

Optimal Gateway Placement and Reliable Internet Access in Urban Vehicular Environments

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Abstract—Internet of Vehicles requires reliable Inter-Vehicular communications. Such a requirement is challenging since the wireless communication channel is very erroneous and lossy in city environments. A lot of solutions for connecting vehicles to the internet have been proposed. However, existing multi-hop gateway discovery solutions do not consider, a key issue, the unreliability of broadcast in city environments. In this paper, our objective is to find out the minimum communication hops, with very high reliability (e.g., 97%), to gateways. To accomplish this, we model the gateway placement problem (called GP) as a k-center optimization problem. We solve it in $O(n^2 * \log(n))$ time using a (2-1) dimension reduction technique. We make use of M-HRB [2] to discover reliable multi-hop paths to gateways. Simulation results demonstrate that applying M-HRB with GP provides high packet reception rate and generates smaller end-to-end delay compared to existing solutions. Furthermore, our proposal makes efficient use of wireless channel bandwidth.

Index Terms— Gateway placement, reliability, internet of vehicles, vehicular networks, k-center optimization problem.

I. INTRODUCTION

The main contribution of Intelligent Transportation Systems (ITS) is to significantly increase road safety. However, ITS is attracting the interest of network operators and service providers for the provision of infotainment services [1]. In modern cities, people spend a considerable amount of their time commuting by car from one place to another. To improve the driving experience and making trips more productive, a plethora of infotainment applications including content download, media streaming, VoIP, social networking, gaming, cloud access, etc., have been made available to vehicular users anytime and anywhere. This calls for vehicular communication networks to support Internet services in vehicles [2]. Indeed, In-vehicle Internet access [31] allows a vehicle to connect to the Internet through an Internet gateway. Traditionally, an internet gateway is a road side unit (RSU), installed in fixed position along a roadside. A main benefit of such an infrastructure is to relieve poor network connectivity (e.g., RSUs can increase the overall coverage of a vehicular network and enhance network performance (i.e., delay) between disconnected vehicles) [8]. Unfortunately, Internet access through RSUs requires pervasive roadside units (RSUs) to ensure each vehicle is in RSU's transmission range [8] (i.e., the typical range of an RSU is 250m). Such a requirement incurs high infrastructure deployment cost. Several contributions [11][12][13][26][32] are proposed to optimally place RSUs. Indeed, deploying a new RSU needs intensive investigation [8]; for instance, the land where to place a new

RSU may be private requiring owner permission. It may be difficult, if not impossible, to get such a permission. Therefore, deploying new RSUs often requires a large amount of investment and elaborate design, especially at the city scale. Consequently, internet access systems that rely only on roadside infrastructure are impracticable to be implemented. Recently, the concept of LTE-connected vehicles [3] (i.e. a vehicle equipped with 802.11p and UTRAN interfaces) has received a lot of attention. Once in the range of a LTE base station, the vehicle gets internet access. Actually, LTE provides a robust mechanism for mobility management of vehicles [28] (i.e., supports a data rate of 10 Mbps with a speed up to 140 km per hour). LTE also fits the bandwidth demands and the quality of service requirements of infotainment applications [28]. However, mobile data is experiencing explosive growth [25]; this makes LTE cellular infrastructure bandwidth not able to keep up with connecting high number of connected vehicles [33]. Also, it has been reported that cellular infrastructure connectivity cannot evolve once it is installed [3]. Furthermore, many vehicles incur frequent handoffs, because of high mobility, requiring higher bandwidth [10]. Hence, allowing only some connected vehicles to operate as gateways (mobile gateways) to other vehicles may be effective [9]. Several contributions [16] [17] [18] [20] have focused on proposing various Internet access systems using connected vehicles as gateways. Getting internet access through either RSUs ([11] [12] [13]) or connected vehicles ([16] [17] [18] [20]) relies on multi-hop communication links. Typically, a vehicle connects to a gateway in its vicinity. In case no internet gateway in the range, a vehicle relies on multihop communications to connect to a gateway beyond its transmission range. A gateway discovery protocol is required to discover routes (i.e., an established route is a fixed succession of nodes between the source and the destination) to gateways not in the range. Random loss in wireless ad hoc networks is caused by lossy wireless communication channels and node mobility. Typically, transmission in wireless medium is always vulnerable to packet collisions and interferences due to various wave propagation issues such as signal attenuation, noise and jitter. These effects are quite predominant in vehicular networks in the presence of high rise buildings making vehicular networks quite unreliable. Achieving very high reliability in the presence of all kinds of wireless network vulnerabilities is a major challenge in vehicular networks. Gateway discovery protocols use IEEE 802.11p broadcast communication mode. However, IEEE 802.11p broadcast does not support acknowledgement. Therefore, losses

of messages due to packet collisions, poor channel conditions, etc., cannot be easily detected. Gateway discovery protocols should be able to establish reliable paths in the presence of all such conditions. In this paper, we introduce a reliable multi-hop internet access system (called RICS) for urban vehicular environments. Basically, we make use of both LTE-connected vehicles and the already deployed RSUs infrastructure as gateways. RSUs have a considerable impact on network reliability, as they are fixed reliable nodes [27]. Because of random mobility of vehicles, there is the possibility of network fragmentation. Static RSUs may act as bridges between fragmented groups of vehicles [8]. LTE-connected vehicles enhance gateways availability because adding such vehicles (e.g. buses and taxis) doesn't require additional infrastructure (e.g. land). In [9], it has been reported that using connected vehicles as gateways increases the probability, for moving vehicles, to set up paths with fewer hops. To ensure reliable multi-hop In-vehicle Internet access, our objective is to find out the minimum possible communication hops, from a requesting vehicle to a fixed/mobile gateway, with high reliable message dissemination (e.g., 97%). To accomplish this, we model the gateways placement problem (called GP) as a 2-dimentional k-center [37] optimization problem. This problem is known to be NP-hard. We make a dimension reduction of the optimization problem and propose an exact time resolution algorithm to solve it. On top of the minimum communication hops, we implement a gateway discovery protocol M-HRB [2] which exploits the reception quality of 802.11p wireless links to establish high reliable communication paths. The remainder of this paper is organized as follows. Section II presents related work. Section III presents our assumptions and the basic idea of the proposed scheme. Section IV presents the gateway placement optimization problem. Section V presents the gateway discovery protocol. Section VI described the proposed solution. Finally, Section VII concludes the paper.

II. RELATED WORK

Several gateway discovery schemes (i.e., [19][20][21][22]) have been proposed in the literature. These schemes can be classified into three categories: (1) Proactive approaches [19][22], where gateways advertise themselves in the whole network. In [19], the gateway with the maximum route connection's duration is selected (The route connection's duration represents the time elapsed before a connection breaks along the route, which is estimated using traffic density and distance to gateway). In [22], gateways employ the concept of connected dominating set (CDS) to retransmit the advertisement message. Every vehicle is either in CDS or adjacent to at least one node in CDS. The CDS nodes are selected using route lifetime parameter. The route lifetime is the minimum of the lifetimes of its constituent links; link lifetime is the time difference between link initiation and link breakage/termination; (2) Reactive approaches [20][21][30], where vehicles (called requesters), that want internet access, need to flood the network for gateway discovery. In [20], the discovery protocol uses location and speed of vehicles to predict when the route to the gateway will break and preemptively creates new routes to

replace old ones before they break. In [21], the discovery protocol selects few forwarding nodes to reduce overhead of the protocol in [20]. Speed of neighboring vehicles is a main parameter to predict lifetime of links between two vehicles. The gateway with the maximum predicted route lifetime to the source is selected. In [30], the route that can stay longer (i.e. has biggest lifetime), between the vehicle and the gateway, is selected. The discovery process makes use of predictable vehicle mobility, which is limited by traffic pattern and road layout. We conclude that reactive schemes suffer from poor scalability in discovering gateways as all vehicles send requests; and (3) Hybrid approaches [23][29], where gateways advertise themselves to their neighbors (1 or n hops away); then, requesters send packets to find a gateway in these advertisement areas. The selection of advertisement zones depends on the dimension of the network. A small advertisement zone could result in high reactive overhead, and a large advertisement zone could result in high proactive overhead. In [29], the authors use the characteristics of vehicle movements (e.g. speed and direction of movement) to predict the future behavior of vehicles, and to select a route with the longest lifetime to connect to the wired network. In [23], the position of the destination and the position of neighboring nodes are used to forward data without establishing routes in the advertisement area. Any node that ensures progress toward the destination can be used for forwarding. The forwarding decision is based on the position of destination vehicle and position of one hop neighbors. However, the link to the selected node may be unreliable in harsh network conditions leading to packet loss. From above discussions, we can conclude that the route discovery schemes do not guarantee reliable communication, in city settings. Existing schemes (e.g., [20][21][30][29]) make use of link stability metric, which is based only on mobility metrics (e.g. relative motion between neighboring vehicles, speed, etc.), to determine paths to gateways. In city settings, such a selected route can be broken frequently owing to the high mobility of vehicles. In [9], it has been proved that the number of breakages of a path increases with the number of hops in the path. Thus, the node centric view of the routes in [20][21][22][29][30] leads to frequent broken routes in the presence of VANETs' random loss (high mobility and lossy wireless communication channel). Consequently, many packets can be dropped, and the overhead due to route repairs or failure notifications significantly increases, leading to low delivery ratios and high transmission delays of advertisement messages. Thus, vehicles that are far away from the mobile gateway transmission range will have limited or very poor internet connectivity.

III. PROPOSED SCHEME

A. Assumptions

In this paper, we consider a scenario where vehicles are moving on urban streets. We choose a city map where the length of a road segment is random. We assume that (1) vehicles are equipped with a Global Positioning System (GPS) and digital road maps; (2) RSUs (equipped with 802.11p interface and wired access to the backbone internet) are distributed randomly with a predefined density; (3) all vehicles are equipped with

IEEE 802.11p [28] wireless technology and computation capabilities; (4) LTE-connected vehicles (equipped with both IEEE 802.11p and LTE interfaces) are distributed randomly with a predefined density; (5) connected vehicles are in the range of an LTE base station; (6) obstacles (e.g., buildings) exist; thus, this may impact communication among vehicles; and (7) vehicles density information is transmitted according to the scheme in [38] to a central server, for each time period T_g (e.g., $T_g=1$ minute).

B. Basic Internet Access Strategy

Figure.1 shows the gateways architecture providing vehicle-to-Internet communication. A set of static gateways (RSUs) and mobile gateways (Connected vehicles) are distributed randomly. Vehicles intend to get internet connectivity. A vehicle v connects to a gateway, if it exists, in its direct vicinity. Alternatively, v uses multi-hop communication to access a gateway beyond its transmission range. Given the density information, the basic idea of the proposed scheme is to select a predefined number of gateways k and their locations to cover all vehicles. Each gateway sets the minimum radius, in terms of communication hops, of its advertisement area forming an Extended Range (Ex-Range). The gateway provides reliable internet access to all vehicles in its Ex-Range using multi-hop communication. The proposed scheme consists of two main phases: (1) Gateway Placement Phase (GP), where the gateways define their minimum communication hops with the objective to cover all vehicles (See Section IV); and (2) Gateway Discovery Phase (GD), where each selected gateway applies a gateway discovery protocol in the network region defined by the number of hops determined in the first phase. The gateway discovery protocol exploits the quality of 802.11p wireless link of neighbors to ensure a very high reliability requirement of internet connectivity (e.g., $r_{th}=97\%$) in urban settings (Section V).

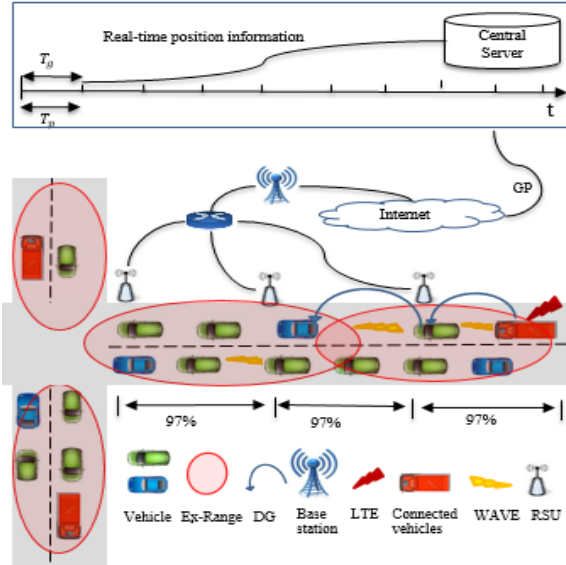


Figure 1. Internet access architecture

IV. GATEWAY PLACEMENT

A. Network Model

Basically, as defined in [2], each street is divided into a number of zones. The length of each zone is same as the transmission range of a vehicle (i.e., $Tr = 250$ meters). Each zone is divided into partitions with predefined length (e.g. length of a Car ~ 6 meters) to have either 1 vehicle or no vehicle in each cell. Thus, a cell represents a possible vehicle location. We define transit-time T_s (e.g., $T_s = 0.2$ seconds) as the cell transit time. In a cell, during T_s , moving vehicles are assumed to be stationary. We assume no fragmentation in the network. For each T_s , we model the network connectivity graph as an undirected weighted connected graph $G = (V, E)$, where V denotes the set of nodes (vehicles and RSUs) and $E \subseteq V \times V$ the 802.11p communication links between neighboring nodes. The number of nodes is $|V| = Ng + Nv$, where Ng is the number of gateways and Nv is the number of vehicles. We consider a 2-dimensional metric space $(V \times V, Hop)$ to model the distance (i.e. number of hops) between two vertices in G ; the weight of an edge $e \in E$ is equal to 1. Let $(u, v) \in V$ denote two nodes in G and $Hop(u, v)$ the minimum number of hops between u and v .

$$Hop(u, v) = Hop(u, y) + Hop(y, v) \quad (1)$$

where y is a vertex in G . $Hop(u, y)$ is the shortest path between u and y . $Hop(y, v)$ is the shortest path between y and v . $Hop(u, v)$ is the shortest path between u and v .

B. Problem formulation

The gateway placement problem (GP) consists of selecting a predefined number of gateways k with the lowest number of communication hops to cover all vehicles. Thus, the maximum distance (in terms of hops) of any vehicle to its gateway is minimized. Let $g_i, 1 \leq i \leq Ng$, denote a binary variable that indicates whether gateway i is selected and $v_j, 1 \leq j \leq Nv$, denote a binary variable that indicates whether vehicle j is covered (by a selected gateway) and t_{ij} denote a binary variable that indicates whether vehicle v_j is covered by gateway g_i . The integer linear programming (ILP) [40] of the GP problem can be expressed as follows:

$$\text{Min}_{1 \leq i \leq Ng} \left(\text{Max}_{1 \leq j \leq Nv} (Hop(g_i, v_j) * t_{ij}) \right) \quad (2)$$

S.t

$$\sum_{i=1}^{Ng} g_i \leq k \quad (3)$$

$$g_i \geq t_{ij} \quad \forall i, \forall j \quad (4)$$

$$\sum_i t_{ij} \geq 1 \quad \forall j \quad (5)$$

$$g_i, v_j, t_{ij} \in \{0, 1\} \quad \forall i, \forall j \quad (6)$$

The objective function (2) determines the minimum number of hops that enables every vertex (vehicle) to be connected to one of the k Internet gateways. Constraint (3) ensures that the number of gateways is not greater than k . Constraint (4) guarantees that a gateway is placed before being used. Constraint (5) guarantees that each non-gateway vehicle can

reach at least one of the gateways. Constraint (6) is the integrity constraint of the decision variables. In contrast to cellular networks, in vehicular networks, the availability of a gateway changes frequently due to high mobility. Hence, a vehicular gateway enables short connection duration when compared to the connection duration to a cellular base station [19][15][4]. In our model, the GP problem is resolved each update time T_p . The update time T_p represents the average road segment transit time (e.g., $T_p = 62s \approx 1$ minute, average length of road segment is 500 m and average vehicles speed is 30 kilometer/hour). The central server (Figure 1) provides real-time density information each 1 minute [39]. Therefore, $T_p \approx T_g$.

- *Proposition:* GP is NP-hard.

- *Proof:* To prove this, we use a reduction from the Euclidian k-center [14] problem (a variant of the Facility Location Problem (FLP) [14]). Given a two dimensional metric space with a set S of n points in the plan and a positive integer k , the k-center problem is to find k congruent disks of minimum radius r that cover S . The Euclidian distance between two points in S is denoted by d . In the k-center problem, the radius r of a disk represents the maximum distance d from a point, in S , to its closest disk center. The Euclidian distance d between any two points in S satisfies the triangle inequality [28]. The k-center aims to minimize r . In the GP problem, the k Internet gateways are referred to as the centers of the network connectivity graph G . As for the distance d , the linear equality (in terms of hops) property defined in Equation (1) refers to the triangle inequality property. The length of the path which is longest among all shortest paths represents the radius r of a disk. Note that, in GP, a path is a route from a vehicle to its closest gateway. Thus, the GP problem is an example of the 2-dimensional k-center problem which is known to be NP-hard [37]. Consequently, GP is NP-hard. Despite its NP-hardness, the GP problem could be solved using a simplified model [7]. In fact, it is quite natural to assume that Internet gateways moving one beside the other on parallel street lanes cover the same set of vehicles. Similarly, vehicles moving one beside the other on parallel street lanes are in the range of the same Internet gateway. We call this assumption a 2-1 space dimension reduction [36] of a city street. This assumption can be geometrically proved.

- *Proposition:* The city street is 2-1 dimension reducible.

- *Proof:* Let us consider a 2-dimensional representation of a city street (see Figure 2), independently from the road structure (i.e., straight or curved), the number of intersections, the number of lanes and the length of the street. The horizontal direction from left to right is X-axis (X-axis represents a possible street lane); the vertical direction from down to top is Y-axis. The Y-axis values correspond to street lanes (ranging from 1 to $m+1$, where m is the number of street lanes, the street side where RSUs are placed is considered as a virtual street lane with no vehicles. Thus, the maximum value in Y-axis is $m+1$). An X-axis value is proportional to the cell length [2]. X-axis values are proportional to cell length (6 meters) [2]. Given two gateways locations o_1 and o_2 at the same X-axis value, let disk $D_1(o_1, r)$ and disk $D_2(o_2, r)$ represent the wireless coverage of gateways o_1 and o_2 respectively. r is the disk radius. In figure

2, we suppose $r=1$. Let Δ_1 and Δ_2 represent the street border lanes. The equation of any straight line, called a linear equation, can be written as: “ $y = ax + b$ ”, where a is the slope of the line and b is the y-intercept. Thus, Δ_1 corresponds to $y=m$, where m is the number of street lanes, and Δ_2 corresponds to $y=0$. Let c_1 and c_m be the X-axis coordinates of the rightmost intersection points of the street border lane Δ_1 , with D_1 and D_2 , respectively. The value of $|c_1 - c_m|$ is negligible when compared to a vehicle location (6 meters [2]).

$$|c_m - c_1| \ll 6 \quad (7)$$

Therefore, gateways that have the same X-axis values cover the same set of vehicles. Similarly, vehicles that have the same X-axis value are covered by the same gateway. We denote by p_i , $(1 \leq i \leq \lfloor \frac{n}{m+1} \rfloor)$, n is the total number of nodes on the street and m is the number of street lanes, the orthogonal projection of the nodes (vehicles and RSUs) onto the X-axis. Thus, p_i represents a virtual representation of all street nodes on the same straight line; this line models the street.

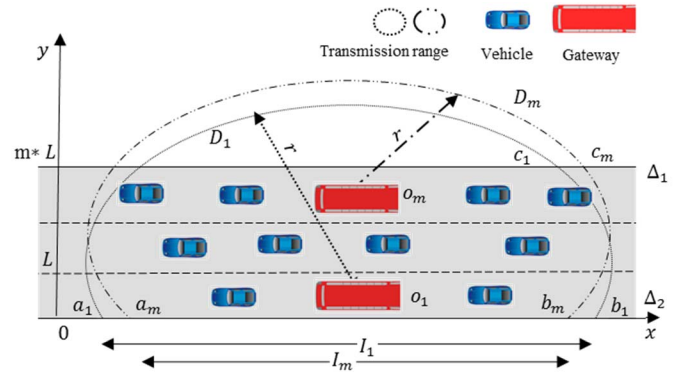


Figure. 2 Candidate gateways locations

C. One-dimensional GP

In this section, we make use of a 2-1 dimension reduction [34] of GP. We convert the GP problem from a $(V \times V, \text{Hop})$ dimensional space to a (V, Hop) dimensional space. Given the one-dimensional representation of the city street, we define the one-dimensional GP problem on a line as follows: Given a set S of n points (i.e., vehicles) lying on a line and an integer $k \geq 1$, find k intervals with centers (i.e., gateways) on that line such that the union of the intervals covers S and the maximum radius of the interval (half of its length) is minimized. The basic idea of the 2-1 dimensional reduction algorithm is to represent the nodes (i.e., vehicles and RSUs) along the street by points p_i obtained by orthogonal projection of the street nodes onto the X-axis. The orthogonal projection of the nodes (vehicles and RSUs) on the X-axis results in three categories of points: (1) a gateway point; (2) a vehicle point; and (3) a combined gateway-vehicle point.

Algorithm I. 2-1 Dimension Reduction

Input: Graph $G=(V,E)$, Line l , n nodes.

Output: Representative points: $p_1, p_2, \dots, p_i$ (i.e., $i = O(n)$)

Step 1: grouping of nodes of G according to their X-axis coordinate

1. **For** any node v and u in G **do**
2. **If** $[\text{proj}(v)=\text{proj}(u)]$ **then** //(see Equation 8)
3. **Make a group** σ_i //insert u and v into the same group
4. **End if**
5. **End for**

Step 2: Orthogonal projection of the nodes of each group onto the X-axis line.

6. **For** each group σ_i **do**
7. **For** each node u in the group **do**
8. $p_i = \text{Proj}(u)$ // (see equation 8)
9. **End for**
10. **End for**

Step 3: Mark the points according to their category

11. **For** each formed group **do**
12. **If** all nodes are gateways **then**
13. **Mark** p_i as a vehicle
14. **Else if** all nodes are vehicles **then**
15. **Mark** p_i as a combined point (gateway and vehicle)
16. **Else if** the nodes are gateways and vehicles **then**
17. **Mark** p_i as a combined point (either gateway or vehicles)
18. **End if**
19. **End for**
20. **Return** the set of p_i points

The 2-1 dimensional reduction algorithm is detailed in Algorithm I. The major steps of Algorithm I are as follows. First, nodes are grouped according to their X-axis coordinate; nodes that have the same X-axis coordinate belong to the same group σ_i , where $1 \leq i \leq \left\lceil \frac{n}{m+1} \right\rceil$, n is the total number of nodes on the street and m is the number of street lanes. These steps are accomplished in lines 1-5 (See Algorithm I). Then, each group of nodes is assigned a representative point p_i , where $1 \leq i \leq \left\lceil \frac{n}{m+1} \right\rceil$. The point p_i is obtained using an orthogonal projection, on the X-axis, of any node of the group. If $e = (1,0)$ the unit vector in the direction of the X-axis and $v_i = (a,b)$ a node that belongs to group σ_i , then the orthogonal projection p_i of $v_i = (a,b)$ onto the X-axis is as follows:

$$p_i = \text{proj}(v_i) = (a, 0) \quad (8)$$

Then, we make use of three markups to obtain three categories of points. If all nodes in the group are vehicles, then the representative point is marked as a vehicle. If the nodes in the group are all gateways, then the point is marked as a gateway. If the group consists of gateways and vehicles, then the point is marked as a combined point. These steps are accomplished in lines 6-19 (See Algorithm I). Finally, we return the set of points in line 20.

D. Exact solution

In this section, we present the decision algorithm to solve the 1-dimensional GP problem. The resolution process is described in Algorithm II. The basic idea of the algorithm is to increase the radius r until covering all points (vehicles) using k intervals. Indeed, if we increase radius r , then the required number of gateways k will decrease. We start by an optimal radius which is equal to 1 hop (the transmission range).

Algorithm II. Gateway Placement

Input: Set of p_i points (Output of Algorithm I)

Required number of gateways k .

Output: Radius r (minimum communication hops).

A set of selected gateways locations.

1. **Initiate** radius $r=1$
2. **For** each gateway p_i **do**
3. $a_i(r) = p_i - (r, 0)$ (See Equation 8)
4. $b_i(r) = p_i + (r, 0)$ (See Equation 8)
5. $I_i(r) = [a_i(r), b_i(r)]$
6. **End for**
7. $I = \{I_i(r)\}$
8. **Sort** intervals in I according to the X-axis coordinate of the left endpoint a_i .
9. $k(r) = 0$
10. **While** $[(k(r) \leq k) \text{ and (not all vehicles are covered)}]$ **do**
11. **While** $(I \neq \emptyset)$
12. **Select** the leftmost endpoint $a_i(r)$ in the sorted I
13. **Mark** its center p_i as a selected gateway point
14. $k(r)++$
15. **Binary Search of any interval** $I_i(r)$ in I that covers the selected gateway point p_i
16. $I = I \setminus \{I_i(r)\}$
17. **End while**
18. **End while**
19. **If** $[(k(r) \leq k)]$ **and** (all vehicles are covered) **then**
20. **Return** radius r **and** the selected gateways
21. **Else**
22. $r++$
23. **Go to step 2**
24. **End if**

Then, we increase the radius r each time by 1 hop. The algorithm ends if it meets the required number of gateways k and returns radius r . The major steps of Algorithm II are as follows: (1) we initiate the radius of gateways to 1 in line 1. Then, we generate the coverage intervals $I_i(r)$ (the interval center is a gateway representing point p_i ; the length of the interval equals $2 * r$) of all points marked as gateways or combined points, in lines 2-7; (2) we sort the intervals according to their left endpoints $a_i(r)$; this is accomplished in line 8; (3) we select the gateways as follows: In line 12, we select the leftmost endpoint in the sorted intervals set. We mark its center as a selected gateway, in line 13. We increase the number of selected gateways k , in line 14; (4) in lines 15-16, we perform a binary search in the set of intervals I to find all intervals that cover the selected gateway center. If any, we remove that interval from intervals set I . These steps are briefly listed in line 15; and (5) in lines 19-24, we check whether the number of selected gateways $k(r)$ is smaller than the predefined number of gateways k and all vehicle points are covered. If the response is no, we increase the radius r and repeat steps of lines 2-18; otherwise, we identify the gateways placement set and the minimum radius in line 20.

• *Proposition:* Algorithm II selects $k(r)$ gateways and minimizes the length r of the path which is longest among all shortest paths in $O(n^2 * \log(n))$, where n is the total number of nodes along the street. Note that, a path is a route from a vehicle to its closest gateway.

- *Proof:* The number of gateways k is bounded by n . For each radius r , we sort the intervals, in line 8, which takes $O(n \log(n))$. Then, in line 10, we iteratively select at most $k = n$ gateways. Therefore, the complexity of this step is $O(n)$. For each selected gateway, we do binary search in line 15. The complexity of the binary search is $O(n \log(n))$. The complexity of lines 10-18 is $O(n^2 * \log(n))$. Therefore, the total running time of the decision algorithm is $O(n^2 * \log(n))$.

- *Proposition:* Algorithm II returns optimal radius (called r^*). Note that optimal radius means the minimum radius such that there exist k gateways of that radius with union covering n input points.

- *Proof:* To prove this, we suppose the proposition were false, i.e., let us assume that there exists an optimal radius r_{opt} , such that $r_{opt} < r^*$ and that there exist k gateways of that radius with union covering n input points. Let S be the set of input points. Let d_{max} be the maximum distance in terms of hops from a vehicle to its closest gateway; $d_{max} = \max \left\lfloor \frac{|x_i - x_j|}{Tr} \right\rfloor$, where x_i is the X-axis value of a vehicle point and x_j is the X-axis value of a gateway point, $1 \leq i \leq n$, $1 \leq j \leq n$. It is clear that $r_{opt} \geq d_{max}$. Algorithm II increases the radius r each iteration by 1 hop. If the following conditions: 1) number of selected gateways $k(r)$ is upper bounded by k ; and 2) all points in S are covered; are true, the algorithm returns r^* . Therefore, in case the number of selected gateways when $r = d_{max}$ is not greater than k , and all points in S are covered, then $r^* = d_{max}$. However, we have already supposed that $r_{opt} < r^*$. As a result, $r_{opt} < d_{max}$ which is not possible. This contradiction shows that $r_{opt} = r^*$. Now, in what follows we suppose $r_{opt} > d_{max}$ and $r > d_{max}$. As r increases, the endpoint $a_i(r)$ of an interval $I_i(r)$ decreases (the endpoint point $b_i(r)$ increases) and the number of gateway points in the interval $I_i(r)$ increases. Thus, $k(r)$ decreases only when the relative order of the endpoints $a_i(r)$ (or $b_i(r)$) and the gateway points p_i changes. When r increases, the binary search in line 15 of Algorithm II removes more gateway points from the interval of the selected gateway point. Consequently, the number of remained intervals in line 16 decreases and the number of selected gateways $k(r)$ computed in line 14 decreases. Our goal is to find the minimum radius r^* such that $k(r^*)$ is the largest integer with $k(r^*) \leq k$ and covering all points in S . Since $k(r)$ can decrease only when the radius increases, a straightforward way to find the radius r^* is to keep increasing radius r by 1 hop (line 22). For each iteration, we do a binary search (line 15) and we remove intervals containing the selected gateway. In line 19, we evaluate if $k(r) \leq k$ and if all points in S are covered. If the condition is false, we increase r until the first time the condition is true. Finally, we return r^* in line 20. As we supposed, above, that $r_{opt} < r^*$. This means, $\exists r$, such that $r < r^*$ and $k(r) \leq k$ covering all input points. This is not possible because Algorithm II returns r^* the first time the two conditions are true). This contradiction concludes the proof and shows, as before, that $r^* = r_{opt}$. Therefore, Algorithm II returns optimal radius.

V. GATEWAY DISCOVERY

In this section, we present the gateway discovery protocol. Each gateway periodically broadcasts advertisement messages to all vehicles located in its Ex-Range. In [2], we already proved the effectiveness of M-HRB protocol to ensure very high reliability for multi-hop emergency message dissemination in city environments. For this reason we make use of M-HRB to establish reliable paths between gateways and vehicles. As the vehicle can move in any direction to travel, this creates a rapid changing topology at any speed resulting in difficulties to handle the vehicular node mobility. Thus, M-HRB makes use of the vehicle location to select the forwarding node. The main idea of M-HRB is to ensure very high reliability for each hop. To achieve this, M-HRB estimates the reception quality of 802.11p wireless link in cells to select forwarding nodes locations [2]. Basically, M-HRB exploits periodic beacons to estimate the quality of 802.11p wireless link. Using this information, each hop, minimum possible forwarding locations are selected to enforce achieving very high reliability.

VI. PERFORMANCE ANALYSIS

In this section, we evaluate the proposed RICS (GP with M-HRB). We run simulations using Omnet++ 4.3 and Sumo traffic simulator. Our C++ code uses Omnet++ as a discrete event simulator and Veins 2.0 for DSRC simulated components [24]. Our simulation scenario is composed of 4 km fragment of a real map street [35]. We configured Omnet++ to model the impact of both distance and obstacles (building and moving vehicles) on signal propagation. Table 1 shows the simulation parameters. We use shell script to extract vehicles positions from Omnet++ and run Algorithm I and Algorithm II to select the required number of gateways k and fix the radius r . The number of gateways k is a function of the vehicles density; it varies from 5% to 15%. We did consider two simulation scenarios: (1) Scenario 1: In this scenario, the density assumes 80 vehicles/km (40 vehicles/lane/km); we vary the gateway penetration rate from 5% to 15% gateways; (2) Scenario 2: In this scenario, the density assumes 120 vehicles/km (60 vehicles/lane/km); we vary the gateways penetration rate from 5% to 15%. In both scenarios, each gateway generates an advertisement message at a rate of w messages/second. We performed 5 simulation runs for a confidence interval of 95%. The performance parameters, we did consider in the evaluation of RICS, are: (1) Packet reception ratio (PRR): the average percentage of vehicles that receive the advertisement message; (2) Network load: it includes beacon overhead, advertisement/discovery transmissions and data retransmissions; and (3) Average propagation delay: the propagation delay represents the time it takes an advertisement/discovery message, sent by the source (gateway), to be received by vehicles in the advertisement/discovery area (see Table 2). To evaluate the effectiveness of the proposed RICS, we compare it with the following gateway discovery approaches: (1) Proactive approach [22], where the route to the gateway is CDS with the longest lifetime. To build CDS, the moving direction is the main mobility parameter to predict link lifetime between two

neighboring vehicles; (2) Reactive approach [20], where the discovery protocol uses location and speed of vehicles to predict routes to the gateways; and (3) Hybrid approach [29], where the gateway discovery protocol uses the characteristics of vehicle movements (e.g. speed and direction of movement) to predict the future behavior of vehicles, and to select the route with the longest lifetime to connect vehicles to the gateways. For the hybrid approach [29], we implemented two instances: (i) 2-Hybrid, where the size of the proactive area is 2, and (ii) 4-Hybrid, where the size of the proactive area is 4.

TABLE.1. SIMULATION PARAMETERS

Simulation parameter	Value
Fading model	Rayleigh [42]
Transmission range (Tr)	250 meters [41]
T_x power	20 dBm
WM, Beacon length	292,72 bytes.
Vehicle density	80-120 cars/km
Reliability requirement r_{th}	0.97
Simulation duration	10 minutes
Vehicle speed V_e	10-50 km/hour
Number of street lanes m	2 lanes
Cell transit time T_s	0.2 seconds [2]
Update time period T_p	1 minute
Density collection period T_g	1 minute [39]
Advertisement period	1 second
Beacon period	0.1 second

TABLE.2. GATEWAY DISCOVERY APPROACHES

Category	Advertisement/Discovery area	Advertisement/Discovery protocol
GP + M-HRB	Ex-Range	M-HRB[2]
Proactive [22]	All the network	CDS-based advertisement
Reactive [20]	All the network	PBR[20]
4-Hybrid [29]	4 hops	ODAM[6]+ CFB[5]
2-Hybrid [29]	2 Hops	ODAM[6]+ CFB[5]

A. Results

Figure 4 shows the variation of radius r with gateways penetration rate. When the number of selected gateways increases, radius r decreases considerably. For example, when gateways penetration rate is 10%, the radius r is 3 hops against 9 hops when gateways penetration rate is 5. This can be explained by the fact that when gateway penetration rate is 5, the condition (covering all vehicles) in step 10 of Algorithm II is not fulfilled for values of r smaller than 9 hops. Thus, gateways increase their radius r (step 22), until covering all the vehicles. Figure 5.a and Figure 5.b show the variation of PRR with gateways penetration rate. For both densities (80 vehicles/kilometer and 120 vehicles/kilometer), when gateways penetration rate increases, we observe that our approach outperforms the other approaches. For example, PRR achieved by RICS is 100 percent when gateways penetration rate is higher than 10% and vehicles density is 120 vehicles/kilometer, against 81% scored by 4-Hybrid and 73 % scored by 2-Hybrid. This is due to the route establishment mode which is based on the highest route lifetime. In city environments (the wireless communication channel is very erroneous and lossy), the links between vehicles are unreliable resulting in high packet loss.

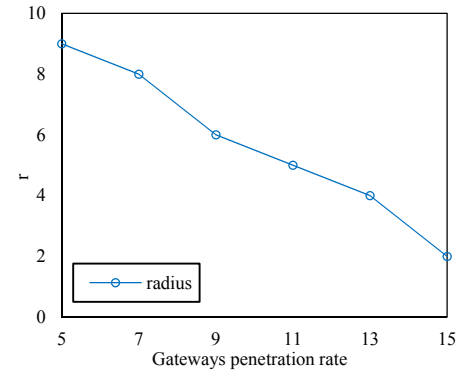


Fig.4 Variation of minimum communication hops

The outperformance of RICS in terms of PRR is related to the reliability method in M-HRB; which, for each hop along the path, selects forwarders having high reception quality [2]. In contrast, the reactive approach ensures the lowest PRR (PRR is 40% when gateway penetration rate is 15% and vehicles density is 120 vehicles density). The poor performance of the reactive approach in terms of PRR is related to its route discovery method. More specifically, the routes are established based on the predicted lifetime of links between two vehicles, where speed of neighboring vehicles is a main link parameter. In city settings, with high channel loss due to random interference, the resulting paths are not reliable incurring high packet loss. The worst performance of the proactive approach (PRR is 63% when gateways penetration rate is 15% and the density is 120 vehicles/kilometer) is related to its CDS nodes selection mode. More specifically, it selects forwarding nodes (forwarders) based on their link lifetime. In adverse network conditions (high vehicle density and high gateways penetration rate), CDS nodes may have low reception quality resulting in packet loss. This is because, the higher the gateway penetration rate, the higher the channel load (advertisement messages) and the higher the number of incurred collisions. In such situations, a message may be not delivered to CDS nodes. Unlike reactive and proactive approaches, M-HRB dynamically selects the appropriate forwarders (their number and their positions) based on their quality of wireless links. Figure 6.a and figure 6.b show the variation of average delay with gateway penetration rate. As expected, RICS outperforms the other approaches. This is due to the fact that the GP problem of RICS selects gateways in a way to minimize the number of hops from vehicles to gateways. More specifically, the objective function (see Equation (2)) of GP minimizes the radius r . As the delay is proportional to the number of communication hops, RICS achieves low delay. Especially, when gateways penetration rate increases, the radius r of the Ex-Range decreases. In such a situation, RICS achieves very low delay. For example, the delay is 195 msec, when gateway penetration rate is 15% and vehicles density is 120 vehicles/kilometer. We also observe that the reactive approach ensures the highest delays for both densities. For example, the incurred delay is 650 msec when gateways penetration rate is 15% and vehicles density is 120 vehicles/kilometer).

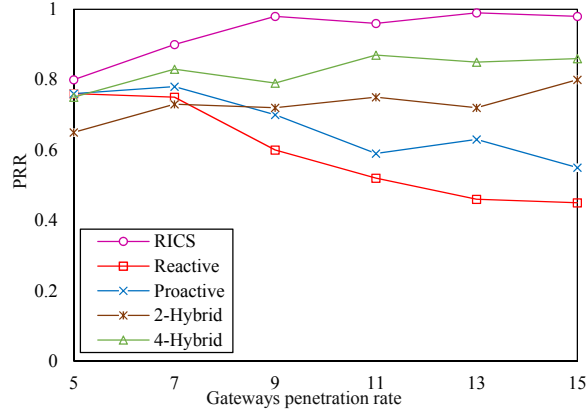


Fig. 5.a PRR (80 vehicles/kilometer)

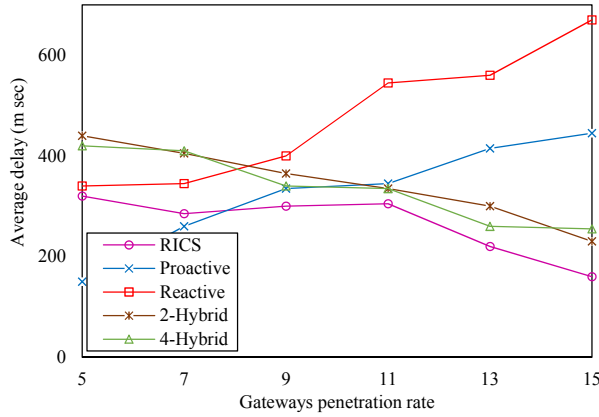


Fig. 6.a Average delay (80 vehicles/kilometer)

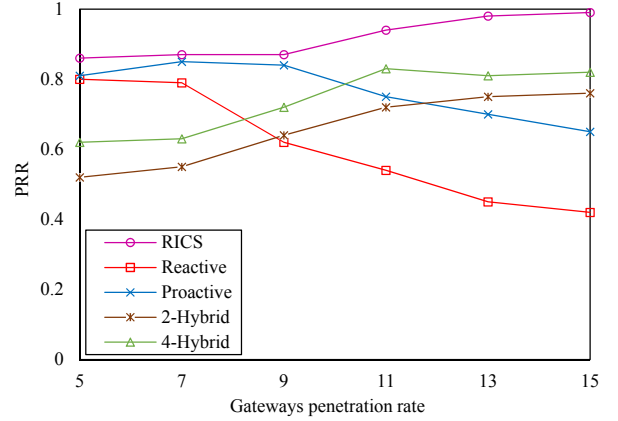


Fig. 5.b PRR (120 vehicles/kilometer)

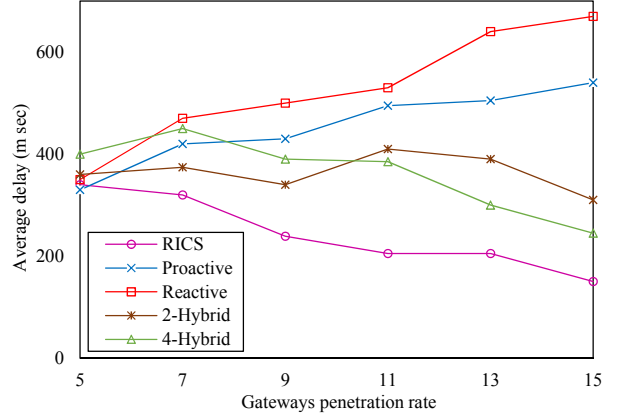


Fig. 6.b Average delay (120 vehicles/kilometer)

This increase in delay can be explained as follows: (1) when the number of vehicles in the network is very high, the number of gateway requests is high as well; and (2) when the gateways penetration rate increases, the total number of gateway replays and the number of transmitted gateway requests increase considerably. Thus, the network is congested resulting in dropping messages increasing the delay. The delay, with the proactive approach, increases with the number of gateways. This is because, in high density scenarios, links between established CDS nodes are unreliable resulting in links breakages. CDS maintenance and messages retransmissions incur high delay. Similarly, the delay, with the hybrid approaches, increases because routes break frequently in high density scenarios. In this case, nodes have to send more route requests resulting in higher delays. Figure 7 shows the variation of the network load with gateways penetration rate. When gateways penetration rate increases, the average network load incurred by our approach is almost uniform for the two network densities. This is expected; indeed, we increase the coverage radius of the gateways only if the condition in step 10 (all vehicles are covered) is not fulfilled. Thus, in almost all the cases, a vehicle is connected to only one gateway (except some vehicles in the border of the Ex-Ranges, in case Ex-Ranges intersect). However, the control overhead drastically increases with the increase of gateways in proactive gateway discovery,

and with the increase of source nodes for reactive gateway discovery. The proactive approach results in very high network load when the gateway penetration rate increases. This is because, more gateways results in high average control overhead due to the creation and maintenance of CDSs over streets. The reactive approach incurs low overhead for small networks but it suffers from poor scalability. This is due to loss of route replay packets which are sent back to source nodes by the gateway using the chain of nodes in the gateway request packets. When the number of vehicles in the network is high and the number of gateway requests is high, the number of transmitted messages increases considerably. The number of route failures is high as well, requiring repair or reconstruction.

VII. CONCLUSION

In this paper, we proposed an Internet access scheme to ensure multi-hop reliable paths between gateways and vehicles in city environments. Basically, internet gateways are deployed in a way that minimizes the communication hops subject to providing internet access to all vehicles. We modeled the gateway placement as a k-center optimisation problem. We make use of space dimension reduction to solve the problem in an exact time. Each gateway makes use of M-HRB protocol to establish communication paths. The main focus of this protocol is achieving reliability requirements of DSRC/802.11p-based

broadcast. Numerical results show that, the proposed gateway placement algorithm together with the reliable gateway discovery protocol establish reliable communication paths in city environments.

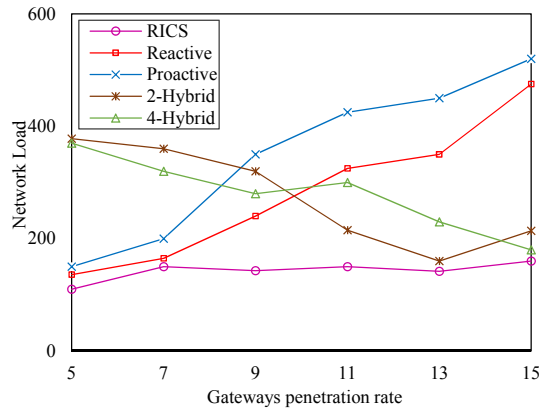


Fig.7 Network load

REFERENCES

- [1] H.T.Cheng, H.Shan, and W.Zhuang, "Infotainment and road safety service support in vehicular networking: From a communication perspective," *Mechanical Systems and Signal Processing*, 2010.
- [2] W.benrhaïem, A.S.hafid, and P.k.Sahu "Multi-Hop Reliability for Broadcast-based VANET in City Environments". *IEEE International Conference on Communications (ICC)*, 2016.
- [3] N.Lu, N.Cheng, N.Zhang, X.Shen, and J.Mark, "Connected vehicles: Solutions and challenges," *IEEE Internet Things J.*, vol. 1, no. 4, pp. 289–299, 2014.
- [4] D.Soldani and S.Dixit, "Wireless relays for broadband access [radiocommunications series]," *Communications Magazine*, IEEE, vol. 46, no. 3, pp. 58–66, 2008.
- [5] H.Füßler, J.Widmger, M.Käsemann, M.Mauve, and H.Hartenstein, "Contention-based forwarding for mobile ad-hoc networks," *Ad-Hoc Networks*, vol. 1, no. 4, pp. 351–369, 2003.
- [6] A.Benslimane, "Optimized Dissemination of Alarm Messages in Vehicular Ad-Hoc Networks (VANET)," *Proc. 7th IEEE Int'l. Conf. High Speed Networks and Multimedia Commun*, pp. 655–66, 2004.
- [7] P.Brass, C.Knauer, H-S.Na, C-S. Shin and A.Vigneron, "Computing k-centers on a line". *Technical report arXiv preprint arXiv:0902.3282*, 2009.
- [8] S. I.Sou and O. K.Tonguz, "Enhancing VANET Connectivity Through Roadside Units on Highways," in *IEEE Transactions on Vehicular Technology*, vol. 60, no. 8, pp. 3586–3602, Oct. 2011.
- [9] V.Namboodiri, M.Agarwal, and L.Gao, "A study on the feasibility of mobile gateways for vehicular ad-hoc networks," in *Proc. VANET*, Oct. 2004, pp. 66–75.
- [10] G.Araniti, C.Campolo, M.Condoluci, A.Iera, and A.Molinari, "LTE for vehicular networking: a survey," *IEEE Communications Magazine* vol. 51, no. 5, pp. 148–157, May 2013.
- [11] A.Abdrahman, W.Zhuang, "Probabilistic Delay Control and Road Side Unit Placement for Vehicular Ad Hoc Networks with Disrupted Connectivity", *IEEE Journal of Selected Areas in Commu.* Vol 29, No 1 2011.
- [12] P.Li, X. Huang, Y.Fang, P.Lin, "Optimal placement of gateways in vehicular networks", *IEEE Trans. Veh. Technol.* 56 (6), 3421–3430, 2007.
- [13] A.Abdrahman, W.Zhuang, "On a stochastic delay bound for disrupted vehicle-to-infrastructure communication with random traffic" *Global Telecommunications Conference, 2009. GLOBECOM*.
- [14] M.Fellows and H.Fernau, "Facility Location Problems: A Parameterized View", *University of Newcastle University Drive, Australia*.
- [15] A.Lo, J.Zhou, I.Niemegeers, "Simulation-based Analysis of TCP over beyond 3G Cellular Multi-Hop Networks", In *Proc. IEEE PIMRC*, 2006.
- [16] T.Taleb, A.Benslimane and R.Sivaraj. "Design Guidelines for a network Architecture Integrating VANET with 3G & beyond Networks". *IEEE Journal on Selected Areas in Communications*, vol 29, No. 3, 2011.
- [17] A.Benslimane, T.taleb and R.Sivaraj. "Dynamic Clustering-Based Adaptive Mobile Gateway Management in Integrated VANET–3G Heterogeneous". *IEEE Journal on Selected Areas in Comm.*, 2011.
- [18] M.Alawi, Rashid. A.Saeed and A.Hassan. "Cluster-based multi-hop vehicular communication with multi-metric optimization". *International Conference on Computer and Communication Engineering*, 2012.
- [19] M.Bechler, L.Wolf, O.Storz and W.J.Franz, "Efficient discovery of Internet gateways in future vehicular communication systems," *Vehicular Technology Conference, 2003. VTC 2003-Spring. The 57th IEEE Semiannual*, 2003, pp. 965–969 vol.2.
- [20] V.Namboodiri and L.Gao, "Prediction-Based Routing for Vehicular Ad Hoc Networks," in *IEEE Transactions on Vehicular Technology*, vol. 56, no. 4, pp. 2332–2345, July 2007.
- [21] A. Adama Ba, A.Hafid and J.Drissi. "Broadcast Control-Based Routing Protocol for Internet Access in VANETS" *IEEE WCNC*. 2011.
- [22] Ngo, Ch.Trung, and O.Hoon. "A Gateway Discovery Approach Using Link Persistence Based Connected Dominating Sets for Vehicular Ad Hoc Networks." *Ad- hoc, Mobile, and Wireless Network. Springer Berlin Heidelberg*, 2013. 305–316.
- [23] K.Abrougui, A.Boukerche, R.Werner and N.Pazzi. "Location-Aided Gateway Advertisement and Discovery Protocol for VANets", *IEEE Transactions on Vehicular technology*, October 2010.
- [24] 802.11p-2010 - IEEE Standard for Information technology– Local and metropolitan area networks– Specific requirements– Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments, 2010.
- [25] G.Araniti, C.Campolo, M.Condoluci, and A.Molinari, "LTE for vehicular networking: a survey". *IEEE Communications Magazine*, 51(5), 148–157.2013, 2013.
- [26] W. Tsung-Jung, W. Liao, Ch.Chang, "A Cost Effective Strategy for Road-Side Unit Placement in Vehicular Networks", *IEEE Transactions on Communications*, vol.60, Issue.8, pp. 2295–2303, 2012.
- [27] L.galati Giordano and L.Reggiani, "Vehicular Technologies Deployment and Applications". In *Tech*, 2013.
- [28] Z.Zheng. "Architecture of Heterogeneous Vehicular Networks. «Heterogeneous Vehicular Networks. Springer International Publishing, pp.9–24.2016
- [29] A. Benslimane, S.Barghi, and Ch.Assi. "An efficient routing protocol for connecting vehicular networks to the Internet." *Pervasive and Mobile Computing* 7.1 98–113. 2011
- [30] M.Alawi, "Simplified gateway selection scheme for multihop relay in vehicular ad hoc network." *International Journal of Communication Systems* 27.12, 3855–3873, 2014
- [31] R.Baldessari. "Car-2-car communication consortium manifesto," *Car 2 Car Communication Consortium*, Braunschweig, Germany, Tech. Rep. 1.1, Aug. 2007.
- [32] B.Aslam, F.Amjad, and C.Zou, "Optimal roadside units placement in urban areas for vehicular networks," in *Proc. IEEE ISCC*, 2012, pp. 000423–000429.
- [33] Online: <http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html>.
- [34] M.A.Carreira-Perpinan. "A review of dimension reduction techniques". *Technical report CS-96-09*, Department of Computer Science, University of Sheffield, 1997.
- [35] Online: www.openstreetmap.org/
- [36] C.S.Sorzano, J.Vargas, and A.P.Montano, "A survey of dimensionality reduction techniques," *arXiv preprint arXiv:1403.2877*, 2014.
- [37] V.Vazirani. "Approximation algorithms". *Springer Science & Business Media*, 2013.
- [38] P.k.Sahu, A.Hafid, and S.Charkaoui. " DMAP: Density Map Service in City Environments," *IEEE Transactions on Intelligent Transportation Systems*, vol 16, no. 5, pp. 2862 – 2877, Oct. 2015.
- [39] Online: <http://kolntrace.project.citi-lab.fr/>
- [40] R.S.Garfinkel and G. L.Nemhauser. "Integer programming". *Wiley*, Vol. 4, New York 1972.
- [41] S.Sachs and P.Varaiya, "A communication system for the control of automated vehicles". *California PATH Research Rep. TECH MENFDMO-93-05*, Sept. 1993
- [42] C.Sommer. (February, 2014). Veins-Vehicles in network simulation. Available: <http://www.veins.car2x.org/>