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Node Re-Routing and Congestion Reduction Scheme for Wireless Vehicular Networks

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Abstract Recently, the interest of research is going to be focused on the emerging vehicular ad-hoc networks paradigm. In these networks, vehicles communicate with each other and have the possibility of exploiting a distributed approach, typical of ad-hoc networks, which allow mobile nodes (vehicles) to communicate with each other. Thanks to the different standards for this kind of network, such as DSRC, WAVE/IEEE802.11p, the researchers have the possibility of designing and developing new MAC and routing algorithms, trying to enhance the mobile users experience in the mobile environment. In this paper, the attention is focused on the optimization of traffic flowing in a vehicular environment with vehicle-2-roadside capability. The proposed idea exploits the information that is gathered by road-side units with the main aim of redirecting traffic flows (in terms of vehicles) to less congested roads, with an overall system optimization, also in terms of Carbon Dioxide emissions reduction. A deep campaign of simulations has been carried out to give more effectiveness to our proposal.

Keywords 802.11p · Congestion · DSRC · Traffic Flow · VANET · WAVE

1 Introduction

In recent years, a new and modern paradigm of communication is becoming increasingly studied and analized by the reserach community. It is known as Vehicular Ad-hoc NETworks (VANETs), where the mobile nodes, represented by vehicles, are able to communicate in a distributed manner with each other, based on the ad-hoc paradigm [1]. In VANET communications, a fully

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infrastructure-based coverage is not strictly needed because vehicles can communicate following a distributed ad-hoc paradigm. These kind of networks is also known as Car-to-Car ($C2C$) communication network, a network of cars communicating with each other. It represents a special type (or a subset) of Mobile Ad Hoc NETwork (MANET). Due to limited channel bandwidth, both technologies need techniques to cope with bandwidth constraints. Also both networks have limited physical security and suffer from eavesdropping, spoofing and Denial of Service (DoS) attacks. Despite the similarities, mobility in VANETs exhibit characteristics that are quite different from MANETs. The topology is more dynamic (it changes rapidly), due to the high speed of vehicles, but also due to driver behavior, which may be affected by the content of messages it receives. In these networks, each mobile nodes are equipped with a communication wireless device, called On-Board Unit (OBU) that allows to exchange messages with each other in Vehicle-to-Vehicle communication ($V2V$) and also to exchange messages with a roadside network infrastructure (Vehicle-to-Roadside Communication $V2R$) in respect of ad-hoc communication mechanism. A lot of applications can be designed for these networks, such as: Vehicle collision warning, Security distance warning, Driver assistance, Cooperative driving, Cooperative cruise control, Dissemination of road information, Internet access, Map location, Automatic parking, Driverless vehicles. The complete architecture provides also the, so-called, Road-Side Units ($RSUs$), which can be also any equipment-certified packet forwarding device, such as GSM, $WLAN$, and/or $WiMAX$ towers. These devices realize the, so-called, Vehicle-2-Infrastructure ($V2I$) paradigm. The RSUs are very useful for guaranteeing the complete coverage when some distributed nodes are disconnected, giving to the driver the possibility of being still able to receive the needed information. New studies on this topic concern the possibility of using satellite communciations in order to have backup links to utilize in case of ad-hoc fault [2]. In this way, the road safety is improved, also because emergency vehicles can act more speedily. VANETs are able to broadcast real-time alerts to drivers about the risks of their planned journey and their immediate surroundings [3], [4]. In addition, if a danger situation is created or, at a particular place, an emergency vehicle is needed to come quickly, VANETs give the chance to improve the effectiveness of the needed operations, by exploiting the effects of dedicated protocols and algorithms [5], for unicast and multicast communications. For instance, if the cars involved in accidents can advise the event instantly to the emergency services, a ready and timely intervention can be immediately scheduled. Neighboring vehicles may benefit from the received updates: platooning would be really helpful in order to leave to the emergency vehicles the right space on the roads, without time wastages. $V2V$ communication allows the development of new applications and one of the main desires of drivers is also to avoid congested roads during their journeys and traveling. In this paper, the attention is focused on the optimization of traffic flowing in a vehicular environment with $V2I$ capability. The proposed idea enables the considered vehicular network to re-route all the vehicles on new paths toward destinations, avoiding useless time wastages and reducing the creation of harmful Carbon Dioxide (CO_2) emissions [6]. As shown later, in the next sections, the proposed algorithm, called Congestion Avoidance in vehiculaR environmentS ($CARS$), exploits the information that is gathered by $RSUs$, with the main aim of redirecting traffic flows (in terms of vehicles) to less congested roads, with an overall system optimization, also in terms of CO_2 emissions reduction. Our proposal is based on system modeling by an oriented graph, able to capture all the real-time system values. Each edge of the graph participates to the evaluation of new paths, giving to mobile users the possibility of following different itineraries to their destinations more quickly. The paper is structured as follows: Section 2 gives an in-depth overview on the related work about optimization schemes in VANETs; section 3 points-out the main contributions given in this paper; Section 4 briefly introduces the standards and, then, section 5 describes in a detailed way the CARS algorithm. Section 6 illustrates the obtained results, which confirm our expectations and, then, conclusions are resumed in section 7.

2 Related Work

The main task of this work is to utilize the VANETs communications in order to build intelligent mechanisms that can lead to a better management of vehicular traffic, reducing the time spent in the city, the emissions of CO_2 and fuel consumptions. Predictive approaches are really appreciated in telecommunication systems, not only in vehicular environments [7]. In fact, in literature there are several works that try to get that bene

t using nodes mobility prediction policies and vehicular traffic re-routing approaches [8]. In the research community, one way to face with this issue is increasing roads capacity in order to improve roads efficiency through the construction and expansion of roads, but it is a very expensive solution. In [9] the authors propose a new approach in vehicles communications that tries to find an optimal path. This permits to have a better travel time and a lower fuel consumption. Moreover, the proposed approach can also reduce congestion and queues in the existing road infrastructures. In [10], the authors provide a re-routing approach based on a pheromone traffic management model. They propose a scheme for avoiding congestion on the roads and, simultaneously, control traffic lights. The idea is that each car agent deposits multiple digital pheromone on its route, so the road infrastructure agents use pheromone to forecast traffic condition. When a congested road is found, they propose to use a proactive algorithm for assigning alternative routes to cars. Moreover, the traffic light control agents use these information to assign long time duration of green traffic lights to roads with huge amount of pheromone. They provide a series of experimental results in order to show the goodness of their proposal. In [11], the authors designed a mechanism for reducing/avoiding traffic waves by integrating Artificial Intelligence and VANET, to create a driver aid that helps in combating traffic congestion as well as embedding safety awareness by dynamically re-routing traffic depending on road conditions. The paper in [12] provides traffic re-routing strategies for congestions reduction. The proposed system aims to collect real-time traffic data both from vehicles and road devices, in order to send towards vehicles a re-routing strategy, able to face with congestion. The authors propose and validate, with simulations, three different strategies. They conclude that all proposed techniques offer good improvements in the considered scenario, compared with a "no re-routing" system. In [13] the authors proposed some traffic re-routing strategies designed to be incorporated in a cost-effective and easily deployable vehicular traffic guidance system, which reduces travel time. These strategies proactively compute individually tailored re-routing guidance to be pushed to vehicles when signs of congestion are observed on their route and they also allow tuning the system to different levels of trade-off between re-routing effectiveness and computational efficiency. In [14], the authors developed an Intelligent Transportation System (ITS) based on multi-mobile agent systems and VANETs. This approach enables individual vehicle drivers to make quick responses to the road congestion. In particular, the drivers around the congestion area can also make the appropriate decision before they reach the congested road. In [15], the authors proposed a system able to reduce the travel times and the fuel consumptions in different European cities. They also designed a Red Swarm architecture based on an evolutionary algorithm and on smart $Wi-Fi$ spots located near traffic lights, which are used to suggest alternative routes to vehicles. In [16], the authors proposed two green driving suggestion models: Throughput Maximization Model and a model that aims to reduce the effects of acceleration and deceleration. The aim of the proposal is to minimize the CO_2 emissions, considering real-time traffic information nearby intersections. In [17], the authors developed and implemented an instantaneous statistical model of emissions ($CO2, CO, HC, NOx$) and fuel consumption for light-duty vehicles, which is derived from the physical load-based approaches. The model is tested for a restricted set of some vehicles models, used with standard and aggressive driving cycles. It is implemented in Veins Framework, that is also used in this work for simulation campaigns. In [18] the authors propose two models namely, the Maximize Throughput Model (MaxTM) and the Minimize Acceleration and Deceleration Model (MinADM), in order to provide green driving suggestions and then, minimize the CO_2 emission. They compare these models with an open traffic model. The provided simulation results demonstrate the efficiency and goodness of proposal, both in simulation cases and real traffic one. In [19], the authors proposed a network infrastructure able to continuously gather information from environment, road conditions and traffic flows. The vehicles can share information with neighbors and $RSUs$. They also considered a smart traffic management, to exploit gathered information by the Control Management Center (CMC), in order to avoid traffic blocks, trying to maintain a constant average speed inside city blocks. This can help to reduce vehicles CO_2 emissions in the city, increasing air quality. In [20], the authors introduce $V2X-d$, a novel architecture designed to estimate traffic density on the road and able to exploits the combination of $V2V$ and $V2I$ communications. In [21], the authors propose a traffic congestion issue comparison study of four different approaches in order to obtain the best solution. Using $V2I$ communications, they accurately estimate the traffic density in a certain area, reducing the emergency services arrival time, and avoiding traffic jams when an accident occurs.

3 Main Contributions

This work focuses the attention on a new re-routing approach for vehicular networks, in which it is very important to reduce traffic congestion and CO_2 emissions. The proposed scheme is able to manage the mobility patterns of vehicles for evaluating new routes on the roads with a lower traffic density and a positive impact on emissions reduction. In particular: (a) a dedicated graph model is used for describing the roads topology, for which the weights are dynamically updated on the basis of the number of present vehicles. In this way the proposed scheme has a converged knowledge of the whole network, in terms of traffic owings; (b) each time a route redirection is needed, the graph structure is consulted and the new paths are evaluated by taking into account the average congestion level on each edge. In this way, the $CARS$ algorithm is able to reduce the average size of the queues, the CO_2 emissions and, consequently, the average density of each road. The impact of discovering alternative paths in the simulation scenario is quantified by carrying out a set of simulative campaigns. A deep performance analysis has been performed in order to understand the real benefits of the CAR_S algorithm. In order to implemet our idea, all the procedures that compose the algorithm and the related signaling messages have been implemented in the exploited OMNet++ simulator. It permits to achieve a more detailed analysis, which is easy comparable with other approaches. Regarding the mobility model, in this work the SUMO [22] application is used. As reference map, a particular area of Cosenza city (in the south of Italy) has been used.

4 Overview on VANETs

VANET are self organized communication networks providing services for ITS. It permits vehicle-to-vehicle and vehicle-to-infrastructure communications and applications that try to improve active safety, traffic management, and performance. In this type of network the exchange of information messages occurs in many time events, both between vehicles that are moving in a particular geographical area ($V2V$) and between vehicles and the fixed devices, $RSUs$ ($V2I$). The ITS aimed at facilitating the efficiency, safety, and convenience of overland transportation by employing wireless communication technologies. Currently, there are different possible paradigms for wireless mobile communication, for example, cellular, ad-hoc, wireless LAN. These standards have allowed a rapid and important developing in the vehicular communications. Clearly, the choice of the appropriate technology depends on the application that the network is intended to support and, then, it is important to have a clearness of what applications and requirements are needed in order to make the right architecture and infrastructure. VANETs represent a particular kind of MANETs paradigm in which nodes are vehicles that follow particular mobility patterns regulated by vial normative. It is possible to make a simply classification of the communication types that we can meet in these networks: (a) single-hop to neighbor cars to advise of an event or (b) multi-hop to either disseminate information or to query for a service. Moreover, it is also possible to make a categorization for the applications: (a) Transportation-related applications (applications that increase the safety of the driver and passengers), and (b) convenience and personalized applications (applications that increase the comfort of the driver and passengers). It is important to provide to the car with different sensors on-board, in order to have the capability of gathering, processing and distributing information. The IEEE 802.11p, also called Wireless Access in Vehicular Environments (WAVE) [23], is an extension of the IEEE 802.11 standards family for vehicular communications. It aims at providing the standard specifications to ensure the interoperability between wireless mobile nodes of a network with rapidly changing topology (that is to say, a set of vehicles in a sub-urban or urban environment). The MAC layer in WAVE is equivalent to the IEEE 802.11e Enhanced Distributed Channel Access (EDCA) QoS extension. Therefore, application messages are categorized into different Access Categories (ACs), where AC0 has the lowest and AC3 the highest priority. Within the MAC layer a packet queue exists for each AC. Fig.1 shows a typical VANET scenario, in which OBUs and RSUs can communicate in the distributed environment. An important issue in VANET is the choice of an appropriate transmission channel [24], not only considering the type of traffic (emergency, security, platooning, etc.) but, mainly, focusing on the reduction of the inter-node interference. The Dedicated Short Range Communication (DSRC) [25] together with other technologies can enable smart and useful services. Starting with simple applications like automatic toll collection, smart infrastructure can be built out that will significantly reduce traffic congestion, travel time, on-road accident, emission, driver stress and other unhealthy social behaviors. DSRC spectrum is divided into 7 channels, each one with a 10 MHz bandwidth; it is allocated in the upper 5 GHz range. A mobile/stationary station switches its channel between the control channel and a service channel every channel interval. The default value for the control/service channel interval is set to 50 ms in the standard. The PHY layer employs 64-subcarrier OFDM. 52 out of the 64 subcarriers are used for actual transmission consisting of 48 data subcarriers and 4 pilot subcarriers. Possible modulation schemes are BPSK, QPSK, 16-QAM and 64-QAM, with coding rates equal to 1/2, 1/3, 3/4 and an OFDM symbol duration of 8s. The WAVE standard relies on a multi-channel concept, which can be used for both safety-related and entertainment messages. The standard accounts for the priority of the packets using different Access Classes (ACs), having different channel access settings. This shall ensure that highly relevant safety packets can be exchanged timely and reliably even when operating in a dense urban scenario.

Each station continuously alternates between the Control Channel (CCH) and one of the Service Channels (SCHs) or the safety channels.

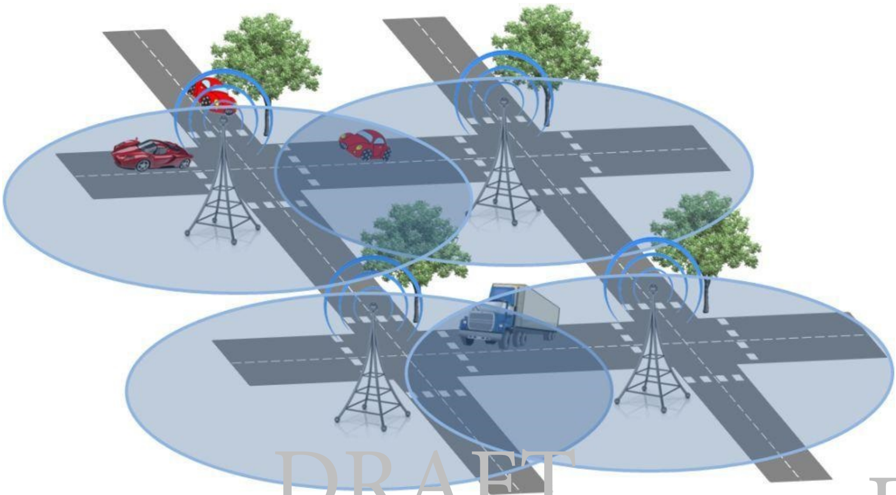

Fig. 1 An example of a typical VANET scenario

5 The Proposed *CARS* Scheme

In this section, the proposed application protocol is deeply explained. First, some basic definitions are given, then the graph model is introduced in order to explain the main steps of the proposal idea.

5.1 Main Definitions for the CARS Algorithm

The proposed idea is suitable for a generic geographical map. In order to introduce the mathematical formulation used in the proposed algorithm, some assumptions have to be done. In our scheme we assume the coexistence of two families of nodes: primary nodes (represented by the network devices which give a fixed coverage and the connection to the backbone, such as road side units), and secondary nodes (nodes that are moving, able to communicate in a peer-2-peer way, and to connect to primary nodes to access the Internet, if needed, such as vehicles). First of all some basic definitions necessary to understand our idea are given:

- $RO = \{r_1, ..., r_m\}$: set of ROads, (paved track for vehicles, people and animals) modeled as lines;

- $P = \{p_1, ..., p_n\}$: set of Primary nodes, modeled as points belonging to one or more lines (a primary node is shared among two roads if its coverage range contains more than one road, as intersections or if there are near parallel roads). Each $p_i \in P$ has an associated couple of coordinates (x_{pi}, y_{pi}) and a coverage range R_i;
- $MOS(t) = \{s_1, ..., s_{q(t)}\}$: dynamic set of MObile hostS (secondary nodes) (in this work the vehicular nodes enter and exit the map dynamically during time);
- $||RO|| = m$, $||P|| = n$ and $||MOS(t)|| = q(t)$, where m and n are constant values and $q(t)$ depends on time, on the basis of the number of vehicles present in the whole considered map;
- $ROSE = rs_{i,j} \mid \exists r_k \in RO,\ rs_{i,j} \subseteq r_k$, set of ROad SEgments contained in the roads r_k. It is clear that a road segment $rs_{i,j} \in ROSE$ may coincide with a whole road $r_k \in RO$.

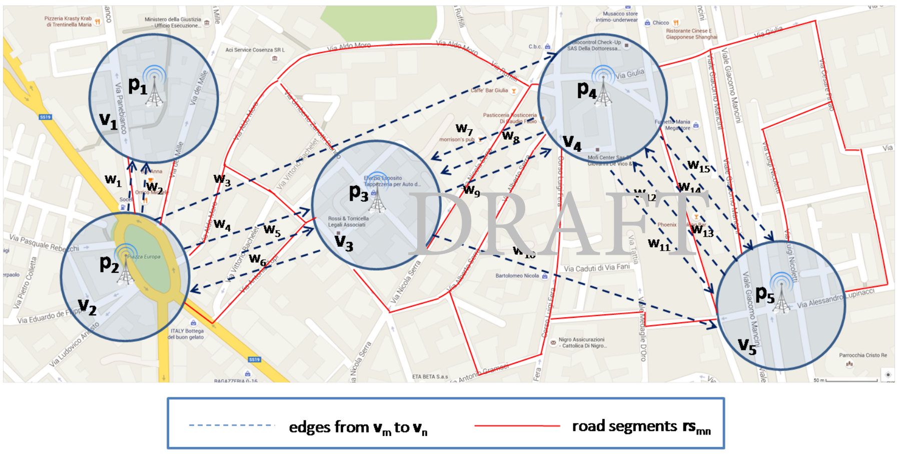

Fig. 2 An example of RSU (primary node) placement in a map

The network topology can be modeled by a Dedicated Graph so defined $DG =< V, E, W >$, where V is the set of vertices (each $v_i \in V$ represents a unique primary node p_i), so $||V|| = ||P|| = n$. DG is just a normal graph, dedicated to the particular geographic map that is considered for nodes re-routing. The set E represents the edges e_j (two nodes v_g and v_h in DG are neighbors if there exists $rs_{gh} \in ROSE$ such as vehicles can flow from p_g to p_h, by following a single rs_{gh} or a sequence of elements belonging to $ROSE$) and W is the set of weights w_l associated to each element of E. The meaning of the elements of W will be clearer in the following. Differently from the classical approaches, where a coverage extension has been always considered, in DG two nodes are connected if there is a sequence of road segments (which may be composed of a single road), starting from a node to another one. This choice is justified since the $CARS$ scheme considers vehicles traffic, instead of data traffic. Moreover, we assume that DG is not disconnected (there are no isolated primary nodes into the system). So, under these assumptions, the considered traffic map can be completely modeled by a DG, as illustrated in fig.2, where $m = 15$, $n = 5$, and $R_k = 60m$ for each $p_k \in P$. If there is more than one road segment that interconnects two primary nodes, then the set E will contain some so-called multi-edges (DG will not be a simple graph). It is also possible that all the weights $w_l \in W$ can be resumed in the M_{DG} matrix (see eq.1), since it represents the weighted adjacences matrix associated to DG. If for a given couple of nodes v_i, v_j there is more than one connecting road segments sequence, a vector element is considered in M_{DG}.

$$M_{DG} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ (w_1, w_2) & 0 & (w_4, w_5) & w_3 & 0 \\ 0 & w_6 & 0 & w_9 & w_{10} \\ 0 & 0 & (w_7, w_8) & 0 & (w_{11}, w_{14}, w_{15}) \\ 0 & 0 & 0 & (w_{13}, w_{14}) & 0 \end{bmatrix} \quad (1)$$

In the following, the mechanism to determine the weights is illustrated.

5.2 Detailed Description of the *CARS* Scheme

In this subsection, the main steps of $CARS$ are deeply discussed. All the nodes of the DG store the weights of the edges in the M_{DG} since it is a shared structure, each primary node can send an update message, called *weight_update* to a dedicated server, as referred in fig.3. Each time a secondary node $s_g \in MOS(t)$ leaves a primary node coverage area $A|p_i$, the node p_i knows exactly the itinerary of s_g, so its destination is known, as well as its next serving road-side unit p_j. At this point, there will be another mobile node traveling on the road segment $rs_{i,j}$, and node p_i can signal to the server an increment of one unit of the weight $w_{i,j} \in W$ through the *weight_update_up* message ($w_{i,j}$ represents the number of vehicles on the edge from v_i to v_j). Viceversa, each time a secondary node $s_h \in MOS(t)$ enters a primary node coverage area $A|p_j$, the node p_j, aware about the road segment from which s_h arrived, knows the primary node p_i that was serving s_h before. At this point, node p_j can signal to the server (through the *weight_update_down* message) that the number of mobile nodes $w_{i,j}$ traveling on segment $rs_{i,j}$ is decreased by one unit. The logical scheme of the $CARS$ protocol for the server side is illustrated in fig.4 (left side). The behaviors of the server node and primary nodes are depicted in fig.4.

The OBU of each secondary node $s_l \in MOS(t)$ is integrated with a GPS device, on which the driver has set its own itinerary before starting the trip. Each primary node bradcasts a periodical "Presence Polling REQuest" ($PPREQ$) message to all covered secondary nodes. The answers are needed for giving the knowledge to the primary node of the presence of each vehicle in the covered area. When the secondary node $s_l \in MOS(t)$ arrives under the cover-

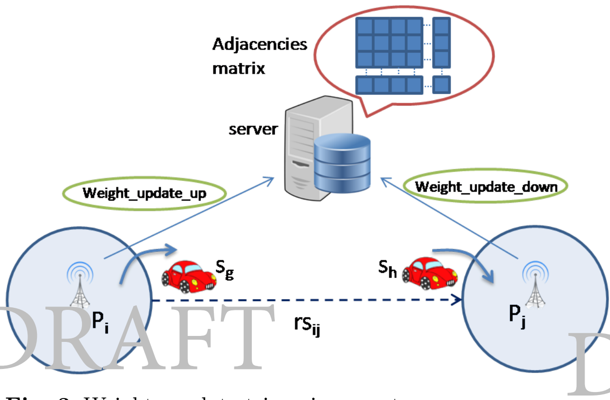

Fig. 3 Weights update triggering events

age of the first road-side unit of the system, it points-out its $l-th$ PLanned Trip (PLT_l) by sending to the primary node the sequence of road-segments:

$$PLT_l = \{rs_{l1}, rs_{l2}, ..., rs_{lm}\} \tag{2}$$

In this way the system is aware about the trajectory that the mobile node wants to follow and the node s_l will be inserted in the set of nodes covered by the local road-side unit. Finally, each secondary node $s_l \in MOS(t)$ puts into Presence Polling REPly ($PPREP$) its GPS coordinates: this information is necessary to the primary node that is covering s_l, in order to know the last position of the node before leaving the coverage area and, then, the road to which s_l is flowing out.

Each primary node p_i has to check if the received PLT_l contains any congested road segment. In that case, it will send to s_l the new suggested path to destination. The logical scheme of the $CARS$ algorithm for the primary node side is illustrated in fig.4 (right side). Based on the definitions and studies in [26], [27], a density term can be defined as follows:

$$\pi_{i,j} = \frac{w_{i,j}}{length(rs_{i,j})} \quad \Pi_{u,z} = \frac{1}{N_{u,z}} \cdot \sum_{(u,z)} \pi_{u,z} \tag{3}$$

where $\pi_{i,j}$ is the traffic density for the road segment $rs_{i,j}$ defined as the ratio of $w_{i,j}$ (the number of vehicles in the road segment $rs_{i,j}$) and the length of $rs_{i,j}$, while $\Pi_{u,z}$ is the average density for the edge v_u, v_z, connecting primary nodes p_u, p_z ($N_{u,z}$ is the number of road segments belonging to the considered edge). Clearly, $\pi_{i,j}$ depends on time; the only constant term is length $rs_{i,j}$. In our work, we are not considering bigger roads with more lanes on the same direction. Considering ideal conditions, the maximum density can be numerically obtained by fitting the curves, but more complex analytical analysis should be carried out for real cases. In particular, from [28] it can be written that, for a motorway, the capacity $c_{i,j}$ of the road-segment $rs_{i,j}$ is: $c_{i,j} = C_{i,j} \cdot N_{i,j} \cdot FW_{i,j} \cdot FHW_{i,j} \cdot FP_{i,j}$, where $C_{i,j}$ is the ideal capacity, $N_{i,j}$

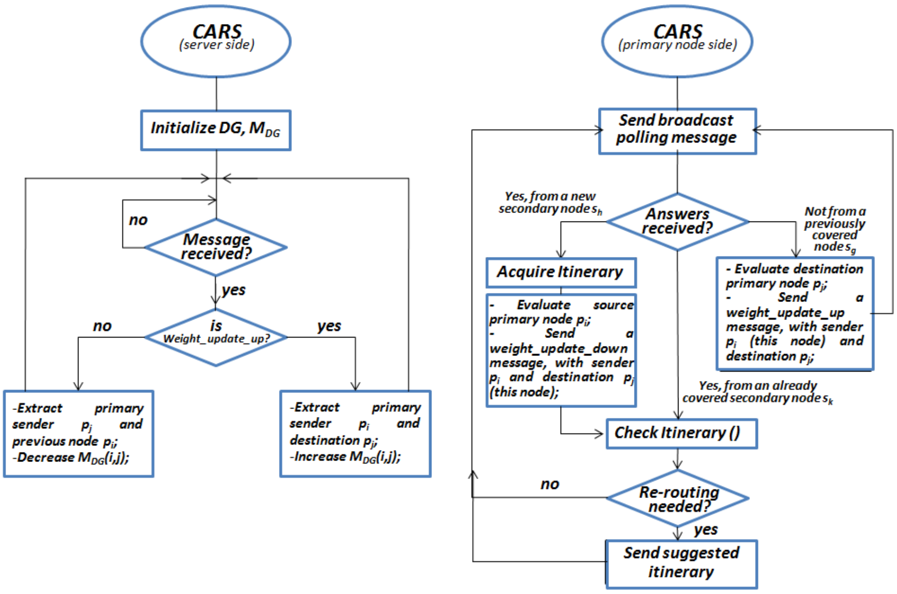

Fig. 4 *CARS* logical behavior for server and primary node sides

is the number of lanes, $FW_{i,j}$ is a factor related to the width of $rs_{i,j}$, $FHW_{i,j}$ is related to the probability of having heavy vehicles and $FP_{i,j}$ is a factor that derives from the driver population. The main aim of this proposal consists in guaranteeing that:

$$\pi_{i,j} \cong \bar{\pi}_{i,j} \quad \forall rs_{i,j} \in ROSE \tag{4}$$

where $\bar{\pi}_{i,j}$ is the desired average density for $rs_{i,j}$. So, after these considerations, a planned itinerary PLT_l is considered as congested if:

$$\exists rs_{i,j} \in PLT_l \mid \pi_{i,j} > \beta \cdot \bar{\pi}_{i,j} \tag{5}$$

where β is equal to $(1+thr_{i,j})$. $thr_{i,j}$ is a near-to-zero value representing the maximum tolerable deviation from the desired value. When eq.5 is satisfied, a primary node will evaluate, if exists, an alternative itinerary for s_l which involves different/alternative road-segments, with lower weights (in terms of density and trip delay). From the theory expressed in [26], each road (and segment) can be characterized by a particular value of $\bar{\pi}$, which brings the road segment to be in the ideal situation, with the maximum traffic volume (measured in vehicles/time). Clearly, it depends on the topography and intrinsic characteristics of the considered lanes. Once the PLT_l has been received by $p_k \in P$, it can evaluate all the possible paths from the current vertex v_k to the destination vertex v_D (for example, applying the Dijkstra algorithm directly on M_{DG}). In particular, p_k can build the set $PATHS_{kD} = \{path_1, ..., path_t\}$, where each $path_i \in PATHS_{kD}$ starts from v_k and ends to v_D: $path_i = \{v_k, v_2, v_3, ..., v_D\}$. Among all the elements of $PATHS_{kD}$, the best one is chosen and suggested to

s_l, through the *suggest_itinerary* message (as illustrated in fig.4, right side). The criterion for choosing the best path is now illustrated. As said before, in this work, the attention is focused on the reduction of road congestion and CO_2 emissions. To this aim, the algorithm is based on reducing the instantaneous road density on all segments and, consequently, the time spent on the road segments. The best path is chosen by:

$$BEST\_P_{kD} = \min_{MCARS}\{PATHS_{kD}\} \quad (6)$$

where the $MCARS$ term represents the considered metric and, for the road segment $rs_{i,j}$ belonging to $path_i$, it is defined as:

$$MCARS_{i,j} = \alpha \cdot \left[\frac{w_{i,j}/length(rs_{i,j})}{max\_\pi\_path_i}\right] + (1-\alpha) \cdot \left[\frac{length(rs_{i,j})/\bar{\nu}_{i,j}}{max\_delay\_path_i}\right] \quad (7)$$

where α is a weighting term (for giving more emphasis to density or to travel delay), $max\_\pi\_path_i$ and $max\_delay\_path_i$ are the maximum density and delay terms provided on $path_i$ and $\bar{\nu}_{i,j}$ is the average speed on road segment $rs_{i,j}$. Given a particular $path_i$ from v_k to v_D, then:

$$MCARS(path_i) = \sum_{v_i, v_j \in path_i} MCARS_{i,j} \quad (8)$$

By eq.6 the quantity in eq.8 is minimized when choosing $BEST\_P_{kD}$. At this point, the primary node p_k can send the *suggest_itinerary*$(BEST\_P_{kD})$ to node s_l.

6 Performance Evaluation

This section of the paper is entirely dedicated on describing how the simulator has been configured and what results have been obtained. The considered comparing protocols are the Wave Short Message Protocol ($WSMP$, no rerouting) [29] and the Smart Traffic Management Protocol ($STMP$) [30]. First of all, a description of the simulation environment is given, with a deep analysis of the main features that OMNet++ [31] offers; then, the simulation results are deeply described.

6.1 OMNet++ and the Veins Framework

The OMNet++ Simulator [31] with Veins [32] environment has been used to develop and implement our proposal. In particular, Veins is a simulator framework, based on OMNet++ for event-driven simulations, and SUMO [33] for road traffic and mobility dynamics. With the integration of these three tools, it is possible to consider realistic communication traces of vehicular nodes.

Table 1 Emissions Parameters

Parameter Name	Value
λ	$1.11\ g * s^{-1}$
Λ	$0.1326\ kW * m^{-1} * s$
ξ	$0.013\ g * m^{-1}$
Ξ	$2.738\ kW * m^{-2} * s^2$
γ	$1.98 * 10^{-6}\ g * m^{-3} * s^2$
Γ	$1.084 * 10^{-3}\ kWm^{-3} * s^3$
δ	$0.24\ g * m^{-2} * s^2$
k_{CO_2}	$0.97\ g * s^{-1}$
M	$1.5 * 10^3\ Kg\ (avg\ value)$

As known, in OMNet++ different scenarios can be created, by a set of reusable C++ modules. Their relations can be graphically edited and stored into the NEtwork Description (NED) files. In order to take into account real movements, SUMO has been used to import city maps from OpenStreetMap data [34]. The concept of road segments has been easily integrated in the simulator, because SUMO allows the simulation of roads consisting of multiple lanes and junctions and traffic lights, while vehicles can follow static routes, dynamic patterns or timely-configured paths. All the integrated simulators have been extended with new modules, related to the primary nodes and the remote server. The re-route mechanism has been managed through the TraCI interface, which allows to a connected network simulator to send the *suggest_itinerary* message, influencing the dynamics of mobile hosts. For more details, please refer to [35].

In order to evaluate the level of CO_2 emissions, the model proposed in [36] has been integrated with the OMNet++ mobility model. It evaluates the emissions depending on vehicle speed, acceleration, weight, and catalyzer (with an average error of approximately 2%). Following the proposal in [36], two polynomials can be used to calculate CO_2 Emissions (CO_2E):

$$CO_2E = \begin{cases} \lambda + \xi \cdot v + \gamma \cdot v^3 + \delta \cdot a \cdot v & x > 0 \\ k_{CO_2} & x \leq 0 \end{cases} \tag{9}$$

where:

$$x = \lambda \cdot v + \Xi \cdot v^2 + \gamma \cdot v^3 + M \cdot a \cdot v \tag{10}$$

The term x represents the tractive power at mobile nodes wheels (under planar road assumption), while λ, Λ, ξ, Ξ, γ, Γ, δ are sumarized in the table 1; a and v represent the acceleration and speed of the vehicle.

The other simulation parameters are sumarized in table 2. We refer to fig.2 for the simulated map.

All the obtained results reflect the main philosphy of the proposed idea. Fig.5 shows the trend of CO_2 emissions (mg) for different CARS parameters (α and thr). It can be seen how for increasing value of thr (from negative to positive), the congestion situation is recognized in a longer time, giving

Table 2 Simulation Parameters

Parameter Name	Value
Number of stops per vehicle	$0, ..., 3$
Stop duration	$30, ..., 200s$
Size of the map	$550 * 250m^2$
average speed	$15m/s$
Mobility model	$Krauss$
Max acceleration	$2.5m * s^{-2}$
Max deceleration	$5.3m * s^{-2}$
Primary nodes range	$60m$
Secondary nodes avg length	$4.5m$
Number of roads (m)	15
Number of primary nodes	6
Number of runs	50
Run duration	$2000s$
PP_REQ	$15s$
α	$0, 0.2, 0.4, 0.6, 0.8, 1$
$thr_{i,j} = \bar{thr}$	$-0.1, -0.05, 0, 0.05, 0.1$

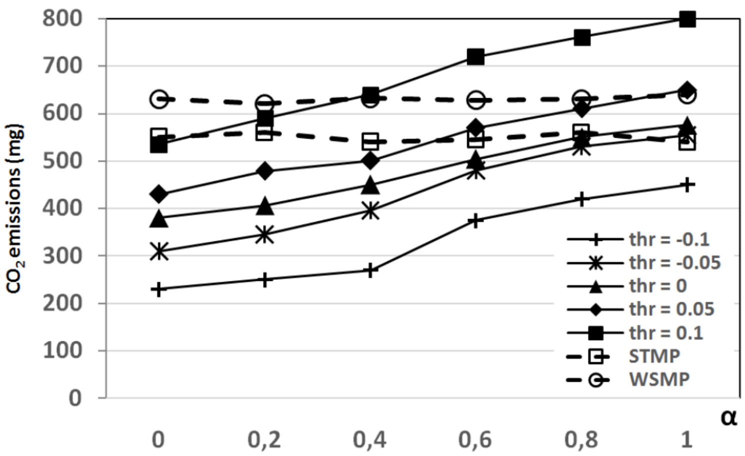

Fig. 5 Average CO_2 emission values versus $CARS$ parameters

the possibility to the roads to become more congested, in fact the emissions reach unacceptable values (for $thr = 0.1$ and $\alpha = 1$ the perceived value is near $800mg$). The same trend is obtained by increasing α (from 0 to 1): more emphasis is given to the delay term, so the best choice in respect of CO_2 emissions goes to be misregarded. For $\alpha \in [0 - 0.5]$ and $thr \in [-0.1 - 0.05]$ STMP and WSMP are outperformed (clearly STMP and WSMP do not depend on CARS parameters).

Fig.6 shows the obtained $Delay\ (s)$ time (we refer to the average time taken by a vehicle to cross a road in the considered map). The same considerations for the CO_2 emissions can be made: an increasing trend for both higher α

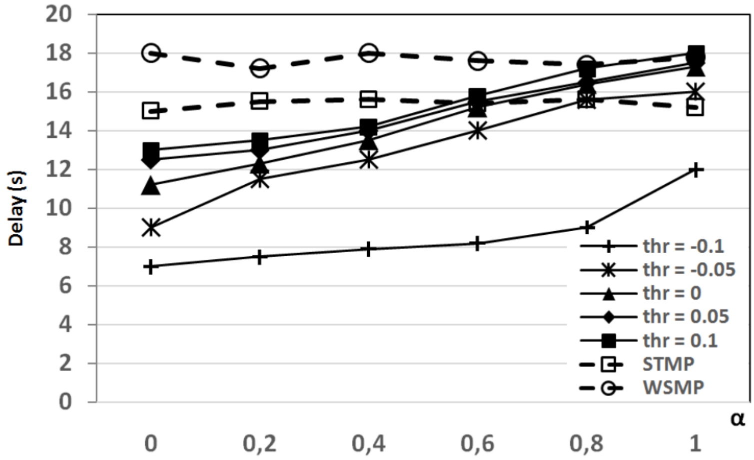

Fig. 6 Average road travel time versus *CARS* parameters

and *thr* is obtained. For α lower than 0.5 and $thr < 0.1$ the CARS scheme outperforms STMP and WSMP.

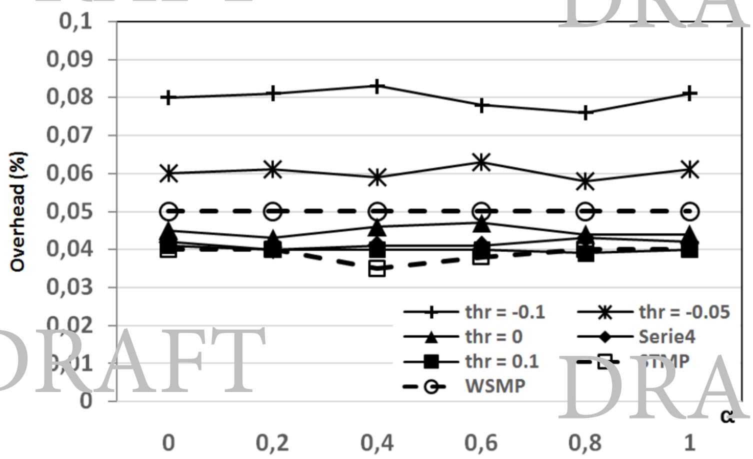

Fig. 7 Average *CARS* overhead versus *CARS* parameters

Fig.7 shows the variations of the overhead, evaluated as the ratio among signaling messages and data messages: it could be seen that it does not depends on α (it weights the metric attention on CO_2 or Delay component), but it is very sensible to *thr* variations. For $thr > 0$ the performance are comparable with the ones of STMP and WSMP ($<= 5\%$).

Fig.8 illustrates the average number of vehicles on the roads, during the simulation time. Except for $thr <= -0.05$, *CARS* performs worse than STMP

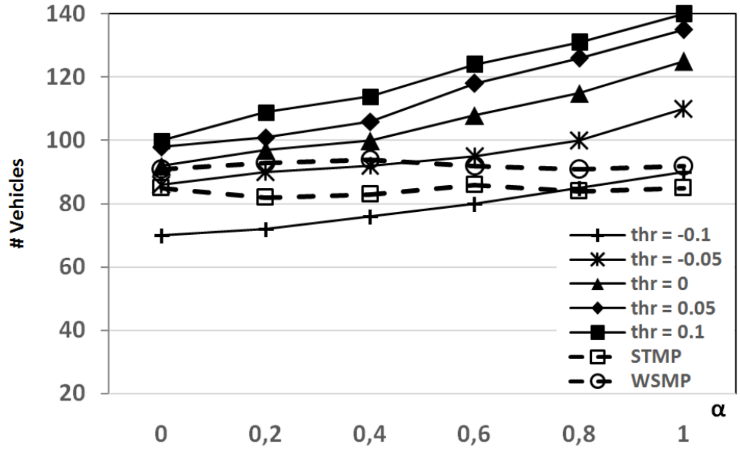

Fig. 8 Averaged number of vehicles on different road segments versus $CARS$ parameters

and WSMP. The trend is, also in this case, increasing for higher α and thr. The worsening is acceptable for $thr = -0.05$, but for other values the performance of $CARS$ cannot be compared with the ones of STMP and WSMP.

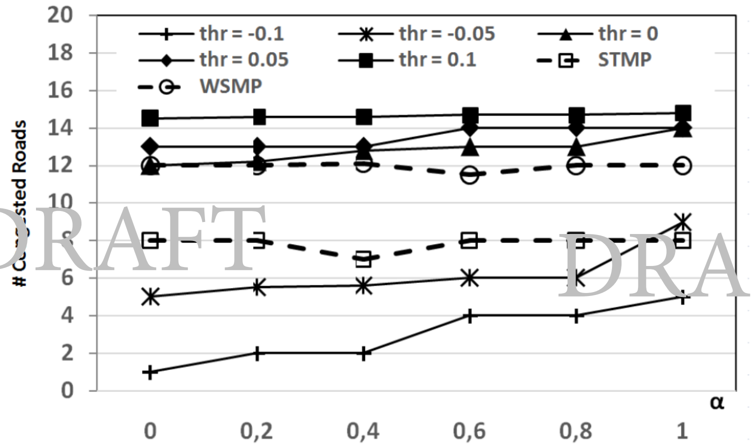

Fig. 9 Averaged number of congested roads versus $CARS$ parameters

The last figure, fig.9, depicts the obtained number of congested roads into the system: it does not heavily depend on α, but has a huge increasing trend for increasing values of thr. For $thr < 0$ the obtained result is comparable with the ones of STMP and WSMP.

7 Conclusions

In this work we proposed a new approach, in terms of protocol and algorithm, for enhancing the performance in a mobile network with vehicular nodes. Our scheme is aimed to reduce CO_2 emissions and traveling delays, by simply considering a dedicated graph, able to model the dynamics of the whole network. In particular, the covering nodes (RSUs) can estimate the number of vehicles along the roads of the considered map, having a complete and converged view of the whole map. If needed, each primary node is able to suggest a new itinerary to moving nodes, giving them the possibility of traveling on less congested paths, while reducing CO_2 emissions. Different simulations have demonstrated that, in most cases, the proposed $CARS$ scheme performs better than other protocols, and, if the values of α and thr are chosen belonging to $[0 - 0.5]$ and equal to -0.05 respectively, a good trade-off can be obtained. Further research activity will be focused on investigating how the parameters can be adjusted dynamically for each road segment, giving the possibility to the proposed scheme to adapt itself to different topographic conditions.

References

1. Da Cunha, F.D., Boukerche, A., Villas, L., Viana, A.C., Loureiro, A.A.F., "Data Communication in VANETs: A Survey, Challenges and Applications", [Research Report] RR-8498, INRIA Saclay. (2014)
2. Vegni A.M., Vegni C., Little T.D.C., "Opportunistic Vehicular Networks by Satellite Links for Safety Applications", In Proc. of the The Fully Networked Car Workshop, Geneva International Motor Show, Geneva, Switzerland, March 34, (2010)
3. Santamaria, A. F., S Giang, A.T., Busson, A., Veque V., "Message Dissemination in VANET: Protocols and Performances", Wireless Vehicular Networks for Car Collision Avoidance, pp 71-96, (2013)
4. Santamaria, A. F., S Socievole, A., Yoneki, E., De Rango, F., and Crowcroft, J., "Opportunistic message routing using multi-layer social networks". In Proceedings of the 2nd ACM workshop on high performance mobile opportunistic systems (pp. 39-46). ACM. (2013)
5. Fazio P., De Rango F., Lupia A., "Vehicular Networks and Road Safety: an Application for Emergency/Danger Situations Management Using the WAVE/802.11 p Standard", Advances in Electrical and Electronic Engineering 11 (5), pp. 357-364, (2013)
6. Fazio P., De Rango F., Lupia A., A new application for enhancing VANET services in emergency situations using the WAVE/802.11 p standard in Wireless Days (WD), IFIP, pp. 1-3, (2013)
7. Fazio P., De Rango F., Sottile C., Manzoni P., Calafate C., A distance vector routing protocol for VANET environment with Dynamic Frequency assignment, in Wireless Communications and Networking Conference (WCNC), IEEE, pp. 1016-1020, (2011)
8. De Rango F., Veltri F., Fazio P., Interference aware-based ad-hoc on demand distance vector (ia-aodv) ultra wideband system routing protocol, Computer Communications, Vol.34, Issue 12, pp. 1475-1483, (2011)
9. Toulni, H., Nsiri, B., Boulmalf, M., Bakhouya, M., & Sadiki, T. (2014, May). An approach to avoid traffic congestion using VANET. In Next Generation Networks and Services (NGNS), Fifth International Conference on (pp. 154-159). IEEE. (2014)
10. Pan, J.; Khan, M.A.; Popa, I.S.; Zeitouni, K.; Borcea, C., "Proactive Vehicle Rerouting Strategies for Congestion Avoidance,"Distributed Computing in Sensor Systems (DCOSS), 2012 IEEE 8th International Conference on, vol., no., pp.265,272, 16-18 May (2012)

11. De Rango F., Gerla M., Marano S., "A scalable routing scheme with group motion support in large and dense wireless ad hoc networks," in Computers & Electrical Engineering, 32 (1), pp.224-240, (2006)
12. Lee, W.; Lai, Y.; Chen, P., "A Study on Energy Saving and Emission Reduction on Signal Countdown Extension by Vehicular Ad Hoc Networks,"Vehicular Technology, IEEE Transactions on, vol.64, no.3, pp.890,900, March (2015).
13. Fazio P., De Rango F., Sottile C., Calafate C., "A new channel assignment scheme for interference-aware routing in vehicular networks," in IEEE 73rd Vehicular Technology Conference (VTC Spring), pp.1-5, (2011)
14. De Rango F., Veltri F., Fazio P., Marano S., "Two-level trajectory-based routing protocol for vehicular ad hoc networks in freeway and Manhattan environments," in Journal of Networks 4 (9), pp.866-880, (2009)
15. Fazio P., De Rango F., Sottile C., Santamaria A.F., "Routing optimization in vehicular networks: A new approach based on multi-objective metrics and minimum spanning tree," in International Journal of Distributed Sensor Networks, (2013)
16. Kurmis, M., Dzemydiene, D., Andziuli, A., Voznak, M., Jakovlev, S., Lukosius, Z., Gricius, G., Prediction based context data dissemination and storage model for cooperative vehicular networks, Advances in Intelligent Systems and Computing, 289, pp. 21-30, (2014)
17. De Rango F., Fazio P., Marano S., "Cell stay time analysis under random way point mobility model in WLAN", in Communications Letters, IEEE 10 (11), 763-765, (2006)
18. Li Zhu, F. Richard Yu, Bin Ning, Tao Tang: A joint design of security and quality-of-service (QoS) provisioning in vehicular ad hoc networks with cooperative communications. EURASIP J. Wireless Comm. and Networking 2013: 88 (2013)
19. Zhou B., Lee Y.Z., Gerla M., De Rango F., "GeoLANMAR: a scalable routing protocol for ad hoc networks with group motion," in Wireless Communications and Mobile Computing, Wiley, 6 (7), pp. 989-1002, (2006)
20. Sanguesa J. A., Barrachina J., Fogue M., Garrido P., Garrido P., Martinez F. J., Cano J.-C., Calafate C. T., and Manzoni P., "Sensing Traffic Density Combining V2V and V2I Wireless Communications", Sensors, vol. 15, issue 12, pp. 31794 - 31810. 2015.
21. Barrachina J., Garrido P., Fogue M., Martinez F. J., Cano J.-C., Calafate C. T., and Manzoni P., "Reducing Emergency Services Arrival Time by Using Vehicular Communications and Evolution Strategies", Expert Systems With Applications, 2013. ISSN 0957-4174.
22. Task Group p, IEEE P802.11p: Wireless Access in Vehicular Environments (WAVE), draft standard ed., IEEE Computer Society, (2006)
23. Fazio P., De Rango F., Selvaggi I., "A novel passive bandwidth reservation algorithm based on Neural Networks path prediction in wireless environments", in Performance Evaluation of Computer and Telecommunication Systems (SPECTS), 11-14, pp. 38-43, (July 2010)
24. De Rango, F., Veltri, F., and Marano, S., "Channel modeling approach based on the concept of degradation level discrete-time Markov chain: UWB system case study". Wireless Communications, IEEE Transactions on, 10(4), 1098-1107. (2011)
25. Kurmis, M., Andziulis, A., Dzemydiene, D., Jakovlev, S., Voznak, M., Drungilas, D., Development of the real time situation identi
cation model for adaptive service support in vehicular communication networks domain, Advances in Electrical and Electronic Engineering, 11 (5), pp. 342-348, (2013)
26. Festa D.C., Astarita V., Rilievi, Modellizzazione e controllo del traffico veicolare, Collana Trasporti, (2012)
27. Van Woensel T. and Vandaele N., "Modelling traffic ows with queueing models: A review AsiaPaci
c", Journal of Operational Research, 24(4):127, (2007)
28. Highway Capacity Manual, Transportation Research Board, Washington D.C., (2000)
29. Sajjad Akbar M., Asim R., Amir Q., "VANET Architectures and Protocol Stacks: A Survey", Communication Technologies for Vehicles Lecture Notes in Computer Science Volume 6596, pp.95-105, (2011)
30. Santamaria A.F. and Sottile C., "Smart Traffic Management Protocol Based on VANET architecture," AEEE, vol. 12 (4), December 2014.

31. Varga A. and Hornig R., "An overview of the OMNeT++ simulation environment", Proceedings of the 1st international conference on Simulation tools and techniques for communications, networks and systems workshops, (2008)
32. Sommer C., German R., Dressler F., "Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis," IEEE Transactions on Mobile Computing, vol. 10 (1), pp. 3-15, January (2011)
33. Behrisch M., Bieker L., Erdman J., Krajzewicz D., "SUMO Simulation of Urban MObility, An Overview", The Third International Conference on Advances in System Simulation, SIMUL (2011)
34. http://openstreetmap.it/
35. http://sumo.dlr.de/wiki/TraCI
36. Cappiello A., Chabini I., Nam E., Lue E., and Abou Zeid M., A statistical model of vehicle emissions and fuel consumption, 5th IEEE International Conference on Intelligent Transportation Systems (IEEE ITSC), pp. 801809, 2002