

# Vehicle density in VANET applications

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**Abstract.** This paper analyzes how street-level traffic data affects routing in VANETs applications. First, we offer a general review about which protocols and techniques would fit best for VANET applications. We selected five main technical aspects (Transmission, Routing, Quality of Service, Security and Location) that we consider are differential aspects of VANETs from current Ad-Hoc Networks. Second, the paper analyzes how to configure each technical aspect according to the goal of a wide range of VANET applications. Third, we look at the routing aspect in depth, specifically focusing on how vehicle density affects routing, which protocols are the best option when there is a high/low density, etc. Finally, this research implements a sensor technology, based on an acoustics sensor that has been deployed around the city of Xalapa in México, to obtain reliable information on the real-time density of vehicles. The levels of density were discretized and the obtained data samples were used to feed a traffic simulator, which allowed us to obtain a global picture of the density of the central area of the city. According to the specific levels of vehicle density at a specific moment and place, VANET applications may adapt the routing protocol in a real-time way.

Keywords: Vehicle communication, density of vehicles, VANET applications, routing protocols

## 1. Introduction

The deployment of Intelligent Transport Systems in Europe [1] deals with the integration of the information and communications technologies of vehicles and road facilities. Particular attention is paid to next generation vehicles, information and communication strategies, services and facilities [2].

In this paper, we look at the likely trajectory of emerging Vehicle Ad Hoc Networks (VANETs) applications and their subjacent technology. Five technical aspects (Transmission, Routing, Quality of Service, Security and Location) that we consider are differential aspects of VANETs from current ad hoc networks were reviewed.

There are several research works related to VANETs applications, as we can see in [3,4]. Authors in [5] developed an application in an urban area that quantifies the lost time and pollution generated in thousands of dollars a day when a person is looking for a parking space. In [6] there is the example of Cooperative Collision Warning Systems, where vehicles were equipped with sensors, communication

hardware, wireless protocols, estimators, and collision warning algorithms.

VANET applications examples reported by the literature conclude that designing a VANET application is a complex process that requires analyzing all the technical aspects involved in the context where the application will be used. It is necessary to define communications systems that feature a convenient, stable, secure and economic distribution of data over highly mobile nodes. Vehicles require reliable location mechanisms and also a communications capability able to distinguish between critical and informative messages.

We look into the routing aspect in depth and we consider the density of vehicles as one of the main context characteristics that affect routing protocols in VANETs.

In a concrete example we show a procedure to compute vehicle density in the streets of Xalapa city, México. The setup considers the use of acoustic sensors which allow the detection of the presence of a vehicle moving freely, or vehicles that are waiting in front of red lights or in a traffic jam. The system is

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able to detect a cluster of vehicles moving in the street.

The main contribution of this paper is our approach to determining the density level according to the signals collected from the acoustic sensors, the distance of the street and the time intervals. Once the density level has been determined, we propose that VANET applications change their routing protocols according to these density levels in a dynamic way.

The paper is structured as follows: Section 2 briefly reviews related work; Section 3 analyzes the main technical aspects that distinguish the VANETs from other ad hoc networks. We detail how the technical aspects of VANETs should be involved in VANET application designs. Section 4 details how our simulation model detects the density of vehicles within urban environments based on acoustic signals. We determine a convenient routing protocol according to the vehicular density levels. The Conclusions are in Section 5.

## 2. Vehicular ad hoc networks

Today vehicles include in their facilities a broad variety of sensors providing the driver with information related to the vehicle's functioning conditions, journey development and security guidance. Along with the increasing capabilities of radio communications systems, it is now possible to monitor remotely vehicles' functions and the conditions of the surrounding environments, such as the traffic on the road, available parking places, etc., a main focus of open interest being the best way to deliver vehicle sensor data about the vehicles or infrastructure.

VANETs are ad hoc networks that have predictable node movements due to the existing infrastructure (roads, motorways, etc.) and traffic laws. However, context awareness becomes difficult because the immediate context changes very fast. In fact, the high velocity and density of vehicles are clear characteristics that make VANETs very distinct from other ad hoc networks. The same occurs with routing and security mechanisms that have to deal with highly unstable network topologies.

VANETs have their own unique characteristics, such as:

In the physical layer, the 802.11p wireless standard is the most generalized protocol for VANETs [7]. This standard, also called wireless access in vehicular environments, uses the multi-hop technique



Fig. 1. VANET representation [1].

for routing within a range of between 300 and 1000 meters.

Network routing protocols for VANETS have been analyzed in several pieces of research: The work in [8] proposes a proactive routing where the movement of vehicles is expected and studied to improve performance. In [9] the authors consider the current location of vehicles to reduce the number of signal collisions in broadcast messages. In [10] the use of directional MAC protocol to reduce the collision rate is proposed. This protocol takes advantage of the vehicles' predictable movements because of the road and driving rules.

At the application level there are different ways for classifying VANET applications. For example, in [11] the authors mention four application categories: Active safety, public service, improved driving and business/entertainment. In contrast, [12] classifies applications based on their requirements of security and types of information: Vehicle-to-Vehicle Cooperative Awareness, Vehicle-to-Vehicle Unicast Exchange, Vehicle-to-Vehicle Decentralized Environmental Notification, Infrastructure to Vehicle (One-Way), Local Road Side Unit (RSU) Connection, and Internet Protocol RSU Connection. In [13], applications have three main categories: Safety, traffic monitoring/optimization, and infotainment. In [14] the classification is: Life-Critical Safety Applications, Safety Warning, Electronic Toll Collection, Internet Access, RSU Service Finder, and Group Communication. In this research we use this last classification.

## 3. Technical aspects involved in the design of VANET applications

VANETs are a very distinct category of ad hoc networks, so, the diverging requirements of VANET applications making the design of a comprehensive

communication system a very complex topic. We based it on the VANET classification of Yi and Moayeri [14], which divides the applications into six groups: Group A: Life-Critical Safety Applications, Group B: Safety Warning Applications, Group C: Electronic Toll Collections, Group D: Internet Access, Group E: RSU Services Finder, Group F Communications.

A lot of previous work exists on communication in VANETs; however, that research is very diverse and has not yet been well categorized [11,14,15].

We therefore start with an analysis of the VANETs application requirements. We have seen that, depending on the type of road, the density of vehicles, the speed of the vehicles, and so on, the communications requirements would not be the same. Traffic communications are more chaotic in cities than on highways, and node density is not the same on highways as in cities or on rural roads.

So, we have categorized the VANET characteristics by considering a set of five main technical aspects that differs from other ad hoc networks: Transmission, Routing, Quality of Service, Security and Location

Finally, we suggest the best configuration option for each VANET application group.

*Technical aspect 1 – transmission means* The communication standard for vehicle-to-vehicle communication and vehicle-to-infrastructure communication is the Dedicated Short Range Communication (DSRC) [14] that supports Wireless Access in the Vehicular Environment (WAVE) [16]. WAVE allows data exchange between vehicular devices in rapidly changing communications environments, where mobile nodes may move up to 200 km/h and the distances between them are between 5 and 500 meters.

The reserved bands of the radio electric spectrum were divided into seven 10MHz-wide channels. Channel Ch178 was reserved for protocol control. Channels Ch172 and Ch184 were reserved for accident avoidance applications and public safety communications. The rest, (Channels Ch174, Ch176, Ch180 and Ch182) were used for both safety and non-safety applications. Thus, the correct selection of channel for Group A applications is Ch172, but for the rest of the applications (Groups B, C, D and E) it can be any out of Ch174, Ch176, Ch180 and Ch182.

*Technical aspect 2 – routing capabilities* Conventional topology-based routing schemes are not suitable for VANETs. Reactive routing schemes fail to discover a complete path due to frequent network

partitioning, and proactive routing protocols are overwhelmed by rapid topology changes and even fail to converge during the routing information exchange stage [17].

Routing must also consider mobility of nodes from zero kilometres per hour (stationary vehicles), to over 140 km/h on highways. So, routing cannot be based on group addresses, as in ad-hoc networks. Routing must rely on the locations of the nodes to determine the delivery of packets.

In [18] the authors present a survey of geocast, broadcast and multicast technologies, which can be applicable to V2V networks.

Intelligent opportunistic forwarding using speed information is explored in [19]. Our proposal is to use geocast in application Groups A and B to limit the destination region of the message related to safety; to broadcast in Group F with continuous updates of information among neighbouring nodes; and unicast in the rest of the groups. Also, Groups A and B are specific in not involving bidirectional protocols, as opposed to Groups C and D. Group C is the only type of application where single-hop protocols are more adequate than multi-hop. Finally, for Groups E and F, location-based routing approaches are suggested as being the most suitable.

*Technical aspect 3 – quality of service* In road traffic scenarios, when an emergency event occurs, the number of vehicles that approach the accident may increase dramatically. This might create a spike in emergency messages in the VANET if they are broadcast by every vehicle, leading to a collapse of the channel [10]. Our proposal provides time restrictions to ensure quality of service for the different types of application groups. On one side, we have Groups A and B, which do not have any restrictions on the response time since they use one-way no-response messages. The proposed maximum transmission delay is 250 ms, with a maximum jitter of 100, and a 52 Mbps bandwidth. Less restrictive are applications on Groups C, D and E. We propose for them a 2–5 second response time, 400 ms for the transmission delay, and 24–32 Kbps for the bandwidth. For this application group the jitter is not considered critical. Finally, for Group F there is a maximum response time of 1s, but with delays of up to 200 ms. a bandwidth needed of 1 Kbps is enough since the messages are short and plain-characters.

*Technical aspect 4 – security levels* In VANETs malicious behaviour could be fatal to other users. VANET security requirements such as: Message

Non-Repudiation, Access Control, Message Confidentiality, Privacy and Anonymity, and Liability Identification are detailed in [14].

Group D applications require only access control and some degree of confidentiality on up-stream messages, which can be achieved with symmetric keys. We suggest extending the two previous requirements of Group D only with message authentication and integrity for Group E. In fact, message authentication and integrity is also suggested for the rest of the groups, except for Group F, where only authentication could be requested. Special attention is given to Groups A and B, because they should be given a grant of access without confidentiality requirements and with no access control. Group C has a high requirement for Message Confidentiality and Liability Identification.

*Technical aspect 5 – location accuracy* VANET applications require different levels of accuracy regarding location. Some applications can work with errors from 10 to 30 meters, while others, for example security distance warnings, require errors to be lower than 1 meter.

The most common solution is the Global Positioning System (GPS); however, it is not always available. A variant of GPS is Differential GPS, which calculates position with a known physical one. Map-matching techniques combine road databases with the actual position of a vehicle. It is able to estimate a trajectory by obtaining several position changes periodically. Dead reckoning calculates current position by knowing the initial position and data such as speed, acceleration, time, distance or direction. According to [15], in 30 seconds, at a speed of 100 km/h, the accumulated positioning error will be from 20 to 30 meters. In [8], a data-fusion technique calculates the lane in which a vehicle is driving using neighbouring messages.

We propose a differential GPS solution for Groups A and B, and data fusion techniques for Groups D and F. The applications of Group C can rely on the location information provided by the local infrastructure. Finally, we propose to combine GPS and map-matching techniques for Group E.

#### 4. Network node density impact

When facing the design of VANET applications, it is necessary to consider all the technical aspects (see Section 3) involved in the context where the application will be used.

Moreover, before the implementation and deployment of any technology it is important to know where the problematic intersections are, what times of day are more or less busy, what the traffic major flows are, etc.

We will focus on technical aspect 2 (routing), which means analyzing the kind of traffic, vehicle density, the type of road, speed of vehicles, etc. Specifically, we look in depth into how node density affects routing.

The VANET application design should consider on one hand that in urban roadway conditions, the number of vehicles is usually high, the inter-vehicle spacing is small, and a fixed communication infrastructure is available. However, in this case, a very high traffic density can saturate the network very easily. Authors in [20] analyze VANET routing in high node density conditions.

On the other hand, if the node density is very low, then inter-vehicle spacing can be large. There is very little or no fixed communication infrastructure available. A combination of low node density and high node mobility message forwarding could make VANET communication impossible. In [17] there is a range of VANET routing protocols for low density rural areas and for describing their associated limitations.

In [21] authors find that protocols based on topology, such as Advanced Adaptive Gossiping, and Multi-Point Relaying tend to have a decreasing retransmission efficiency as the node density increases, indicating they scale poorly with node density. Stochastic broadcast and the distance methods have thresholds that are set directly by node density.

Our simulation model determines the routing protocol that may affect the VANET application design.

The model is based on the vehicular density of an urban environment at a given moment.

In the validation of the proposed models, we have employed a connection between a vehicle traffic simulator and a wireless network simulator.

The vehicle traffic simulator allows us to simulate under controlled conditions the traffic with different programmable parameters, such as the displacement velocity of the vehicles, the time that traffic lights are active, traces of the vehicles' position within the scenario, etc. In addition, we can change traffic flow density at some points, and in consequence we can observe how the propagation of these conditions affects the traffic in other places in our scenario. In order to capture near real-world traffic behaviour, the simulated car rate follows traffic measurements that we have gathered at five conflicting points in the



Fig. 2. City map of Xalapa, México.

1. The initial collection time was established.
2. The program was executed to acquire data during a period of 5 minutes.
3. The program stopped for a delay period of 5 minutes.
4. The sequence was repeated as from step 1.

Listing 1. Procedure for collecting traffic data.

streets and avenues of Xalapa de Enríquez city, see Fig. 2, by use of an acoustic sensor, (see in the next section the details of this sensor implementation), and finally by putting car traffic estimations into the wireless network simulator via a socket connection. In particular, the streets under consideration and their main features are:

**Juan de la Luz Enríquez:** A one-way avenue in the centre of Xalapa city that traverses it from east to west.

**Manuel Ávila Camacho:** Also a one-way street running from east to west, with a very busy intersection that affects the rest of the city traffic.

**Miguel Hidalgo:** A one-way street that allows drivers to leave from the center towards the south.

**Rafael Murillo:** A two-way main road, its car flow is a continuation of Juan de la Luz Enríquez Street.

**Venustiano Carranza:** A two-way street that runs from east to west and vice-versa. It has a bridge which allows only one line of cars to cross at a time. There is a traffic light that controls the direction of flow over the bridge. This is a conflicting point that can cause heavy traffic jams when the traffic is heavy, which can extend along adjacent streets.

Over one week, three times a day, we systematically collected traffic data (see the procedure in Listing 1). The sensor data consists of sets of continuous traffic readings of five minutes. In the case of the conflicting intersections, we recorded the traffic readings on the adjacent streets by counting the car flow contributions at each branch of the intersection. In the case of the two-ways street, we deployed one sensor for each lane. In all the cases, the wireless

nodes were synchronized so that all the sensors started and finished the collection of traffic data at exactly the same time.

The wireless network simulator allows us to simulate the adapting wireless routing protocol behaviour according to the conditions of the scenario under study; for instance the protocol can be switched into a specific mode when the observed car traffic density changes to a determined specific distribution, or when the wireless communication Quality of Service (QoS) scales up or down to a certain pre-programmed value, at packet level or received signal strength indicator (RSSI) figures for example. In fact, this last mentioned feature can only be handled by a simulator that implements any sort of loss wireless communication propagation model.

The next section shows the technology used to detect the number of stationary vehicles with their engine on, the number of vehicles driving individually, with no traffic surrounding them, and the number of times that vehicles drives in a traffic flow.

#### 4.1. Acoustic sensor signal processing

In this section we provide technical details about the implementation of our system to detect the density of vehicles within urban environments. The system utilizes car engine sounds to determine the occurrence of three movement events: A single car passing, a stationary car, and a flow of cars moving along the street. Roughly, the system is made up of four modules: Filtering, signal energy computing, event detection, and car counting [22–24].

Our experimentation procedure followed an incremental approach; therefore, in order to achieve predictability of the system module's behaviour; we carried out the experiment's trials on a portable computer with a microphone attached; we collected car engine sounds of the car movement events previously mentioned and recorded them onto the computer hard drive. In order to process the signal sounds with signal processing algorithms at different resolution degrees, we collected the sound signals at the highest performance rates permitted by the computer hardware. The sound recordings were ten seconds, the samples were 16-bits, and the sounds were acquired at a data rate of 44100 samples per second. We started the experiment by feeding the filtering stage with the recorded sound signals; output was passed to the signal energy module. Afterwards, we adjusted the parameters of the event detection module, whose output fed into the car counting module. In Figs 3, 4,

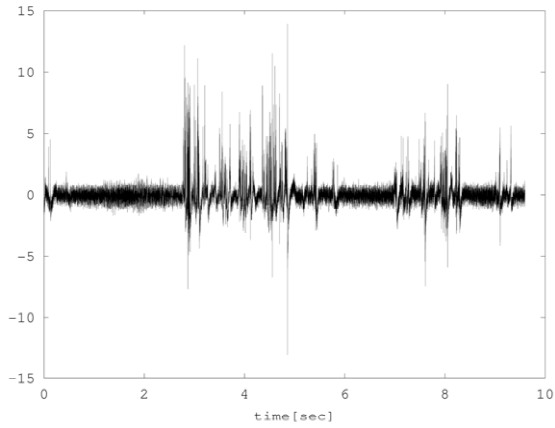


Fig. 3. Raw acoustic signal of one single car moving along a street.

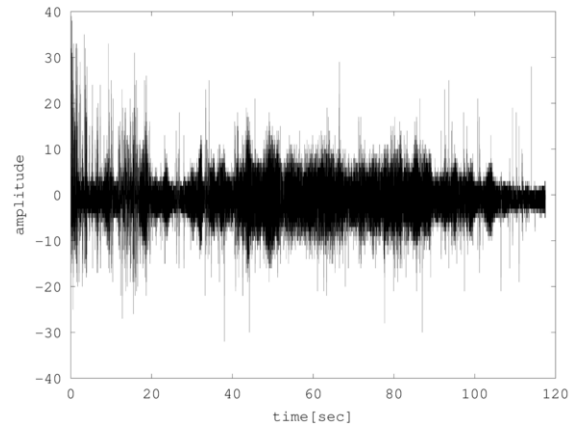


Fig. 5. Raw acoustic signal of vehicles moving along a street.

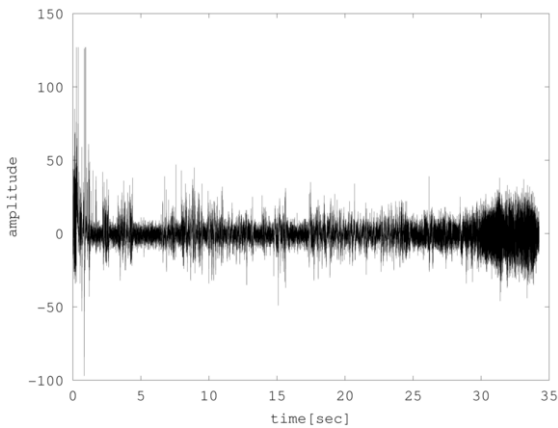


Fig. 4. Raw acoustic signal of one stationary car.

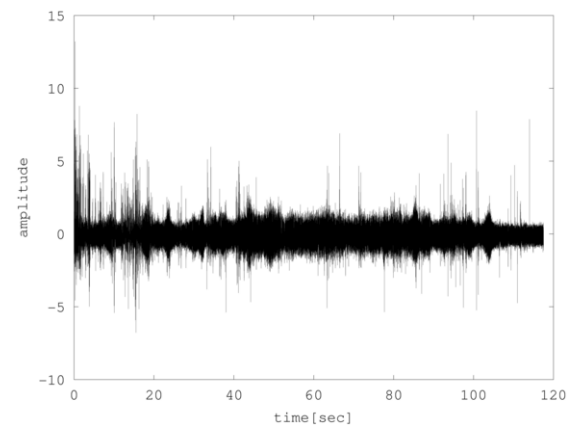


Fig. 6. Filtered acoustic signal vehicles moving down the street.

and 5 respectively are plotted recordings of the car events: one single car passing, one stationary car, and one flow of cars moving along a street.

In the filtering stage, the sound signal was processed by a 40-tap Hamming band pass filter. Essentially, the purpose of the filter was to reject the signal frequencies that did not belong to the car engine sounds, which were acoustic signals within the range of the 50 Hz and 5 KHz band frequency; this filter implementation was realized by the use of the following relationship:

$$y_k = b_0 s_k + b_1 s_{k-1} + \dots + b_N s_{k-N}$$

where  $y_k$  is the filter output,  $\{b_0, b_1, \dots, b_N\}$  is the filter taps set and  $\{s_k, s_{k-1}, \dots, s_{k-N}\}$  is a  $N+1$  length vector of the acoustic input samples  $s_k$ . Figure 6 shows the vehicles moving along a street signal filtered by our filter implementation.

To compute the vehicles' signal energy we use the next relationship [22]:

$$e_k = |s_k - \langle s_k \rangle|$$

where  $s_k$  is the current sound sample and  $\langle s_k \rangle$  is the current estimated average value of the sound signal. In the case of an embedded computer, this representation is more convenient because the settling of any threshold or the searching of outliers in the signal avoids the implementation of complex zero crossing algorithms and occurs in the analysis of only positive numbers. Figure 7 shows the computation of the signal energy of the acoustic signal of vehicles moving along a street.

In our implementation each one of the deployed wireless nodes sensed the sound signals while looking in the sound signal energy for subsets that contained substantial variations that we called events,

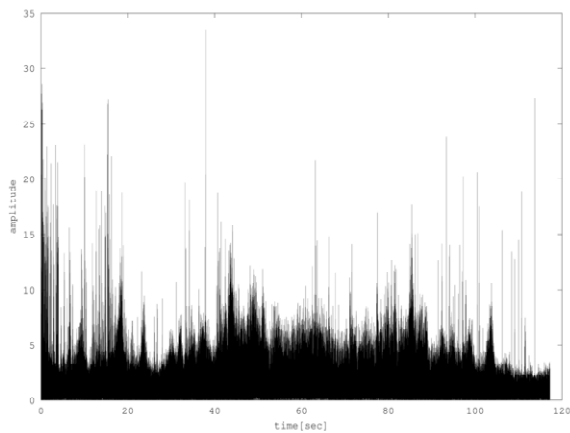


Fig. 7. Signal energy from the signal vehicles flowing along a street.

and that our algorithm related to one of the states of the car engine signals recorded at the recollection procedure. From a distributed system approach, the computation of events locally was more efficient than the transmission to a central host, because this can significantly reduce the number of data transmissions by up to 90% [21].

In the literature there have been reported a large number of event computing algorithms [22,23]. In [24] it was shown that in many cases the scenario strongly determines the selection of the event computing procedure, which can lead to better outcomes. In particular it was shown that in a one-car counting system the threshold-based algorithms work more effectively than standard deviation rate algorithms [22,23]. In the threshold approach two amounts were computed, a signal energy reference and an outlier, which were intensively analyzed one against the other to get an estimation of the occurrence of vehicle presence; in particular we observed the behaviour of the following energy reference and outlier values: 1) energy average and the energy standard deviation, and 2) energy average and the energy variance. In Fig. 8 are shown the computations of the average and variance values of the sound signal energy of the one car moving along a street signal. In Fig. 9 are plotted the computations of the sound signal energy average and standard deviation values of the one car moving along a street signal.

From Figs 8 and 9 we observe that in some places the sound energy average stands below the both the variance and standard deviation values when there are no significant changes in signal energy. More specifically, in the first case, see Fig. 8, we can observe that the signal energy average values are al-

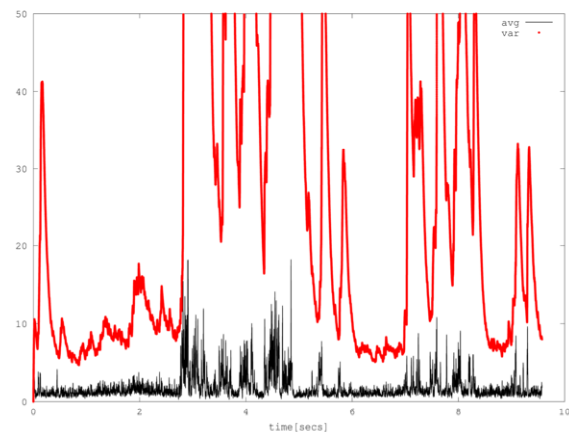


Fig. 8. The energy average vs. energy variance.

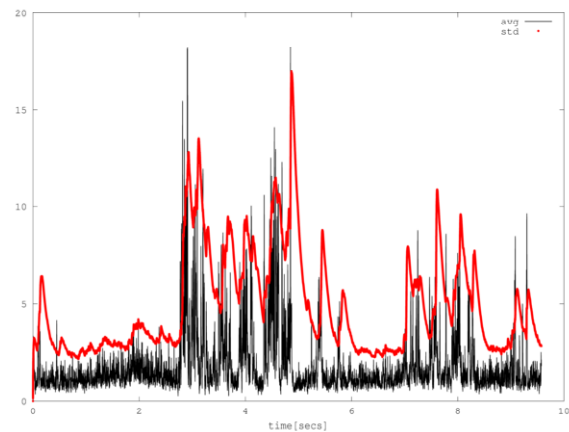


Fig. 9. The energy average vs. energy standard deviation computations.

ways kept below the energy variance even when significant changes are observed in the energy average estimations. Whereas in the case presented in Fig. 9, when the signal energy changes little, there are observed some crossovers between the energy average and the standard deviation estimations, which are due principally to ambient noise. On the other hand, we can see a large number of crossovers when the changes of the energy average are present, as seen in Fig. 10, where it is shown that all the energy average crossovers observed occur within ten-second time periods.

In this manner, we adopted the number of times the energy average crossed the energy standard deviation within a given time interval as the car detection criteria.

At this point, the problem was to program the detector time interval that achieved the highest number

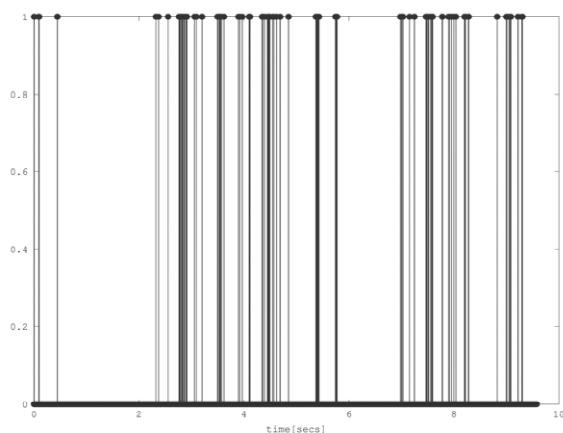


Fig. 10. All detected crosses.

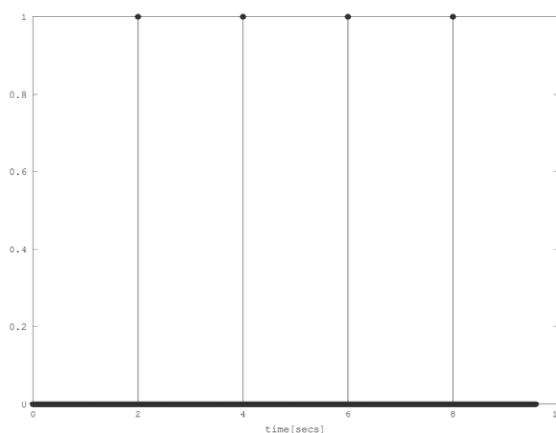


Fig. 12. Two-second window detection.

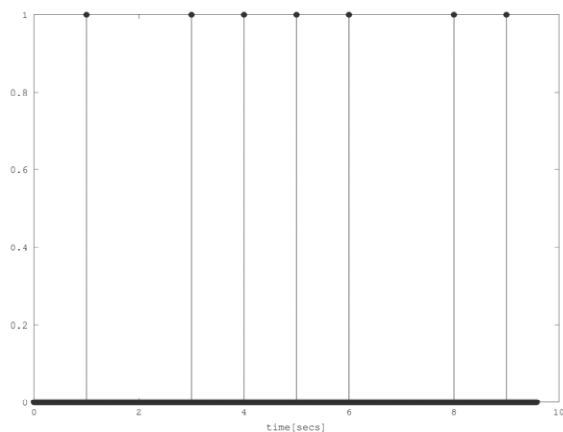


Fig. 11. One-second window detection.

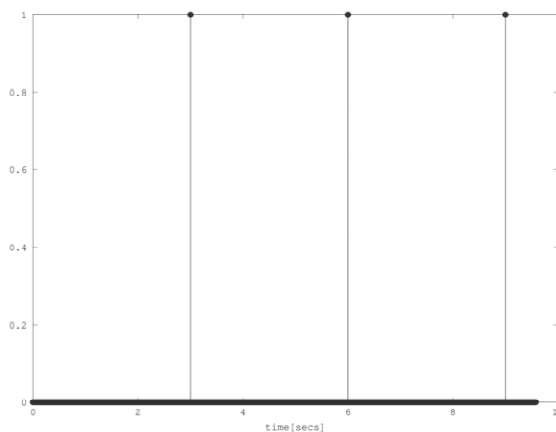


Fig. 13. Three-second window detection.

of positive car detections and the minimum number of false detections. We followed an incremental approach in the following manner: An initial time interval was set, running the event detector and registering the number of detections observed. Whenever the number of detections observed was far from the actual number of vehicles expected for the car movement event under consideration, then the time interval was adjusted, widening or reducing it, depending on the output observed from the event detection module, and the event detector operations were repeated. For instance, in Fig. 11 we observe detections issued by the sensor when the system was fed with a signal from one single car moving. In particular, the crossover number was fixed to a value of  $20 \leq \text{detection\_number} \leq 200$  times within a time period of one second. In this case, we counted ten one-second time periods and seven car detections

where most of the detections happened within a two to seven-second period.

In Figs 12–15, the computed detections are plotted for time windows of two, three, four, and five seconds respectively. In Fig. 12, there are five windows of two seconds and the algorithm issued four detections. Figure 13 shows that there were three windows of three seconds and the detector reported three cars observed. In the case of Fig. 14 there were two windows of four seconds, and the event detector sensed two car occurrences. Finally, in Fig. 15, there is shown two five-second windows, and the detector reported the presence of one car.

From the outcomes observed for the case of a single car moving, we can see that the five-second time window enabled the best performance of the vehicle detector. However, it should be observed that the limitations of the system car detector were



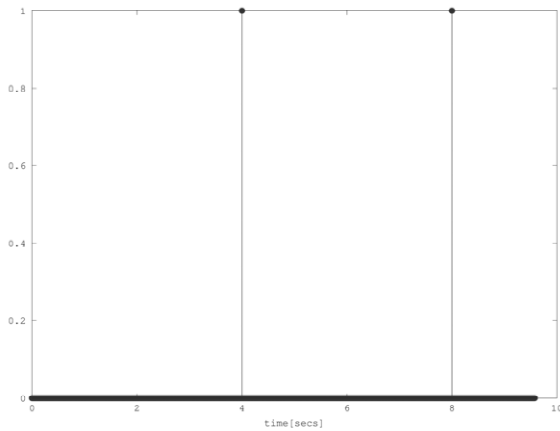


Fig. 14. Four-second window detection.

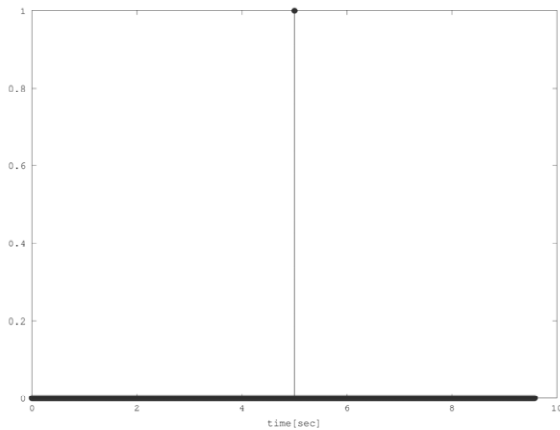


Fig. 15. Five-second window detection.

constrained to the car speeds and the distance between the advancing cars. In fact, if two adjacent nodes were separated by a distance of 400 meters, the maximum speed a car could still be observed by the nodes was around 299.33 km/h. On the other hand, within an interval of five seconds a car could advance around 25 meters at a velocity of 19.95 km/h, which is the system where vehicles could be observed which were separated by a minimum distance of around 12.5 meters.

The car counter module computed sums and statistics, such as the variance and standard deviation, of all the car detector module outputs. The car counter module could be programmed to compute the figures of the car traffic behaviour for fixed periodic time intervals, such as seconds, minutes or hours, according to the car detector module computing time window's minimum computing time period. Rather than the granularity of the traffic estimations being in the

```

if(0 < tk < time_window)
    current_cars_number +=
    current_detector_value;
else
{
    transmit(current_cars_number,
    cars_number_avg,current_cars_number_
    variance);
    clean_variables(tk,current_cars_
    number, current_detector_value);
}

```

Where:

$t_k$  is the current time instant

current\_cars\_number is the accumulated value of the observed vehicles within the time window,

current\_detector\_value is the car detector module output and is a number that can take only one of two values {0, 1},

current\_cars\_number\_avg is the average number of computed cars per time window,

current\_cars\_number\_variance is the variance number computed per time window.

Listing 2. Car counter algorithm.

order of seconds, better estimations could be obtained if the counter module ran estimations for extended time periods, for instance of one hour or more. The algorithm of this procedure is illustrated in Listing 2.

At the end of the procedure shown in Listing 2, the next variables are cleared, and the procedure starts again.

Variables:

```

current_cars_number
current_cars_number_avg
current_cars_number_variance
current_detector_value

```

$t_k$

It should be noted that within a long enough time period, the reported partial sums provided information about the car traffic density probability histograms. In fact, the sum outcomes can be considered as the density probability maximums multiplied by a certain normalization factor and the bin wide is the time window the car counting system ran freely, the car detection module with a five-second time window being the minimum function density bin wide.

For instance, the expected normalized distribution of the traffic in a jammed street can be like the one shown in Fig. 16, which is the density probability observed within one hour for a time window, a bin wide of five minutes.

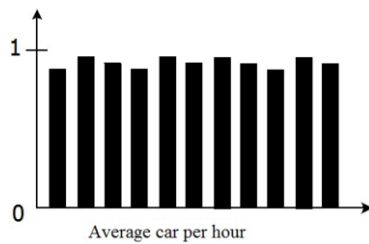


Figure 16. Weighted vehicle traffic density probability of an avenue with heavy traffic.

Finally, the car traffic estimations were transmitted wirelessly travelling in a multi-hop fashion along the nodes in the WSN and delivered to a data collector.

The next section explains the simulation scenario of the five selected streets from Xalapa city in México, which we mentioned in at the beginning of Section 4.

#### 4.2. Traffic simulation and density extrapolation

There are two main types of traffic simulation: Microscopic and macroscopic, which are related to the depth of analysis to be performed. The microscopic simulation is the movement of each vehicle individually, requiring a large amount of data and computational resources, such as memory, computing power, storage units of data, and so on. This type of simulation provides results that give a detailed picture of network performance and sensitivity of the system to specific changes in traffic.

Whereas a macroscopic simulation is based on traffic analysis from a global perspective, where traffic is considered continuous and its application is essentially in urban planning.

In order to generate the simulation scenario (street map) and the vehicular mobility patterns we used the Mobility model generator for Vehicular networks (MOVE), which uses an open-source micro-traffic simulator called SUMO (Simulation of Urban Mobility) [25] for simulating our traffic scenario. In this way, we have been able to simulate realistic vehicular movements such as traffic jams and stops at intersections. We configured the scenario based on the five streets selected in Xalapa city, México, and we considered different traffic densities to enrich the SUMO simulation. SUMO generates an output file with vehicular mobility traces. This file was put into the network simulator NS-2 [26] to obtain the final simulation results. We configured the maximum speed of the vehicles as limited to 50 km/h. The transmission range was fixed at 150 meters.

After a simulation from 9:30 to 11:30 (120 minutes, with 24 time intervals of 5 seconds) on Venustiano Carranza Street, we counted 29 vehicles, which meant 0.24 vehicles per second.

Density factor is one of the elements that most affects the good performance of VANET routing protocols. So, this research is proposing the VANET application design with a dynamic change of routing protocols according to traffic density changes. The next section explains how we propose to carry out the dynamic election of the protocols.

#### 4.3. Dynamic election of the routing protocols

Several environmental factors have an effect on the communication performance of routing protocols. In urban areas, one of the most important factors is the density of vehicles. It generally depends on the hour, and may change accidentally. If vehicle density is too high (traffic jams) then nodes are too crowded in the network, hops between them would cause redundancy, increase the network overhead, and also create the possibility of causing load imbalance. On the other hand, low traffic density could make difficult to establish a network connection.

Thus, aspect 2 (Section 3.2) for VANET application design has to take dynamic changes in road traffic conditions into consideration, including vehicle density.

This section analyzes how the vehicle node density affects the selection of the routing protocol. The proposal of this research is not only to compensate for different levels of vehicle density in reconfiguring the routing protocols, we also propose to switch dynamically between different routing protocols when the vehicle density changes.

The five selected streets in Xalapa have highly variable vehicle densities, which depend on the time of day or night. We defined three main time intervals:

Time Interval<sub>1</sub>: From 00:00 hrs to 06:00 hrs

Time Interval<sub>2</sub>: From 06:00 hrs to 07:30 hrs, from 09:30 hrs to 13:00 hrs and from 18:30 hrs to 00:00 hrs

Time Interval<sub>3</sub>: From 07:30 hrs to 9:30 hrs and from 13:00 hrs to 18:30 hrs

We discarded the use of protocols such as the Urban Multi-Hop Broadcast protocol that does not work well in urban environments with very low density. This kind of protocols requires each node to rebroadcast messages to all of its neighbours, and if there are no vehicles within transmission range, then

neighbours cannot be found to maintain the seamless connectivity of the network. Such protocols require flooding the work with a very high density because the bandwidth requested for one broadcast message transmission can increase exponentially.

We have also ruled out protocols that have low communication throughput and are inefficient in quickly finding and maintaining routes in VANETs environments such as: The Ad-hoc On-demand Distance Vector, and the Dynamic Source Routing. Likewise, cluster-based routing protocols such as Clustering for Open IVC Networks did not work well. These kinds of protocols can achieve good scalability for large networks, but have some problems in fast-changing VANET systems due to the delays and overheads involved in forming and maintaining these clusters.

Since our scenario simulated streets in an urban environment, we also discarded protocols such as the Broadcomm protocol that was designed for highway networks.

In order to design VANET applications such as cooperative crossing at intersections, the possible protocols to be used in the five analyzed streets are:

*High density:* The Greedy Perimeter Coordination Routing works with street maps. In this protocol street crossings are the only points where packets are forwarded. This protocol is useful in urban environments with high vehicles densities. The Anchor-based Street and Traffic Aware Routing uses a street map to compute the sequence of street crossings while incorporating traffic awareness.

*Low density:* The Greedy Perimeter Stateless Routing bases forward decisions on location information. It combines the Greedy Routing with Face Routing by using the Face Routing to avoid the local minimum where Greedy fails. This kind of protocol works best with low vehicle densities, but a minimum number of vehicles is necessary to be able to do Face Routing. In high densities this protocol can induce routing loops for Face Routing. History-enhanced Vector-based TRACKing Detection is a message broadcasting protocol based on position and movement information. This protocol has routing overhead, as long as the forwarding nodes are selected in every hop.

The next protocols support high and low vehicle densities: Geographic Source Routing assumes the aid of a static street map. It combines Geographic Routing and topological knowledge from street maps.

Abiding geocasts is where the packets need to be delivered to all nodes that are at some time

```

Static void protocol (s, d, p, RDi, ITj)
{
  if (s, d ∈ range de transmission)
  {
    ACCESS-ROUTING-PHASE (s,d)
    SEND (p)
  }
  else
    WAITING-ROUTING-PHASE (s,d,
    p)DENSITY RDi = (current_cars_
    number_avg/time intervalj)
  While (DENSITY RDi > 0,5)
  //high density, more than 60 vehicles per
  //hour at //a specific point
  Apply (Greedy Perimeter Coordination Routing
  // Anchor-based Street_Traffic Aware Routing)

  While (DENSITY RDi <= 0,25)
  //low density, less than 30 vehicles per hour
  //at a/specific point
  Apply (Greedy Perimeter Stateless Routing,
  History-enhanced Vector-based TRACKing)

  Where
  s = source, d = destination, p = packet
  RDi street distance, where
  i = 1. Juan de la Luz Enriquez: 0.4 km
  i = 2. Manuel Ávila Camacho: 2.4 Km
  i = 3. Miguel Hidalgo: 0.56 km
  i = 4. Rafael Murillo: 1.33 km
  i = 5. Venustiano Carranza: 0.7 Km
  ITj time interval, where
  j = 1. 00:00 to 06:00
  j = 2. 06:00 to 07:30, 09:30 to 13:00,
  18:30 to 00:00
  j = 3. 07:30 to 09:30, 13:00 to 18:30

```

Listing 3. Dynamic election of routing protocols according to vehicle density changes.

during their lifetime inside the geocast destination region.

Most papers focus on how to modify existing protocols to better fit a VANET. We do not change the protocol configuration in order to solve the problem of continuous changes on traffic density. However we propose to design VANET applications based on a dynamic election of routing protocols according the changes on traffic density.

Our dynamic selection algorithm explains how to change of routing protocols in the five analyzed streets. The algorithm is illustrated in Listing 3.

## 5. Conclusions

This research focuses on which protocols and technologies would best fit VANET applications. We discussed the advantages and shortcomings of the

different alternatives of five main technical aspects (transmission, routing, quality of service, security and location), which are very significant to VANETs, and differential from Ad-Hoc Networks. The analysis was extended to six different groups of VANET applications (Life-Critical Safety Applications, Safety Warning, Electronic Toll Collection, Internet Access, Group Communication and RSU Service Finder). The best alternatives for each pair (technical aspect and application type) were suggested. The analysis demonstrated that a third dimension to the study became necessary: The environmental conditions. The paper extended the research in one topic that directly affects routing: Network node density.

Network node density is the number of vehicles driving concurrently on a road. It has a great impact on the performance of VANET networks by influencing factors such as capacity, routing efficiency, delays, and robustness. Using a practical approach, we analyzed traffic densities via a two-way methodology; 1) we computed densities from actual traffic data provided by an acoustic sensor network with nodes deployed at few locations in an urban scenario in the Xalapa municipality, 2) we employed the computed local densities to feed an urban traffic simulator extending the density data to neighboring streets. With the proposed method we were able to classify the traffic density on three levels with a high reliability. It was shown that the performance results of the acoustic detectors came from identifying car sounds such as: A stationary car, a single car that was moving and a flow of cars moving.

With factor density, making decisions about the best routing protocol to use in a VANET application becomes an easy configuration parameter that allows the dynamic change of routing protocol when vehicle density changes.

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