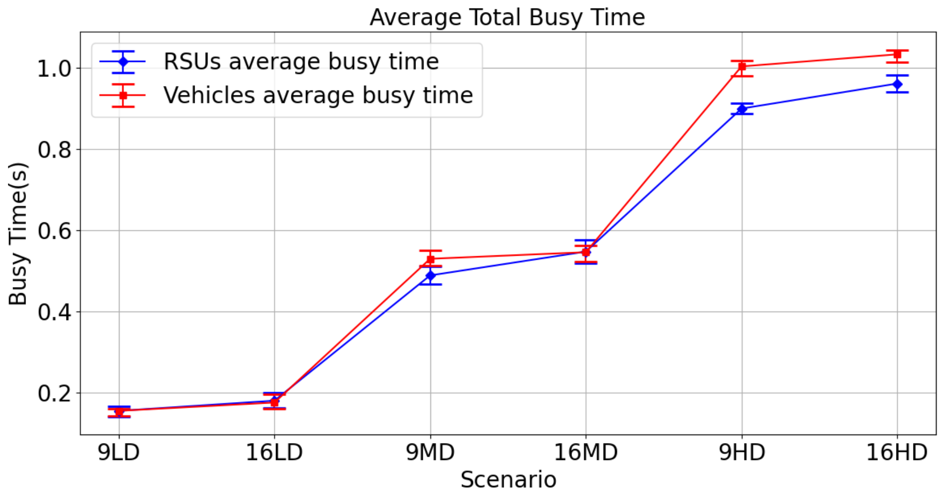
Source: authors' development with the simulation data

As it can be seen, the effectiveness of the system decreases when the vehicular density increases. In LD the percentage of offenders detected compared to the total of offenders is between 85% and 92% depending on the number of RSUS(increases when more RSUs are used) while in HD the percentage decreases to 18% to 29% depending on the number of RSUs.

This decreasing of the efficiency in the system can be explained due to the channel busy time and the total lost packets of the mac layer. Figure 10 shows the average of the total busy time of the channel in both vehicles and RSUs while Figure 11 presents the average of total lost packets in each scenario for vehicles and RSUs. In both figures the average busy time and average total lost packets increase when the vehicular density or the number of RSUs increase, this due to the increment of messages sent in the network, as more messages are sent and received the channel busy time increases and there are more packet loss that do not arrive to their destination. In the case of the proposed system, if a vehicle sends its infractions' list via WSM this message might not reach the destination RSU and be one of the lost packets, this translates to an incomplete infractions' list in the cloud-base database.

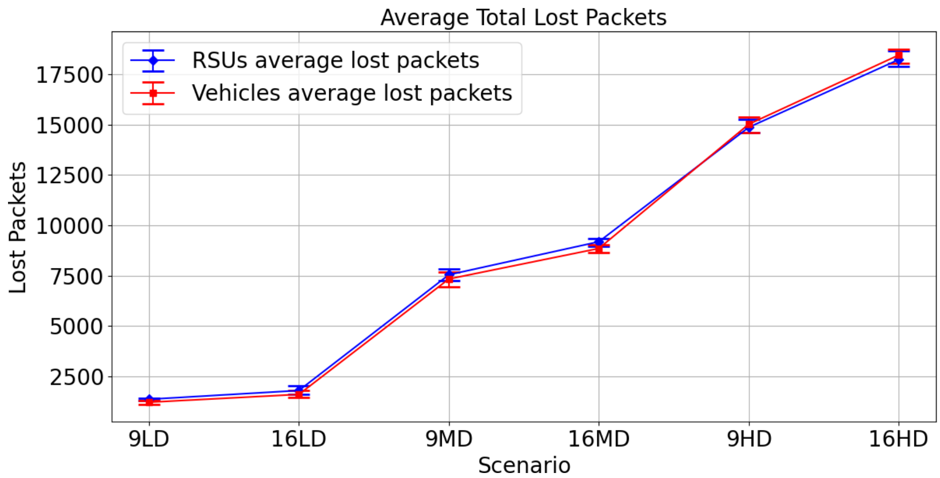
Even though the infractions' list is not complete, this can be solved by analyzing the OBU of the vehicles. If all the OBUs in the network are analyzed the infractions' list obtained would be complete. To address this problem, the solution in Quito is to analyze the OBU in the mandatory annual vehicle registration. Before you can register your vehicle to be able to drive it, you first have to pay all the fines registered in the transit system (actual process). In this way less RSUs will be needed(cheaper implementation) and a more complete list of offenders will be generated.

Figure 10. Average busy time for RSUs and vehicles



Source: authors' development with the simulation data

Figure 11. Average lost packets for RSUs and Vehicles



Source: authors' development with the simulation data

FINAL REMARKS

Although speed and mobility restriction's control have been implemented in Quito, they have several flaws that led to the offender not being fined. This paper presents a system that controls and monitors all the vehicles that have an OBU, and informs about their infractions. The RSUs send all the collected data to a database managed by the authorities to fine the offenders. The proposed solution achieve the goals as it identifies the offenders inside an area, identifies the type of infraction the vehicle committed and save the data of the offenders. Most important, it eliminates the human factor and other inaccurate control methods in the identification of the offenders.

This solution is applicable in the city of Quito and can improve the control methods as well as the mobility in the city. The efficiency of this solution decreases when the vehicular density increases, but this solution keeps the way open for a different implementation designed for the case of Quito, which is the analysis of the OBUs during the mandatory annual vehicle registration. In this way it does not matter if a vehicle does not send it infractions' list to an RSU, all the offenders will be fined at some point.

For future works many things can be optimized and other added to this proposed solution. For example, the distinction of different type of vehicles(heavy, light, transport) as they have different speed and mobility restrictions depending on its type. Identify new areas inside the city where speed limit is other than 90 km/h or 50 km/h, for example it is known near schools the speed limit is 30 km/h.

Another option is to expand the area of research in new ones to identify possible problems encountered in other parts of the city. As RSUs are the most expensive components of the network, the amount of RSUs can be optimized by identifying hotspots where the effectiveness of the RSU increase and spots where no RSU is needed. VANET can solve several mobility problems in Quito, not only the ones mentioned in this research, there are other functionalities that can be implemented through VANET like automated toll collection which will improve mobility, so this research open the way for new implementations and functionalities that can be added.

REFERENCES

Abbas, M. K., Jung, L. T., Mahmood, A. K., and Abdulla, R. (2019a). Intelligent software agents for managing road speed offences. In *Computer Science On-line Conference*, pages 180–191. Springer.

Abbas, M. K., Low, T. J., and Abdulla, R. (2019b). Automated fining system for high speed driving offences via vanet. In *2019 International Conference on Green and Human Information Technology (ICGHIT)*, pages 36–38. IEEE.

Agrawal, R., Kumar, A., and Singh, S. (2023). Vehicular ad hoc network: Overview, characteristics, and applications. In *AIP Conference Proceedings*, volume 2721. AIP Publishing.

Ahmed, S. H., Yaqub, M., Bouk, S., and Kim, D. (2015). Towards content-centric traffic ticketing in vanets: An application perspec- tive. In *2015 Seventh International Conference on Ubiquitous and Future Networks*, pages 237–239. IEEE.

Ahmed, S. H., Yaqub, M. A., Bouk, S. H., and Kim, D. (2016). Smartcop: Enabling smart traffic violations ticketing in vehicular named data networks. *Mobile Information Systems*, 2016.

Behrisch, M., Bieker, L., Erdmann, J., and Krajzewicz, D. (2011). Sumo–simulation of urban mobility: an overview. In *Proceedings of SIMUL 2011, The Third International Conference on Advances in System Simulation*. ThinkMind.

Chehri, A., Quadar, N., and Saadane, R. (2020). Communication and localization techniques in vanet network for intelligent traffic system in smart cities: a review. In *Smart Transportation Systems 2020: Proceedings of 3rd KES-STS International Symposium*, pages 167–177. Springer.

Engoulou, R. G., Bellaïche, M., Pierre, S., and Quintero, A. (2014). Vanet security surveys. *Computer Communications*, 44:1–13.

FLACSO (2015). Quito ciudad, capital del Ecuador. https://www.flacso.edu.ec/flax15/_upload/etnobiologia/pdfs/QUITO_ INFORMACION_GENERAL.pdf.

Hernafi, Y., Ahmed, M. B., and Bouhorma, M. (2016). An approaches' based on intelligent transportation systems to dissect driver behavior and smart mobility in smart city. In *2016 4th IEEE international colloquium on information science and technology (CiSt)*, pages 886–895. IEEE.

Hozouri, A., Mirzaei, A., RazaghZadeh, S., and Yousefi, D. (2023). An overview of vanet vehicular networks. *arXiv preprint arXiv:2309.06555*.

Informa, Q. (2020). 465.908 vehículos fueron matriculados en el 2019. http://www.quitoinforma.gob.ec/2020/01/10/465-908- vehiculos-fueron-matriculados-en-el-2019.

Isong, B., Khutsoane, O., Dladlu, N., and Letlonkane, L. (2017). Towards real-time drink-drive and over-speed monitoring and detection in south africa. In *2017 International Conference on Computational Science and Computational Intelligence (CSCI), pages 1338–1344. IEEE.*

Joshua, C. J., Jayachandran, P., Md, A. Q., Sivaraman, A. K., and Tee, K. F. (2023). Clustering, routing, scheduling, and challenges in bio-inspired parameter tuning of vehicular ad hoc networks for environmental sustainability. *Sustainability*, 15(6):4767.

Karabulut, M. A., Shah, A. S., Ilhan, H., Pathan, A.-S. K., and Atiquzzaman, M. (2023). Inspecting vanet with various critical aspects–a systematic review. *Ad Hoc Networks*, page 103281.

Khatoun, R. and Zeadally, S. (2016). Smart cities: concepts, architectures, research opportunities. *Communications of the ACM*, 59(8):46–57.

Laouiti, A., Qayyum, A., and Saad, M. N. M. (2016). *Vehicular ad-hoc networks for smart cities*. Springer.

Mohamed, S. A. E. (2019). Automatic traffic violation recording and reporting system to limit traffic accidents: based on vehicular ad-hoc networks (vanet). In *2019 International Conference on Innovative Trends in Computer Engineering (ITCE)*, pages 254–259. IEEE.

Parveen, Singh, R., and Kumar, S. (2022). Crash detection-based fleet tracking system using vanets. In *Advances in Micro- Electronics, Embedded Systems and IoT: Proceedings of Sixth International Conference on Microelectronics, Electromagnetics and Telecommunications (ICMEET 2021), Volume 1*, pages 407–417. Springer.

Raut, C. M. and Devane, S. R. (2017). Intelligent transportation system for smartcity using vanet. In *2017 International Conference on Communication and Signal Processing (ICCSP)*, pages 1602–1605. IEEE.

Sathyapriya, A., Sathiya, K., Sneha, T., Rohit Raja, D., and Manikandan, T. (2021). Automatic speed control system in vehicles using vanet. In *Advances in Smart System Technologies: Select Proceedings of ICFSST 2019*, pages 719–726. Springer.

Sommer, C., German, R., and Dressler, F. (2010). Bidirectionally coupled network and road traffic simulation for improved ivc analysis. *IEEE Transactions on mobile computing*, 10(1):3–15.

Toh, C. K. (2001). *Ad hoc mobile wireless networks: protocols and systems*. Pearson Education.

Uyaguari Guachisaca, A. V. (2020). Análisis del requerimiento operativo y legal para los vehículos eléctricos en el distrito metropolitano de quito, dmq. B.S. thesis, Quito: UCE.

Varga, A. (2010). Omnet++. In *Modeling and tools for network simulation*, pages 35–59. Springer