A New Distributed Predictive Congestion Aware Re-Routing Algorithm for CO_2 Emissions Reduction

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***Abstract*—In the last years, 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 dedicate short range communication (DSRC), wireless access for vehicular environment (WAVE)/IEEE802.11p, have given to the research community the possibility of developing new medium access control (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 traffic flowing in a vehicular environment with vehicle-2-roadside capability. As shown later, the proposed idea exploits the information that is gathered by road-side units to redirect traffic flows (in terms of vehicles) to less congested roads, with an overall system optimization, also in terms of carbon dioxide emissions reduction. An analytical model, as well as a set of pseudo-code instructions, have been introduced in the paper. A deep campaign of simulations has been carried out to give more effectiveness to our proposal.**

***Index Terms*—VANET, IEEE 802.11p, wireless access for vehicular environment (WAVE), dedicate Short Range Communication (DSRC), congestion, traffic flow, predictive re-routing, CO_2 emissions.**

I. Introduction

IN THE last years, the interest in vehicular opportunities and potentialities has drastically grown, due to the numerous advantages inherited from mobility solutions in urban/suburban environments. In particular, *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], [2].

VANETs are going to be considered as one of the first adhoc networking reality in nowadays applications, enabling the transmission among nearby vehicles as well as between vehicles and nearby external devices. In fact, each node is equipped with a wireless device, the *On-Board Unit* (OBU), which is able to interact with the infrastructure equipment for comfort/security applications, trade and infotainment services.

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The main reason for which VANETs have been standardized consists in the deployment of real-time and safety applications for drivers and passengers: they are able to broadcast real-time alerts to drivers about risks on their planned journey and their immediate surroundings [3]. Under these considerations, it can be stated that especially in the last years, vehicular networks are promising in a number of useful driver and passenger oriented services which include, for example, on-demand Internet connections and multimedia services. In general, scalability and interoperability are two important issues that should be satisfied, deploying adequate protocols and mechanisms able to interoperate with numerous vehicles and different wireless technologies. On this subject, it is known that *Vehicle-2-Vehicle* (V2V) communication allows the development of new applications which lean on reliable lower-layer protocols [4]–[6]. Moreover, drivers would like to avoid congested roads during their journeys. In this paper, we focus our attention on the optimization of traffic flowing in a vehicular environment with*Vehicle-2-Infrastructure* (V2I) capability.

A statistical predictive approach is proposed, based on the analysis of vehicles dynamics. Our idea allows the considered vehicular network to re-route all the vehicles on new paths towards destinations, avoiding useless time wastages, reducing the traffic density, intensity and the creation of harmful Carbon Dioxide (CO_2) emissions [7]. In this way, the traffic is distributed among different alternative roads, obtaining a probabilistic load balancing, based on a deep statistical characterization of user movements. The proposed algorithm, called *Predictive RE-routing in Vehicular Environments* (PRE-VE), exploits the information that is gathered by *Road Side Units* (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. In particular, and differently from the existing works, in PRE-VE each RSU is able to collect mobility information from mobile hosts, using this knowledge to predict the best route for each user. The proposed approach learns the current traffic situation by a proper message exchange among RSUs and OBUs, while the needed information is stored: a statistical analysis is performed on the collected data and the system is modeled by an oriented graph, strictly related to the mobility directional behavior of mobile nodes. Different simulation campaigns have been carried out, to verify the goodness of PRE-VE protocol. In this work, we propose different scenarios with a different configuration in an urban environment to investigate the influences of protocol parameters on the goals meets.

We also propose a brief comparison between static and dynamic approaches presented in the literature to compare the results. We focused on the effectiveness of the protocols to reduce the side effects of high congestion level in terms of city traffic. To achieve these results, we propose a dynamic traffic generator that can be tuned to create different scenarios (light/moderate/high traffic levels). In such scenarios, we analyze the results in terms of CO_2 emission, distances traveled by vehicles and their traveling time. Finally, we investigate PRE-VE performances in terms of the communication protocol for V2V and V2I segments, showing the protocol overhead. The paper is structured as follows: Section II 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 III introduces an overview of the main standards and, then, describes in detail the PRE-VE algorithm, with a deep explanation of the joint statistical approach. Section IV illustrates the simulation environment and the obtained results, which confirm our expectations and, then, Section V concludes the paper.

II. State of the Art and Contributions

In recent literature, there are several works that try to exploit *Intelligent Transportation Systems* (ITS) to improve environmental conditions using vehicular traffic re-routing approaches. One of the common trends is to increase roads capacity in order to improve roads efficiency, while significant reductions in emissions can be obtained through the deployment of green applications, improving environmental performance [8], in terms of air pollutants (e.g., CO, NO, NO_2), energy consumption (diesel or gasoline for example) or greenhouse gases (e.g., CO_2, CH_4, and N_2O). In vehicular environments, different approaches for applying green ITS principles exist:

Speed variation: the driver may adapt the travel speed to the driving context when a warning message is displayed, or a vehicle control system may analyze the collected traffic information and automatically slow-down or speed-up the vehicle. In [9] the authors propose a new approach for vehicles communications which tries to find an optimal path. This solution lower travel time and fuel consumption. Moreover, the proposed approach can reduce congestion and queues in the existing road infrastructures. In [10] the authors propose two models: the *Maximize Throughput Model* (MaxTM) and the *Minimize Acceleration and Deceleration Model* (MinADM), to provide green driving suggestions and to 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 [11], the authors developed an ITS based on multi-mobile agent systems and VANETs. This approach enables individual vehicle drivers to make quick responses to the road congestion. The drivers around the congestion area can also make the appropriate decision before entering a congested road. In [12] real time performance traffic data gathered from real-world experiments are used to dynamically define vehicle speed against local congestion. The results are sent to vehicle drivers using wireless communication (GPRS, dedicate short range communication (DSRC)) and then displayed. Authors of [13] show how to reduce energy waste and emissions without significantly increasing travel time. A model-based traffic controller is presented in [14], to reduce pollutant emissions. An important trade-off between travel time and total emissions is pointed out by various simulation results. Furthermore, this work demonstrated that speed limit control can improve travel time or area-wide emissions in non-congested conditions.

Itinerary management: gathered information are used to suggest the best path to destination to drivers. The needed information is collected in real-time and local state information systems are needed. In [15], the authors proposed some traffic re-routing strategies designed to be incorporated in a cost-effective and easily deployable vehicular traffic guidance system able to reduce travel time. These strategies proactively compute individually tailored re-routing paths pushed to vehicles when signs of congestion are observed on their route and they also allow the tuning of the system to adapt to different trade-off levels between re-routing effectiveness and computational efficiency. In [16], 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 [17], the content dissemination issue in VANET has been explored. The authors formulated an optimization problem to maximize content dissemination from the infrastructure (cellular) to vehicle. They found that content can be spread among a large number of vehicles with a minimal use of the cellular infrastructure (at low cost), if some delay is allowed.

Deployment of road devices: junction conflicts can be solved through the deployment of dedicated control systems (for example traffic lights), statically (a-priori computed and fixed signal plans) or dynamically (the plans are adapted to traffic conditions). In [18], 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. 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 this 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 [19] a metric based on control delay and queue length is proposed to describe and adaptive traffic signal control exploiting V2I communication. Classical control methods are outperformed by the new proposed system in terms of CO_2 emissions by 6.5%. In [20] an innovative co-operative vehicle intersection control system for autonomous vehicles is proposed. The results in a corridor scenario reported in [21] show a significantly improved traffic (up to 20% travel time reduction), a remarkable safety increase (up to 87% less crash events) and a fuel consumption reduction that affects also CO_2 emissions (up to 37% less fuel consumption). These results are obtained again for a conventional intersection control in which vehicles stop and restart.

Vehicle control: the in-vehicle sensors give the possibility to follow the vehicles ahead and the system adapts the speed of the following vehicle to respect inter-vehicle distance. Generally, it is referred as a collaborative approach. The article [22], in fact, proposes a new traffic congestion avoidance approach which aims to a collaborative identification and reduction of vehicular traffic congestion. It is based on V2V and V2I communications and it uses a fuzzy logic-based system to manipulate qualitative vehicles information in order to find a local traffic congestion. The authors provide a series of simulation results showing how their proposal can efficiently detect and face congestion situations. To maintain a good travel efficiency and comfort minimizing CO_2 emissions an Adaptive Cruise Control system is presented in [23]. Through many simulations, the authors show that the EcoACC system is capable of lowering emission rates due to a smoother vehicle behavior. These results heavily depend on variables as level of disturbance, system penetration rate or specific scenario. In [24] the authors show the mobility and environmental benefits of a cooperative ACC version. This system ensure that vehicles arrive at stop light on a green light by adjusting speed avoiding stop light decelerations/accelerations. In this way a significant reduction in delay (91%) and fuel consumption (75%) is obtained.

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:

- A predictive approach has been introduced, in order to take into account the directional behavior of vehicles; each RSU is aware of the average mobility behavior of vehicles, the directional preferences of mobile hosts are statistically analyzed and deployed when re-routing operations are needed;
- The vehicular network is modeled through an oriented and weighted graph, for which the weights are dynamically updated on the basis of the number of vehicles on the different streets;
- Evaluation of new paths by taking into account the average congestion level on the graph edges, so the PRE-VE algorithm is needed for reducing the average queue sizes, CO_2 emissions and the average density of each road.

Differently from the existing approaches, PRE-VE does not take into account only the current congestion level, but it considers also the future movements of mobile hosts, knowing statistically and in-advance the dynamics of the roads of the considered geographical map. In the next section, the main idea of PRE-VE is described.

III. The PRE-VE Algorithm

This section gives a detailed description of the proposed PRE-VE algorithm. We avoid to give several details about VANETs and their standards [25], [26]. The proposed idea is deeply illustrated: first of all the considered problem is briefly described, then some basic definitions are given. The graph model is introduced, as well as the statistical approach and the main steps of the algorithm.

TABLE I
Main PRE-VE Abbreviations and Symbols

$r_1, \ldots, r_m$	Set of roads
$p_1, \ldots, p_n$	Set of Road Side Units or primary nodes, placed at intersections can belong to different roads
$s_1,\ldots,s_{q(t)}$	Secondary Nodes (vehicles)
x_{0k}, y_{0k}	Primary Nodes coordinates
R_k	Coverage radius of a generic RSU p_k
m	Roads set cardinality
n	RSU set cardinality
$q(t)$	Secondary nodes cardinality (time dependant)
rs_{ij}	Road segment that interconnects p_i and p_j
S^i_{ho}	Set of possible directions $d_{1i},\ldots,d_{ni}$ that secondary nodes can take in each vertex
$m_i \in M$	Mobility Matrix associated at p_i *vertex*
d_{1i}	Direction 1 from vertex i
v_i	Vertex of the weighted oriented graph.
w_{ij}	Edge Weight as the number of secondary nodes that are moving from A|p_i *to* A|p_j
$m_i(j,k)$	Probability that a secondary node goes through d_{ik} given that it comes from d_{ij}

A) Problem Statement

The proposed idea aims to optimize vehicle movements among a geographical area, with the main objective of reducing congestion levels on the roads and, consequently, the overall emissions. Differently from the existing schemes (already illustrated in the previous section), each RSU has the possibility of storing vehicles' mobility traces, analyzing and statistically deploying them when a re-route operation is needed. In this way, each RSU predictively contributes to new itinerary suggestion, since it is possible to have a statistical knowledge of the future vehicle density on the considered roads. First of all, in the next sub-sections, the system model is illustrated, then the core of PRE-VE is deeply explained. Table I summarizes the main symbols and abbreviations.

B) Geographical Map Representation

The proposed idea is applicable to a generic geographical map (a square, rectangular or circular area). It is composed by 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 RSUs (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) $MH(t) = \{s_1, \ldots, s_{q(t)}\}$ (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

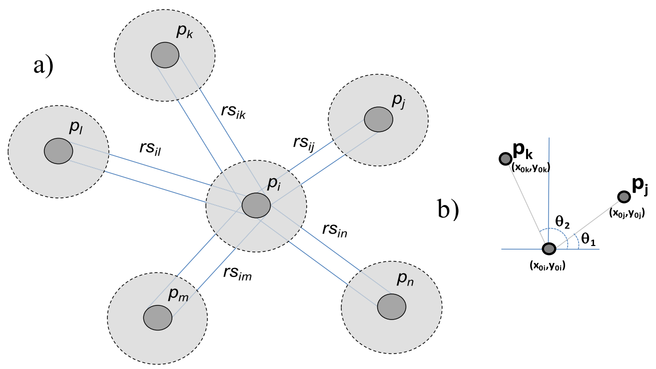


Fig. 1. Primary nodes and vertices representation in *WOG*.

a coverage radius R_k. We have $||RD|| = m$, $||RSU|| = n$ and $||MH(t)|| = q(t)$. A road segment is defined as a portion of 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:

$$RS = \{rs_{ij} | \exists r_k \in RD, rs_{ij} \subseteq r_k, vertices\, p_i, p_j \in RSU\} \quad (1)$$

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

C) The Weighted Oriented Graph (WOG) Associated to the Map

Given the definitions above, the whole system topology can be modeled by a *Weighted Oriented Graph WOG* = <*V,M,E,W*>. *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, *W* is the set of weights associated to each element of *E*, and *M* is the matrices set, defined later, with $||M|| = n$. The set *E* is time-dependent because, as shown later, some edges can be temporary deleted. A couple of nodes v_i and v_j in *WOG* are neighbors if there exists $rs_{ij} \in RS$ such as vehicles can flow from p_i to p_j. In our work, the entities related to $p_i \in RSU$ and $v_i \in V$ are different, but the concept is the same: p_i represents the road-side unit of the vehicular network, while v_i is the related vertex belonging to the *WOG*, used to model the whole network in the considered map. So, for each vertex $v_i \in V$ a set S^i_{ho} of n_i movement directions $d_{1i} \ldots d_{ni}$ can be introduced: $S^i_{ho} = \{d_{1i}, \ldots, d_{ni}\}$ and $||S^i_{ho}|| = n_i$. On the basis of the adjacency definition given above, we can write that $||Adj(v_i)|| = ||S^i_{ho}|| = n_i, \forall v_i \in V$, where $Adj(v_i)$ is the set of nodes neighbors to v_i. Each moving direction is associated to a road-segment rs_{ij}, connecting p_i to p_j. Following the representation in Fig. 1a, we have the primary node p_i, connected with primary nodes p_j, p_k, p_l, p_m, p_n, through the road segments rs_{ij}, rs_{ik}, rs_{il}, rs_{im}, rs_{in}. So we have $S^i_{ho} = \{d_{1i}, \ldots, d_{5i}\}$ and $||S^i_{ho}|| = n_i = 5 = ||Adj(v_i)||$. The road-segment directions can be expressed as θ degrees [rad.], as in Fig. 1b.

In our abstraction, we are not caring if a *RSU* is deployed at the road-side or at its center. So, differently from the classical approaches based on the electromagnetic coverage, two nodes in the graph are directly connected only by roads, disregarding

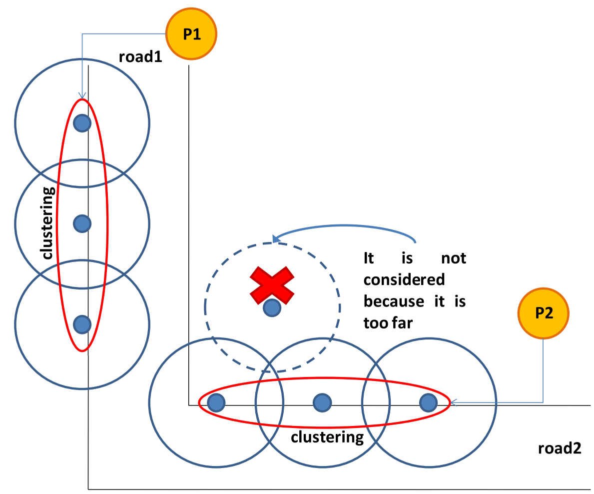


Fig. 2. The concept of primary nodes coverage overlapping and the new logical primary node p_k.

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 several primary nodes $p_1, \ldots, p_n$ are reciprocally covered (in the sense that p_i and p_{i+1} share a common coverage area), then a particular clustering approach is considered, in order to obtain only one RSU. In general, referring to Fig. 2, if $\exists p_1, \ldots, p_n \in RSU$ such that $p_i \in A|p_{i+1}\, p_{i+1} \in A|p_i$, where $A|p_i$ represents the coverage area of node p_i, belonging to $(x - x_{0i})^2 + (y - y_{0i})^2 = R_i^2$, with *i = 1…n*, then, under certain conditions, the nodes p_1, p_n are removed from RSU and the new node p_k with coordinates and coverage radius

$$x_{0k} = \frac{x_{01} + x_{02} + \cdots + x_{01} + x_{0n}}{n},$$
$$y_{0k} = \frac{y_{01} + y_{02} + \cdots + y_{0(n-1)} + y_{0n}}{n}$$
$$R_k = \sum_{i=1}^{n} 2R_i - \sum_{i=1}^{n-1} Overlap_{i,i+1} \quad (2)$$

is added to *RSU* (and, consequently, to the set *V* of *WOG*).

The term $Overlap_{i,i+1}$ represents the average diameter of the coverage area shared among p_i and p_{i+1}. The conditions that have to be satisfied are: the primary nodes with a common shared coverage area should belong to the same road (in Fig. 2 two clusters are created with two new primary nodes P1 and P2) and, if the distance of the RSU from the road is above a given threshold, then it is not considered in the clustering approach, even if shares its coverage with other primary nodes (tie-break).

Just to be clear, the concept of merging two (or more) primary nodes into a newer one is an abstraction we have introduced in order to handle the possible situations that can occur in a real scenario. From a modeling and simulative point of view, merging two (or more) RSUs into a newer one with an extended coverage permits us to respect the WOG structure and topology; from a real point of view, instead, the situation is managed in a clustered way. Each approaching vehicle is managed (in terms of PRE-VE

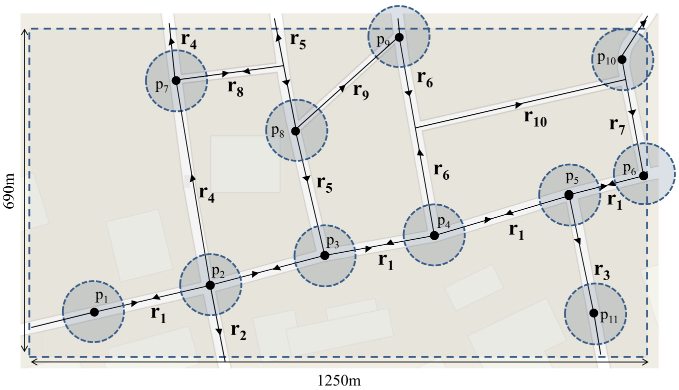


Fig. 3. An example of vehicular environment, with primary nodes and road-segments.

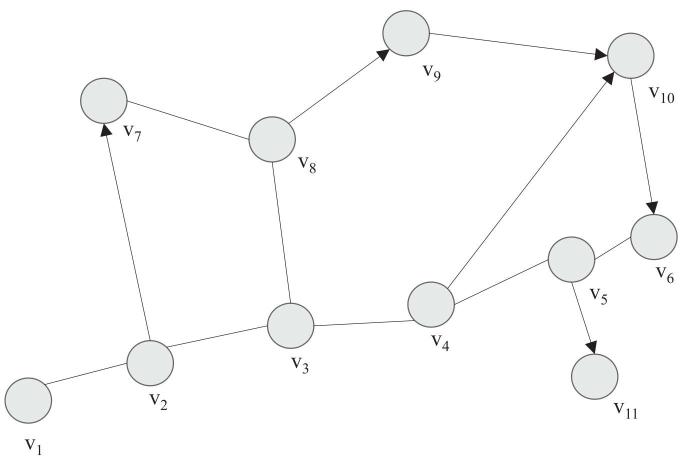
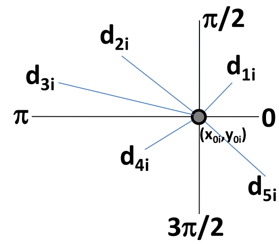


Fig. 4. The *WOG* associated to the map illustrated in Fig. 3.

signaling) by the covering RSU with the strongest SNR value (there are different coverage swappings in real communications, the hand-over management among two, or more, cells is out of the scope of the paper). Each RSUs of the network is externally interconnected by a backbone (this is valid for the entire set of primary nodes) and, given that after their deployment they know that there are many "shared" road segments, then the received messages (sent by secondary nodes) are sent reciprocally between the overlapped RSUs, while the messages to secondary nodes are sent by the currently covering RSU.

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 $n = 11$, $RD = \{r_1,..,r_{10}\}$, 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, $\forall p_k \in RSU$). So, under these assumptions, the considered traffic map can be completely modeled by a *WOG*, as illustrated in Fig. 4.

The elements *V* and *E* of the WOG have been explained. Now the details of *M* and *W* are introduced. *M* represents a vector $1 \times n$ vector $M = [m_1, \ldots, m_n]$: we assume that each primary node p_i (with its associated vertex v_i) can store some information about secondary nodes mobility in a square matrix $m_i \in M$. So



$$m_i = \begin{bmatrix} m^i_{11} & m^i_{12} & m^i_{13} & m^i_{14} & m^i_{15} \\ m^i_{21} & m^i_{22} & m^i_{23} & m^i_{24} & m^i_{25} \\ m^i_{31} & m^i_{32} & m^i_{33} & m^i_{34} & m^i_{35} \\ m^i_{41} & m^i_{42} & m^i_{43} & m^i_{44} & m^i_{45} \\ m^i_{51} & m^i_{52} & m^i_{53} & m^i_{54} & m^i_{55} \end{bmatrix}$$

Fig. 5. An example of the 5×5 m_i matrix for primary node p_i.

$\|M\| = n$ and each m_i has a dimension of $n_i \times n_i$ (an example is shown in Fig. 5). Each row and column of m_i is associated to each moving direction, and its elements are defined as follows:

$$m_i(j,k) = p(going\,through\ \ d_{ik}|\,co\min g\ from\,d_{ij}). \quad (3)$$

Eq. 3 defines the elements of matrix m_i associated to a primary node p_i. It keeps track of the probability of a generic secondary node of going into the coverage of p_k along the road-segment associated to direction d_{ik}, given that it has arrived in the coverage of p_i on direction d_j.

In this way, it is possible to consider a probabilistic approach, suitable to make possible predictions on users' movements, as illustrated later. The way the elements are evaluated is illustrated in next sections. The last element of *WOG* that needs to be defined is represented by *W*, that is the set of edge weights. Each $w(v_i, v_j) = w_{ij} \in W$ represents the number of secondary nodes that are moving from $A|p_i$ to $A|p_j$, through the road-segment $rs_{ij} \in RS$. All 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*.

D) The Needed Signaling for PRE-VE

In order to implement the proposed idea in a real system, some additional messages need to be introduced. Each primary node is able to contact the other ones through a backbone or a mesh topology, so it is able to share information about MH behaviors. We can distinguish among:

- ***Update/Increase***(*UI*) message: each time a secondary node $s_l \in MH(t)$ leaves a primary node coverage area $A|p_i$, it will travel on the road segment rs_{ij}, and node p_i can signal to the other primary nodes an increment of one unit of the weight $w_{ij} \in W$. We assume that the primary node p_i can be aware of the road-segment that has been chosen by s_l;
- ***Update/Decrease*** (*UD*)*:* 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, can signal to the other primary nodes that the number of mobile nodes traveling on segment rs_{ij} is decreased by 1, as well as the weight $w_{ij} \in W$*;*
- ***Update/INhibit*** *(UIN):* as explained in next sub-sections, each time a primary node notices a congested road-segment, it will send this message to its neighbors in order temporary delete an edge from the *E* set. The edge is chosen according to the PRE-VE policy; this message is also flooded

among all the secondary nodes of the system, in order to give awareness of the inhibited road-segments;

- ***Update/REactivate*** (*URE*): when an inhibited road-segment needs to be restored, the involved primary node will send this message to its neighbors. This message is also flooded to mobile secondary nodes;
- ***Periodical Polling*** (*PP*): 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;
- ***Polling Reply*** (*PR*): 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;
- ***Parking Update*** and ***Moving Update*** (*PU, MU*): if a secondary node $s_l \in MH(t)$ signals to the system that it is going to be parked on a road-segment, the first road-side unit that receives the *PU* 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 (*MU*). If s_l is not covered by any primary node, the message will be forwarded on the basis of the V2V paradigm;
- ***Periodical Map REQuest*** (*PM-REQ*): this message is periodically sent by secondary nodes in order to retrieve the updated map from the system;
- ***Periodical Map REPly*** (*PM-REP*): this message represents the answer of primary nodes, containing all the updated information about *WOG*.

We are assuming that each secondary node is able to compute its own itinerary, based on the information that the primary nodes send by the *PM-REP* message. We assume that all the signaling messages above which are destined to primary nodes, such as *UI* and *UD*, are encapsulated on the basis of the backbone architecture (TCP/IP for example). The messages affecting secondary nodes, such as *PP*, *PR*, *PU*, *MU*, *PM-REQ* and *PM-REP*, are encapsulated into wireless access for vehicular environment (WAVE) Short Message Protocol (WSMP) [17], [25], [27] packets. The UIN and URE messages are sent both on backbone and on *WAVE/DSRC* links. Fig. 6 represents a possible scenario for which the PRE-VE messages are exchanged. In particular, the primary node p_i sends to its "adjacent" nodes p_u and p_j two update messages (UD and UI) for the arrival of the secondary node s_p and the departure of node s_l respectively. The periodical messages are also illustrated (PP and PR) and they are exchanged among p_i and the covered secondary nodes (s_k, s_p, s_q). In order to disseminate the *PP*, *PR*, *PU*, PM-REQ, *PM-REP*, *UIN* and *URE* messages, the Extension Field can be used to specify the type of message, while in the Payload the desired data can be inserted.

In this work we are not proposing a new protocol, but only specifying how the steps of the proposed algorithm can be carried-on exploiting the functionalities of the WAVE/DSRC architecture. Fig. 7 represents, instead, the encapsulation in the WSMP packets. *Periodical Polling* (PP) and *Polling Reply* (PR) messages have been provided in order to know if a secondary node has arrived into a primary node's coverage area or if it has left it. PP signaling period is properly set (on the basis of secondary nodes' average speed) and a primary node will wait for missing the reception of more than one PR message (no valuable difference between 3 or 4 waiting times has been noticed) before concluding that the secondary node has left its coverage; in the same way, when a new secondary node arrives into a coverage area, it will start sending PR messages upon the receipt of PP messages.

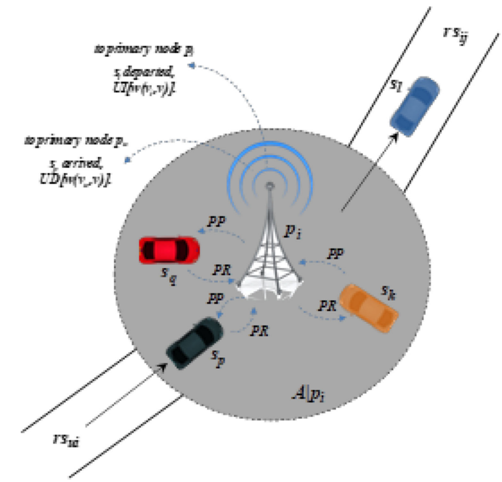


Fig. 6. An illustration of the utilization of *UI*, *UD*, *PP*, and *PR* messages.

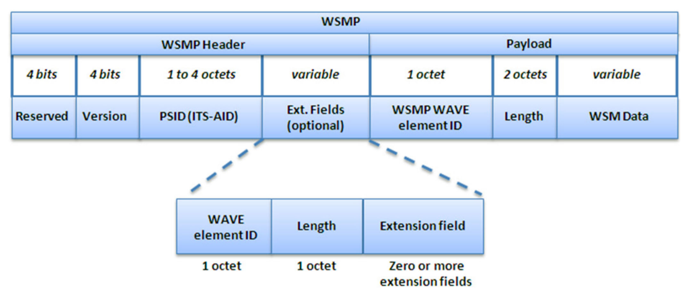


Fig. 7. An illustration of the utilization of *UI*, *UD*, *PP*, and *PR* messages.

The main steps of the PRE-VE *algorithm*

In this sub-section we present the main steps of the PRE-VE algorithm with pseudo-code and a brief explanation.

- **Step 0** (*Initialization and training*): Given the map and the road-side units placement, create the *WOG* = *<V,E,M,W>*. In particular create a vertex $v_i \in V \forall p_i \in RSU$. If two (or more) primary nodes have a shared coverage, generate a new primary node p_k, following the parameters and the conditions indicated in eq. 2. Create an edge $(v_i, v_j) \forall rs_{ij} \in RS$. Set $m_i = [0] \forall p_i \in RSU$, where *[0]* represents a null square matrix. In addition, set:

$$\|V\| = \|RSU\| = n,\ \|E\| = \|RS\| = m,\ w_{i,j} = 0\,\forall (v_i, v_j) \in E \quad (4)$$

This initialization part of 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 PRE-VE. As regards the road lengths, they are directly associated to each edge, after the deployment of primary nodes. In the real scenario, road length can be easily derived by a GIS analysis. For the training phase, each m_i has to store the "mobility behaviour" of secondary nodes. So, before applying the PRE-VE scheme, the system needs to be "observed" by capturing MHs actions. In particular, the elements $m^i(j,k)$ can be evaluated as follows, during a time observation window t^*:

$$m^i(j,k)\big|_{t*} = \frac{obs_i(hand\_out\_k|hand\_in\_j)|_{t*}}{obs_i(hand\_in\_j)|_{t*}} \quad (5)$$

where t^* represents the time for which the system observes the network traffic dynamics; $obs_i(hand\_out\_k|hand\_in\_j)|_{t*}$ is the number of times, during t^*, a secondary node goes out from $A|p_i$ towards d_k given that it arrived from d_j and $obs_i(hand\_in\_j)|_{t*}$ is the total number of times a secondary node arrived in p_i from direction d_j. At the end of t^* period, the *M* vector is updated.

- **Step 1** *(Departure of a mobile node s_l from the coverage of v_i):* When the secondary node s_l leaves a coverage area $A|p_i$ (it cannot answer with *PR* messages, since the *PP* is no more received), the old covering primary node acts as follows:
  If (no PR message is received from s_l) then:
- *Extract the GPS coordinates stored in the last PR message received from s_l;*
- *Determine the destination p_j node, for evaluating the road-segment rs_{ij} of departure;*
- *Send the $UI[w(v_i,v_j)]$ message to the neighbouring p_j node, through a reliable TCP connection.*
- **Step 2** *(Arrival of a mobile node s_l in the coverage of v_j):* When the secondary node s_l arrives into $A|p_j$, the new covering primary node acts as follows:
  If (a new PR message is received from s_l) then:
- *Extract the GPS coordinates stored in the newly PR message received from s_l;*
- *Determine the previous p_j node, for evaluating the road-segment rs_{ij} of departure;*
- *Send the $UD[w(v_i,v_j)]$ message to neighbouring p_j node, through a reliable TCP connection.*
- **Step 3** *(Updating):* After the first round of evaluation, the system will continue observing the MHs dynamics, in order to update the elements of *M*, according to the re-routing policy. Each primary node updates its own matrix by a smoothing approach. The primary node p_i, will update m^i, at the *h-th* updating step, following the equation:

$$[m^i(j,k)]^h = \beta \cdot [m^i(j,k)]^{h-1} + (1-\beta) \cdot m^i(j,k)\big|_{t*} \quad (6)$$

  where β is a smoothing factor weighting the past value $[m^i(j,k)]^{h-1}$ and the last one $m^i(j,k)|_{t*}$.

The previous four steps guarantee that the topology and the mobility information shared among both primary and secondary nodes is always updated.

E) PRE-VE Congestion Detection and Implicit Re-Routing

The core of our proposal is now illustrated. Based on the definitions and studies in [28], [29], we know that the capacity of a road can be defined as "the maximum sustainable flow rate

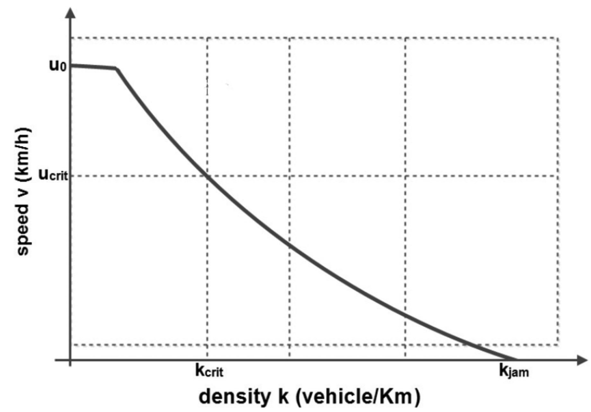


Fig. 8. The classical trend of the function relating density and speed.

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 [30] and the notations used in our paper, we can express some basic relationships and diagrams as follows:

$$k_{i,j} = \frac{w_{i,j}}{\|rs_{i,j}\|}, \quad I_{i,j} = k_{i,j} \cdot \bar{v}_{i,j}, \quad td_{i,j} = \frac{\|rs_{i,j}\|}{\bar{v}_{i,j}} \quad (7)$$

where $k_{i,j}$ is defined as the traffic density on the road segment rs_{ij}, given by the ratio of $w_{i,j}$ (the number of vehicles in the road segment rs_{ij}) and the length of rs_{ij}, 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_{ij}. The term $td_{i,j}$ represents the trip delay of the road-segment rs_{ij}, 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 $||rs_{ij}||$. There are many fundamental diagrams in the traffic flow theory, as the one depicted in Fig. 8, representing the relationship among the density and the speed of a road segment. 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. From [31], the value k_{crit} brings the road segment to be in the ideal situation, with the maximum traffic volume (measured in vehicles/time). Considering ideal conditions, the maximum capacity can be numerically obtained by fitting the curves, but more complex analytical analysis should be carried out for real cases [31]. In particular, from [28] it can be written that, for a motorway, the capacity $c_{i,j}$ of the road-segment rs_{ij} is:

$$c_{i,j} = C_{i,j} \cdot N_{i,j} \cdot FW_{i,j} \cdot FHW_{i,j} \cdot FP_{i,j} \quad (8)$$

where $C_{i,j}$ is the ideal capacity (it can be derived by dividing the length of the lane by the average length of a vehicle), $N_{i,j}$ is the number of lanes, $FW_{i,j}$ formally called "Heavy Vehicle Adjustment Factor" is aimed to modify the average length of each moving node, taking into account the presence of "heavy vehicles" [32], [33], $FHW_{i,j}$ represents to the probability of having "heavy vehicles", while $FP_{i,j}$ is a factor that derives from the driver population (a parameter that accounts for driver characteristics and their effects on traffic). In our proposal, the

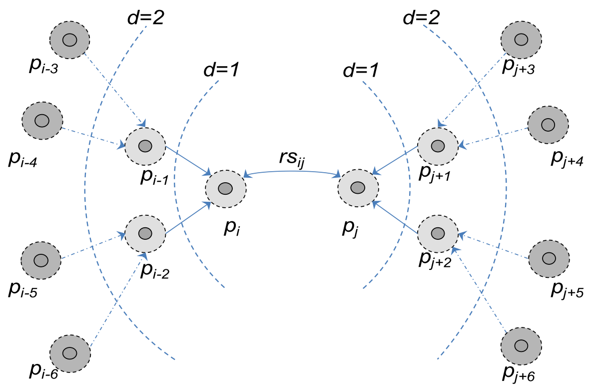


Fig. 9. The illustration of the main concept of PRE-VE: the probabilistic pruning.

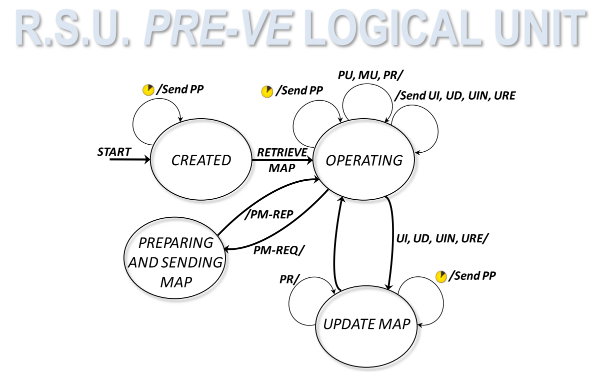


Fig. 10. RSU FSA behavior under the PRE-VE algorithm.

algorithm should guarantee that $k_{i,j} \cong k_{criti,j}$ for each $rs_{ij} \in RS$. So, after these considerations, a description of the core-idea is given.

A generic couple of nodes v_i, v_j can evaluate if:

$$\exists rs_{ij} \in RS|\, w_{i,j} > (1 + a_{i,j}) \times k_{crit\,i,j} \cdot ||rs_{ij}|| \quad (9)$$

where $k_{criti,j}$ is the desired average density for rs_{ij} and $\alpha_{i,j}$ is a near-to-zero value representing the maximum tolerable deviation from the desired value. When eq. (9) is satisfied, it means that a road-segment is going to reach its limit, in terms of congestion. The term $\alpha_{i,j}$ assumes a great importance, since for $\alpha_{i,j} < 0$, the system is able to prevent a congested situation, taking the needed counter-measures. Fig. 9 describes a typical scenario in which the road-segment rs_{ij} may be congested. Both vertices v_i and v_j, related to primary nodes p_i and p_j, have some adjacent nodes, belonging to $Adj(v_i)$ and $Adj(v_j)$ respectively, from which the MHs arrive on the congested link. The term d indicates the distance from nodes p_i and p_j: in the example, the nodes p_{i-1}, p_{i-2} are separated from p_i by only one edge ($d = 1$), as well as nodes p_{j+1}, p_{j+2}, that are only one edge far from p_j. For nodes p_{i-3}, p_{i-4}, p_{i-5}, p_{i-6}, p_{j+3}, p_{j+4}, p_{j+5} and p_{j+6} the distance is $d = 2$. So, it can be written that if:

$$\exists v_t \in Adj(v_l)|\, m_t(k,l) \geq \delta,\; k = 1,\ldots,n_t \quad (10)$$

and WOG is still a connected graph without the edge (v_t,v_l), then it is temporary removed from E, until the condition of eq. 9 is no more satisfied.

This means that the system is going to temporary inhibit the most probable links able to bring new secondary nodes on the congested road-segment. The term v_l can be either v_i or v_j, $Adj(v_l)$ is the set of neighbor nodes of v_l and δ is a system threshold. The primary node v_l will send to its neighbor node v_t the $UIN[(v_t, v_l)]$ message, also flooded among vehicles through the WSMP, in order to avoid considering the edge (v_t, v_l) as part of the *WOG*. When the link rs_{ij} is no more congested, the $URE[(v_t, v_l)]$ message is sent to v_l neighbors, in order to add (v_t, v_l) again in *E*.

F) New Itinerary Evaluation and Finite-State-Automata (FSA) Behavior

At this point, the secondary nodes will be updated every time a topology change occurs, and they will be able to re-compute their itineraries by not considering inhibited links, or by considering the re-activated ones.

We assume that the PRE-VE module of each secondary node s_l can evaluate the best path from v_k to v_D, where v_D is the destination node of the vehicle s_l. The considered metric, indicated as the Weighted Cost Term (*WCT*), associated to each edge (v_i, v_j) is represented by:

$$WCT_P(v_i, v_j) = k_{vi,vj}. \quad (11)$$

At this point, by the execution of the Dijkstra algorithm [34], with a computational complexity of $O(n^2)$, where n is the number of primary nodes.

Before showing the obtained results, an illustration of the FSA of primary and secondary nodes is given, in order to have an idea on how they behave in the system. Each circle represents a possible state of the FSA, while the labels of the arcs represent the received/sent messages; that is to say "*PP/Send PR*" means that a *PP* message is received and a *PR* is sent. The timer logo indicates that the sent message is periodical, on the basis of the previous description. Fig. 10 illustrates the behavior of the Road Side Units (primary nodes) according to the PRE-VE algorithm. A primary node will periodically broadcast the *PP* message to all MHs in the coverage area: all the present nodes will reply with the *PR* message. The secondary node will also receive the *PU*, *MU* messages, as well as the *UI*, *UD*, *UIN*, *URE*, according with the description given in the previous subsection, for the map update. If a secondary node asks for an update (*PM-REQ*), the primary node will reply with a *PM-REP* message.

Fig. 11 shows the behavior of secondary nodes, according to the PRE-VE messages defined in Subsection III.D. Once a secondary node s_l enters into the network, it sends the first *PM-REQ* message, in order to acquire the *WOG* structure. At this point, s_l acquired the map so it can evaluate the optimized itinerary for reaching the desired destination, based on the concepts given in subSection III.B.

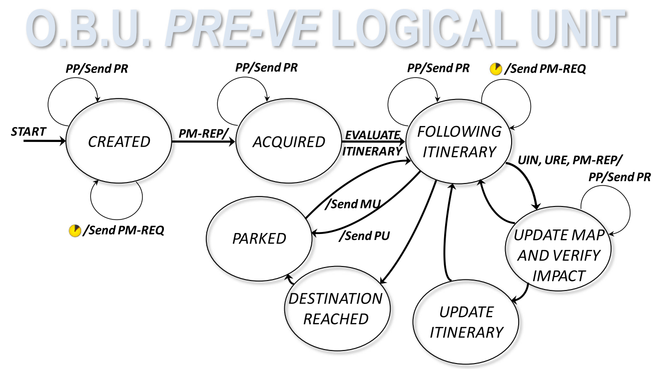


Fig. 11. OBU FSA behavior under the PRE-VE algorithm.

If s_l is under the coverage of a primary node, it will always receive the periodical *PP* message, and will send the *PR* message. Periodically, s_l sends the *PW-REQ* message, obtaining the *PM-REP* message, having the possibility to evaluate if a new itinerary to destination has to be evaluated (verify impact). In addition, when s_l is following its itinerary, it could receive the *UIN* and *URE* messages regarding the update of traffic levels on the map. If s_l is going to be parked or if it is moving again after a parking, then it will send the *PU* or *MU* message respectively to the network.

IV. Simulation Results Analysis

In this section, we show the results achieved using the PRE-VE algorithm, introduced in the sections above, comparing it with the approach proposed in [15]. The next subsection introduces a description of the simulation environment, in order to better understand how the results have been achieved. Then, the obtained results are described.

A. Network Simulator

In this work, the *OMNet++* [35] and Veins [36] frameworks have been used to perform simulation campaigns. A deep performance analysis has been led out in order to understand the real benefits of the PRE-VE algorithm. The AR∗ proposal [15] is also used to compare our results. Here the authors propose the following model known as AR∗. The AR∗ algorithm is a modification of the well-known A∗ path search algorithm. A∗ algorithm is a kind of best first search in which among all possible paths the ones that appear to lead most quickly to a solution are considered. For each iteration, the algorithm chooses which of the candidate paths have to be expanded in one or longer paths on the basis of the estimation of the path cost to the goal node. The AR∗ algorithm introduces in the A∗ algorithm a repulsion factor, that takes into account other vehicle traces on the examined path in order to avoid congestion during re-routing. The cost estimation is calculated exactly like in the A∗ algorithm but with the addition of a weighted repulsive factor R. In order to build up the model, the procedures and the algorithm we exploited OMNet++ simulator, which permits to achieve a more detailed analysis (easy comparable with other approaches). Regarding the mobility model, the SUMO [37] application is used. Some details about simulation environments are given in Table II. The core of the PRE-VE algorithm has been developed in the RSU (primary node) module of Veins. These modules have the possibility to gather information about roads and lanes condition. Moreover, each primary node has the task of monitoring several roads, composed of one or more road-segments. In order to show the CO_2 emissions map, the framework supplies a model, validated by several users [38], [39], able to offer a realistic trend of the emissions in the considered environments. Through another custom module, built for the OMNET++ framework, we have been able to capture simulation data related to the localization of areas that measure a high level of pollution in terms of CO_2.Our goals are to reduce those areas both in number and air pollution concentration. In order to simulate all the WAVE/DSRC layers, several parameters have to be set. Some of the most important are reported in Table III and Table IV.

TABLE II
Map and Mobility Models Parameters

Parameter	Value
Map size x	1,5 Km
Map size y	2,5 Km
Average Car Length	2.5 meters
Stops Signals	Yes
Speed limits	50 Km/h
Car type Number	10
Number of lanes per road	[2,4]
Urban lane width	[2.6, 3.2] meters
Extra-Urban lane width	[3.2,3.6] meters
FW value	[0.78,1]
FHW value	] 0 , 0.7]
FP working days/week-end	1/0.85

TABLE III
Primary Nodes Configuration Parameters

Parameters	Value
Carrier Frequency	5.890e9 Hz
Tx power	107 mW
Bitrate	6 Mbps
Use of Thermal Noise	Yes
Thermal Noise	-150 dBm
Sensitivity	-89 dBm
Loss Model	Yes
Obstacle Shadowing	Yes
Height above ground	9 meters

B. Simulation Campaigns

This section aims to demonstrate the goodness of our proposal, based on the prediction concept related to the incoming vehicles, forcing re-routing operations when the probability of reaching local or global congestion is high. Moreover, by reducing road congestion level, it is possible to limit CO_2 emissions, avoiding dramatic speed variations, such as frequent “starts and stops”. We analyze the obtained results underlining the advantages of our proposal and showing its performance under different points of view. In particular, for the first campaign, our

TABLE IV
SECONDARY NODES CONFIGURATION PARAMETERS

Parameters	Value
Carrier Frequency	5.890e9 Hz
Tx power	10 mW
Bitrate	6 Mbps
Use of Thermal Noise	Yes
Thermal Noise	-110 dBm
Sensitivity	-89 dBm
Loss Model	Yes
Obstacle Shadowing	Yes
Height above ground	1.895 meters

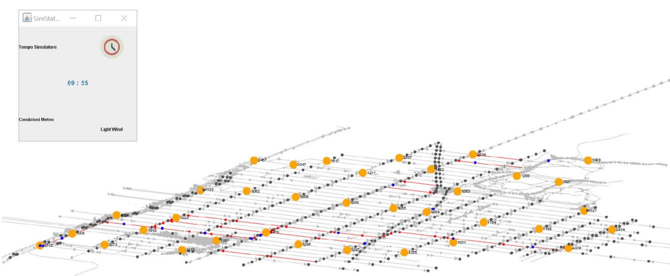


Fig. 12. Reference Map area: Portion of city of New York related to the Hell's Kitchen area.

TABLE V
FIRST SCENARIO CONFIGURATION

Parameters	Value
Area Map	Hell's Kitchen (NYC - USA)
Car load	Light traff.: 8 inc. gates Mod. traff.: 10 inc. gates
Light Traffic Incoming gates	8
Light Traffic Car/h (Average)	45 car/h
Moderate Traffic incoming gates	10
Moderate Traffic Car/h (Average)	100 car/h
Map Update timeout	30s, 60s, 80s, 120sec
Primary Node coverage area	200m, 150m, 100m, 50m

attention is focused on CO_2 emissions in the considered area. The Fig. 12 shows the reference map area, in which simulations are performed. A second campaign of simulations have been performed in order to show how the re-routing policies, adopted by the different investigated protocols, impact on the overall system. We also propose a comparison between static, dynamic and probabilistic algorithms used by the PRE-VE protocol. The parameters shown in Table V represent the main simulation environment while, as area map, we choose a portion of NYC (USA), because its particular road configuration has been already used in several works [40]. The simulation is performed by using two different types of load: the first one limits the number of vehicles across the city and the frequency of vehicle generation; the second one presents a huge number of vehicles generated with a higher frequency. In order to evaluate the reference capacity

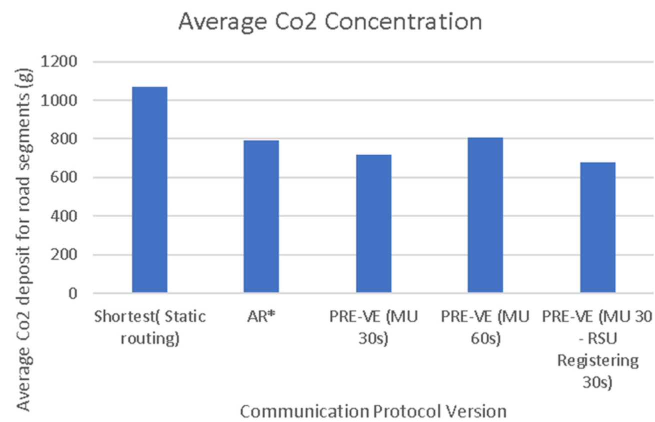


Fig. 13. CO_2 concentration versus protocols.

of a generic road $(c_{i,j})$ between two nodes i and j, we use the eq. (8) with parameters already defined in Table II.

Regarding the physical parameters of radio devices, we can refer to Table III and Table IV for primary and secondary nodes respectively.

1) CO_2 Evaluation: PRE-VE messages supply information about traffic and congestion, suggesting a re-route operation when necessary. Increasing the frequency of queries to the primary nodes, some benefits in terms of CO_2 emissions and traffic reduction can be obtained, this is shown in Fig. 13. It is important to note that the evidence of CO_2 is given only for the portion of the area that overcomes the concentration limits. In terms of numerical results, Fig. 13 shows the histogram of the concentration for static routing strategy, in which only the shortest path algorithm is performed by the secondary nodes to find the better solution in terms of traveling distance. The dynamic AR$*$ protocol and the PRE-VE protocol are also depicted in Fig. 13 to perform a comparison. As previously stated, these results are obtained because of CO_2 concentration, which is directly related to congestion level of the roads involved into vehicle trip, around the map area. It is possible to note that PRE-VE, with a lower Update-map timeout, outperforms PRE-VE configuration with a higher Map-Update timeout. Moreover, PRE-VE outperforms static and AR$*$ protocols as well. Regarding PRE-VE parameters, we can observe that the shorter is the observation window of the system, the worst are the re-routing strategy effects. Making the observation window wider, it is possible to find a better solution in terms of traffic loads, by obtaining a lower level of congestion, a higher average speed and avoiding drastic speed variations (that increase the CO_2 emission levels per vehicle). Therefore, it is important to find a good trade-off among protocol parameters. However, numerical results demonstrate that PRE-VE acts better than other strategies in terms of gas emission and related deposit reductions in the considered area.

2) Re-routing Policy Evaluation: The second simulation campaign brings up some interesting results about re-routing policies, in terms of protocol messages, vehicle distances, and vehicle time (needed to travel city roads and to reach destinations). Moreover, in this work we made a comparison with the protocol proposed in [15]. In Fig. 14 the average distance traveled by vehicles across the city is depicted. It is possible to

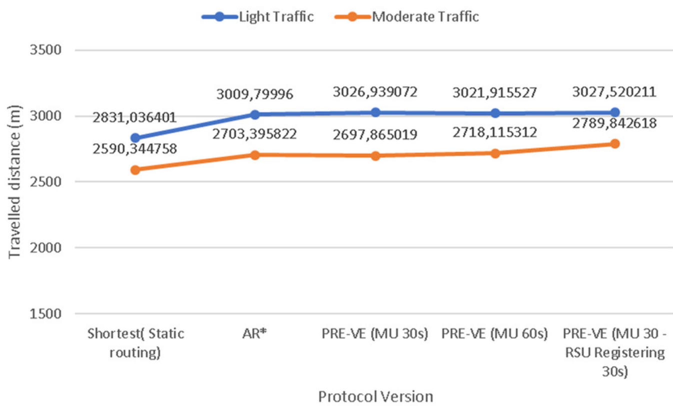


Fig. 14. Average vehicle traveled distance across the city vs. protocol re-routing policies.

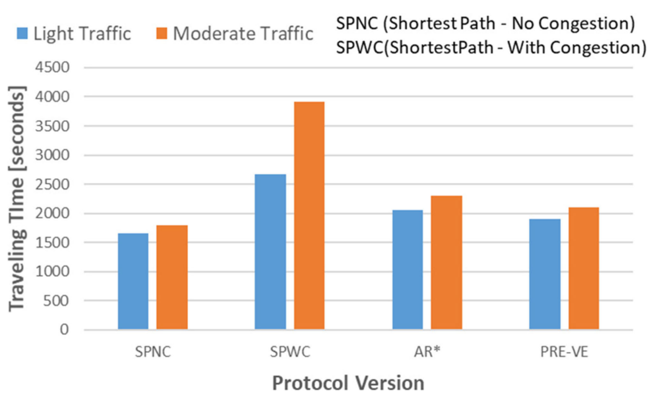


Fig. 15. Average time needed to reach vehicles' destinations. Comparison between protocol versions and configurations.

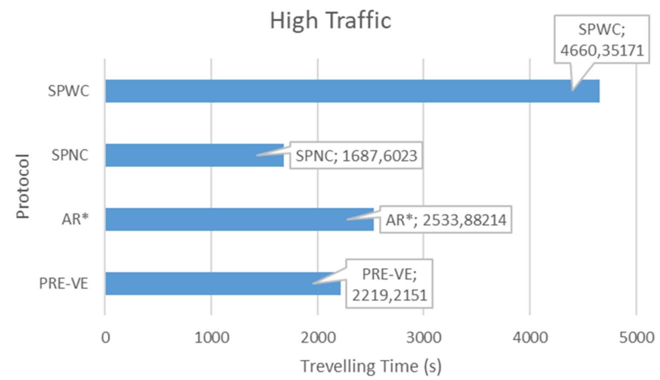


Fig. 16. Average time needed to reach vehicles' destinations in a high traffic condition.

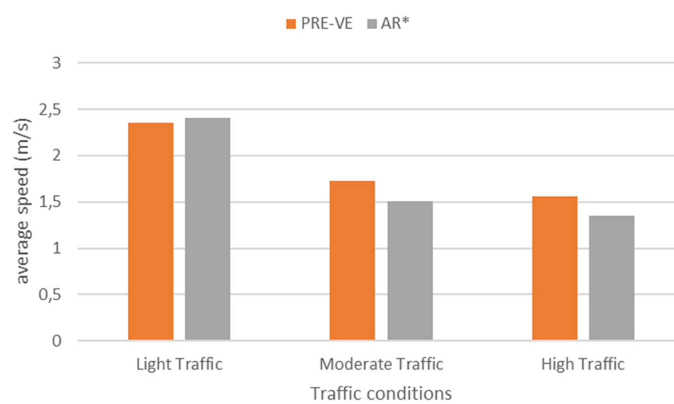


Fig. 17. Average speed in different traffic conditions.

note that, for traffic light conditions, more roads are available to reduce congestion level. Therefore, vehicles may travel longer distances to reach their destinations. Re-routing strategies keep updated information about traffic condition, spreading this info to several roads in accordance with updating timeout and protocol rules.

Instead, in the case of moderate traffic, the possibility to re-route is bounded by the presence of more vehicles that bring up congestion on the other roads. Therefore, re-routing can be made, but its effects are limited. In fact, Fig. 14 shows the trends of moderate traffic related to the traveled distance that presents closer values for both static and dynamic routing. We note that the travelling distances for AR$*$ and PRE-VE is higher than the travelling distance of static routing. This is possible because path is chosen at the beginning of the trip and it is never changed. Regarding other protocols, they act directly on the chosen path, in accordance with the information exchanged by the proper protocol signaling. In particular, PRE-VE keeps the updated information exchange data among primary nodes and vehicles, when a MAP request message is acquired from the network. In Fig. 15, the trend of the traveling time is depicted considering two traffic levels: Light and Moderate. Here, a comparison between static and dynamic protocols has been performed. In particular, we evaluated the traveling time considering the shortest path for achieving reference bounds related to the best (*SPNC*) and to the worst (*SPWC*) case respectively. In the worst case scenario, some collision events among vehicles have been scheduled, in order to generate congestions and traffic jams. For evaluating the performances of the dynamic protocols we consider the worst case. It is possible to note in Fig. 15 that the travelling time of AR$*$ is greater (around 7%) than the travelling time of PRE-VE for a moderate traffic. Moreover, the dynamic protocols perform better than the static one as shown in Fig. 15. In Fig. 16 the protocol comparison is proposed, considering a higher level of traffic. The simulation campaign goal is to demonstrate the better behavior of PRE-VE, when the presence of more vehicles increase the traffic level in the area. In this case, PRE-VE outperforms AR$*$, achieving a reduction of travelling time of 14%. Moreover, considering the SPWC case, the PRE-VE performs better reducing the travelling time of 47%.

In Fig. 17 the average vehicle speed for the scenario used in the second simulation campaign is depicted. In particular, we point out that the average speed measured in the case of PRE-VE is higher than the other; this means that, for the same travelling distance, the needed time is lower. Moreover, a higher average speed demonstrates that each vehicle finds a lower number of congested road segments and vehicles are not forced to change their speed frequently. This fact justifies a lower value of CO_2, a lower level of congestion and a better distribution of the traffic

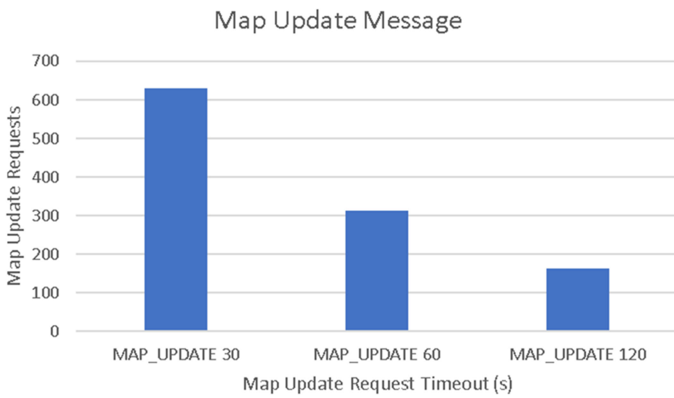


Fig. 18. MAP update request vs. periodical time.

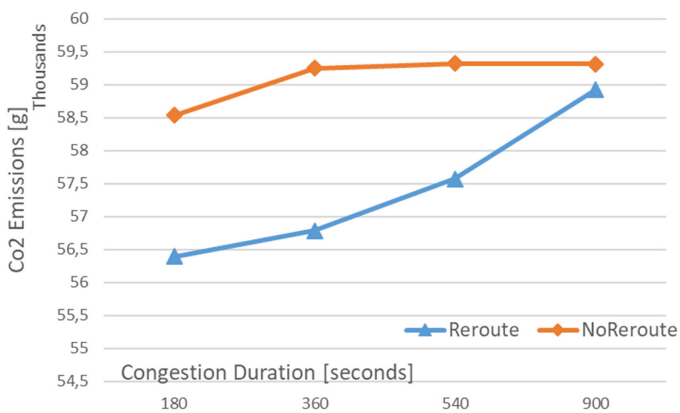


Fig. 19. CO_2 concentration vs. congestion severity.

load around the available roads. Many approaches in literature face the congestion issue by operating a lane/road monitoring, using a threshold-based mechanism to avoid critical traffic congestion level. The schemes [15], [32], [18] trigger the re-routing events on the vehicles that are going to approach with the area involved into congestion. When a huge number of vehicles are involved, congestion level cannot decrease in an easier way. Usually, this may happen because of the higher number of vehicles and limited exit ways in the involved areas. Vehicles continuously arrive in the congested area, due to the lack of information about the event or because the propagation of the information is taking long time. A prediction-based method, instead, tries to bring up the knowledge of these events when a certain probability is close to realize the event.

3) Map-Update Evaluation and Congestion Issues: The trend of Map Update request messages is depicted in Fig. 18. Here the periodical request time is increased. We obtain a sensible reduction of protocol messages that are exchanged between vehicles and primary nodes. The side effect is reported in Fig. 19, where the worst environment condition is visible. Here, vehicles may not find alternative routes for their journeys because of the increasing of congestion duration, therefore congestion has started to spread along closer area. Thus, the higher is the area involved in the congestion the lower is the probability to find an alternate route. The reroute strategy permits to reduce the effect of congestion in terms of CO_2 deposit per vehicle.

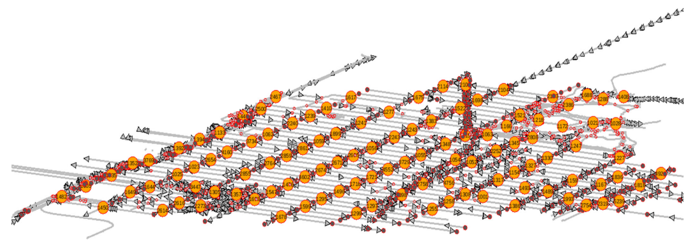


Fig. 20. Primary node city map distribution with an average coverage radius of 100 m.

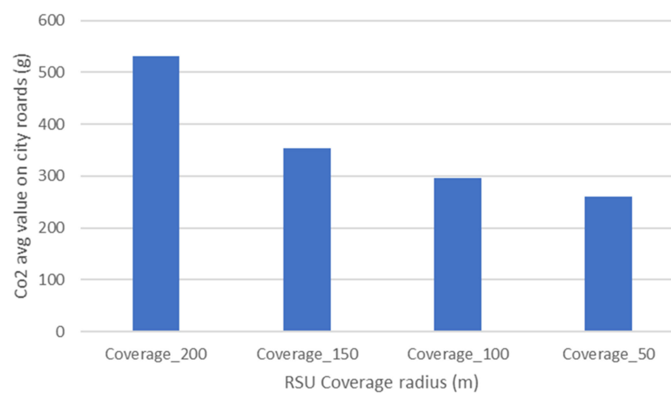


Fig. 21. CO_2 area concentration vs. average coverage radius.

Unfortunately, the effect of reroute are limited by the severity of the congestion. When the duration of the event overlongs a certain level, it is not more possible to find an alternative path. The impact of Update Increase and Update Decrease messages are shown. With the increase of vehicle, PRE-VE reacts by involving several roads, trying to re-route traffic. Road management in PRE-VE is assigned to primary nodes, as shown in previous sections. When a vehicle reaches a novel coverage area, its primary node communicates with the other ones to update their data, exploiting UI and UD messages.

4) Coverage Area Evaluation: In this section, we face the issue of choosing the right coverage area for the RSU devices. In particular, if the coverage area of an RSU is reduced to cover the same area more devices are needed, this scenario is shown in Fig. 20. In this simulation environment, we have considered the same map used in the scenario shown in Fig. 12. It is clear that the lesser is the coverage area the greater will be the number of RSUs needed to cover the area. This is easily observable having a look at the Fig. 12 and Fig. 20. Thus, a higher number of primary nodes is needed to cover each road segment. The effects of the PRE-VE behavior is shown in the following pictures. In Fig. 21 the CO_2 emissions are depicted: it demonstrates that by increasing the number of primary nodes, the average CO_2 concentration per roads decreases. This is possible because primary nodes can take advantage of a better road monitoring process, giving the possibility to properly choose which segment has to be inhibited.

These results are also visible in Fig. 22 where the average travelling distance of vehicles is shown. Here it is possible to note that by decreasing the coverage radius, more available choices

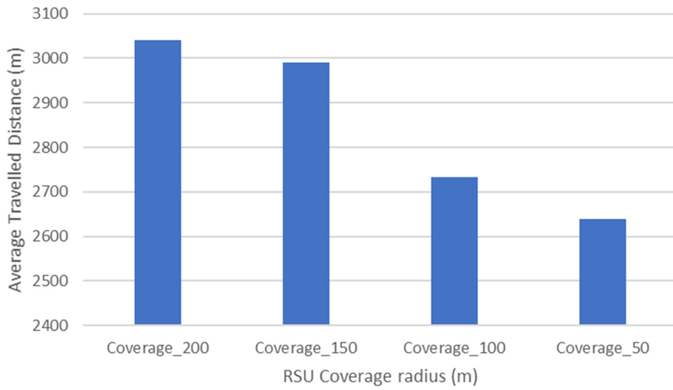


Fig. 22. Average travelling distance for vehicle involved into simulations vs. RSU node average coverage radius.

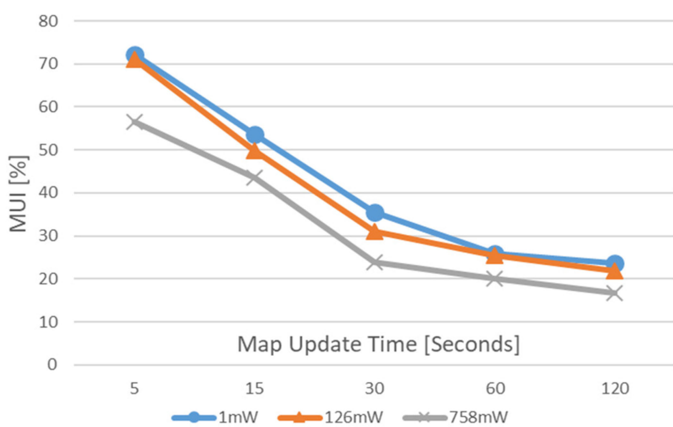


Fig. 23. The impact of the Map update message vs. updated time.

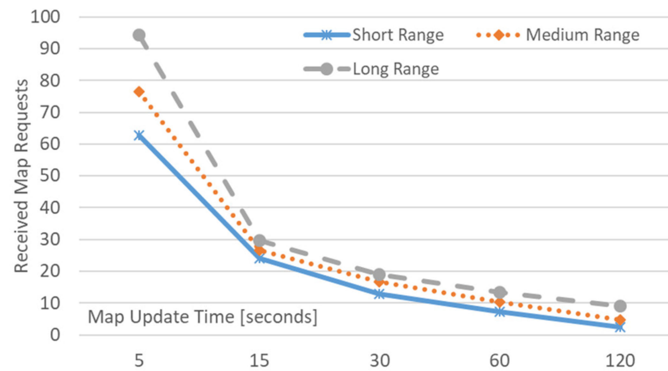


Fig. 24. Map request messages received by primary nodes vs. Map update time interval.

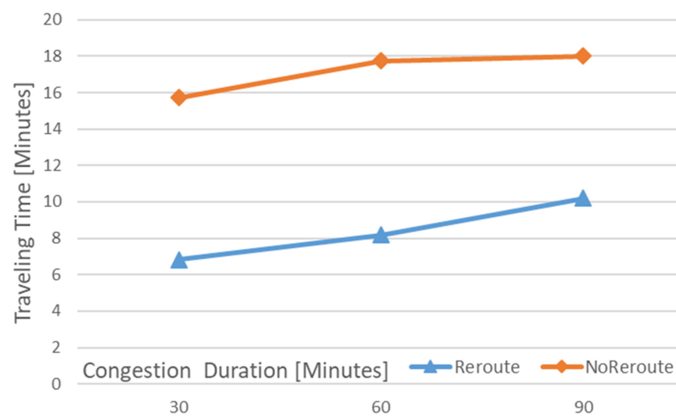


Fig. 25. Average traveling time versus congestion severity.

may produce a shorter trip in terms of travelling kilometers. In Fig. 21 and Fig. 22 each vehicle sends a MAP request every 60 seconds and an update of their route is made if something changes, in accordance with the update procedure of PRE-VE protocol in the primary node. As shown, a higher number of primary nodes permits to better manage road loads and guarantee better performances.

5) PRE-VE Protocol Performance: In previous pictures, we deeply investigate PRE-VE performances under the point of view of CO_2 gas release in the air, average vehicle speed and travelling distances. In the next figures, instead, we propose the analysis of PRE-VE from a protocol point of view (communication messages). In Fig. 23 the protocol overhead measured on secondary nodes is depicted.

As shown in Fig. 23, Map Update time interval influences protocol performances when different coverage radiuses are considered. In particular, the impact of the map update is evaluated as the ratio between the number of Map Updated messages sent on the overall protocol messages sent. Therefore, this value is obtained as shown in eq. 12. Here, the Υ term represents the overall number of Map Update messages sent in the system; the Φ term is the number of other protocol messages sent in the system by primary and secondary nodes; the P term represents the number of service messages sent in the system by secondary nodes.

In Fig. 23, the P term is considered equal to 0.

$$MUI = \frac{\Upsilon}{\Upsilon + \Phi + \mathrm{P}} \tag{12}$$

Fig. 24 shows the trend of protocol Map Request messages exchanged among primary nodes and vehicles. The lower is the transmission power of primary and secondary nodes the lesser are map requests received by primary nodes. This means that a higher number of map request are generated by vehicles and a higher protocol overhead is measured as shown in Fig. 23 because of map request retransmissions. However, the main difference is demonstrated to be when the map request interval is very short. When the interval is increased then the number of generated requests are comparable. The Average Traveling time versus congestion Duration is depicted in Fig. 25. Here, it is possible to note how the traveling time is much lesser than the event of congestion. Therefore, this means that when a vehicle meets a congestion event it applies a reroute to find another route. Once another route is found, it is able to reach its destination by using free lanes that are not involved in other kind of congestions.

V. Conclusion

In this paper, we proposed a new traffic optimization protocol, suitable for vehicular environments. We focused our attention on the proposal of a map modeling, for the reduction of road traffic density. The main idea consists in the evaluation of a rerouting strategy, based on the analysis of the roads structure, able to reduce CO_2 emissions. We investigated about the effectiveness of the proposed idea, obtaining very satisfactory results in terms of gas emissions, travel time reduction and travelling distance. The simulation campaigns show the goodness of our proposal by demonstrating that congestion can be tackled using a predictive model. Several simulation campaigns have been carried out evaluating different aspects of the protocol. We firstly evaluate the performance of the protocol in terms of CO_2 reduction, then we compare its results with other methods known in literature, showing the benefits of dynamic approaches versus static method. We considered a well-known city map area used by several methods in literature for urban environment. Dynamic traffic simulations have been considered by changing simulation parameters such as generation rate, increasing and decreasing incoming and outgoing gates and so on. Moreover, we investigated how the number of primary nodes may influence results both in terms of network protocol performances and main goals of this research article, such as CO_2 and traffic load reduction. However, we noticed that several parameters must be tuned in order to match the requirements and the constraints of the environments. Moreover, ahistorical data-set must be collected to perform a good setup of the needed parameters such as vehicle loads, critical lanes, coverage areas, primary nodes placements and so on. Simulations have demonstrated that the provided model is suitable to face congestion issues, answering fastly to traffic dynamics.

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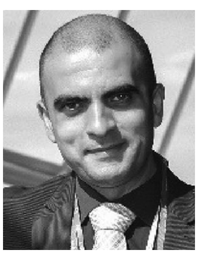

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