Vehicular Traffic Optimization in VANETs: a Proposal for Nodes Re-routing and Congestion Reduction

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Abstract. *Recently, vehicular networking has grown up in terms of interest and transmission capability, due to the possibility of exploiting the distributed communication paradigm in a mobile scenario, where moving nodes are represented by vehicles. The different existing standards for vehicular ad-hoc networks, such as DSRC, WAVE/IEEE 802.11p, have given to the research community the possibility of developing new MAC and routing schemes, in order to enhance the quality and the comfort of mobile users who are driving their vehicles. In this paper, we focus our attention on the optimization of vehicular traffic flowing, where the vehicle-2-roadside device is available. As shown in the next sections, 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. Several campaigns of simulations have been carried out to give more effectiveness to our proposal.*

Keywords

802.11p, congestion, DSRC, traffic flow, VANET, WAVE.

1. Introduction

Vehicular Ad-hoc NETworks (VANETs) represent a new and modern paradigm of communication, where the nodes are able to communicate in a distributed manner, based on the Ad-hoc paradigm [1]. Each node is equipped with a wireless device, the On-Board Unit (OBU), which is able to interact with the mobile user, especially for comfort/security applications, trade and infotainment services. The OBU devices are able to realize the pure Ad-hoc communication networking in VANETs, indicated with Vehicle-2-Vehicle (V2V) communication. The complete architecture also provides the, so-called, Road-Side Units (RSUs) which can also be any equipment-certified packet forwarding, such as GSM, WLAN, and WiMAX towers. These devices realized the, so-called, Vehicle-2-Infrastructure (V2I) paradigm. The RSUs are very useful for guaranteeing the complete coverage of an area when some distributed nodes are disconnected, giving the driver the possibility of still being able to receive the needed information. 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 [2]. 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 [3], [4]. 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. If also the near cars can receive the update, they would reduce inconveniences: platooning would be really helpful in order to leave the right space on the roads for the emergency vehicles, 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, we focus our attention 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. As shown later, in the next sections, the proposed algorithm, called Congestion Avoidance in Vehicular Environments (CAVE), 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 modelling by a weighted oriented graph, able to capture all the real-time system values. Each vertex and 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. As for the majority of the vehicular applications, the routing protocol covers a crucial importance for the whole architecture [5], [6]. It is important to consider scalability properties of protocols and architectures such as in [7], [8], [9], [10], or optimization techniques such as proposed in [11] in order to improve multiple metrics in the defined problem. The paper is structured as follows:

- Section 2. gives an in-depth overview on the related work about optimization schemes in VANETs and points out the main contributions given in this paper.
- Section 3. briefly introduces the standards and, then, describes in a detailed way the CAVE algorithm.
- Section 4. illustrates the obtained results, which confirm our expectations.
- Conclusions are resumed in section 5.

2. Related Works and Main Contributions

The aim of this work is to exploit the potential of the VANETs, building 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 the fuel consumption. Predictive approaches are appreciated in telecommunication systems, not only in vehicular environments [12], [13], [14]. In fact, in literature there are several works that try to get that benefit, using nodes mobility prediction policies and vehicular traffic re-routing approaches [15]. In particular, in [16] 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 tailor-made re-routing guidance to be pushed to vehicles when signs of congestion are observed on their route. They also allow tuning the system to different levels of the trade-off between re-routing effectiveness and computational efficiency. In [17], 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. In [18], 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 [19], the authors proposed a system able to reduce the travel times and the fuel consumption in different European cities. They also designed a Red Swarm architecture based on an evolutionary algorithm and on smart WiFi spots, located near traffic lights, which are used to suggest alternative routes for vehicles. In [20], 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 [21], authors developed and implemented an instantaneous statistical model of emissions (CO_2, CO, HC, NO_x) 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 (also used for our simulations).

The main contribution of this paper consists in the proposal of a new traffic re-routing algorithm, able to manage the mobility patterns of vehicles for evaluating new routes on the roads with a lower traffic density. In particular:

- The vehicular network is modeled by an oriented and weighted graph, for which the weights are dynamically updated based on the number of vehicles on the different streets.
- New paths are evaluated by taking into account the average congestion level on the paths, so the CAVE algorithm is needed for reducing the average size of the queues and the CO_2 emissions.

3. VANETs Introduction and the CAVE Algorithm

This section gives a detailed description of the proposed CAVE algorithm, after a brief introduction of vehicular environments and its different standards.

3.1. Vehicular Communications Through VANETs

Different proposed and accepted standards have contributed to the rapid growth of vehicular architectures. VANETs are able to provide wireless networking capability in situations where the communication among nodes can be either direct or made via relaying nodes, as in classical Ad-hoc networks. The IEEE 802.11p, also called Wireless Access in Vehicular Environments (WAVE) [22], 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 an urban or sub-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 ACs (Access Classes), where AC0 has the lowest and AC3 the highest priority. Within the MAC layer, a packet queue exists for each AC. Figure 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, not only considering the type of traffic (emergency, security, platooning, etc.) but, mainly, focusing on the reduction of the inter-node interference.

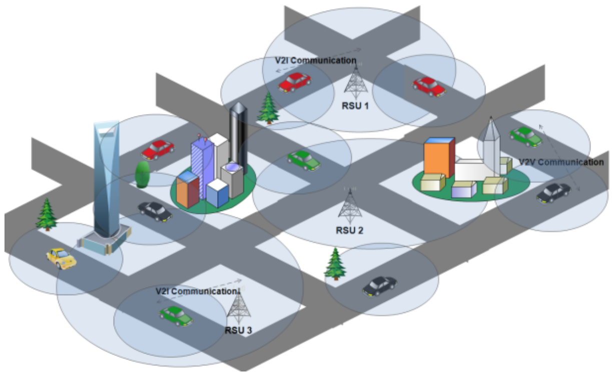

Fig. 1: An example of a typical VANET scenario.

The Dedicated Short Range Communication (DSRC) [23] 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 8 μs. 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 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.

3.2. The Congestion Avoidance in Vehicular Environments (CAVE)

Now the proposed idea is deeply illustrated. First, some basic definitions are given. Then the graph model is introduced, as well as the main steps of the algorithm.

1) Geographical Map Representation

The predictive forwarding scheme applies to a generic map (a square, rectangular or circular area). It is composed of a set of RoaDs $RD = \{r_1, \ldots, r_m\}$ (considered, traditionally, as hard flat surfaces for vehicles, people, and animals to travel on) modeled as lines, a set of Road Side Units (primary nodes) $RSU = \{p_1, \ldots, p_n\}$ modeled as points belonging to one or more lines (e.g. if their coverage range contains more than one road, as at intersections or if there are near parallel roads), and a dynamic set of Mobile Hosts (secondary nodes) $MH(t) = \left\{s_1, \ldots, s_{q(t)}\right\}$ (vehicular nodes enter and exit the map dynamically during time). Each primary node p_k on the map is considered as a point with coordinates $(x_{0k}, \ y_{0k})$ and a coverage radius R_k. We have $\|RD\| = m$, $\|RSD\| = n$ and $\|MH(t)\| = q(t)$. A road segment is defined as a portion of the road that interconnects two primary nodes p_i and p_j, starting from $p_i = (x_{0i}, \ y_{0i})$ and ending in $p_j = (x_{0j}, \ y_{0j})$. So, the set Road Segments (RS) can be defined as:

$$RS = \{rs_{ij} \mid \exists r_k \in RD, \ rs_{ij} \subseteq r_k, \ vertices \ p_i, \ p_j \in RSU\}. \tag{1}$$

Clearly, a road segment $rs_{ij} \in RS$ may coincide with a whole road $r_l \in RD$.

2) The Weighted Oriented Graph Associated to the Map

Given the definitions above, the whole system topology can be modeled by a Weighted Oriented Graph $WOG = \langle V, E, W \rangle$, where V is the set of vertices and each vertex is associated to a single primary node, so $\|V\| = \|RSU\| = n$, E is the set of edges, and W is the set of weights associated with each element of E. A couple of nodes v_i and v_j in WOG are neighbors if there exists $r_{si} \in RS$ such as vehicles can flow from p_i to p_j.

In our abstraction, we are not caring if an RSU is deployed at the road-side or its center. So, differently from the classical approaches based on the electromagnetic coverage, two nodes in the graph are directly connected by roads, disregarding the coverage radius of the associated $RSUs$. This is because we are caring about vehicles traffic (not data traffic) and the roads physical parameters need to be taken into account. In addition, if two primary nodes p_i and p_j are reciprocally covered (classical adjacency), then they are considered as one RSU node p_k. That is to say, if $\exists p_i,\ p_j \in RSU$ such that $p_i \in A|p_j$ and $p_j \in A|p_i$, where $A|p_l$ represents the coverage area of node p_l, belonging to $(x - x_{01}) \cdot 2 + (y - y_{01}) \cdot 2 = R_{12}$, then the nodes p_i, p_j are removed from RSU and the new node p_k with coordinates and coverage radius:

$$x_{0k} = \frac{(x_{0i} + x_{0j})}{2}, \tag{2}$$

$$y_{0k} = \frac{(y_{0i} + y_{0j})}{2}, \tag{3}$$

$$R_k = \frac{(2R_i + 2R_j - Overlap_{i,j})}{2}, \tag{4}$$

is added to RSU (and, consequently, to the set V of WOG). The term $Overlap_{i,j}$ represents the average diameter of the coverage area shared among p_i and p_j. Figure 2 illustrates the overlapping for two primary nodes p_i, p_j. In this way, we are assuming that, in our WOG, there are no nodes with overlapping coverage area. Moreover, we assume that WOG 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 WOG, as illustrated in Fig. 3. If there are more than one road segments that interconnect two primary nodes, then the set E will contain some so-called multi-arcs (WOG will not be a simple graph). In Fig. 3 $RSU = \{p_1,\ \ldots,\ p_{11}\}$, so n=11, $RD = \{r_1,\ \ldots,\ r_{10}\}$, so $m = 10$, $V = RSU$; for sake of simplicity, the coverage radius has been represented to be the same for each primary node (R_k=65 meters, $\forall p_k \in RSU$).

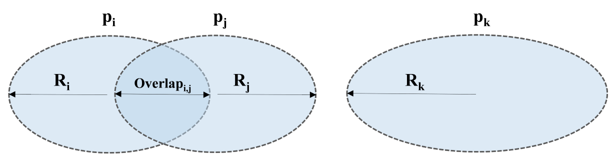

Fig. 2: The concept of primary nodes coverage overlapping and the new logical primary node p_k.

3) How to Define the Weights of the Oriented Graph and Assumptions

At this point, some assumptions have to be made:

- We assume that each vehicle knows exactly the best path to arrive to destination: the OBU of each secondary node $s_l \in MH(t)$ is integrated with a GPS device, on which the driver has set the itinerary before starting the trip.
- When the secondary node s_l arrives under the coverage of the first road-side unit of the system, it points-out the itinerary that will be followed, by sending to the primary node the sequence of road-segments $IT_{sl} = r_{sl1},\ r_{sl2},\ \ldots,\ r_{slm}$ and the related moving directions; 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.
- If the secondary node $s_l \in MH(t)$ signals to the system that it is going to be parked on a particular road-segment, the first road-side unit that receives the message will temporary remove node s_l from $MH(t)$; the node s_l will belong to $MH(t)$ again when it decides to move on the road; if s_l is not covered by any primary node, the message will be forwarded on the basis of the V2V paradigm.
- After the initial communication (as described in the previous point), there is also a periodical communication: each primary node broadcasts a polling message to all the covered secondary nodes; this approach is needed for giving knowledge to the primary node of the presence of each vehicle in the covered area.
- Finally, each secondary node $s_l \in MH(t)$ puts into polling answers 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.

Now, the way the weights are determined is illustrated. All the nodes of the WOG store the weights of the edges in a data-structure (we do not care if it is a data-base or something different), associated to the adjacencies matrix of WOG.

It is a shared structure, so each primary node can send an update message to a dedicated server. We can distinguish among update/increase and update/decrease messages. In fact:

- Update/increase: each time a secondary node $s_l \in MH(t)$ leaves a primary node coverage area

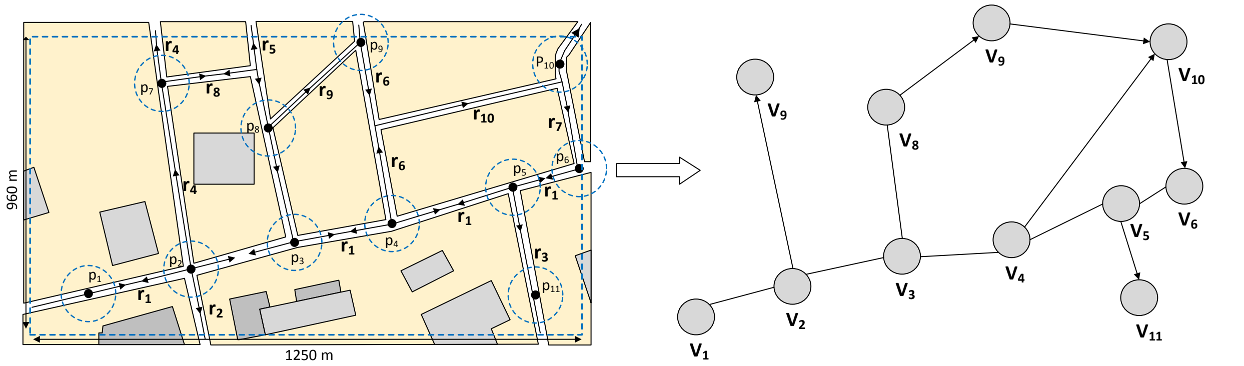

Fig. 3: An example of *RSU* placement in a map of 1250×690 square meters (on the left) and the related *WOG* (on the right).

$A|p_i$, the node p_i knows exactly the itinerary of s_l, 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_{ij}, and node p_i can signal an increment of one unit of the weight $w_{i,j} \in W$. Based on the definition given before for the set W, we recall that the term $w_{i,j}$ represents the number of vehicles on the edge from v_i to v_j.

- Update/decrease: each time a secondary node $s_l \in MH(t)$ enters a primary node coverage area $A|p_j$, the node p_j, aware about the road segment from which s_l arrived, knows the primary node p_i that was serving s_l before. At this point, node p_j can signal to the system that the number of mobile nodes traveling on segment rs_{ij} is decreased by 1, as well as the weight $w_{i,j} \in W$.

4) The CAVE Steps

The core of our proposal is now illustrated. We resume the main steps of the CAVE algorithm in a pseudo-code and, then, we explain them.

- **Step 0** (Initialization): Given the map and the *RSU* placements, create the $WOG =< V, E, W >$ with Eq. (5), Eq. (6) and Eq. (7).

  This step simply consists in the construction of the main structure, the *WOG*, shared in the whole system and able to store the main parameters needed for CAVE.

- **Step 1** (Departure of a mobile node s_l from the coverage of v_i): Increase $w_{i,j}$; This step simply consists in the increasing of the $w_{i,j}$ weight, because of a departure of a mobile secondary node s_l from $A|p_i$ towards $A|p_j$.

- **Step 2** (Arrival of a mobile node s_l in the coverage of v_j): This step represents the core of the CAVE algorithm Alg. (1). When a secondary node arrives into the coverage of a road-side unit p_j, if it is the first primary node, the itinerary IT_{sl} is acquired, otherwise, if the node arrives from the road-side unit p_i, the weight $w_{i,j}$ is decreased (the number of vehicles on the road-segment rs_{ij} has decreased by one). The following pseudo-code explains the main operations that are carried out in the case of mobile node arrival.

$$\|V\| = \|RSU\| = n, \tag{5}$$

$$\|E\| = \|RS\|, \tag{6}$$

$$w_{i,j} = 0 \forall (v_i,\ v_j) \in E. \tag{7}$$

Algorithm 1 The CAVE pseudo-code in the case of MH arrival.

```
if ∃v_j ∈ V / s_l ∈ A|p_j{
if s_l ∉ MH(t){
add s_l to MH(t);
acquire IT_sl;}
else degrease  w_i,j;
if is_congested (IT_sl){
update (IT_sl);
re-route (s_l);}}
```

In every case (in the sense that p_j may not be the first visited primary node), the itinerary of the secondary node s_l is checked. Each primary node checks if IT_{sl} contains any congested road segment. In particular, the *is_congested*(.) function is based on the following observations. Based on the definitions and studies in [24], [25], we know that the capacity can be defined as "*the maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental, and control conditions*". Following the theory in [24] and the notations used in our paper, we can express some basic relationships and diagrams as follows:

$$K_{i,j} = \frac{w_{i,j}}{\| rs_{i,j} \|}, \tag{8}$$

$$I_{i,j} = K_{i,j} \cdot v_{i,j}, \tag{9}$$

$$td_{i,j} = \frac{\|rs_{i,j}\|}{v_{i,j}}, \tag{10}$$

where $k_{i,j}$ is defined as the traffic density on the road segment $rs_{i,j}$, given by 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 $I_{i,j}$ is the traffic intensity, defined as the product of $k_{i,j}$ and the average speed $v_{i,j}$ of $rs_{i,j}$. The term $td_{i,j}$ represents the trip delay of the road-segment $rs_{i,j}$, that is to say, the time needed to travel across the road-segment. Clearly, $k_{i,j}$ and $I_{i,j}$ are functions of time; the only constant term is $\|rs_{i,j}\|$. There are many fundamental diagrams in the traffic flow theory, as the one depicted in Fig. 4, representing the relationship between the density and the speed of a road segment. From the previous figure, we can observe how the average speed on a road segment decreases when the density increases, until the value k_{jam}, for which the mobility on the road is completely blocked.

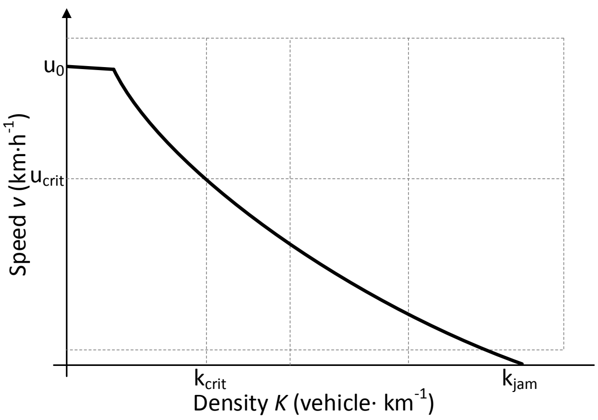

Fig. 4: The classical trend of the function relating density and speed.

From [25]; the value k_{crit} brings the road segment to be in the ideal situation, with the maximum traffic volume (measured in *vehicles/time*). In our work, we are not considering bigger roads with more lanes on the same direction. Considering ideal conditions, the maximum capacity can be numerically obtained by fitting the curves, but the more complex analytical analysis should be carried out for real cases. In particular, from [26] it can be written that, for a motorway, the capacity $c_{i,j}$ of the road-segment $rs_{i,j}$ is:

$$c_{i,j} = C_{i,j} \cdot N_{i,j} \cdot FW_{i,j} \cdot FHW_{i,j} \cdot FP_{i,j}, \tag{11}$$

where $C_{i,j}$ is the ideal capacity, $N_{i,j}$ 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. In our proposal, the algorithm should guarantee that $k_{i,j} \cong k_{criti,j}$ for each $rs_{i,j} \in RS$. So, after these considerations, the $is\_congested(.)$ function returns true if and only if the following condition is satisfied:

$$\exists rs_{li,j} \in IT_{sl} | w_{i,j} > (1 + \alpha_{ij}) \cdot k_{criti,j} \cdot \|rs_{i,j}\|, \tag{12}$$

where $k_{criti,j}$ is the desired average density for $rs_{i,j}$ and $\alpha_{i,j}$ is a near-to-zero value representing the maximum tolerable deviation from the desired value. With the term $\alpha_{i,j}$ we want to analyze what happens to the system when we consider a different maximum capacity on a given road. When Eq. (12) is satisfied, the algorithm will find an alternative itinerary for s_l, if it exists, which involves different/alternative road-segments, with lower weights (in terms of density and trip delay). So, each road-side unit $p_k \in RSU$ is able to evaluate the alternative paths since it exactly knows the WOG structure.

In the paper, we are not caring about the signaling protocol needed to carry out the proposed idea. Generally, a Modified Adjacencies Matrix (MAM) can represent the entire WOG. It is an n×n matrix, with each element equals to:

$$MAM(i,j) = (w_{i,j} \, \|rs_{i,j}\| \, I_{i,j}, td_{i,j}), \tag{13}$$

We assume that the CAVE module of the covering node p_k can apply the Dijkstra algorithm to evaluate the best path from v_k to v_D, where v_D is the destination node of the vehicle s_l using, in general, the Weighted Cost Term (WCT) associated with each edge (v_i, v_j) of path P:

$$\begin{aligned} WCT\ _p(v_i, v_j) &= \Theta_1 \cdot \frac{k_{v_i,v_j}}{k_P^{max}} \\ &+\Theta_2 \cdot \frac{I_{v_i,v_j}}{I_P^{max}} + \Theta_3 \cdot \frac{td_{v_i,v_j}}{td_P^{max}}, \end{aligned} \tag{14}$$

where Θ_i are weighting terms and k_P^{max}, I_P^{max}, td_P^{max} are the maximum terms evaluated on path P. In this way, more effectiveness to different factors can be given, when choosing the metric that has to be evaluated. The relation $\sum_{i=1}^{3} \Theta_i = 1$ should always be satisfied. From Eq. (14), we can write the expression of the average WCT for a whole path P:

$$WCT\ (P) = \frac{1}{\|P\|} \sum_{k=1}^{\|P\|} WCT\ _p(e_k), \tag{15}$$

where $\|P\|$ represents the length of P expressed in number of edges. So, once the Θ_i terms are set, we can evaluate all the possible paths from v_k to v_d as the set $P(v_k,\ v_D) = P_1,\ \ldots,\ P_m$ with the related weights. The best path $P^*(v_k,\ v_D)$ will be evaluated as:

$$P^*(v_k, v_D) = min_{WCT(P)}\,\{P_1,\ \ldots,\ P_m\}\,. \qquad (16)$$

In this way, the CAVE algorithm will complete the update (IT_{sl}) operation by substituting $IT_{sl} = P^*(v_k, v_D)$ if:

$$WCT(IT_{sl}) > WCT\left[P^*\left(v_k, v_D\right)\right]. \qquad (17)$$

If the relation in Eq. (17) is satisfied, the *re-route*(s_l) function will send to the MH s_l the updated itinerary. In the next section, simulation results are shown.

4. Performance Evaluation

In this section, we show the results achieved using the CAVE algorithm that we have already introduced in previous sections, comparing it with the behaviors provided in Wave Short Message Protocol (WSMP) [27] and the Smart Traffic Management Protocol (STMP).

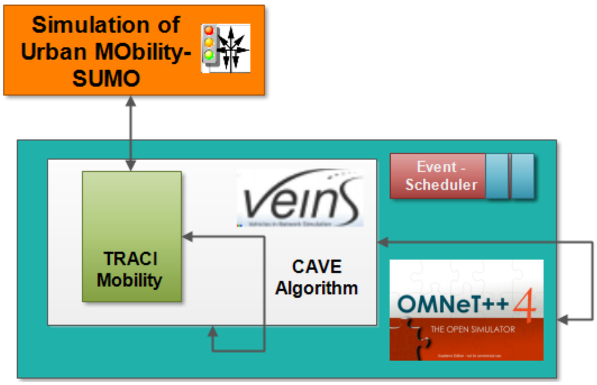

Fig. 5: Simulation Environment.

First of all, we introduce a description of the simulation environment and used constraints in order to better understand how we proceeded. Then, the obtained results are described. The OMNet++ Simulator [28] with Veins [29] framework has been used to develop our proposal. It is a network simulator based on a modular implementation, written in C++. To manage vehicles mobility, the network simulator is connected with SUMO [30] (Fig. 5). The CAVE algorithm has been implemented on the Veins framework, also introducing the main IEEE 802.11p rules and components, such as $RSUs$. The aim of this section is to show the goodness of the proposal in terms of traffic management and reduction of CO_2 emissions.

Using the whole framework, it is possible to spread the traffic load better along the considered area. It is also possible to observe that the new algorithm helps the vehicles to reduce their travelling time around the map. The main simulation parameters are illustrated in the table:

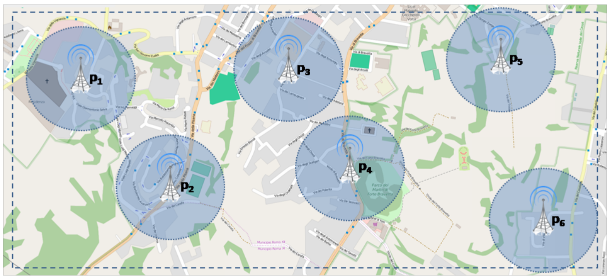

Fig. 6: The considered roads map.

Tab. 1: Simulation parameters.

Parameter Name	Value
Vehicles Input Rate	80, 150, 300, 500 [vehicles $\cdot$ h^{-1}]
Size of the map	[3000×1500] m
Average speed	15 m $\cdot$ s^{-1}
Number of Road (RD)	$\{r_1,\ \ldots,\ r_{20}\}$
Road Side-Unit (RSU)	$\{p_1,\ \ldots,\ p_6\}$
Road Segments $(rs_{i,j,n})$	$\{rs_{1,3,5},\ rs_{1,2,2},\ rs_{2,3,4},\ rs_{3,5,1}$ $rs_{3,5,1},\ rs_{4,5,1},\ rs_{5,6,1},\ rs_{4,6,1}\}$
RSU coverage radius	300 m

Regarding the notation of the road segments (rs), we used this terminology: $rs_{i,j,k}$ where i and j are the pedices related to the two adjacent primary nodes $p_i,\ p_j \in RSU$ and k is the total number of road segments present between p_i and p_j. In Fig. 7 the trend of CO_2 emissions is shown, varying the density of nodes.

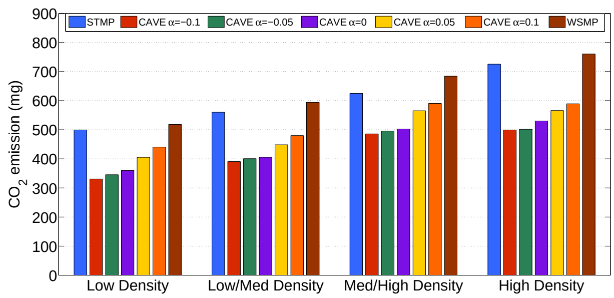

Fig. 7: Average CO_2 Emission versus nodal density.

The CAVE algorithm obtains a better result in terms of emissions reduction, because it uses the mechanism of the re-routing strategy for the vehicles, in order to spread the mobile nodes in the various available road segments, mitigating the vehicular congestion. Figure 8 shows that the CAVE algorithm reduces the residence time of the vehicles on the map, with a consequent reduction of fuel consuption, emissions and road congestion. This is due to the re-routing of the new itinerary, which brings the drivers to choose less congested paths. Figure 9 shows that using the mechanism of vehicles re-routing, the proposed algorithm outperforms the other approaches in terms of an average number of vehicles present on the considered road segments. This is possible because the CAVE algorithm can address the vehicles on the less congested available road segments.

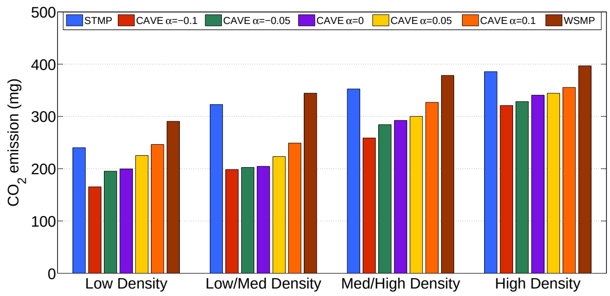

Fig. 8: Vehicles travel time versus nodal density.

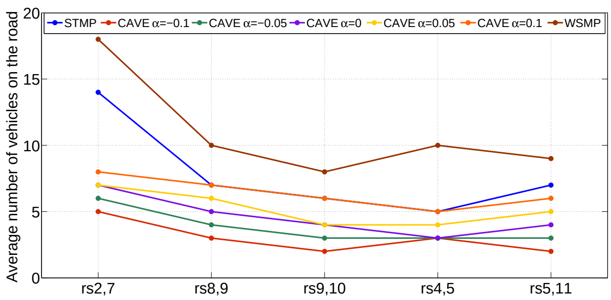

Fig. 9: Average number of vehicles on the considered road segment (rs_{ij}).

5. Conclusions

In this paper, we proposed a new traffic optimization algorithm, very suitable for vehicular environments. We focused our attention on the reduction of roads density, with the proposal of a map model, based on a weighted oriented graph. The core idea consists in the evaluation of a re-routing strategy, based on the analysis of the roads structure, able to reduce also the CO_2 emissions. We investigated about the effectiveness of the proposed idea, obtaining very satisfactory results in terms of emissions and travel time reduction.

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