

Smart city for VANETs using warning messages, traffic statistics and intelligent traffic lights

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Abstract—Road safety has become a main issue for governments and car manufacturers in the last twenty years. The development of new vehicular technologies has favoured companies, researchers and institutions to focus their efforts on improving road safety. During the last decades, the evolution of wireless technologies has allowed researchers to design communication systems where vehicles participate in the communication networks. Thus, new types of networks, such as Vehicular Ad Hoc Networks (VANETs), have been created to facilitate communication between vehicles themselves and between vehicles and infrastructure. New concepts where vehicular networks play an important role have appeared the last years, such as smart cities and living labs [1]. Smart cities include intelligent traffic management in which data from the TIC (Traffic Information Centre) infrastructures could be reachable at any point. To test the possibilities of these future cities, living labs (cities in which new designed systems can be tested in real conditions) have been created all over Europe. The goal of our framework is to transmit information about the traffic conditions to help the driver (or the vehicle itself) take adequate decisions. In this work, the development of a warning system composed of Intelligent Traffic Lights (ITLs) that provides information to drivers about traffic density and weather conditions in the streets of a city is proposed and evaluated through simulations.

Index Terms—Vehicular Ad Hoc Networks (VANETs), Traffic Information Centre (TIC), Smart Cities, Intelligent Transportation System (ITS).

I. INTRODUCTION

During the last few years, progress in wireless communications has offered new research fields, providing network connectivity in environments where wired solutions are impossible. Among these, vehicular ad hoc networks (VANETs) are attracting a growing attention due to the promising important applications, from road safety to traffic control and entertainment for passengers. Smart cities would like to plan how to minimize their transportation problems due to the increasing population that produces congested roads. VANETs aim at helping to alleviate this issue improving vehicles' mobility, increasing road safety and also seeking to have more sustainable cities.

At the beginning of the development of vehicular technologies, the main goal was to have more efficient and safer roads. Nowadays, thanks to the huge development of wireless technologies and their application in vehicles, it is possible to use Intelligent Transportation System (ITS) that will change our way to drive, improve road safety, and help

emergency services. VANETs may soon allow vehicles to easily communicate among themselves and also with fixed infrastructure. This will not only improve road safety, but also raise new commercial opportunities such as infotainment for passengers.

Car accident prevention, safer roads, pollution and congestion reduction are some of the goals of VANETs. The deployment of an efficient system to manage warning messages in VANETs has important benefits, from the perspective of both road operators and drivers. Efficient traffic alerts and updated information about traffic incidents will reduce traffic jams, increase road safety and improve the driving in the city. Furthermore, from the sustainable and economic perspective, real-time traffic alerting will reduce trip time and fuel consumption and therefore decrease the amount of CO₂ emissions [2].

In this work, a smart city framework has been developed in where intelligent traffic lights (ITLs) set in the crossroads of a city are involved. These ITLs are in charge of gathering traffic information (e.g. traffic density) from passing vehicles, updating traffic statistics of the city and reporting those statistics to the vehicles. Also, ITLs will send warning messages to vehicles in case of accidents to avoid further collisions.

The rest of the paper is organized as follows. Section II gives a state of the art of some relevant works of VANETs using ITS. Section III introduces our smart city framework. Section IV presents our proposal to calculate the vehicles' density in the city using ITLs. Section V summarizes our proposed scheme of warning messages. Section VI shows simulation results. Finally, section VII gives conclusions and future work.

II. STATE OF THE ART

During the last decades, Intelligent Transportation Systems (ITS) have emerged as an efficient way to improve the performance of the flow of vehicles in the roads. The goals of ITLs are road safety, comfortable driving and distribution of updated information about the roads. Many proposals about ITS have been presented in recent years. In this section some works about ITS in smart cities are highlighted.

The work in [3] is a survey about multifunctional data-driven intelligent transportation system (D²ITS), which are supported by a large amount of data collected from various resources: Vision-Driven ITS (input data collected from video

sensors and used recognition including vehicle and pedestrian detection); Multisource-Driven ITS (e.g. inductive-loop detectors, laser radar and GPS); Learning-Driven ITS (effective prediction of the occurrence of accidents to enhance the safety of pedestrians by reducing the impact of vehicle collision); and Visualization-Driven ITS (to help decision makers quickly identify abnormal traffic patterns and accordingly take necessary measures).

In [4] and [5] two adaptive traffic light systems based on wireless between vehicles and fixed controller nodes deployed at intersections are designed and developed. These systems improve traffic fluency, reduce the waiting time of vehicles at intersections and help to avoid collisions.

The e-NOTIFY [6] system was designed for automated accident detection, reporting to the Emergencies Coordination Center, and assistance of road accidents using the capabilities offered by vehicular communication technologies. e-NOTIFY focus on improving post collision care with a fast and efficient management of the available emergency resources, which increases the chances of recovery and survival for those injured in traffic accidents.

In this work, we focus on the development of a smart city framework using intelligent infrastructure in the streets, in our case intelligent traffic lights (ITLs). ITLs provide warning messages to the passing vehicles to inform drivers about traffic and weather conditions of the different streets of the city. This way, the smart city framework can help drivers to have a better trip, reducing time to destination, preventing accidents and traffic jams and also saving petrol and reducing pollution. As [3], our proposal manages traffic information seeking to avoid accidents, although the information here is gathered from the vehicles themselves so no further infrastructure is needed. Also our proposal could easily be used by the traffic information centre to design an adaptive traffic light system similar to [4] and [5].

III. SMART CITY FRAMEWORK

The smart city framework we have designed includes ITLs set in some of the crossroads. These ITLs collect real-time traffic data from the passing vehicles and calculate traffic statistics such as traffic density in the adjacent streets (between consecutive crossroads). At the same time, these ITLs can communicate the traffic information to passing vehicles and alert them with warning messages in case of accidents. These ITLs also form a sub-network that allows ITLs to share the collected information and calculate statistics of the whole city. Thus, vehicles are well informed of the traffic situation in the city. The following sections describe how this smart city framework is designed and which use the ITL will have.

In the smart city projected, blocks have a regular square design and buildings on its four sides. ITLs are responsible of managing the traffic of the vehicles, which form a VANET. These ITLs do not have to be located at each intersection. Within all the traffic lights that are traditionally located in a city, only a few will be replaced by ITLs. This is because each ITL covers a whole intersection and the 4 streets that

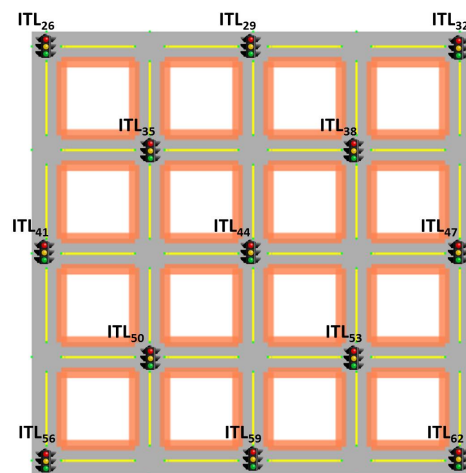


Fig. 1. Intelligent Traffic Lights distribution

converge on this intersection. ITLs are placed as shown in Fig. 1. To cover all this area the antenna pattern used is an omnidirectional propagation pattern. Therefore, each ITL receives data from all passing vehicles on its cover range (the four streets and the intersection). Not having an ITL on each intersection is more economic when implementing this framework.

It is assumed that vehicles have a global positioning system (GPS) device, a driver assistant device, full map information of the city including the position of the ITLs. Thus, vehicles can easily select which is the nearest ITL.

Every ad-hoc node (i.e., ITLs and vehicles) set on the scenario was configured with Ad hoc On-Demand Distance Vector (AODV) [8] routing protocol. AODV was selected because of its simplicity. Although it is well known that AODV is not suitable as routing protocol of general use in VANETs, there are some applications that might work well with AODV. The advantage of AODV is its simplicity and widespread use. The main drawback is that AODV needs end-to-end paths for data forwarding, which is difficult to handle because in VANETs end-to-end paths last not much due to high speeds of vehicles. Other routing protocols that use other strategies like greedy forwarding and geographical routing. For instance, GPSR (Greedy Perimeter Stateless Routing) [9] and GOSR (Geographical Opportunistic Source Routing) [10] have shown good performance in VANETs, but at the cost of greater complexity and increased delay. Nonetheless, for some applications that require a short delay AODV can perform well. In this paper we are considering smart city services where vehicles send warning messages (weather conditions and traffic density) to the closest ITL, so it is not necessary to establish long paths that last long. Instead, vehicles need to establish very short paths (1-2 hops) to the nearest ITL. Besides, the communication must be quickly since vehicles move fast and the period in coverage range of the ITL is short. Thus, AODV is suitable for our purposes.

TABLE I
FORMAT INFORMATION OF MESSAGE STAT

Type	Statistic Message (SM)	STAT
<i>stat_type</i>	Traffic density (TD_{st})	0
<i>stat_my_id</i>	Car sending statistics	C_i
<i>stat_neighbours</i>	Number of neighbours (NoN)	NoN_i
<i>stat_time</i>	Time of statistics report	t_i
<i>stat_dst</i>	ITL IP address	ITL_i

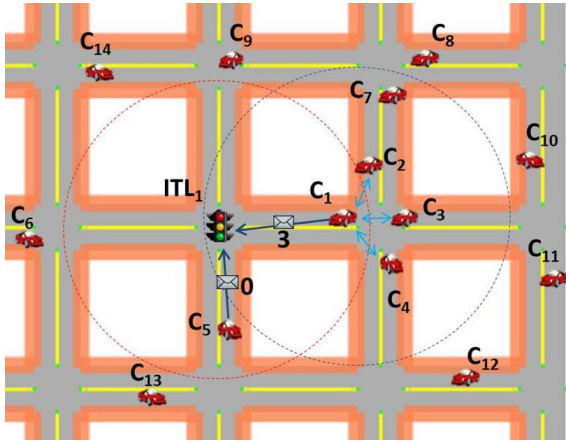


Fig. 2. ITL obtaining traffic statistics in its intersection

IV. MANAGEMENT OF TRAFFIC DENSITY

In this work we focus on the analysis of traffic density, although similar analysis could easily be done for other traffic statistics (e.g. number of passengers, trip time).

The messages sent by each vehicle to an ITL include the type of message (a new message called Statistic Message, SM), the identification of the vehicle (C_i) sending the message, the current value of the number of neighbours (NoN_i) in its coverage range at that moment, the moment in which the message was sent (t_i) and the IP address of the ITL destination (ITL_i). This message is sent by the vehicles each 2 sec. This way, a car ($v=40$ km/h) sends 5 messages while it crosses a 100 m. street. The format of this message is shown in Table I. The ITL will update the traffic statistics upon the reception of each new message, as it is explained below.

Fig. 2 shows the procedure of getting and sending traffic statistics from the vehicles to the ITLs. Each vehicle interchanges hello messages (HM) with its neighbours and this way it knows the amount of vehicles on its transmission range. Then, the vehicle sends a Statistic Message (SM) with the number of neighbours to the nearest ITL. For example, C_1 counts with three neighbours (C_2 , C_3 , and C_4). Notice that although C_7 is inside its range they cannot establish any communication because of the buildings that represent obstacles. The car C_5 does not see any neighbour around so it sends a SM to the nearest ITL with a zero on it.

ITL_1 will receive the SMs and will update the traffic density statistics by using an exponential weighted moving average (EWMA) to average current and historical values. Then, ITL_1 will store the results properly and will share its statistics

with the others ITLs in the city through the sub-network they form. The day has been divided into five periods due to the usually variable traffic densities in a city throughout the day. Thus, every ITL updates the traffic density per periods: $TDst_{6-9}$, $TDst_{9-12}$, $TDst_{12-15}$, $TDst_{15-18}$, $TDst_{18-21}$. For instance, $TDst_{6-9}$ gathers the average traffic density in the city, during week days, from 06:00 AM to 09:00 PM. The value $TDst_{6-9}$ will continuously be updated using Eq. (1), where w is a small weight (e.g. $w=0.25$) to smooth out isolated deviations, $\overline{TDst}_{6-9,i}$ is the updated average in iteration i and $TDst_{6-9}$ is the last value received by that ITL. The same computation will be done for the other periods of the day.

$$\overline{TDst}_{6-9,i} = w \cdot \overline{TDst}_{6-9,i-1} + (1 - w) \cdot TDst_{6-9} \quad (1)$$

The ITLs of the city share that traffic information and after that, each ITL will send back to each passing vehicle a message with the updated traffic statistics of the city on that period of time. With this information, the driver's assistant device can take proper trip decisions (e.g. avoiding congested roads). Also, data routing protocols may use that information to take suitable forwarding decisions (e.g. forward the packet through denser streets where there are more possible forwarding nodes).





V. MANAGEMENT OF WARNING MESSAGES

In the promising smart cities of near future, communications between vehicles and the city will be constant, including infrastructure-to-infrastructure, car-to-car and infrastructure-to-car communications, by means of city infrastructure and Traffic Information Centres (TICs). These packets will contain different type of information and should be prioritized accordingly. For instance, packets containing information about an accident have to be prioritized over those containing other kind of data such as entertainment data.

Upon the reception of a warning message, a vehicle should consider its current distance to the initial source of the warning message and act consequently. For instance, a car being a long distance away from an accident will not act the same way (i.e., will not brake) when receiving a warning about the accident since it does not affect the immediate security of that car. Nonetheless, that warning message will inform the driver of that car (actually, the driver's assistant device), who may vary the trip plan consequently.

We have implemented a simple warning service to prevent further collisions by alerting drivers about accidents and dangerous road conditions. To achieve that goal, vehicles send short warning messages once one of the situations depicted in Table II has been detected. This information can be obtained from different sources. Regarding weather, data can be collected by a Wireless Sensor Network (WSN) that periodically transmits the weather conditions to the nearest ITL. Also, from small weather stations set in a few ITLs of the city. This information is spread through the city using

TABLE II
WARNING MESSAGES: TRAFFIC AND WEATHER CONDITIONS

Traffic density (2-bit)	Weather (2-bit)	Warning message: reduce speed
Free road segment 	Sun	U
	Rain	85% · U
	Storm	65% · U
	Ice	40% · U
Semi-congested road segment 	Sun	75% · U
	Rain	50% · U
	Storm	25% · U
	Ice	10% · U
Very congested road segment 	Sun	50% · U
	Rain	40% · U
	Storm	30% · U
	Ice	10% · U
Accident 	Sun	0
	Rain	0
	Storm	0
	Ice	0

U: Initial driver speed

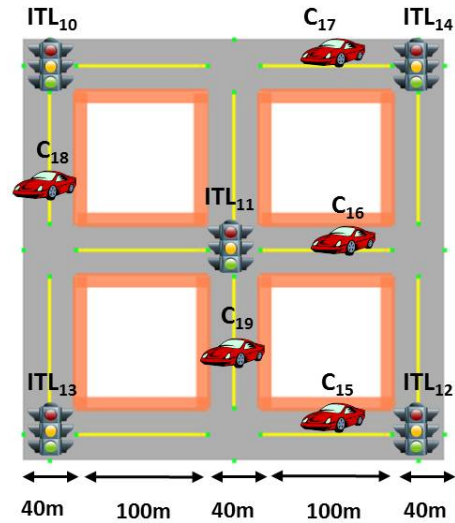


Fig. 3. Simulation scenario of a car accident

the sub-network formed by the ITLs. Complementarily, the forecast proportioned by local public weather services could be used as well. The sub-network of ITLs could share that forecast information obtained from an Internet access point set in one of the ITLs. In case of accident, the vehicle itself (using sensors that detect that the car suffered an accident) communicates this situation to the closest ITL and to the neighbouring vehicles.

To know the traffic density, each ITL uses the statistics collected by the network of ITLs in the city (as explained in the previous section) regarding the average number of neighbours per vehicle in the streets along the day. Thus, depending on the average number of neighbours, two adaptive thresholds determine the traffic density of the road: free, semi-congested or very congested (see Table II).

We use a 4-bit field in the warning messages to code traffic density (2 bits) and weather information (2 bits). The warning message also includes a field with the location of the initial place of the warning message. Nearby vehicles that receive such message will reduce their speed depending on the warning message according to Table II. For instance, in a very congested road with rain condition, warning messages inform nearby vehicles to reduce their speed to 40% of the initial driver speed (U in Table II). The driver’s assistant device in the vehicle will make the vehicle brake accordingly.

VI. SIMULATION RESULTS

In this work, we evaluate the performance of the vehicles of a VANET in a smart city using warning messages and traffic statics managed by the ITLs set in some crossroads of the city. To achieve this evaluations we use the network simulator NCTUns 6.0 [7]

A. Configuration of Intelligent Traffic Lights (ITLs)

ITLs are implemented using Multi-Interface Mobile nodes with two wireless ad-hoc interfaces configured in two different

sub-networks. One of the interfaces of the ITL will communicate with vehicles and the other interface will communicate with the other ITLs in the city.

To ensure node connectivity between ITLs, interface two (used to connect with other ITLs) is determined by the distance needed to cover 300 m between crossroads. Interface one (used to connect with vehicles) communicates with the passing vehicles. As the streets have a length of 100 m, and the intersection of 40 m, this interface is configured to cover 130 m. Both interfaces have an omnidirectional propagation diagram. As each vehicle is only supposed to connect to interface one of the ITL and also to other cars, the transmission range of vehicles is configured to cover 130 m in an omnidirectional pattern.

To ensure that it could be possible to differentiate data communication of the two wireless ad-hoc interfaces, they are configured with two different sub-networks. The sub-network used by the ITLs to collect, send and calculate statistics from the vehicles is “1.0.3.XX/24”, whereas the sub-network used to communicate ITLs among themselves is “1.0.2.XX/24”.

There are only a few ITLs among the regular traffic lights. In this case, an ITL receives data from any passing vehicle from any of the four streets covered by that ITL.

B. Benefits of Using Warning Messages after Accidents

To evaluate the operation of warning messages, we use an urban scenario to show how the vehicles react under different traffic and weather conditions. Fig. 3 shows a neighbourhood of the city where a car accident will happen. The simulation recreates a Manhattan 280x280 m² scenario. The length of the streets is 100 m, and the size of every cross is 40 m. These values were chosen to emulate the regular streets in the city of Barcelona, Spain. In the scenario there are 5 vehicles and 5 ITLs. During the simulation, vehicle C_{18} has an accident and remains broken close to the intelligent traffic light ITL₁₁ situated in the centre, see Fig. 3. Vehicles C_{15} , C_{16} , C_{17} and C_{19} are all travelling towards ITL₁₁. In this simulation

TABLE III
TRAFFIC AND WEATHER CONDITIONS DURING THE SIMULATION

Traffic conditions	Weather conditions	Period of time	Average vehicle velocity
Free segment	Sun	30 s	40 km/h
Accident	Sun	50 s	0 km/h

TABLE IV
SIMULATION SETTINGS

Parameter	Value
Medium capacity	11 Mbps
Packet size	256 bytes
Transmission range	130 m
Carrier sense range	180 m
Simulation time	80 sec
MAC specification	IEEE 802.11b
Area	320 x 320 m ²
Maximum Average speed	40 km/h
Number of nodes	5 ITLs and 8 vehicles
Mobility model	CarAgentMod (NCTUns)
Routing protocol	AODV

it is shown how the use of ITL helps to avoid collision among the other vehicles and the broken vehicle, thanks to our warning scheme that makes them brake beforehand. Table III summarizes the traffic and weather conditions during the simulation.

The accident will occur in the second 30. The traffic lights number ITL₁₀, ITL₁₂, ITL₁₃ and ITL₁₄ will send messages of *good weather conditions* and *free traffic segment* during the 80 sec of this simulation. The traffic light number ITL₁₁ will send during 30 sec messages of *good weather conditions* and *free traffic segment*. After that, ITL₁₁ will send *good weather conditions* and *accident* during the next 50 sec. Each of the ITLs sends these packets to the vehicles in the four streets that go from the crossroads where they are located to the next 4 closest crossroads.

ITLs will broadcast 256 bytes messages every 0.2 seconds (i.e. 5 messages each second) with information about traffic conditions, weather conditions and accident warnings. Vehicles move randomly through the streets at an average velocity of 40 km/h (it automatically decreases when approaching an intersection and the vehicle turns). Simulation settings are summarized in Table IV.

The cars in the simulation were represented using smart vehicles equipped with IEEE 802.11b interface on ad-hoc mode. These vehicles are controlled by a program called *agent* (CarAgent.cc) that makes vehicles move through the

TABLE V
DRIVER'S REACTION TIME AND DISTANCE TRAVELLED

	Use of ITLs	Non use of ITLs
Driver's reaction time	0,084 s	1 s
Distance travelled till reaction	0,93 m	11,11 m
Braking period of time	1,355 s	1,355 s
Distance travelled during braking	7,52 m	7,52 m
Total distance travelled	8,45 m	18,63 m

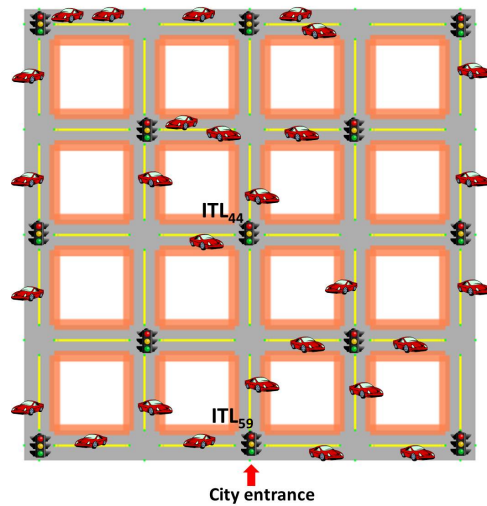


Fig. 4. Traffic density simulation scenario

city respecting streets, crossroads and traffic lights.

As it was said in Section III, ad-hoc nodes (i.e. ITLs and vehicles) use AODV. We simply modified AODV to be able to collect traffic statistics while establishing the routing paths. To do that, we use modified RREQ messages that carry SMs (see Table I).

The objective of these simulations is to evaluate if the use of ITLs reduce the driver's reaction time after accidents. According to the *Dirección General de Tráfico* (DGT) [11], responsible of the transportation policy in Spain, the average reaction time of a driver is 1 sec, so a car ($v = 40$ km/h) before start braking still travels 18,63 m. Using our framework the driver's reaction time was 0,084 sec, which represents that the distance travelled will be reduced to 8,45 m. Table V shows the time and distances that a vehicle, in average, travels with and without the use of our smart city framework. In this case, it can be appreciated that the safety distance from the car to the obstacle has been reduced around 55% from 18,63 m without the use of ITLs to 8,45 m using them, which increases road safety notably.

C. Measure of the Traffic Density in the Smart City

To evaluate the operation of the traffic statistics system, we use a Manhattan scenario with streets that form 4x4 blocks (100m x 100m each) (Fig. 4). It has obstacles that represent buildings, and ITLs which are responsible to manage the traffic of the vehicles that form the VANET.

The simulation consists on a random number of smart vehicles moving around the city and establishing communications with the nearest ITL to send information of the current number of neighbours. Traffic statistics are updated as explained in section IV and according to eq. (1). This data is collected every 2 sec. Every time an ITL receives data from a passing car it updates the statistics of traffic density on its surrounding area, stores it on an individual file and shares it with the rest of the ITLs of the city.

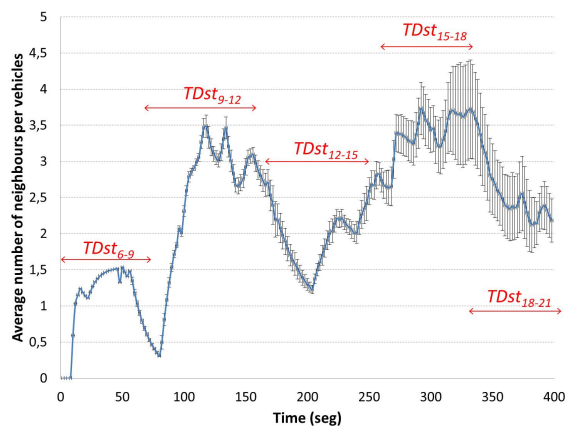


Fig. 5. Average number of neighbours per vehicle measured by ITL₄₄, set in downtown

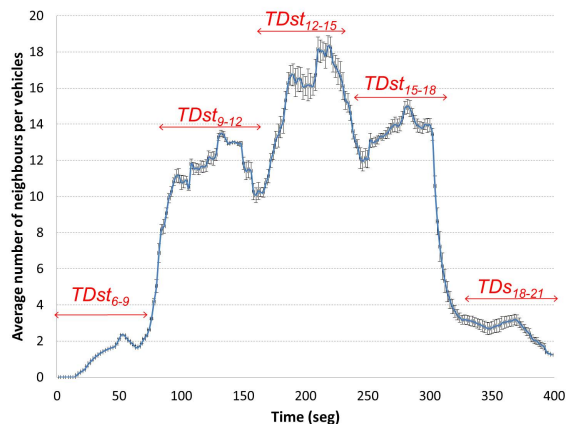


Fig. 6. Average number of neighbours per vehicle measured by ITL₅₉, set in the city entrance

Fig. 5 shows the behaviour of the statistics collected by ITL₄₄ (set in downtown, see Fig. 5). Here, simulations show 400 sec (i.e. 15 h from 6 AM to 9 PM), so that 27 sec in the simulations represents 1 h. The results show the density of cars in downtown along the day. With this information drivers can obtain which are the roads more congested in each part of the city. Fig. 6 shows the results obtained by ITL₅₉, which is located in the entrance of the city. We can see the behaviour in one day, where the more congested periods of time are between 12-15 PM. Streets are almost free between 6-9 AM, and 18-21 PM.

VII. CONCLUSION AND FUTURE WORK

In this work we have designed a smart city framework for VANETs that include intelligent traffic lights (ITLs) that transmit warning messages and traffic statistics. We have implemented the framework in the NCTUns 6.0 [7] simulator. Simulation results show that the use of ITLs in smart cities can not only improve road safety but also the driver's quality of life. We have explained how the ITLs gather traffic and weather conditions of the roads and how they update those

statistics. The goal is that the driver's assistant device can take proper trip decisions, for instance to avoid congested roads, and therefore reducing the trip time and pollution as well. Besides, our smart city framework includes warning messages sent by possible broken vehicles to make approaching vehicles brake beforehand and thus avoid more collisions. Simulation results show the effectiveness of this scheme, reducing the distance to brake and the driver's reaction time.

As a near future work, ITLs could communicate to passing vehicles indicating where are the free parking spots in the city. With this information, the driver assistant device could indicate the driver where free spots are located. This system could use a WSN to get the data about free parking spots and communicate it to the nearest ITLs. The ITLs could share that information through the sub-network they form. This would save trip time, petrol and CO₂ as a consequence, which helps to have sustainable smart cities.

Also, statistics collected by the ITLs can improve data routing protocols selecting the path that offers a higher chance to forward a packet to the destination successfully. We will design a VANET routing protocol that considers those statistics in its operation.

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