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# Thèse

En vue de l'obtention du diplôme de

**Doctorat en Informatique**

par

**Abderrahim Guerna**

## THEME

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# Le Déploiement Optimal des Stations de Base Routières dans un Réseau Véhiculaire ad-hoc

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**Soutenue devant le jury**

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# Thesis

Presented in Partial Fulfillment of the Requirement for the Degree of

**Doctor in Computer Science**

by

**Abderrahim Guerna**

## THEME

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# Optimization of Roadside Units Deployment in Vehicular ad hoc Networks

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**Abstract**

Recently, road safety and vehicle security are enhanced using a networking technology known as Vehicular Ad hoc Network (VANET), aiming at serving digital needs of car drivers and passengers. One of the most important challenges of VANETs is the high dynamic of network topology, often leading to intermittent transmissions. To cope with this issue, stationary nodes called roadside unit (RSU) are conceived as VANET infrastructure-based components to play a crucial role in VANET in order to provide continuous transmission coverage and permanent connectivity. However, deploying RSUs involves additional investment and maintenance costs, which implies leading new research activities to optimally place a limited number of RSUs in a given road traffic area to achieve maximum network performance. Precisely, RSUs placement is described as the process of finding the best combination of RSUs on the adequate intersections in order to improve VANET performance in terms of network connectivity. The works presented in this thesis quantifies the benefits of Roadside Unit deployments and proposes innovative approaches to optimize the placement of RSUs set that is able to maximize network performance with a reduced cost. The first part of the thesis focuses on state of the art: First, the way how the information is collected, stored, and harvested using vehicle-to-infrastructure (V2I) communication is reviewed. The proposed survey distinguished two main categories of VANET RSU deployment; namely static and dynamic deployment based on the mobility of vehicles. Also, a comparison between the existing RSU deployment schemes proposed in the literature based on different networking metrics are presented and discussed. Our comparative study confirms that the performance of the proposed RSU placement systems is compromised by several factors such as roads shape, particularity, road segments like frequently occurring accident areas, wireless access methods, mo-

bility model, vehicles distribution over time and space. Finally, this survey is concluded by presenting some future research directions in this domain. In addition to what has been presented, we suggest a new genetic intersection-coverage algorithm (GICA) based on the priority concept. GICA considers putting RSUs within the most popular intersection aiming to maximize the connectivity between RSUs and at the same time to minimize the interference rate and RSUs costs. After a set of simulations and comparisons to the conventional greedy approach, the obtained results demonstrated that GICA ensures the largest network connectivity with a minimum number of RSUs placed in the tested area with a reduced overlapping ratio.

The last part of the thesis focuses on the RSUs deployment formulation issue as a maximum intersection coverage problem through a graph-based modeling. Moreover, we propose a new bio-inspired RSU placement system called Ant colony optimization system for RSU deployment in VANET (AC-RDV). AC-RDV is based on the idea of placing RSUs within the more popular road intersections, which are close to popular places like touristic and commercial areas. Since RSU deployment problem is considered as NP-Hard, AC-RDV inspires by the foraging behavior of real ant colonies to discover the minimum number of RSU intersections that ensures the maximum network connectivity. After a set of simulations and comparisons to traditional RSU placement strategies, the results obtained showed the effectiveness of the proposed AC-RDV in terms of number of RSUs placed, the average area coverage, the average connectivity and the overlapping ratio.

***Keywords***— Vehicular ad hoc network, roadside unit deployment, intersection-priority, intersection-coverage, genetic algorithm, ant colony system, dynamic heuristic function

# Résumé

Récemment, la sécurité routière ainsi que la sécurité des véhicules ont été améliorées grâce à une technologie de réseau connue sous le nom : Vehicular Ad hoc Network (VANET), visant à répondre aux besoins numériques des automobilistes et des passagers. L'un des défis les plus importants des VANET est la haute dynamique de la topologie du réseau, conduisant souvent à des transmissions intermittentes. Pour faire face à ce problème, les nœuds stationnaires appelés unité routière (RSU) sont conçus comme composants basés sur l'infrastructure VANET, pour jouer un rôle crucial dans VANET afin de fournir une couverture de transmission continue et une connectivité permanente. Cependant, le déploiement des RSUs implique des investissements et des coûts de maintenance supplémentaires, ce qui exige de mener de nouvelles activités de recherche pour placer de manière optimale un nombre limité d' RSUs dans une zone de trafic routier donnée afin d'obtenir des performances réseau maximales. Plus précisément, le placement des RSUs est décrit comme un processus consistant à trouver la meilleure combinaison de RSUs sur les intersections adéquates afin d'améliorer les performances du VANET en termes de connectivité réseau. Les travaux présentés dans cette thèse quantifient les avantages des déploiements d'unités en bordure de route et proposent des approches innovantes pour optimiser le placement d'un ensemble de RSUs capables de maximiser les performances du réseau à un coût réduit. La première partie de la thèse se concentre sur l'état de l'art qui focalise sur: La manière dont laquelle les informations sont collectées, stockées, et récoltées à l'aide de la communication véhicule-infrastructure (V2I). L'enquête proposée distingue deux grandes catégories de déploiement de RSUs; à savoir déploiement statique et dynamique en fonction de la mobilité des véhicules. En outre, une comparaison entre les schémas de déploiement RSUs, existants proposés dans la littérature basée

sur différentes métriques de mise en réseau, est présentée et discutée. Notre étude comparative confirme que les performances des systèmes de placement RSUs proposés sont compromises par plusieurs facteurs tels que la forme des routes, la particularité des segments de route comme les zones d'accidents fréquents, les méthodes d'accès sans fil, le modèle de mobilité, la répartition des véhicules dans le temps et dans l'espace. Enfin, cette enquête se conclut en présentant quelques futures orientations de recherche dans ce domaine. Ensuite, un nouvel algorithme de couverture d'intersection génétique (GICA) basé sur le concept de priorité est suggéré. GICA suggère de placer les RSU dans l'intersection la plus populaire visant à maximiser la connectivité entre les RSU tout en minimisant le taux d'interférence et les coûts des RSU. Après un ensemble de simulations et de comparaisons avec l'approche gourmande conventionnelle, les résultats obtenus ont démontré que GICA assure plus grande connectivité réseau avec un nombre minimum de RSUs placées dans la zone testée avec un taux de chevauchement réduit. La dernière partie de la thèse se consacre à la formulation du problème de déploiement des RSUs en tant que problème de couverture d'intersection basée sur des graphes. De plus, nous proposons un nouveau système de placement de RSUs bio-inspiré appelé système d'optimisation des colonies de fourmis à appliquer sur le déploiement de RSU dans VANET (AC-RDV). AC-RDV est basé sur l'idée de placer les RSU dans les intersections routières les plus populaires, qui sont proches de lieux populaires comme les zones touristiques et commerciales. Étant donné que le problème de déploiement de RSUs est considéré comme NP-Hard, AC-RDV s'inspire du comportement de recherche de nourriture des colonies de fourmis réelles pour découvrir le nombre minimum d'intersections de RSU qui assure la connectivité réseau maximale. Après la simulation et la comparaisons avec les stratégies de placement des RSU traditionnelles, les résultats obtenus ont

montré l'efficacité du AC-RDV proposé en termes de nombre de RSU placées, de couverture de zone moyenne, de connectivité moyenne et de taux de chevauchement.

**Mots clés**: Réseau ad hoc de véhicules, déploiement d'unités en bordure de route, priorité aux intersections, couverture des intersections, algorithme génétique; système de colonies de fourmis; fonction heuristique dynamique.

# ملخص

في الآونة الأخيرة، تم تعزيز السلامة على الطرق وأمن المركبات باستخدام تقنية الشبكات العروفة باسم الشبكة المخصصة للمركبات ( *VANET* ) ، والتي تهدف إلى تلبية الاحتياجات الرقمية لسائقي السيارات والركاب. أحد أهم تحديات هذه الشبكة هو الديناميكية العالية لطوبولوجيا الشبكة ، مما يؤدي غالبًا إلى عمليات إرسال متقطعة. للتعامل مع هذه المشكلة ، تم تصميم منشآت وحدة جانب الطريق الثابتة ( *RSU* ) لتلعب دورًا مهمًا من أجل توفير تغطية إرسال مستمرة واتصال دائم. غير أن تنصيب هذه المنشآت يستلزم استثمارات وتكاليف صيانة ، مما يعني ضمناً البحث عن طرق جديدة لوضع عدد محدود منها في منطقة حركة مرور معينة ليتحقق أقصى أداء للشبكة. تحدد الأعمال المقدمة في هذه الأطروحة فوائد عمليات نشر منشآت جانب الطريق وتقترح أساليب مبتكرة لتقليل تكاليف تنصيبها مع تفعيل أداء الشبكة إلى أقصى حد. يركز الجزء الأول من الأطروحة على أحدث ما توصلت إليه التقنية : أولاً ، تقديم جملة من التعاريف والمصطلحات المستعملة في هذا الميدان وكذا بنية الاتصالات المستعملة. يليها، جرد مدقق لمجمل البحوث المنجزة في هذا الميدان ، ليتم تصنيفها ضمن فئتين رئيسيتين وهي : النشر الثابت والديناميكي. ليختتم الجزء الأول بتقديم بعض اتجاهات البحث المستقبلية في هذا المجال. بعد ذلك ، تم اقتراح خوارزمية تغطية جينية جديدة (*GICA*) على أساس مفهوم الأولوية. تقترح هذه الخوارزمية وضع وحدات جانب الطريق في ملتقى الطرق الأكثر كثافة للسيارات بهدف زيادة الاتصال بين وحدات جانب الطريق مع تقليل معدل تداخل مدى تغطيتها وتكاليف وضعها. بعد مجموعة الاختبارات والمقارنات مع بعض الخوارزميات الشائعة مثل نهج الجشع التقليدي ، أظهرت النتائج التي تم الحصول عليها أن *GICA* تضمن أكبر اتصال للشبكة مع أقل عدد من وحدات *RSU* الموضوعة في المنطقة التي تم اختبارها مع نسبة تداخل منخفضة. يخصص الجزء الأخير من الأطروحة إلى شرح مقترحنا الجديد حول مسألة نشر *RSU* المستوحى من مسارات مجتمع النمل ( $Ant-Colony$ ) المتخذة أثناء عن عملية البحث عن الغذاء وتخزينه والذي تمت تسميته بـــ : $AC-RDV$ . يعتمد هذا النظام على وضع *RSU* داخل تقاطعات الطرق الأكثر شيوعًا ، والتي تكون قريبة من الأماكن الشهيرة مثل المناطق السياحية والتجارية. نظرًا

لأن مشكلة نشر $RSU$ تعتبر جد صعبة، فإن $AC-RDV$ يستلهم سلوك بحث مجتمع النمل لإكتشاف الحد الأدنى من $RSU$ و التي تضمن أداء جيدا لشبكة المركبات. بعد مجموعة من عمليات المحاكاة والمقارنات مع عدة طرق وضع تقليدية ، أظهرت النتائج التي تم الحصول عليها فعالية $AC-RDV$ من حيث عدد وحدات $RSU$ الموضوعة ، متوسط تغطية ( *Couverture* ) المنطقة ، متوسط الإتصال ( *Connectivité* ) ونسبة التداخل .

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# Published papers

- ***Journals***

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- ***Conferences***

  – Abderrahim GUERNA, Salim BITAM. "GICA: An evolutionary strategy for roadside units deployment in vehicular networks". In : 2019 International Conference on Networking and Advanced Systems (ICNAS). IEEE, 2019. p. 1-6.

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# CHAPTER I

# INTRODUCTION

## I.1 Context and motivations

With the sharp increase of vehicular traffic and congestion on roads in recent years, driving ceaselessly keeps being more and more challenging and dangerous. Consequently, year by year, the rate of car accidents and casualties is increasing worldwide. Recent statistics published by the World Health Organization in 2018 annual report on road safety from 180 countries, indicates that the total number of road traffic deaths around the world has plateaued at 1.35 million per year [1]. Therefore, securing traffic becomes not only a necessity but also an imperative.

In fact, leading car manufacturers have decided to develop more secured solutions by making roads and vehicles intelligent. They have endowed vehicles by embedded system, radio communication interface and wireless communication devices such as sensors, intelligent applications, and localization systems (GPS) [2]. Therefore, these new vehicles form together a new technology known as an intelligent transport system (ITS) in which a particular kind of network is born, called vehicular ad hoc networks (VANETs).

## I.2 Problematic and objective

Due to short life of inter-vehicles communication called Vehicle to Vehicle (V2V) communication, and in reason to the presence of traffic environment obstacles [3], a new vehicular infrastructure was conceived to ensure the sustainability of the vehicles' communication; it is the roadside units (RSU). The roles of RSU are mainly focusing for collecting and analyzing traffic messages given from smart vehicles. Besides, RSUs can make the controlling traffic flow of vehicle's secure driving by broadcasting locally analyzed data and forwarding some important messages. The cooperation between vehicles and RSUs was then emerged to improve V2V communication by introducing a new transmission mode called Vehicle-to-Infrastructure (V2I) communication. With a V2I communication, the connectivity of links will less degrade even though the topology is highly dynamic, especially when there is a long distance between the source node and the destination node [4]. The connectivity between a vehicle and RSU is defined in two ways; either by a direct delivery of messages to an RSU, which occurs when the vehicle is in the transmission range of the RSUs, or through a multi-hop relay, when the vehicle is out of RSU transmission area. Therefore, it is mandatory to think of an efficient scheme to deploy RSUs in VANET, trying to ensure that all vehicles are within the RSU transmission range permanently.

Deploying RSUs requires investment and maintenance costs, hence the deployment scheme should place a limited number of RSU in a traffic region, in the aim to reach a maximum transmission connectivity. Finding an optimal RSU deployment is considered as NP-Hard combinatorial optimization problem [5]. In fact, there have been a large number of researches focusing on the RSUs deployment optimization issues in vehicular ad hoc networks. After a state-of-the-art synthesis presented in third chapter, we found that most of the reviewed works have focused on optimally deploying a limited number of RSUs to improve network coverage, but they did not consider the variations in data traffic, which depend on critical parameters such as placement locations, deployment budget, and road topology.

## I.3 Contributions

To overcome this limitation, we propose in this PhD thesis two main contributions: In the first one, we propose a new Genetic Intersection-Coverage Algorithm (GICA) as VANET RSU deployment scheme [6]. Hence, we formulate the RSUs deployment problem as a multi-objective optimization problem, where the intersection priority, intersection coverage, and the average interference (overlapping rate) are integrated in the evaluated objective (fitness) function. The tests lead to prove that GICA has better results over the well-known greedy approach.

In the second, a new bio-inspired RSUs placement system called Ant colony optimization system for RSUs deployment in VANET (AC-RDV) is proposed [7]. To the best of our knowledge, the ant colony optimization was not applied in the literature to solve the RSUs deployment problem in VANET. AC-RDV is based on the idea of placing RSUs within the more popular road intersections. Thus, each RSU placed at any intersection can cover a subset of intersections when these intersections are located within the transmission range of this RSU. Thereafter, all intersections belonging to the transmission range of this RSU are excluded from the deployment candidate set of intersections. The performance of AC-RDV strategy has been evaluated in terms of number of RSUs placed, average area coverage, average connectivity, and the overlapping ratio. The results obtained showed that the proposed scheme outperformed the traditional RSU placement scheme based on the greedy approach (GA) [8], genetic intersection coverage (GICA) [6], and heuristic genetic algorithm (HGA) proposed also in this chapter for RSU placement scheme.

## I.4 Organization of the thesis

The rest of the thesis is organized as follows:
Chapter II firstly introduces the background of VANETs, then explains the deployment of roadside units in VANET, the optimization constraints and the most important optimization metrics. Also, the existing challenges and main problems in VANETs deployment are stated.

Chapter III reviews and classifies the works relevant to this research. On the basis of vehicles mobility and of the principles of placing RSUs in geographic areas, we propose to classify the reviewed studies into two categories, namely schemes based on static deployment and those based on dynamic deployment. Additionally, the most important RSUs placement approaches are reviewed, highlighting their strengths and limitations.

Chapter IV introduces our first contribution called genetic intersection-coverage algorithm (GICA) based on the priority concept. The purpose of this proposal is to focus on popular intersections to put RSUs, aiming to maximize the coverage of RSUs while minimizing the interference rate and RSUs costs.

Chapter V suggests a new bio-inspired RSU placement system called Ant colony optimization system for RSU deployment in VANET (AC-RDV), aiming at placing a reduced number of RSUs that cover a large geographic area, and improve network connectivity with a limited overlapping ratio.

The manuscript ends with a general conclusion, which presents a synthesis of all our contributions and some perspectives that we have outlined for the continuation of the work.

# CHAPTER II

# VANETS: AN OVERVIEW

## II.1 Introduction

Given the advances in information and communication technology, vehicular networking has received immense attention all over the world. A current trend is to provide vehicles and roads with capabilities to make the transportation infrastructure more secure, more efficient, urban aware, and to make passengers' time on the road more enjoyable. To do this, a new technology dealing with issues regarding traffic management and road safety is named intelligent transport systems (ITS). Using many ITS applications involves the development Vehicular ad hoc networks (VANET) aiming at reducing congestion and improving road safety traffic flow to fully reduce the number of accidents. In this chapter, we review some definitions, architectures of VANETs and its various applications, we, then, outline major characteristics of VANETs. Finally, we present diverse VANET deployment environments and tackle the main objectives related to the RSUs deployment to achieve the best network performance.

# II.2 VANETS background

## II.2.1 Definition and features of vehicular ad hoc networks

A Vehicular Ad-hoc Network (VANET) is considered as particular type of Mobile Ad-hoc Network (MANET), where its mobile nodes are smart vehicles, each equipped with a communication device called on-board unit (OBU), allowing them transmitting data packets in wireless transmission mode [9]. A VANET is also formed by stationary units along the road called roadside units (RSUs) [10], which contribute to the data transmission.

### *Smart vehicle*

Such vehicles comprise of On Board Units (OBU) for computing and transmitting messages, GPS for location detection, and digital map including geographical road information [11, 12]. OBU enables short-range wireless ad hoc network to be made between vehicles [13] and serves to save, calculate, locate and send messages via network interface.

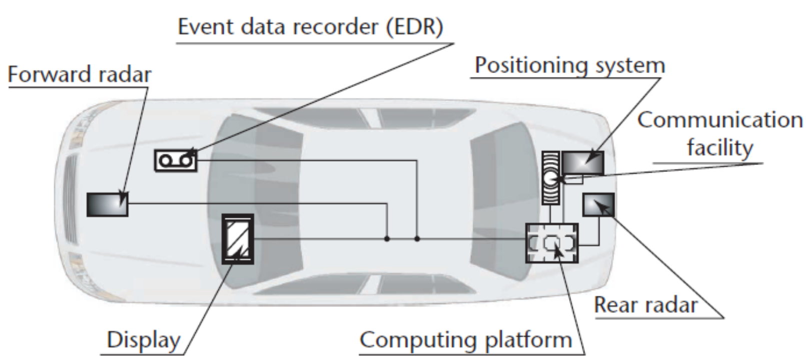



Figure II.1: Smart vehicle [14]

Smart vehicles also have such features as depicted in figure II.1. An event data recorder (EDR), inspired from the "black boxes" found on airplanes (EDRs record all major data from the vehicle for crash reconstruction). A GPS receiver, the accuracy of which can be improved by knowledge of road topology (GPS is currently used in many navigation systems). Front-end radar for detecting obstacles at distances as far as 200 meters (such a radar is often used for adaptive cruise control) and short-distance radar or an ultrasound system, typically used for parking.

#### *Roadside unit*

A Roadside Unit (RSU) is a physical device located at a fixed location along roads and highways. It is considered to be one of the most important components in vehicular networks (VANET) for collecting and analyzing traffic data given from smart vehicles. Furthermore, RSU has a crucial role in the spread of the communication range of vehicles and to maintain the relevant messages in their coverage area. Some RSUs can act as a gateway for connectivity to other communication networks, such as the Internet in addition to its standard wireless access point functionality [15]. Hence, its deployment has to be efficient to ensure the communications between senders and receivers.

### II.2.2 Communication modes in VANETs

The goal of VANET architecture is to allow the communication among nearby vehicles and between vehicles and roadside units. In the literature, many communication architecture of VANETs networks are available [2, 16]. All VANET applications depend on either one or more of these communication types. Figure II.2 presents the architecture of VANET communication. This section discusses major communication modes in vehicular networking.

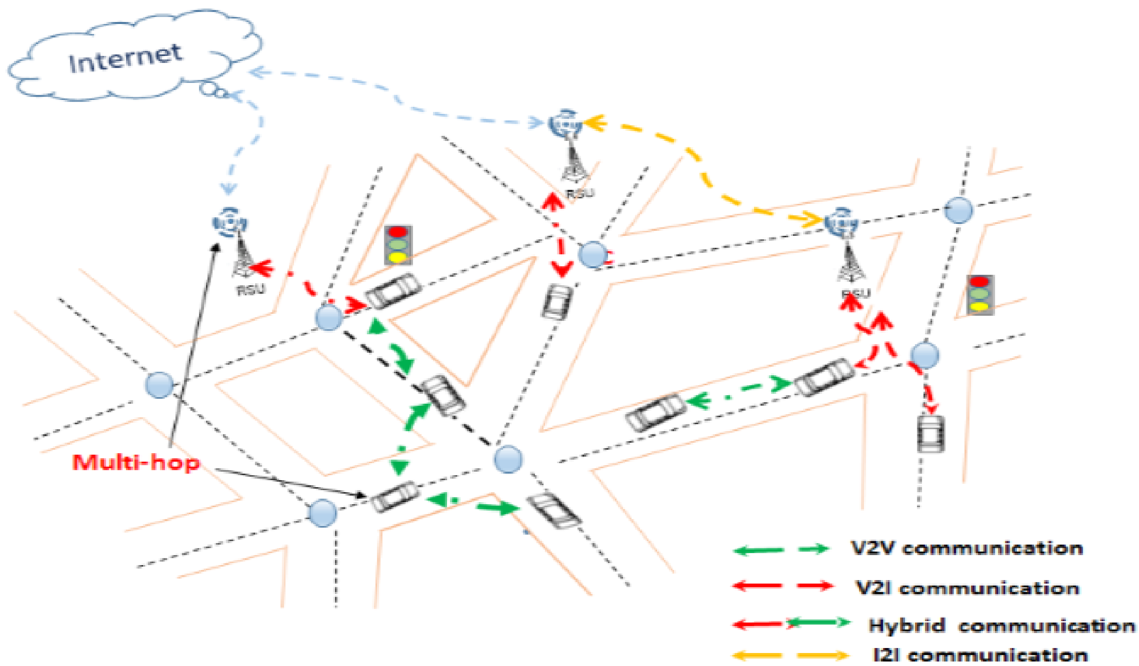



Figure II.2: Communication modes in VANETs

*Vehicle-to-Vehicle communication*

In this case, the vehicle-to-vehicle (V2V) communication is a pure Ad-hoc, of no any infrastructure (i.e., roadside units, access point, etc.) needed for communication between vehicles, but V2V transmission range is limited [2]. This type of communication is used in so many applications like cooperative driving and safety warnings.

*Vehicle-to-Infrastructure communication*

V2I communication allows a vehicle to communicate with the roadside units mainly for collecting information and analyzing traffic data. Vehicle-to-roadside communication configuration provides a high bandwidth link between vehicles and roadside units. The roadside units may be placed every kilometer or less, enabling high data rates to be maintained in heavy traffic [17] . In this communication technology, a vehicle establishes a connection with the RSU to connect and communicate with external networks such as the Internet.

***Hybrid communication***

The hybrid communication is the combination between (V2V) and (V2I) communications. Whereby, a vehicle can communicate directly with the road infrastructure, also a vehicle can communicate by a multi-hop to other vehicles when direct transmission to RSU is not possible with a single hop [4].

***Infrastructure to-Infrastructure communication***

When the RSUs are interconnected, an RSU can communicate its traffic information with neighbor RSU through infrastructure to infrastructure (I2I) communication [16]. Using forwarding function of an RSU and the backbone established by I2I, connectivity of links will less degrade even though the topology is highly dynamic, especially when there is a long distance between the source node and the destination.

### II.2.3 Characteristics of VANETs

VANET characteristics are essentially a mixture between the ad hoc mode where the vehicle communicate with each other via the multi-hop mode and communicate with the fixed infrastructure along roads wireless medium mode. We can mention the following VANET characteristics:

### *High mobility*

The high mobility of VANET nodes is one of the most important features; it implies a more dynamic environment by the availability of multiple paths where cars frequently swap positions with a very high speed especially on roads and highways. The high mobility also leads to a dynamic network topology.

### *Highly dynamic topology*

Vehicles are free to move arbitrarily; thus, the network topology that is typically multi hop changes rapidly due to high speed (i.e., 10 m/s in urban environments to more than 20 m/s in highways)[18] and vehicles may move at different directions. Consequently, these vehicles can quickly join or leave the network in a very short period of time, leading to frequent and fast topology changes.

### *Frequent disconnected network*

The highly dynamic topology results in frequently disconnected network since the link between two vehicles can quickly disappear while the two nodes are transmitting information. For example, in highways, two vehicles are moving at the speed of 25m/s, then the link lifetime will last 10 seconds link lifetime [18]. We consider that the link lifetime is measured by the relative speed and the distance between two adjacent vehicles. The problem is compounded when the roads are not frequently used by a sufficient density of vehicles, especially during rush hours, also the lack of roadside unit leads to frequent disconnections.

### *Mobility modelling*

VANET vehicles move in a predefined manner, as the roads are fixed, vehicles must obey and follow the road signs, and traffic lights. Moreover, a mobility model is needed to determine the vehicle's location in the topology at a given time, which directly affects the network connectivity. It depends on traffic environment, roads structure, the speed of vehicles, driver's driving behaviour and so on. This features of mobility modelling in VANETs is based on the availability of predefined roadmap models, some mobility models are cited in [19].

### *Unlimited Battery Power and Storage*

In MANET, power constraint is one of the most important challenges which has shadowed all other aspects namely routing, fusion. On the other hand in VANET, huge battery is carried by the vehicle (i.e. car's battery), so, energy consumption is not a salient issue for VANETs [20].

### *The communications environment*

As the mobility model may have different features depending upon road architecture, highways, or city environments. In these situations, a communication environment between vehicles is different in sparse network and dense one. In the dense network of buildings, trees and other objects act as obstacles.

## II.2.4 VANET applications

VANET applications can be classified into three major categories: safety, efficiency and comfort applications [2, 4]. The following are some of the conceivable applications of the VANETs.

*Safety Applications*

Crucially, the goal of safety applications in VANETs is to decrease the number of road accidents and improve general safety. In this category, often the applications use the information delivered by other vehicles like alerts on the state of the road (ice, obstacle), alerts of braking or collision upstream to the route, etc. This category is sensitive to the transmission delay. Whenever an accident happens, all the vehicles near the location of accident should alert about it by sending an emergency message to nearby vehicles.

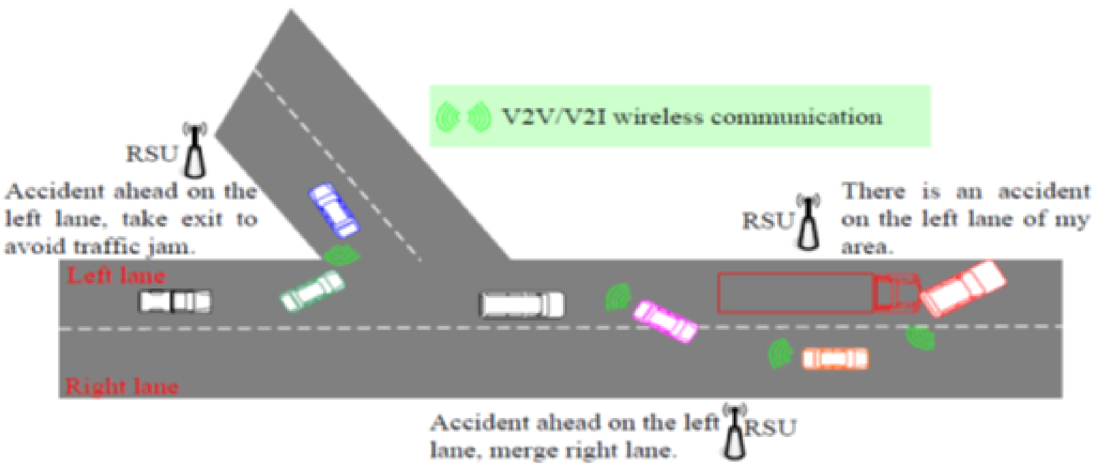



Figure II.3: A concrete example of road safety applications in VANETs [21]

A concrete example of road safety applications is presented in figure II.3. When there is a traffic accident on the left lane, safety messages including this accident information are broadcasted to the posterior vehicles by V2V/V2I wireless communications to make them change to the right lane or directly leave the left lane at the exit, so this scheme can avoid serious traffic congestion and further traffic accident.

### *Efficiency applications*

These applications provide traffic information and recommendations for traffic optimisation, to help car drivers make decisions during their journey. These applications mostly involve a V2I or I2V communication, they access to the channel in a low priority mode compared to safety applications. The goal of efficiency applications is road congestion management to reduce, prevent traffic jams and maintain a smooth traffic flow.

### *Comfort applications*

These applications are conceived to improve driver and passengers comfort. Such application type comprises weather, traffic information, tourist information, availability of parking place, access to the Internet, finding nearest restaurant, hotel, and gas station. Normally, the typical requirements of these applications are reliability, availability and connectivity, so as to provide the information in the right moment that the drivers need.

## II.3 VANETs standards

For VANETs, standardization affects virtually all the different layers of the OSI (Open System Interconnection) model which is a communication system integrating all the features from the physical to the application layer. It should be noted that in the literature, often DSRC (Dedicated Short Range Communications) [22], WAVE (Wireless Access in Vehicular Environments) or even IEEE 802.11p [23] are used to designate the entire protocol stack of standards dealing with VANETs.

### II.3.1 Dedicated short-range communication

Dedicated Short-Range Communication (DSRC) is a short to medium range communication technology operating in the 5.9 GHz range, will use the physical layer of IEEE 802.11a and quality of service enhancements of IEEE 802.11e [24]. DSRC supports vehicle speed up to 200 km/h, nominal transmission rage of 300m (up to 1000 m), and default data rate of 6 Mbps (up to 27 Mbps) [15]. This will enable to support communication requirements for safety applications used in the V2I communication environment [2]. DSRC has two modes of operations: (1) Ad hoc mode characterized by distributed multi-hop networking (vehicle–vehicle), (2) Infrastructure mode characterized by a centralized mobile single hop network (vehicle-gateway) [25].


Figure II.4: DSRC in USA, 7 channels of 10 MHz. [4]

According to [23] the DSRC band is divided into seven channels of 10 MHz (see Figure II.4), respectively numbered 178, 172, 174, 176, 180, 182, 184. Every channel is associated with certain application type: from the range 5.855 MHz to 5.875 MHz is dedicated to ITS non-safety applications (Information services), 5.875 MHz to 5.905 MHz is dedicated to safety (traffic efficiency) applications, and 5.905 MHz to 5.925 MHz to future applications in ITS. The channel 178 is the CCH channel (Control CHannel). The other six are SCH channels (Service CHannels). The entire spectrum in DSRC is divided into 50ms time slots. SCH channels is categorized as low priority channel and used to transmit data dissemination messages. CCH channels has high priority and used for safety, security and control related messages.

### II.3.2 Wireless access in the vehicular environment

Wireless access in the vehicular environment (WAVE) is the next-generation (DSRC) technology, which provides high-speed V2V and V2I data transmission [22]. The WAVE system is built on IEEE 802.11p and IEEE 1609.x. standards (IEEE 1609.1,2,3,4,5,6) operating at 5.850–5.925 GHz with data rates of 6–27 Mb/s, covering a range of up to 1 km. Each one handles different issues at different layers. Figure II.5 provides an insight into the six sub-standards and their relationship with respect to the tasks at the various OSI layers [26]. WAVE architecture can be used by roadside equipment to collect useful information about vehicles safety, automatic tolls, improved navigation, traffic management and many other applications.

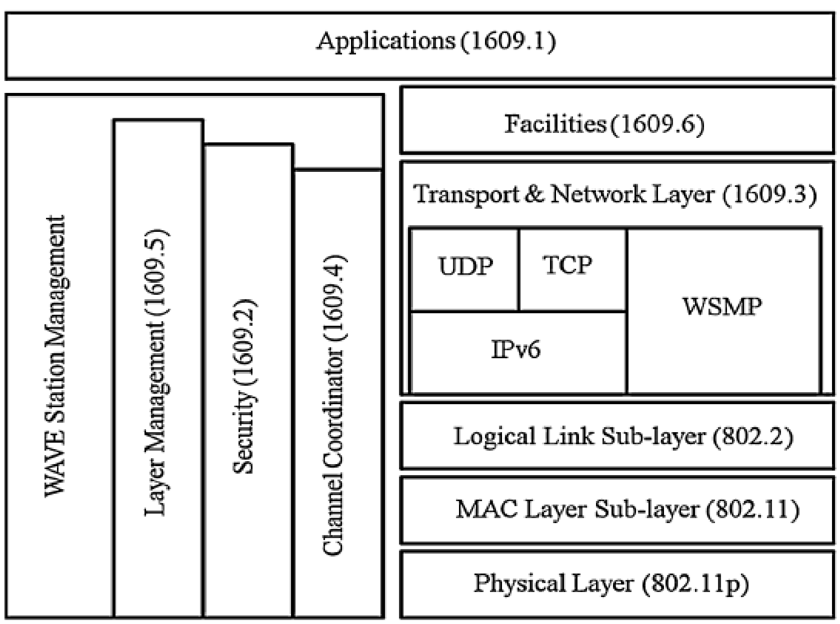



Figure II.5: WAVE Architecture [22]

### II.3.3 IEEE 802.11p

In addition to the IEEE 1609 standards, IEEE has expanded its family of IEEE 802.11 protocols by adding 802.11p to accommodate vehicular networks, in accordance with the DSRC band. The definitions of the physical and medium access layers for VANETs are specified by the standard IEEE 802.11p , who adapted PHY and MAC layers to be suitable for vehicular networks. IEEE 802.11p is specially based on the IEEE 802.11a for the definition of the PHY layer and on IEEE 802.11e for the definition of the QoS [4].

## II.4 Vehicle traffic environment for VANET

The road network is defined in various travel environments. These environments are differentiated by their location (urban, suburban, rural, and mountainous) and their means (highway, county, highway road, communal roads, etc.). Due to their specificities (speed, density of traffic), VANETs operate in three different environments with certain particularities. Next subsections illustrate these different environments and their particularities.

### II.4.1 Highway environment

Usually, a highway is formed by a multi-lane road, which has very large segments and well-defined exits and on-ramps. It is characterized by a high speed of vehicles, lower density compared by urban areas. We also find there is a large variety of vehicles (truck, cars). Due to the absence of obstacles such as buildings, this environment seems less disruptive to radio waves. However, it encounters frequent disconnected network problems due to the high speed. The most dangerous is situation in which a vehicle approaches or passes by in a relatively high speed. This situation can cause more serious accidents and emergency breakings, which should be mitigated with the road traffic safety applications.

### II.4.2 Urban environment

Urban area is defined as a form of roads and intersections breakpoints (lights, stop, yield, etc.). Due to the strong presence of obstacles such as buildings, trees and other objects, the propagation of the signal will be disrupted. The urban environment is characterized by a model complex mobility, a high density of vehicles and reduced speed (lower is 16.6 m /s). It seems so easy to add an infrastructure to deploy vehicular networks (V2I). In this environment, V2V networks are frequent and may have the advantage of avoiding the deployment of RSU.

### II.4.3 Rural environment

Rural environment is composed of roads and usually have many lengthy segments which mean that intersections are rarer than in cities. Traffic conditions often do not allow the formation of a connected network. This could be the case in rural areas where the vehicles' density is low.

## II.5 Deployment of roadside units in VANET: an overview

Due to short life of V2V communication, high vehicle speeds and unpredictable node density in various mobility patterns become critical tasks. To meet these needs, deploying a vehicular infrastructure (RSU) is a key solution to improve dissemination message performance in the VANET. By this way, RSUs placement is described as the process of finding the best combination of RSUs on an available place according to the given conditions to meet the requested requirements (e.g., best connectivity, coverage, low deployment cost). In this section, we tackle the problem of RSU deployment in a studied area to achieve the best network performance.

### II.5.1 Problem statement

Due to the high cost of deploying and maintaining RSUs, the big challenge is how to deploy a minimal number of RSUs in way that guarantees a high connectivity performance. In other words, the primary goal of the optimization is to make a compromise between network coverage and cost. RSU deployment is formulated as a constrained optimization problem, with the multiple objectives such as increasing network coverage, maximizing network connectivity, and minimizing the cost of RSU deployment. In a geographical area, there are usually many possible subsets of locations to deploying RSUs. If there were 100 candidates places and 10 RSU, there would $1.73 \times 10^{13}$ possible placements [27]. Identifying this subset is formulated as a combinatorial optimization problem [4, 20].

### II.5.2 Tackled objectives in RSU deployment

In the literature, most of the proposed RSUs placement schemes have focused on the goals to increase transmission coverage and to achieve strong network connectivity. The transmission coverage of the monitored area can be ensured by careful planning of the vehicle densities on the concerned traffic, while achieving a strongly connected network topology. Generally, the RSUs deployment mainly includes the following performance factors.

### *Transmission coverage area*

Maximizing transmission coverage of an area in a VANET is the objective that has received the most attention in the literature, especially when this objective is combined with connectivity and RSUs deployment. An area is covered by a RSU if this area is situated in its transmission range. The RSU coverage has answered the question: how long the vehicles are able to detect a RSU? Additionally, transmission coverage formulations can try to find best location in the physical space in the objective to have at least one transmission range of a RSU. The definitions related to this problem were the following:

**Definition II.1 (Maximum Coverage Problem)** *Suppose a collection of sets $S = \{S_1, S_2, \ldots, S_n\}$ defined over a domain of elements $V = \{V_1, V_2, \ldots, V_m\}$. Sets may share elements.*

*The goal is to find a k collection of sets $S^{'} \subseteq S$ such as the number of covered elements $|\bigcup_{(S_i \in S')}|$ is maximized [28].*

The majority of studies such as in [28, 29] denote S as the candidate sites for where a VANET infrastructure could be placed, $S^{'}$ are the locations set when the RSUs have been installed, and $V$ are the number of vehicles covered by $k$ RSUs. Due to mobility of vehicles, the cars move over a given road topology during an observation time according to a Poisson distribution [30]. Therefore, a $n \times m$ matrix $P$ is given, where $n$ and $m$ are the the cardinally of intersection set and vehicle set, respectively, i.e.,

$$p_{ij} = \begin{cases} 1, & \text{if } v_j \text{ crosses intersection } \mathrm{I}_i \\ 0, & \text{otherwise} \end{cases}$$

Maximize the coverage area returns to maximize the vehicles number that come into contact with an intersection $I_i$ during the observation time. Also, for $i = 1, .....n$ we have $S_i = \{v_j \in V, j = 1, .., m : p_{ij} = 1\}$. $S_i$ includes all vehicles that cross intersection $i$ at least once over the observation period.

for each $S_i \in S$ , a decision variable $x_i$ is given as:

$$x_i = \begin{cases} 1, & \text{if } \mathrm{S}_i \in S' \\ 0, & \text{otherwise} \end{cases}$$

So , this objective can be expressed by the following formula:

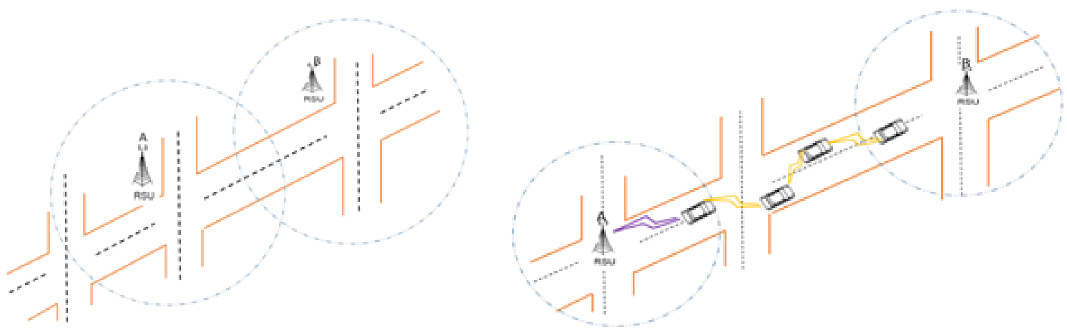
$$\text{Maximize} \quad \sum_{\forall S_i \in S} \sum_{\forall v_j \in S_i} v_j \times x_i \tag{II.1}$$

$$\text{Subject to:} \quad \sum_{\forall S_i \in S} x_i \leq k \tag{II.2}$$

$$x_i \in \{0, 1\} \tag{II.3}$$

***Network connectivity***

Network connectivity is the communication between the RSUs and real traffic formed by the moving vehicle on the road network. Provide reliable connectivity to VANETs services, must rely on the knowledge of the network topology properties and the way it operates. This connectivity is defined in two ways: a) direct connection, which occurs when two RSUs are within each other's transmission range (see Figure II.6 case (a) ), and b) indirect connection, which takes place when two RSUs are distant in terms of transmission range (see Figure II.6 case (b) ). In this case, the number of vehicles, which pass between these two RSUs, determines the connectivity [31].




(a) Directly connected (b) indirectly connected.

Figure II.6: RSU Connectivity.

*Cost deployment minimization*

The RSUs deployment in a road network requires investment and maintenance costs. Hence, solutions need to optimally place a limited number of RSUs in a given region in order to achieve maximum performance in terms of transmission range and network connectivity. For example, if the RSUs are pervasively deployed in the city, the coverage will be extended but the RSU setup cost is too expensive (from 13,000 $ to 15,000 $ per RSU) [32]. Therefore, the RSU deployment should be optimized depending on various factors such as traffic patterns and vehicle density, variety of services that appear and a communication profile and, technical progress as well as limits of the underlying communication mechanisms [33].

From the information mentioned in (definition II.1), for each $S_i \in S^{'}$ , a decision variable $y_i$ is given as $y_i = 1$ if a RSU has been installed in site $i$ and 0 otherwise. In order to minimize the deployment cost under a given k number of RSU, the objective function is:

$$\text{Maximize} \quad \sum_{\forall S_i \in S'} c_i \times y_i \tag{II.4}$$

$$\text{Subject to:} \quad \sum_{\forall S_i \in S'} y_i \leq k \tag{II.5}$$

$$y_i \in \{0,1\} \ \forall S_i \subseteq S \tag{II.6}$$

Where $c_i$ is the installation cost of a RSU placed at site $i$.

## II.6 Performance metrics of RSU deployment

### II.6.1 Overlapping

The large coverage areas overlapping with neighboring RSU represent a waste of resources and loss of the ability to disseminate information on larger areas. Also, such RSUs may deal with some redundant duplicated traffic messages generated by vehicles within the overlapped area covered by two different RSUs [6]. Thus, it's necessary during the proposal of any approach of RSUs deployment to consider reduce the size of the overlapped coverage of RSUs to the minimum.

### II.6.2 Packet delay

The packet delay is a primary metric to guarantee the quality of service for VANET. It is ont only important to receive the packet, but to receive it within the maximum eligible delay as well. Any packet received after this time limit hinders service availability.

### II.6.3 Packet loss

Packet loss refers to the number of packets dropped in transmissions, which is used to measure the ability of a network to relay [33]. This metric is depends on the maximum allowable delay. Any packet received after this limit is considered as lost.

### II.6.4 Packet delivery rate

The packet delivery rate is a metric calculated by dividing the number of packets received by the target RSUs using the number of packets originating from vehicles [33].

## II.7 Conclusion

The context of VANETs is presented in this chapter, in particular, VANET architectures components, VANET communication domains, wireless access technologies, VANET characteristics, challenges and requirements and VANET applications. In addition, we explain the deployment of roadside units in VANET, the main optimization constraints and the most important optimization metrics. The RSUs placement research aims to construct an economical yet efficient vehicular network by making an optimal location deployment scheme in the frequent partitioning network. Here, we summarize the development of RSUs placement research. Several works have been carried out to deal with the RSU deployment problem. In the following chapter, we will present the relevant approaches related to the optimization of RSUs deployment problem and compared them depending on their objectives, placement and applications.

# CHAPTER III

# STATE OF THE ART ON RSUS DEPLOYMENT

## III.1 Introduction

Roadside Unit (RSU) is an essential unit in a vehicular ad-hoc network (VANET) for collecting and analyzing traffic data given from smart vehicles. In order to maximize the availability of RSUs in the VANET, RSUs need to be fully distributed over an entire area. Thus, RSUs can make the best use of all traffic data gathered from every placement. Several researchers have reviewed the roadside units' approaches in VANETs. These works are different in many aspects, such as the factors and restrictions taken into considerations. In this chapter , we conduct a study of recent and relevant work. In the basis of the mobility of vehicles and of the principles of placing RSUs in geographic areas, we propose to classify the reviewed studies into two categories, namely schemes based on static deployment and schemes based on dynamic deployment. In the static deployment, the

RSUs are deployed in fixed places on the studied geographical area. In dynamic deployment, the vehicles equipped of DSRC can be served as roadside units. In this review, the most important RSU placement approaches are reviewed by highlighting their strengths and limitations.

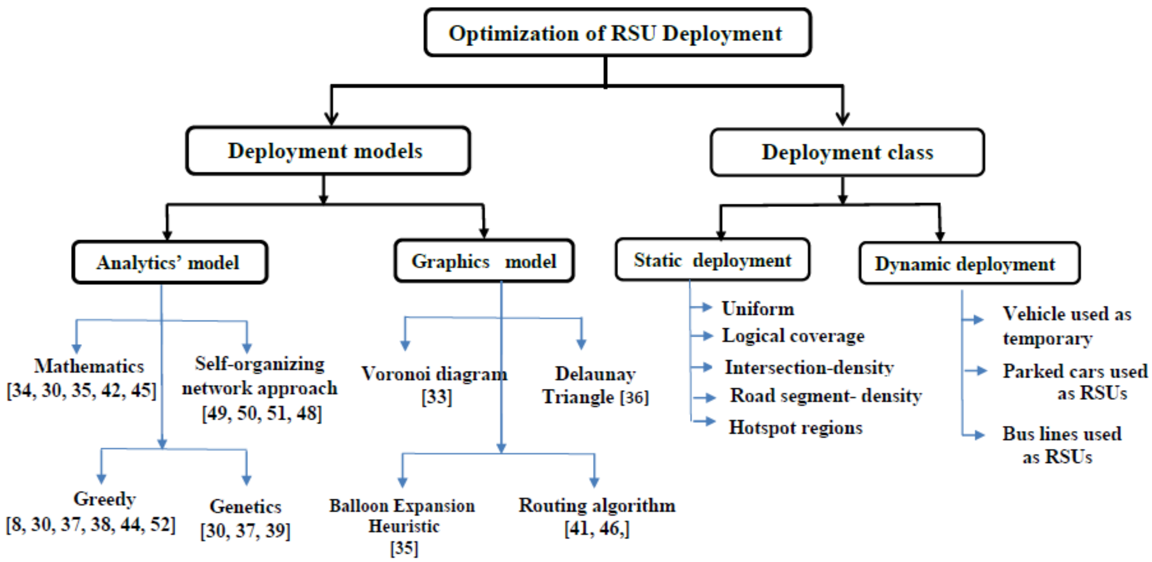



Figure III.1: Taxonomy of RSU deployment

## III.2 Taxonomy of RSUs deployment

Extensive research activities have been conducted to develop efficient schemes integrating network coverage and low-cost RSUs deployment. According to the coverage objectives and deployment cost, we classify the RSU deployment approaches into two categories: static deployment and dynamic deployment, as presented in figure III.1. In the static deployment, the RSUs are placed in a static point on the geographic areas to improve network coverage composed of moving vehicles. Whereas, the dynamic deployment is based on the idea of considering some vehicles equipped by on-board computer and wireless communication device to be used as RSUs. In next subsection, both static and dynamic VANET RSU deployment schemes are surveyed.

### III.2.1 Static deployment schemes

For simplicity, many deployment studies usually assume that RSUs are deployed in fixed locations in the road network. In this section, we will look at each of the different research studies and we propose to classify them into five subclasses according to the location where they are placed on the road network as shown in figure III.1. For each study, we describe the proposed model and the main idea proposed as an optimal solution for RSU deployment in VANET. Moreover, we perform a qualitative comparison between the different strategies of static RSUs deployment. Table 1 provides a comparative summary of the characteristics of various approaches while Table 2 provides objectives of each work including constraints, algorithms and simulators.

***A. RSUs deployment based on uniform distribution***

Uniform distribution of RSUs is the most practical way in road network. In this model, RSUs are spaced apart at equal distance. The goal of [34] is to find an optimal distance between RSUs on the highway so that a security message can be transmitted to the RSUs from all of accident site with at least a given probability parameter $p$ in time $t$. A randomized algorithm is used to estimate an approximate optimal distance $d$ for deploying the RSUs. This distance is calculated by approaching the optimal distance step by step from an initial distance until the VANET cannot meet the connectivity. The initial distance is calculated as $d_0 = 2 \times R_0$, where $R_0$ is the greatest distance for wireless transmission from one vehicle or one RSU to another vehicle or to another RSU.

- ***Assumptions***
  – Vehicles move at a speed over a predefined transmission range.
  – Vehicles and their movements are obtained from historical data.
- ***Advantages***
  – This scheme proposed a mathematical proof of the used algorithm correctness.
  – It considers two moving directions of a car: forward and backward directions.
  – It is efficient for massive deployments.
- ***Weaknesses***
  – It did not consider vehicle traffic.
  – It did not consider the QoS parameters such as packet loss and the maximum tolerable delay.
  – This scheme uses only wire-connected RSUs for VANETs.
  – It is expensive when the number of RSUs placed is important.

Liu et al. in [30] analysed the delay of broadcasting alert messages along a highway such so alert messages can be transmitted to the nearest RSU within a given delay bound. They proposed an analytical model to analyze the delay with fixed transmission distance in VANETs. Moreover, the problem is formulated as a coverage problem, since the problem is to cover the roads with RSUs such that emergency messages would be transmitted to RSUs within the given delay bound. Then, vehicles are grouped into clusters, where cluster members can communicate with each other within no more than two hops. If the vehicle clusters are disconnected, the messages should be carried by vehicles until they encounter an RSU. To solve this problem, the authors proposed a genetic algorithm combined with greedy algorithms. Simulation results showed that the solutions are efficient and the time complexity is lower than in those existing algorithms (greedy and genetic approaches).

- ***Advantages***

  − This proposal derives the relationship between key 65 system parameters such as traffic flow density, transmission range and delay.

- ***Weaknesses***

  − The approach is tested on only one topology.

***B. RSUs deployment based on logical coverage area***

In this category, each RSU coverage area is considered as a logical coverage area that develops dynamically expanding in a 2-dimensional space. This occurs due to vehicles becoming carriers of RSU-generated packets to an area outside the real signal range of this RSU, which is called a logical range. The authors of [35] proposed two optimization methods such as Binary Integer Programming (BIP) and Balloon Expansion Heuristic (BEH) to optimally place a limited number of RSUs in an urban environment. The BIP utilizes branch and bound approach to find an optimal analytical solution, whereas the BEH uses balloon expansion analogy to find optimal solution. In BEH, the coverage area of each RSU is considered a balloon dynamically dilated gradually in a 2-dimensional space until the desired percentage of the area covered under the constraint of the average reporting which should be obtained. Note that the reporting time is defined as the time duration from the occurrence of an event till it is reported by a vehicle to an RSU.

Compared with BEH method, the BIP has successfully produced optimal solutions; however, the minimum average reporting time on each path found by BIP is higher than that of BEH.

- ***Assumptions***

  – The use of Manhattan urban topology for placing RSUs in road intersections.

- ***Advantages***

  – This approach is based on a solid mathematical modeling.

  – It introduces real traffic information: the speed, traffic density, and likelihood of incidents for the computations.

- ***Weaknesses***

  – It did not take into consideration realistic topologies where road complexity is present.

  – The proposed method didn't analyze the coverage achieved by this technique.

Patil and Gokhale [33] proposed a Voronoï diagram-based algorithm to optimize RSU deployment in an urban area. The extensive range of RSU determines the contours of the polygon based on a delay threshold of a packet transmitted between two RSUs (see Figure III.2). The resulting map of RSUs performed by this phase produces very likely areas of overlap of between RSUs. To remove overlapping areas and unattended areas the second part is applied to adjust the RSU setting in ordered to balance load and to mitigate packet loss. If the extended ranges of any two pairwise RSUs overlap, the RSUs in the pair are deemed to be neighbors. In other words, there may be gaps between the extended ranges.

- *Advantages*

  – This approach can not affected by many factors such as traffic density and junction priority.

  – It ensures a dynamic network resources management.

- *Weaknesses*

  – The proposed technique did not consider the obstructions such as hills and buildings.

  – This approach can involve private land for deployed RSU.

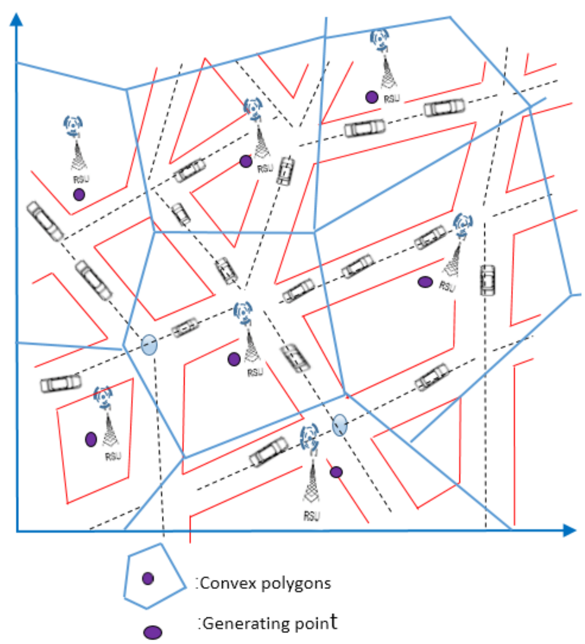



Figure III.2: Voronoi diagram approach for RSUs deployment in an urban region

Ghorai and I. Banerjee in [36] introduced Constrained Delaunay triangulation approach (see Figure III.3). Accordingly, the topology area is partitioned into some convex triangle, whose vertices represent RSUs candidate locations, so that no other RSUs are inside the circumcircle of any triangle. The first target of the proposed method is to place the RSUs in that obstructed area of an urban environment to achieve full coverage, followed by an optimization procedure to get the best RSUs position and reduce the communication delay in V2I contexts. The simulation results showed that the proposed method outperforms the GeoCover algorithm and $\alpha$-coverage algorithm [37] methods in terms of the packet delivery rate, packet loss and end-to-end delay.

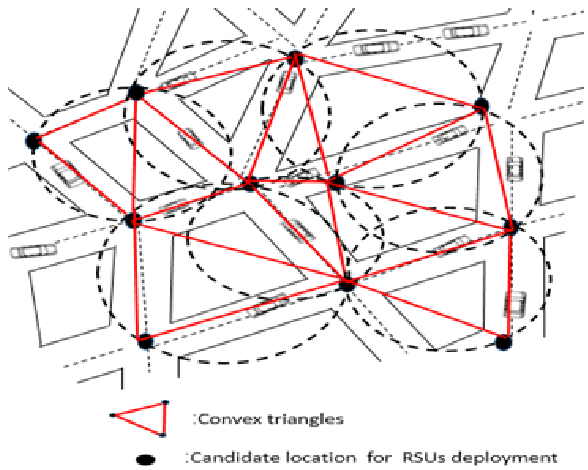



Figure III.3: Constrained Delaunay triangulation approach

- ***Advantages***

  – The proposed approach is tested within different scenarios.

  – It introduces an optimal multi-metric RSU selection strategy to reduce the communication delay between OBU and RSU.

- ***Weaknesses***

  – The proposed algorithm gives better results in a simple map than in a medium or complex one.

### *C. RSU deployment based on intersection-density*

Due to Network coverage propagating at an intersection, the RSU deployment based on Intersection considers the intersections as potential deployment locations of RSUs. Furthermore, the network coverage is greater at an intersection with dense traffic than an intersection with light traffic.

Chi et al. [8] presented an RSU deployment approach based on intersection priority approach so that the RSUs are preferably placed at important intersections. The priority of each intersection can be calculated according to some traffic factors including vehicle density, intersection popularity. Greedy, dynamic, and hybrid algorithms are presented to serve this purpose. The greedy algorithm deploys RSUs at intersections in descending order of the intersection priority. When an intersection is located within the transmission range of the RSU, this intersection is excluded from the candidate set of intersections for RSU placement. The dynamic algorithm concentrates on achieving an even distribution of RSUs in order to reduce the size of the overlapped area. Finally, the hybrid algorithm combines both greedy and dynamic algorithms to distribute RSUs as uniformly as possible, while keeping the order associated to intersection priorities.

- ***Advantages***

  − This approach provides a compromise between the intersection priority concept and the overlapped rate.

  − It implements three algorithms for allocating the RSUs: greedy, dynamic, and hybrid algorithms.

  − This proposal minimizes the deploying RSUs cost and the coverage overlap.

- ***Weaknesses***

  – It did not consider the vehicle traffic between intersections to eliminate the overlapping area.

  – It did not consider the budget constraint.

To provide vehicles with the multi-hop data delivery, the authors of [38] suggested a Greedy Set-Coverage algorithm to optimize the number of RSUs and satisfy the required QoS in terms of delivery delay. The goal is to select optimally a subset of road intersections for RSUs deployment, in order to reduce packet delivery delay using vehicular traffic statistics. This problem is modeled as a graph, whose vertices can be divided into two disjoint sets V and E. Where, V denotes the intersections set and E denotes a road segments set. It is noticed that one intersection cannot cover the whole edge set in almost all cases.

- ***Assumptions***

  – The Set-covering algorithm uses a grid road topology.

- ***Advantages***

  – This mechanism considers both road traffic and data delivery Quality of Service (QoS).

- ***Weaknesses***

  – Greedy Set-Cover does not select the optimal positions of that number of intersections.

  – The obtained results showed that Greedy Set-Cover algorithm does not always perform well compared to Uniform Placement.

Cavalcante et al. [39] applied a genetic algorithm to solve the deployment of RSUs in vehicular networks. The authors model the problem as Maximum

Coverage and they impose a time limit. This problem is solved based on a genetic algorithm, and these results will be compared by the greedy approach proposed in the literature [40]. Furthermore, the population initialization is given by four variants: the initialization is purely random, the greedy solution was inserted to the initial random population, the population is half random and half initialized by the modified version of greedy approach, and in the last case the three previous variations are combined. The test results proved that the population initialized by hybridization between the greedy approach and random initialization gives better results compared to greedy approach.

- ***Assumptions***

  – The authors assumed that the contact time between every vehicle and RSUs is known.

- ***Advantages***

  – The genetic algorithm uses a modified greedy algorithm to initialize the population in order to accelerate the convergence of the GA algorithm.

  – This mechanism takes into account knowledge of vehicular mobility for achieving an optimal roadside deployment.

- ***Weaknesses***

  – Actually, it is not evident to know the contact time between vehicles and RSUs.

  – This GA-based strategy focuses on V2I communication and did not consider cooperative V2V communications.

  – The simulations results did not show the impact on the QoS parameters.

*D. RSU deployment based on road segment-density*

In this subcategory, RSU Deployment Scheme with Power Control is proposed [41]. The authors have demonstrated how to properly deploy the RSUs to improve the performance of message propagation, as well as minimizing the energy consumption of RSUs when they continuously working all the time. Then, a cluster-based RSU deployment (CRD) scheme is proposed to improve the network connectivity. In order to optimize the energy consumption, the Traffic-Aware Power Control (TAPC) is exploited to reduce the energy consumption of RSUs without degrading the network connectivity. Moreover, the authors developed a data propagation algorithm named Data-Driven Message Propagation (DDMP), to improve the performance of message propagation in RSU-assisted VANETs.

- ***Assumptions***

  − The vehicles follow the same direction and move in the same fixed speed.

- ***Advantages***

  − The road segment-density based strategy aims to minimize the energy consumption of RSUs.

  − It is considered as a Good Cluster-based RSU Deployment (CRD) scheme to improve the network connectivity.

- ***Weaknesses***

  − The authors did not consider the vehicle density and vehicle speed.

  − The network did not reach full-connection.

Jalooli et al. in [42] propose Safety-Based Disconnected RSU Placement algorithm (S-BRP) applied to large-scale urban environment, and aiming at reducing the dissemination delay for VANETs safety application in multi-hop broadcast scheme. In addition, this proposal takes into account the deployment at the road segments where the length of segments is greater than the transmission range. Since the RSUs are placed autonomously without any I2I communication, the RSU placed at road segment plays the same role as a relay between vehicles. According to this drifting assumption, the absence of I2I communication can make the process of deployment very expensive.

- ***Assumptions***

  – The authors assume that the road intersections consider a high probability of accidents.

- ***Advantages***

  – This deployment strategy is based on a safety disconnected message using multi-hop scheme.

  – This proposal reduced the dissemination delay for VANETs safety application.

  – This strategy was applied to large-scale urban environment.

- ***Weaknesses***

  – Absence of I2I communication, which can make the process of deployment very expensive.

  – This approach needs to find a trade-off between the cost of deploying standalone RSUs and the average dissemination delay.

Sarubbi et al. proposed in [43] a Delta-r-GRASP algorithm to guarantee the QoS for the roadside units. Delta-r-GRASP is based on two parameters $\rho_1$ and $\rho_2$, where $\rho_1$ is the connectivity duration factor, denoting how time each vehicle must stay connected to belong to the communication process, however $\rho_2$ designates the rate of vehicles (i.e. the percentage of the total number of vehicles) experiencing the contact time defined by $\rho_1$[43]. This approach aims to find the minimum set of urban cells where $\rho_2$ percent of the vehicles are $\rho_1$ percent of its travel time connected. The results obtained showed that this scheme can reduce the number of RSUs by more than when compared to Delta-r algorithm [44].

- ***Advantages***
  – This Roadside units deployment is under QoS constraints.
  – It guarantees a minimal communication based on delta metric.

- ***Weaknesses***
  – This algorithm presents no more than from the optimal value of minimizing the number of roadside units.

***E. RSUs deployment based on hotspot regions***

In this subclass, the coverage area is considered as a hotspot region, which is a region accumulating more vehicles. In order to deploy RSUs based on hotspots, the road segments are divided into fixed-sized clusters, then the corresponding coverage value is assigned to each cluster (see Figure III.4 ).

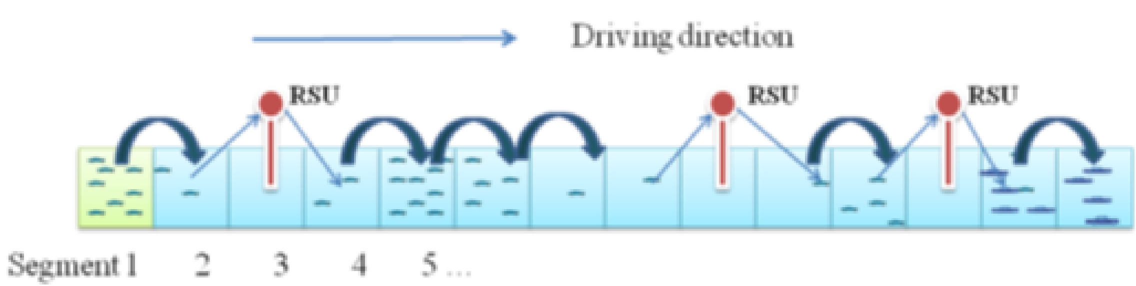



Figure III.4: The network model for CMP placement [45]

In this section, two works are introduced to discover the hotspot area as the most valuable region for RSUs deployment in a road network.

In [45] the authors proposed a placement strategy of RSUs called the Capacity Maximization Placement (CMP). This approach uses two communication modes to access a RSU; direct access or multi-hop access. Also, the RSUs are placed in the centre of segments. The hotspots area are discovered by dividing the zone in question in fixed size cells and assign the coverage value corresponding to each cell, with geometry characteristics such as: wireless interference, vehicle population distribution, and vehicle speed. To formulate this problem, an integer linear programming model (ILP) has been used so the total flow in the network can be maximized. The results obtained showed that CMP strategy outperforms the other two placement strategies, namely, uniformly distribution and hotspot placement in terms of the aggregate throughput and the deployment budget, and the number necessary of RSUs.

- ***Advantages***

  − This method helps to study and determine the insufficiently covered regions.

  − It proposed a solid mathematical model of vehicles mobility it includes the impact of wireless interference, vehicle population distribution, and vehicle speeds.

- ***Weaknesses***

  − This is not implemented by any algorithm and simulation.

In [37] the authors proposed a geometry-based sparse coverage protocol called GeoCover on urban VANETs, it focuses on solving three coverage problems in the vehicles networks: Road geometry, distribution of vehicle traffic, and resource constraints. A side from these of problems, a sparse coverage is addressing the challenges of budget and quality. Budgeted Sparse Coverage (BSC) keeps the total cost of RSU deployment under a predefined budget. Qualified Sparse Coverage (QSC) is a necessary standard to specify the lower bound of performance in which these RSUs are able to cover the network area. For solving the coverage problem, two algorithms were proposed as follows: Genetic (GeoCover-genetic) algorithm and greedy (Greedy Cover) algorithm. The simulation results showed that the greedy GeoCover is more scalable and salable then as GeoCover genetic.

- ***Advantages***

  – This proposal introduced strong model to design a practical VANET RSU deployment based on road geometry.

  – It acheived a good coverage within an expected in question as well as scalable delay.

- ***Weaknesses***

  – In real life scenario if the hotspot area is changed due to some other factors, the RSUs need to be deployed according to the new hotspot discovery process.

  – It didn't analyze the global coverage achieved by their method.

We perform a qualitative comparison between the different approaches discussed above. Table III.1 provides a comparative summary of the characteristics of various static deployment approaches.
In Table III.2, we summarize the static deployment strategies in terms of objective, constraints and technique being applied.

Table III.1: A comparison between the various static deployment approaches

| Ref | Topologies | V2X | Sub-class | Coverage type | Application |
|---|---|---|---|---|---|
| [34] | Highway | V2X | Uniform distribution | Continuous | Safety |
| [30] | Highway | V2I | Uniform distribution | Continuous | X |
| [35] | Urban grid | V2I | Logical coverage | Continuous | Safety |
| [33] | Urban | V2V/V2I | Logical coverage | Continuous | Safety |
| [36] | Urban | V2V/V2I | Logical coverage | Continuous | Safety |
| [8] | Urban grid | V2I | Intersection-density | Continuous | X |
| [38] | Urban grid | V2I | Intersection-density | Continuous | X |
| [39] | Urban/ Rural | V2I | Intersection-density | Continuous | Efficiency |
| [41] | Highway | V2V/V2I | Road segment-density | Continuous | X |
| [42] | Urban | V2V/V2I | Road segment-density | Sparse | Safety |
| [43] | Urban | V2I | Road segment-density | Continuous | X |
| [45] | Highway | V2V/V2I | Hotspot | Sparse | X |
| [37] | Urban | V2V/V2I | Hotspot | Sparse | X |

### III.2.2 Dynamic deployment schemes

Because of high installation and maintenance costs for RSUs, the large-scale deployment of these installations has become an unfeasible task. To meet this challenge, the vehicles equipped of DSRC can be used as RSUs [46]. The dynamic aspect of this placement technique is represented in the dynamic selection of the vehicles. In this subsection, we review the RSU deployment approaches that are based on a dynamic deployment. These RSUs deployment schemes can be classified into three subclasses such as: Vehicle used as temporary RSU, Parked cars

Table III.2: A qualitative overview of static deployment approaches

| Ref | Objective | Constraints | Algorithms | Simulators |
|---|---|---|---|---|
| [8] | Maximize coverage by minimizing RSUs number | overlapped area | Greedy, Dynamic and Hybrid | SUMO/ Ns2 |
| [30] | Minimize deployment cost | Delay bound of transmitting alert messages | Mathematical model | X |
| [33] | Maximize the coverage | Delay and loss packet | Voronoi diagram | Ns2 |
| [34] | Maximize deployment distance | A given probability parameter $p$ and the time $t$ | Randomized | SUMO |
| [35] | Minimize reporting time average | A given number of RSUs | BIP/BEH | SUMO |
| [36] | finding RSUs position for maximum coverage | Constrained Delaunay Triangulation(DT) | DT Approach | Ns2 |
| [37] | Maximize the coverage. Minimize the deployment cost | Budget sparse coverage, and qualified sparse coverage | $\alpha$-DBSCAN. genetic. greedy | Ns2 |
| [38] | Minimize RSUs number | Reduce packet delivery delay | Greedy Set-Cover | SUMO/Ns2 |
| [39] | Maximize coverage Time Threshold Problem | limit number of RSUs | Genetic | Specific simulator |
| [41] | Maximize spread performance. Minimizing the energy consumption | Cluster-based RSU deployment | Data-Driven Message Propagation (DDMP) | SUMO |
| [42] | Minimize dissemination delay | Limited number of RSUs | Safety-Based RSU Placement (S-BRP) | SUMO/Ns2 |
| [43] | Optimize the QoS performances | Limited number of RSUs | Delta-r-GRASP | SUMO |
| [45] | Maximize Capacity Placement. Minimize deployment cost | Impact of wireless interference, vehicle population, distribution, and vehicle speeds | ILP | VanetMobisim Ns2 |

and bus line used as RSUs. Moreover, we perform a qualitative comparison between the different strategies of dynamic RSUs deployment. Table.III.3 provides a comparative summary of the characteristics of various approaches while table.III.4 provides objectives of each work including constraints, algorithms and simulators.

### *A. Vehicle used as temporary RSU*

In the temporary RSU, a vehicle can make a brief stop to fulfil the tasks performed by a classic RSU, disseminating messages to nearby vehicles, and making communication relay function to other vehicles in the network [46]. The main goal of this scheme is to disseminate a security message (information about the incident -time, rental, etc.) using a vehicle involved in the accident or a police car, and issued to all vehicles in a Region of Interest (ROI). Therefore, the best candidates for temporary RSUs are vehicles that are positioned at the boundary of the coverage polygon. These vehicles make a brief stop for a certain period of time (not the vehicles moving toward the accident location) and periodically rebroadcast the safety message. To meet these needs, a distributed gift-wrapping algorithm is proposed in [47]. The simulation results showed a substantial improvement in terms of message accessibility.

- ***Assumptions***

  – Vehicles acting as temporary RSUs must make brief stops while they act as communication bridges for other vehicles in the network.

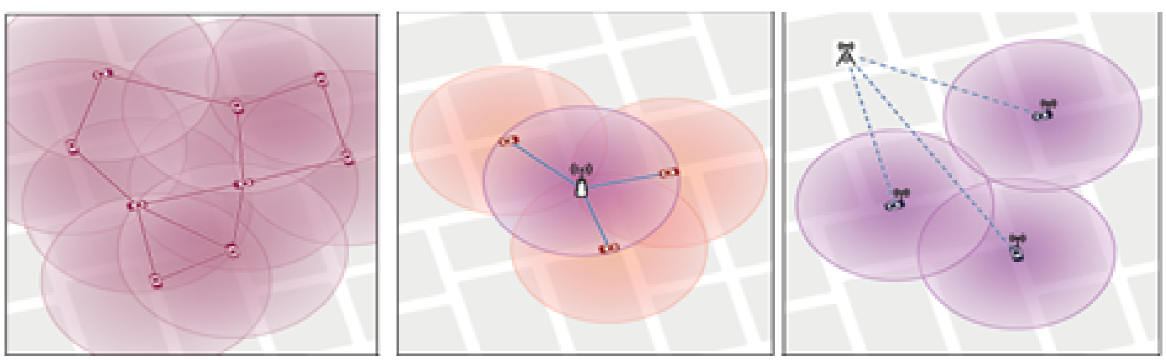
  – Upon receiving a message, the vehicle determines whether it lies on the boundary of a coverage polygon.

  – In the coverage polygon, considering a stable and sustained connection between any two given nodes.

- *Advantages*
  - It optimizes the high investments required to deploy RSUs in large cities.
  - It employs a self-organizing network paradigm.
- *Weaknesses*
  - The cars move too far apart from each other, and the channel disappears.
  - The stops of the ordinary vehicles (temporary RSUs) still leave a question mark on the robustness and reliability of the system.

### *B. Parked cars used as RSUs*

The existence of large numbers of parked cars is a motivation to give those cars the role of RSUs using self-organizing approach. This approach consists of three modes (figure.III.5 summaries these three modes).



(a) Parked cars form a mesh network with point-to-point links to other parked cars.

(b) Parked cars extend the range of a fixed 802.11p RSU, acting as relays to it.

(c) Parked cars with access to an uplink establish them selves as standalone RSUs.

Figure III.5: Modes of operation for parked cars acting as RSUs [48].

When there are no fixed RSUs existing in the urban area, parked cars create a network to support network connectivity to other moving vehicles (see Figure III.5.a). If there is a limited number of fixed RSUs in the area, hence parked cars in the vicinity of an RSU can act as relays to other nodes, extending the transmission range of the current fixed RSU (see Figure III.5.b). A parked car which is linked to a backbone uplink can leverage that link via the Internet, to establish itself as a standalone RSU (see Figure III.5.c).

The authors of [49] suggested two operation modes for parked car of an existing RSU and or standalone RSUs. The goal of this proposal is to improve safety applications where an accident occurs. For this situation, an emergency message needs to be sent to nearby parked cars (nodes). Each node received this message broadcasts in its turn a beacon to its neighboring cars and so on. This information serves to divide urban area into equal cells (i.e., map of cells) and to know which areas can be reached by each vehicle. A decision algorithm is used to decide whether a parked car should become an RSU or switch to a power-saving (sleep) mode. A method has been proposed in this paper to decide which car should become RSUs. The simulations showed that this method improved the transmission coverage for safety applications, even when only small numbers of parked cars are available.

- ***Advantages***

  − Considering a more comprehensive realistic simulation.

  − The idea of activation of parked cars can extend the network by additional RSUs.

- ***Weaknesses***

  − The used algorithm is limited by only one-hop exchange.

  − This approach can be affected by a mobile obstruction. A correction process is needed to oversee the decreased transmission range.

To improve cooperative awareness and road traffic safety in an urban, the authors of [48] proposed use to parked vehicles as relay nodes through two hop transmissions. To achieve this, each moving car emits periodically beacon messages containing its position and speed, and then parking nodes will overhear these messages. A parked car will rebroadcast this beacon message playing the role of an RSU, so other moving cars will then pick up the beacon. This study is compared to the message dissemination via static RSUs, and shown that the number of RSUs has drastically reduced. In addition, the moving vehicles can receive emergency messages sent by its neighboring cars in an acceptable time.

- ***Assumptions***

  – This approach assumes that all cars always have enough energy left to operate the 802.11p OBU even if the vehicle is turned off.

- ***Advantages***

  – It is a low-cost self-organizing network approach.

  – The influence of obstacles has been modeled in simulators.

- ***Weaknesses***

  – This proposal requires more energy to be operational.

  – This approach did not address the coverage when an obstruction appears near a parked car.

In this subcategory, Reis et a. proposed in [50] proposed a dynamic decision process to improve [49]. This work considered all three modes of operation for parked cars in urban areas as shown in figure III.10. For all these modes, a coverage maps will be created for each particular car based on received signal strength, so the urban area is divided into a logical 2D cell map. The authors defined and used signal strength measurements from the DSRC radios to determine obstructions and to ensure effective coverage by others neighbor parked cars. Additionally, to conserve energy in the parked cars, the authors give a dynamic decision process to decide when a parked car should become a RSU or should enter into sleep mode. The results of the simulations showed an excellent connectivity coverage using a small number of parked cars in the urban area. Moreover, the use of such a relay system for a parking time of less than one day is without any critical impact on the usability of the vehicle.

- ***Advantages***

  – It reduces the time for emergency messages to be broadcasted by 40-50 % by small numbers of parked cars to acting as RSUs.

- ***Weaknesses***

  – Despite the operation mode (active / sleep), parked cars are energy-constrained and can leave the parking at any time.

  – The proposed algorithm is limited to one-hop exchange between RSUs.

***C. Bus line management as RSU***

When there are no fixed RSUs existing in the urban area, the buses can constitute the backbone network and can also play an important role in improving the messages dissemination as presented in figure III.6. Whereas there is a limited number of fixed RSUs, the bus lines can be used as a relay nodes to serve the traffic data between the vehicles and the existing RSUs [51, 52].

Based on the predictable routes and schedules of buses, the authors of [51], proposed a two-tier architecture named BUS-VANET, which are high-tire and low-tier. The high-tier includes RSUs, Traffic control Centre (TCC) and combines them with buses lines. However, the vehicles with DSRC devices compose the low-tier. This architecture is summarized in figure III.7. If a low-tier node wants to send a message, it is obliged to be registered with a neighbor high-tier node in order to determine the delivery path provided by the high-tier node. The simulation results showed that the two-tier BUS-VANET offers a reduced delivery delay and a best packet delivery ratio.

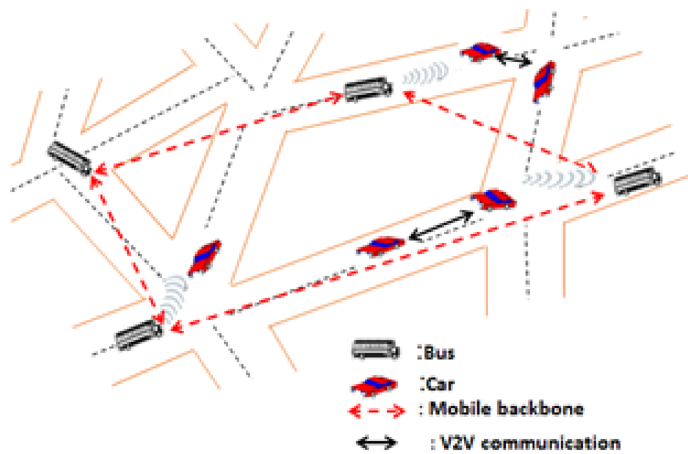



Figure III.6: Mobile infrastructure based on backbone bus

- *Assumptions*

  – Vehicles are uniformly distributed over the road and buses – represent 20 % of the vehicles.

  – Buses and RSUs are additionally equipped with either a Wi-Fi or WiMAX communication capability. They truly form a backbone of VANET.

  – The known route and the bus schedule are shared among vehicles.

- *Advantages*

  – The two-tier BUS-VANET offers a reduced delivery delay and a best packet delivery ratio.

- ***Weaknesses***

  −This approach did not take into account transmission services provided by existing RSUs.

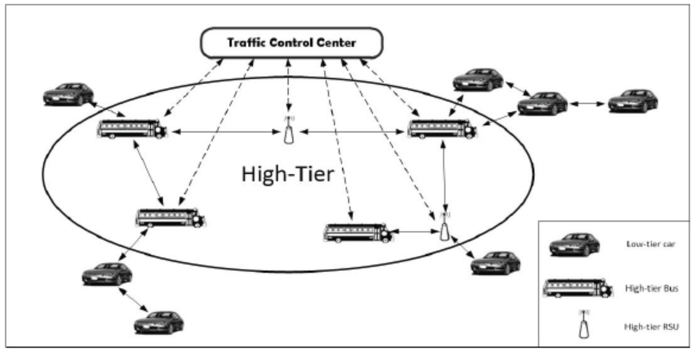



Figure III.7: Mobile infrastructure based on VANET architecture [51]

Given a limited budget to deploy RSUs, the problem is how to find the best locations to install these RSUs so that more roads are covered. Due to the high cost of a massive RSU deployment in wide metropolitan areas, Kim et al. [52] suggested a new strategy to optimize RSU deployment using three different deployment techniques, i.e., static locations, public transportation units that are not controllable (i.e. Buses) and fully controllable mobile nodes (i.e. vehicles). The proposed algorithm consists of two independent stages using is a directed acyclic graph. In the first stage, a greedy algorithm is applied for the Maximum k Coverage Problem. The second stage uses also a greedy strategy to solve the maximum coverage budget problem. The simulation result showed that this framework provides a cost-effective solution compared to the case adopting a single deployment strategy.

- ***Assumptions***

  − The cost to deploy an RSU on each deployment type is fixed and known in advance.

– The mobile public transportation does not suffer from any delay, and their travel schedule is known.

– The Government vehicles do not suffer from traffic jam.

- ***Advantages***

  – This study is considered as an innovative RSU deployment framework.

  – Combining three deployment strategies is a general platform for future research.

- ***Weaknesses***

  – This work considers that each mobile transportation does not suffer from any delay and the controllable mobile does not suffer from traffic jam, which is not the case in a real scenario.

We perform a qualitative comparison between the different approaches discussed earlier. Table III.3 provides a comparative summary of the characteristics of various dynamic deployment approaches.

Table III.3: A comparison between the various dynamic approaches deployment

| **Ref** | **Topologies** | **V2X** | **Sub-class** | **Coverage Type** | **Application** |
|---|---|---|---|---|---|
| [46] | Urban | V2V | Vehicle as temporary RSU | Continuous | Safety |
| [49] | Urban | V2V/V2I | Parked cars as RSU | Sparse | Safety |
| [50] | Urban | V2V/V2I | Parked cars as RSU | Sparse | Safety |
| [48] | Urban | V2X | Parked cars as RSU | Sparse | Safety |
| [51] | Urban | V2X | Bus line management | Continuous | X |
| [52] | Urban | V2X | Bus line management | Continuous | X |

In table III. 4, we compare dynamic deployment strategies in terms of objectives, constraints and techniques being applied.

Table III.4: A qualitative overview of dynamic deployment approaches

| Ref | Objective | Constraints | Algorithms | Simulators |
|---|---|---|---|---|
| [46] | Disseminate a safety message to all vehicles within a region of interest (ROI) within a short time. | Boundary of the network coverage polygon | Biologically inspired approach | SUMO |
| [49] | Make parked cars self-organize ad-hoc RSUs | Maintaining a best bandwidth and link probability | A decision algorithm | SUMO |
| [50] | Maximize the reach of this support network, while minimizing the number of active RSUs | Improving broadcast delay in sparse networks | Build Local Maps algorithm and decision algorithm | SUMO/ Ns2 |
| [48] | Signal Attenuation blocked by Buildings or obstacles and uses the parked cars to optimize the coverage area | Obtain an upper bound for the safety benefit obtainable by utilizing 2-hop relaying via parked cars | A relaying algorithm | VanetMobisim/ OMNeT |
| [51] | Minimize the number of switches from vehicles to high-tier nodes | Limitation of package delivery delay into a given threshold T | Longest registration time algorithm | SUMO |
| [52] | Maximize the spatiotemporal coverage of RSUs in a given metropolitan | limited deployment budget | Greedy | SUMO |

## III.3 Deployment approaches comparison

The RSUs deployment models can be classified as static deployment and dynamic deployment. In the static deployment, VANET RSUs are placed on a fixed point on the road network. These RSUs deployment schemes can be classified into five subclasses such as: RSUs deployment based on uniform distribution, deployment based on logical coverage area, deployment based on intersection density, deployment based on road segment density, and deployment based on hotspot regions. Each subclass has its own strategy of placement in a given geographical area.

The dynamic deployment model is used in the case of very important traffic volume. In this case, the DSRC-equipped vehicles can be used as temporary RSUs. In this section, we will look at each of the different subclasses, and summarize them in tables III.3 and III.4 all existing work proposed for RSUs deployment.

The simplest RSU placement strategy is uniform distribution, namely, RSUs are spaced apart at a fixed distance. While simple, this placement strategy does not consider vehicle traffic. However, this placement strategy leads to intermittent connection. However, the data transmitting may not be effective because it does not consider vehicular traffic density. RSUs deployment based on logical coverage area deal with the vehicle networks as ideal graphs of nodes and straight lines, but looks that real-world road networks formed of a set of convex polygons that comprise of turns, forks, curves, etc. This constraint is processed by exploiting a buffering operation [37] method where the obstacles problem is solved by hotspot area discovery. The RSU deployment based on Intersection consider the intersections as potential deployment locations of RSUs[8, 38]. However, that even though most vehicles accumulate in congested intersections, the isolated vehicles are more likely to appear in the middle of road segments or the entering points of the domain. Furthermore, some road segments could be with more importance than other intersections in terms of road traffic. Also, deploying a RSU in a dangerous area may serve better than another in a safe and smoothly fluid area. Therefore, placing RSUs in the middle of the road is a more efficient strategy for avoiding uncovered isolated vehicles [37].

In dynamic deployment, the vehicles equipped of DSRC can be used as RSUs. More specifically, instead of using a costly roadside infrastructure (such as RSUs), this model leverages the use of DSRC-equipped vehicles to serve as roadside units. Consequently, in the early stage of VANET technology a small percentage of all vehicles will be equipped with DSRC devices (low market penetration of DSRC-equipped vehicles). Still, it is mandatory that the OBU of parked vehicles don't discharge the battery below a fixed threshold where the car cannot be moved again [48]. As a solution the main public traffic network in cities gives a motivation for the use of a Bus-VANET in providing information services [52]. These recent studies consider the buses as dynamic infrastructures deployed to improve the network connectivity.

## III.4 Conclusion

In this chapter, we have reviewed the RSUs deployment in VANET, summarized and analysed the recent proposed approaches in this context by examining the reached results and their evaluation methods. Depending to the mobility of vehicles, the strategy of RSUs location in the geographic areas, we classified the state of the art of the RSU placement strategies into two main categories namely, static and dynamic deployment. In the static category, the RSUs are always deployed in a static point on the relevant geographical areas such as uniform distribution, logical coverage area, intersection point, segments centres, and hotspot regions. In dynamic category, the vehicles equipped of DSRC can be used as RSUs, which this role can be given at the some vehicles acts temporary RSUs, parked cars, and buess. We have surveyed the published techniques for optimization of RSUs deploying and compared them depending on their objectives, placement and applications. In addition, we questioned that static deployment are more practical and robust when the deployment cost is taken into consideration. Consequently, temporary RSUs placement can be dynamically relocated to recover from connectivity problems.

The next chapter suggests our first contribution to solve the RSUs deployment problem. In this proposal, we suggest a new genetic intersection-coverage algorithm (GICA) based on the priority concept. In this work,we focus on popular intersections in terms of RSUs installation, aiming to maximize the coverage of RSUs while minimizing the interference rate and RSUs costs.

# CHAPTER IV

# GICA APPROACH FOR RSU DEPLOYMENT IN VANET

## IV.1 Introduction

Since the RSUs placement is described as the process of finding the best combination of RSUs on the adequate intersections to improve VANET performance, in this chapter, we introduce our first contribution that we call GICA: a static deployment strategy. Based on the priority concept [6], the tackled problem is formulated as multi-objective optimization problem, where the intersection priority, intersection coverage, and the average interference (overlap) are integrated in the evaluated objective (fitness) function. In all that follows, we will present in details the system model, algorithms, and simulation tests to validate this proposal.

## IV.2 GICA: System model and proposal details

As it has already been mentioned in the introduction, the main idea of this proposal consists of finding the optimal number and positions of RSUs with a maximal network connectivity, where these RSUs are put in road intersections as the best locations to extend the network connection. To achieve this goal, GICA algorithm adapts to the intersection-priority [8] concept and introduces the intersection-coverage concept to provide the desired connectivity performance. To reduce the redundant duplicated traffic messages generated by vehicles, GICA algorithm analyzes the overlapped area covered by two different RSUs. In this section, the tackled problem description and some definitions are illustrated to be used in the rest of this work.

### IV.2.1 Intersection coverage process followed by GICA

For a given urban topology area, the road network can be represented by unoriented graph. In this model, all the intersections were considered as candidate placements. In urban road topology many intersections exist, however, deploying a large number of RSUs is a costly solution. So, the RSUs deployment is described as the process of finding the best combination of RSUs on the adequate intersections according to the given conditions to meet the requested requirements (e.g. best connectivity, coverage, low deployment cost). Since network coverage is wider at an intersection with dense traffic, compared to an intersection with light traffic [39, 40], we intend to prioritize a subset of intersections to receive the roadside units. Indeed, we consider the idea of intersection priority through the use of the intersection weight concept, as introduced in [8]. Since our purpose is to cover the streets/roads within a target area, we introduce the intersection coverage concept to provide the desired connectivity performance. GICA proposes to put RSUs at intersections in descending order of intersection priority. In this way, an RSU can be placed at the intersection with the highest intersection priority, and so on until all intersections are covered. In order to place the RSUs at high priority intersections, we employ two sets indicated as RSET and CSET. At the beginning, the RSET subset defines a highly prioritized intersection list allowing to determine the location of the first RSU. Thereafter, all intersections within the transmission range of this RSU are excluded from the candidate set of intersections for deployment (updating graph). Notice that RSET contains all intersections where RSUs are placed. On the other hand, CSET includes all intersections covered by RSUs placed at RSET ( see Figure IV.1).

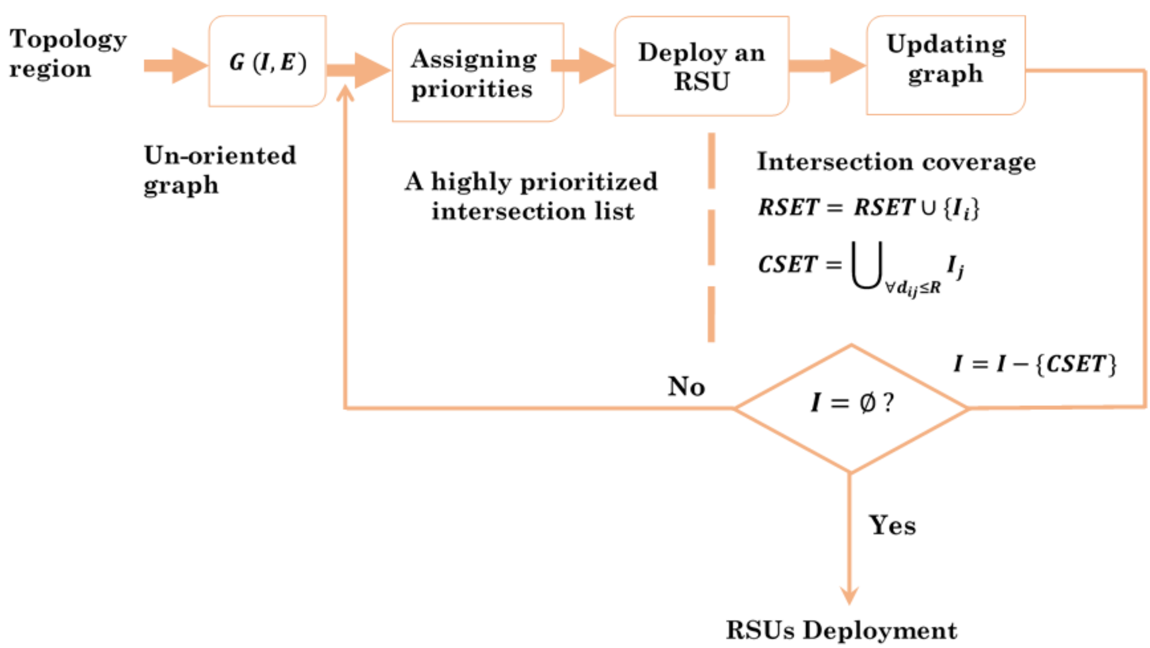



Figure IV.1: Intersection coverage process

### IV.2.2 System model

In given urban road topology, the vehicular network can be represented as a weighted graph $G = (I, E, p)$ given an urban road topology where:

- $I = \{I_1, I_2, \ldots, I_n\}$ denotes the intersections set, $|I| = n$ ($n$ intersections).
- $E = \{E_1, E_2, \ldots, E_m\}$ is segment roads set, where $e_{ij} \in E$ is the road segment connecting $I_i$ and $I_j$. $D = \{D_1, D_2, \ldots, D_m\}$ is distance set of segment roads and $d_{ij}$ is the distance from $I_i$ to $I_j$.
- $p = \{p_1, p_2, \ldots, p_n\}$ is a weight function, where $p_i$ denotes the priority of $i - th$ intersection. $p_i$ is calculated according to traffic parameters such as vehicle density $dnc_i$ and popularity of allocation $poy_i$, it is determined as follows:

  $$p_i = w_1 \times dnc_i + w_2 \times poy_i \tag{IV.1}$$

  Here, $w_j$ is a weight for each traffic factor, where $w_1 + w_2 = 1$. The total number of vehicles that cross each intersection for each time unit measures the vehicle density. While the intersection popularity denotes the geographical importance of each.

Let $I = \{I_1, I_2, \ldots, I_n\}$ , it means that $|RSET| = k$ , $k$ is the RSUs number, since each intersection $I_i$ RSET can cover a subset of intersections $S_i$, where $CEST = \{S_1, S_2, \ldots, S_k.\ S_i\}$ denotes the intersections set covered by the $i - th$ RSU placed at the intersection $I_i$. The communication area covered by all RSUs in the road map is formulated by separating RSET into $k$ subsets: $S_1 \cup S_2 \cup \ldots \cup S_k = CEST$. Let $RSUs = \{RSU_1, RSU_2, \ldots, RSU_k\}$ is the RSUs set. It is worth noting that maximizing the coverage area requires to find a collection of sets $S \subseteq CEST$ such that the number of covered elements $|\bigcup_{(S_i \in S)}|$ is maximized.

According to figure IV.2, the intersections A and E are within the RSET set, while the other intersections build the CSET set.

Consider $C$ the matrix of $|RSET| \times |CEST|$ elements, whose elements $x_{ij}$ is a binary decision ,variable at the location $(i, j)$, $i = \{1, \ldots, k\}$ and $j = \{1, \ldots .(n - k)\}$.

$$x_{ij} = \begin{cases} 1, & \text{if RSU}_i \text{ covering } I_j \\ 0, & \text{otherwise} \end{cases}$$

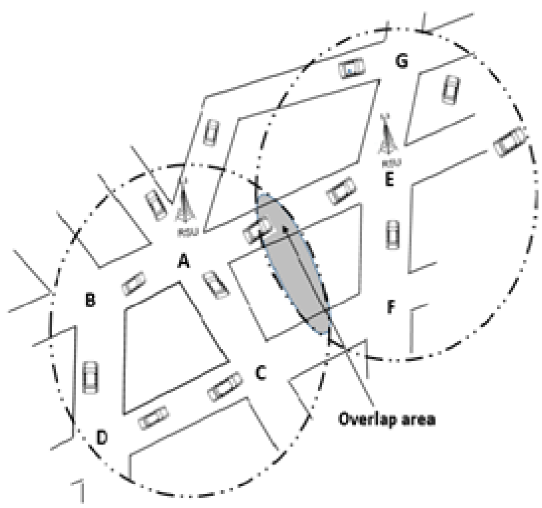



Figure IV.2: Intersection coverage by placed RSUs

For each intersection $I_i$ allocates an RSU, the intersection coverage is given by :

$$c_i = \sum_{I_j \in CSET} x_{ij} \qquad \forall\, I_i \in RSET \tag{IV.2}$$

Since our objective is to place the RSUs at high priority intersections in order to maximize the coverage, the objective function is given as:

$$f(x) = max \sum_{\forall I_i \in RSET} (c_i + p_i) \times x_i \tag{IV.3}$$

Let $\delta_i$ is the overlap rate of a RSU placed at the intersection $I_i \in RSET$. It is calculated as:

$$\delta_i = \sum_{\forall I_j \in RSET} (2 \times R - d_{ij}) \qquad \forall\, d_{ij} < 2.R \tag{IV.4}$$

In order to minimize the deployment cost and overlap rate, the objective function is as follows:

$$g(x) = min \sum_{\forall I_i \in RSET} (\delta_i + 1) \times x_i \tag{IV.5}$$

According to equations (3) and (5) cited above, the RSU deployment problem can be considered as a multi-objective optimization problem specified as follows:

$$Z = max \; [\; \alpha \times f(x) + \beta \times g(x) \;] \tag{IV.6}$$

We note that $\alpha$ is a positive weight since we try to maximize the intersection coverage and intersection priority; however, $\beta$ has a negative value aiming at decreasing the RSU deployment cost and interference average.

## IV.3 Genetic Intersection-Coverage Algorithm (GICA)

In order to explain our proposal, we start by expressing the genetic algorithm [54], considering the main inspiration of GICA algorithm.

### IV.3.1 Genetic algorithm

Genetic algorithms are metaheuristics rooted in the mechanisms of evolution and natural genetics. They were first proposed in the early 1970s by Holland [53]. Genetic algorithms manipulate a population of potential solutions to reach a problem solving optimization. Specifically, they operate on encoded representations of solutions, equivalent to the genetic material of individuals in nature, and not directly on the solutions themselves. The genetic algorithm encodes the solutions as strings of bits from a binary alphabet. As in nature, selection provides the necessary driving mechanism for better solutions to survive. Each solution is associated with a fitness value that reflects how good it is, compared with other solutions in the population. The higher the fitness value of an individual, the higher its chances of survival and reproduction and the larger its representation in the subsequent generation are. There are many different techniques that a genetic algorithm can use to select the individuals to be copied over into the next generation [54]. These include those used the most such as elitist selection, tournament selection and roulette-wheel selection. In elitist selection, the fittest individuals of each generation are guaranteed to be selected. However, in roulette-wheel method, selection is made completely depending on random numbers. Recombination of genetic material in genetic algorithms is simulated through a crossover mechanism that exchanges portions between strings. Another operation, called mutation, causes sporadic and random alteration of the bits of strings. Mutation too has a direct analogy from nature and plays the role of regenerating lost genetic material. In the following we discuss the formulation of GICA algorithm for RSUs deployment problem.

### IV.3.2 GICA algorithm for VANET RSU deployment

As our objective is to maximize the connectivity between RSUs while minimizing and interference (overlap) rate, we propose a new Genetic Intersection-Coverage Algorithm (GICA).

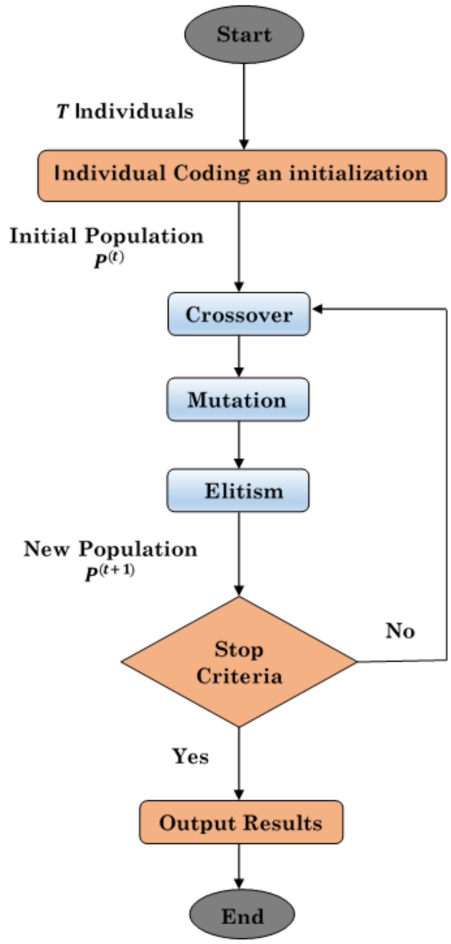



Figure IV.3: Flowchart of GICA algorithm

GICA introduces a set of steps such as individual coding and initialization, Crossover operator, Mutation operator, and a selection operation. Contrary to the standard genetic algorithm, our GICA algorithm suggests that the selection operation comes after the mutation operation so that a new generation is created. This contribution has been proven successful thought many results obtained. More details are included in subsection: Selection. These steps of GICA algorithm is presented in figure IV.3.

### *Individual coding and initialization*

In GICA, a solution (an individual) is represented by an array of $n$ positions (i.e. an array of genes). For instance, if we consider 5 RSUs and $n = 12$ a valid solution individual $\{0, 2, 6, 7, 11\}$, i.e., the RSUs are placed in intersections: $\{I_0, I_2, I_6, I_7, I_{11}\}$ as shown in figure IV.4.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |

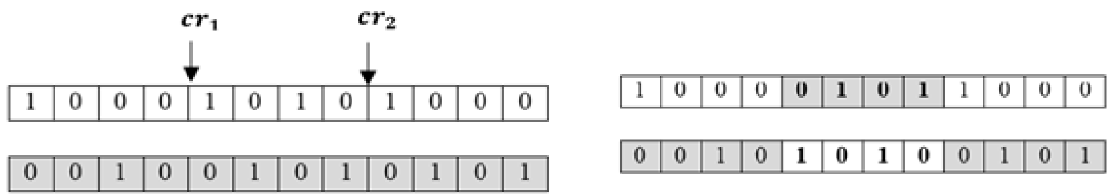
Figure IV.4: Individual coding

To get the nearest value to the optimal solution, it is a need to generate a set of solutions called initial population, where each solution called individuals. The initial population $P^{(0)}$ is composed in $T$ individual, which is usually created randomly without any rules (background knowledge or experience).

### *Crossover*

The crossover operation allows to combine two individual parent generating two children according to a probability $p_{Cros}$, the exchange is made where a random number $\alpha < p_{Cros}$, where $\alpha \in ]0, 1]$. The crossover operation is carried out through browsing the population and regenerate random number $\alpha_i$ of each individual $i$, if $\alpha_i < p_{Cros}$ we crossover the individual i by the following one. To this end, two crossover points $cr_1$ and $cr_2$ are selected randomly from the parent individuals. According to this crossing method, the genes limited by $cr_1$ and $cr_2$ are swapped between the parent individuals. Figure IV.5 shows an example of a crossover operation. The RSU places before applying the crossover are $\{I_0, I_4, I_6, I_8\}$ and

$\{I_2, I_5, I_7, I_9, I_{11}\}$, then after the crossover, the offsprings give $\{I_0, I_5, I_7, I_8\}$ and $\{I_2, I_4, I_6, I_9, I_{11}\}$




(a) Before Crossover. (b) After Crossover.

Figure IV.5: Crossover operation.

### *Mutation*

The mutation operation helps to maintain diversity in the population. This operator acts on an individual according to a probability $p_{Mut}$, for each gene, a random number $\beta \in ]0,1]$ is selected. If $beta < p_{Mut}$ the value of this gene is modified, but it can also make the algorithm converge more slowly. Figure IV.6 gives an example of mutation. The RSU places before applying the mutation are $\{I_0, I_5, I_7, I_8\}$, then after the mutation, the offsprings give $\{I_2, I_4, I_8\}$.


(a) Before Mutation. (b) After Mutation.

Figure IV.6: Mutation operation.

### *Fitness function*

The objective function, the function to be optimized, provides the mechanism for evaluating each solution. However, its range of values varies from problem to problem. To maintain uniformity over various problem domains, we use the fitness function to normalize the objective function to a convenient range of 0 to 1. The normalized value of the objective function (see formula IV.6) is the fitness of the string, which the selection mechanism uses to evaluate the strings of the population.

### *Selection*

Selection models nature are survival-of-the-fittest mechanism. Fitter solutions survive while weaker ones perish. Based on the fitness function, the $\psi$ individuals with a best fitness will (elitist parents) be selected to form the next population, following, selecting the $\varrho$ children according to Roulette Wheel Selection. The Roulette Wheel Selection Procedure is defined in the algorithm 1.

**Algorithm 1** Roulette Wheel Selection

$Com = 0$ // The cumulative probability
$\psi$ // selection size
$T$ // population size
**while** $(i < \psi)$ **do**
  Generate a random number $r \in ]0, 1]$
  $Com += p_{Selection}(a_i)$; // probability
  **if** $(r < Com)$ **then**
    Select the individual
  **end if**
  $i = (i + 1)\%T$
**end while**

So, the size of new population is $n = \psi + \varrho$. For a population $P$ of $n$ individuals, $P = \{a_1, a_2, \ldots, a_n\}$ and the fitness of individual is $z(a_i)$, $a_i \in P$, so we can calculate the selection probability of individual fitness by formula (IV.7).

$$p_{Selection}(a_i) = \frac{z(a_i)}{\sum_{i=1}^{n} z(a_i)} \tag{IV.7}$$

Algorithm 2 details the basic structure of our GICA. It starts by randomly initializing each individual in the first population.

**Algorithm 2** *GICA*

**Input** $G = (I, E), D, p_i, i = \{1, \ldots, n\}$
**Output** $RSET$
Initialize parameters $\alpha, \beta, \psi, \varrho, R, p_{Cros}, p_{Mut}$
Coding the individual
Initialize the population $P^{(t)}$, $|P^{(t)}| = T$, $t = 0$
$best^{(0)} \leftarrow max\{Z_j^{(0)}\}$ and $j = \{1, \ldots, T\}$
**while** ending condition is not met **do**
    Execute two-point crossover with probability $(p_{Cros})$
    Execute one-point mutation with probability $(p_{Mut})$
    Evaluate the parent population according to $(IV.6)$
    Evaluate the children population according to $(IV.6)$
    Insert the elitist parents in next population $P^{(t+1)}$
    Select the children using the Roulette Wheel Selection
    $best^{(t+1)} \leftarrow max\ \{best^{(t)}, Z_j^{(t+1)}\}$
**end while**
**return** best solution $RSET^{(best)}$

*Stopping criterion*

In this algorithm, the main loop is iterated until reaching a fixed number of generation $t$.

# IV.4 Experimental study

## IV.4.1 Parameter settings

This part of the work is devoted to evaluate the performance of the proposed optimization strategy according to different characteristics of road networks and to present the results obtained, with in a depth analysis of how (GICA) algorithm functions differently with the different characteristics of road networks, and finds the optimal number and location of the RSUs deployed in such areas. The network topologies have been generated randomly.Table IV.1 shows details about the six network topologies used during the evaluation process in terms of number of

Table IV.1: Dataset based on random street topologies

| **Topologies** | **Number of intersections** | **density** | | **popularity** | |
|---|---|---|---|---|---|
| | | *max* | *min* | *max* | *min* |
| Map1 | 20 | 3.42 | 13.93 | 0.01 | 8.94 |
| Map2 | 40 | 3.99 | 13.88 | 0.5 | 8.90 |
| Map3 | 60 | 3.60 | 13.91 | 0.5 | 8.92 |
| Map4 | 80 | 3.80 | 13.01 | 0.34 | 8.16 |
| Map5 | 100 | 2.43 | 14.32 | 0.41 | 9.01 |
| Map6 | 150 | 4.01 | 15.20 | 0.27 | 9.26 |

roads intersections, and intersections' parameters including the density of vehicles and intersection popularity. In order to measure the priority of each intersection, two traffic factors were considered as (1) the density of vehicles, and (2) the popularity of an intersection. The vehicle density represents the volume of traffic at each intersection, while the intersection popularity describes the geographical interest of the intersection, which represents the bus lines number passed through an intersection. Table IV.2 summarizes the parameters values used during the simulations.

Table IV.2: Parameter settings and values

| **Notation** | **Parameters** | **Values** |
|---|---|---|
| $R$ | RSU Transmission Range | 250m |
| $(w_1, w_2)$ | Weights of factors | $(0.7, 0.3)$ |
| $T$ | Population size | 100 |
| $t$ | Number of iterations | 200 |
| $p_{Cros}$ | Crossover probability | 0.9 |
| $p_{Mut}$ | Mutation probability | 0.01 |
| $(\alpha, \beta)$ | weight parameters of fitness function | $(0.8, 0.2)$ |

For evaluating the effectiveness of our algorithm, we consider three performance metrics: number of RSUs, average area covered by the RSUs, and overlap ratio. Considering $S_i$ as the intersections set belonging to transmission range of the RSU installed at $i - the$ intersection and $N_i$ his neighborhood, the average area $(Cov)$ indicates the ratio of road segments in the network covered by all RSUs in the city, it is calculated as follows:

$$Cov = \frac{\sum\limits_{i \in RSET} \sum\limits_{j \in S_i} d_{ij}}{\sum\limits_{i \in RSET} \sum\limits_{j \in \{N_i \setminus RSET\}} d_{ij}} \tag{IV.8}$$

The overlapping ratio of all RSUs is denoted as:

$$\delta = \frac{1}{n.R} \sum_{i=1}^{|RSET|} \sum_{j=i+1}^{|RSET|} (2.R - d_{ij}) \quad \forall\, d_{ij} \leq 2.R \tag{IV.9}$$

### IV.4.2 Results obtained

In the basis of the six urban topologies defined earlier, we present now a set of experiments, comparing the performance of our proposed GICA against the greedy algorithm proposed in [8], considered as a conventional algorithm for RSU placement in VANETs. Table IV.3 shows the network coverage, overlap rate and the number of RSUs required of both greedy and the proposed GICA algorithm.

Table IV.3: Summary of the results

| **Topolgies** | $n$ | **Average Coverage**(%) | | **Overlap Rate**(%) | | **RSUs number** | |
|---|---|---|---|---|---|---|---|
| | | ***Greedy*** | ***GICA*** | ***Greedy*** | ***GICA*** | ***Greedy*** | ***GICA*** |
| Map1 | 20 | 38.8 | **46.3** | 12.4 | **9.7** | 14 | **8** |
| Map2 | 40 | 49.3 | **63.8** | 28.2 | **13.5** | 22 | **15** |
| Map3 | 60 | 58.6 | **67.9** | 31.7 | **23.6** | 49 | **28** |
| Map4 | 80 | 53.8 | **72.1** | 42.3 | **43.1** | 55 | **34** |
| Map5 | 100 | 61.7 | **77.6** | 57.5 | **38.6** | 82 | **53** |
| Map6 | 150 | 63.8 | **88.6** | 72.3 | **41.1** | 137 | **93** |

From these experiments, GICA obviously presents much better results than the greedy algorithm for placing RSUs within urban vehicular networks in terms of the number of RSUs required, the network coverage achieved and the overlapping rate.

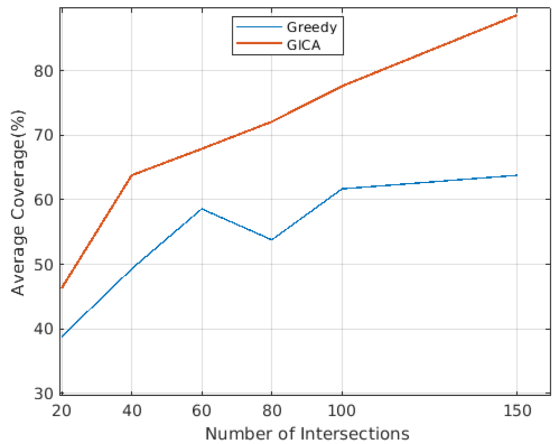



Figure IV.7: Coverage rate depending on the number of intersections

As shown in figure IV.7, our algorithm covers much more area for a given number of RSUs.

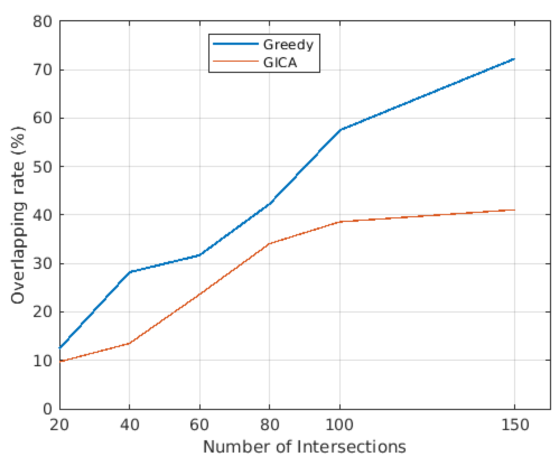



Figure IV.8: Overlapping ratio when varying the number of intersections

Similarly, figure IV.8 shows that the overlapping ratio of each region when

using the GICA algorithm is quite lower than with the greedy algorithm.
We also find that the total number of RSUs decreases when using GICA. For example (see table 3 and figure IV.9), for map4, GICA proposed only 34 RSUs to ensure 72.1% of network coverage with only 34.1% as overlap rate, however the greedy approach requires 55 RSUs to cover 53.8% of the studied area with an overlap rate of 42.3%.

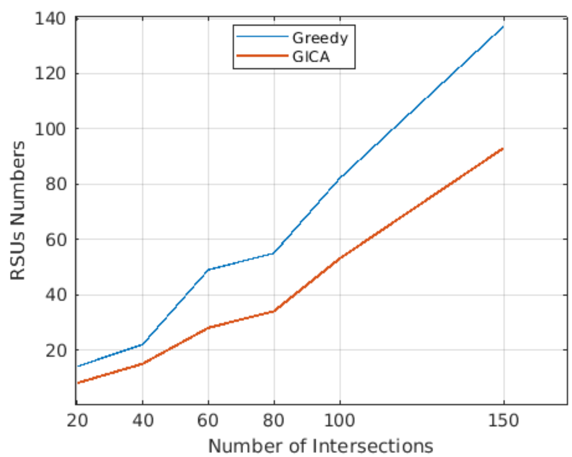



Figure IV.9: RSUs number generated depending on the number of intersections.

From this simulation study, we can conclude that our GICA approach provides good results as in a RSU placement strategy compared to the greedy algorithm in terms of the number of RSUs required, the area coverage achieved, and overlapping ratio generated.

## IV.5 Conclusion

In this chapter, we have dealt with the problem of the RSUs deployment in the vehicular ad hoc networks, introducing GICA as a static deployment srtrategy; an algorithm a based on the intersection-priority concept to deploy RSUs at the intersections having a higher impact on the efficiency of the vehicular networks. To so, we have formulated this issue as a multi-objective optimization problem in order to maximize the intersection coverage while minimizing the number of RSUs required and the overlap rate. The tests lead to prove that GICA has better results over greedy approach, but it does not take into account the average connectivity and deployment budget variation. In the next chapter, we propose a new bio-inspired RSU placement system called Ant colony optimization system for RSU deployment in VANET (AC-RDV), aiming at placing a reduced number of RSUs that cover a large geographic area, and improve network connectivity with a limited overlapping ratio.

# CHAPTER V

# AC-RDV APPROACH FOR RSU DEPLOYMENT IN VANET

## V.1 Introduction

In an urban or suburban area, RSUs can usually be deployed at intersections to provide the optimal connectivity performance [55]. In this model, all the intersections were considered as candidate placements. By this way, RSUs placement issue is defined as the process of finding the best combination of RSUs on candidate places according to given conditions to meet the requested requirements (e.g., best connectivity, coverage, low deployment cost). In this chapter, we have formulated the RSU deployment as a multi-objective optimization problem, with multiple objectives such as maximizing intersection priority and intersection coverage, and minimizing RSUs deployment cost. Moreover, we suggest a new bio-inspired RSU placement system called Ant Colony optimization system for RSU Deployment in VANET ($AC-RDV$) [7]. $AC-RDV$ is inspired by the collective behavior of real ant colonies to discover the optimal path between their nest and the food source. After a set of simulations and comparisons against traditional RSU placement strategies, the results obtained showed the effectiveness of the proposed $AC - RDV$ in terms of number of RSUs placed, the average area coverage, the average connectivity and the overlapping ratio.

## V.2 System model

As for the deployment problem in vehicular networks, [8, 38, 39] consider the road intersections as the best location to deploy RSUs. In urban road topology, many intersections exist; however, deploying a large number of RSUs is a costly solution. Therefore, the RSU deployment is formulated as a multi-objective optimization problem, which includes maximizing intersection priority (intersection coverage) on the one hand, and on the other hand, it minimizes RSU deployment cost. In this section, the problem description and some new definitions are discussed, to be used in the rest of this work.

### V.2.1 Problem description

The first objective of this work is to answer how RSUs can be deployed in urban VANET. Therefore, allocating the RSUs at intersections that have a higher impact on the efficiency of the vehicular networks is the best deployment strategy. The main benefit of this strategy is to deploy the RSUs at high priority intersections in order to maximize the coverage for vehicles within a monitored area.

**Definition V.1 (Urban Road Map)** *This can be represented as an undirected graph, $G = (I, E)$. $I = \{I_1, I_2, , I_n\}$ and $|I|$=n, denotes the intersections set that represents candidate sites for placing RSUs. $E = \{E_1, E_2, \ldots, E_m\}$ is segment roads set, and $e_{ij} \in E$*

*is the road segment connecting two intersections $I_i$ and $I_j$. Furthermore, $d_{ij}$ indicates the distance between two RSUs located at $I_i$ and $I_j$.*

In order to cover a maximum number of vehicles moving near an intersection, we associate the urban road map with a weight function:

$$\begin{aligned} P \;:\; I &\rightarrow \mathbb{R}^+ \\ I_i &\mapsto p_i \end{aligned}$$

Nonetheless $I_i \in I$ of graph $G$, the weight $p_i$ of each intersection represents the importance of each intersection. In other words, we use the concept of *"Intersection Priority"*.

**Definition V.2 (Intersection Priority [8])** *can be calculated according to M traffic parameters. The priority of the $i-th$ intersection is determined as follows:*

$$p_i = \sum_{j=1}^{M} w_j \times f_{ij} \tag{V.1}$$

*Where $f_{ij}$ is a normalized value obtained by the $j-th$ traffic factor for the $i_th$ intersection and $w_j$ is a weight for each traffic factor, where $1 \leqslant j \leqslant M$. Thus,*

$$\sum_{j=1}^{M} w_j = 1 \tag{V.2}$$

Network coverage is greater at dense intersections compared to intersection with light traffic [39]. Thus, to ensure a better coverage, we adopt the intersection density parameter that is represented by the approximate traffic volume at each intersection. Additionally, we opt to put the RSUs within the most popular intersections, close to popular places like touristic and commercial areas. To do this, we introduce the intersection popularity parameter that uses the number of buses lines near to each intersection. So, the intersection priority is computed using a weightage function (formulas V.1 and V.2) that includes both parameters, namely intersection density parameter and intersection popularity parameter, since these weights parameters $(w_j)$ are considered as user parameters selected by the user to express his preference on one parameter compared to the other. It is worth noting that in this study, we have adopted the same values cited in the reference [8] at the aim to allow a valid comparison of our approach against the traditional approaches. We also define that an intersection is covered by RSU if the intersection is located within the transmission range of the RSU (R).

Recall that our goal is to cover all the road segments of a graph $G = (I, E)$ with a minimum number of RSUs. According to the graph theory and combinatory optimization, this problem can be formulated as a classical optimization problem known as the "minimum vertex coverage problem" [56]. In order to place the RSUs at high priority intersections, we employed two sets indicated as $RSET$ and $CSET$. At the beginning, the $RSET$ subset defines a highly prioritized intersection list that allows determining the location of the first RSU. Thereafter, all intersections within the transmission range of this RSU are excluded from the candidate set of intersections for deployment. Notice that $RSET$ contains all intersections where RSUs are placed, on the other hand, $CSET$ includes all intersections covered by RSUs placed at $RSET$.

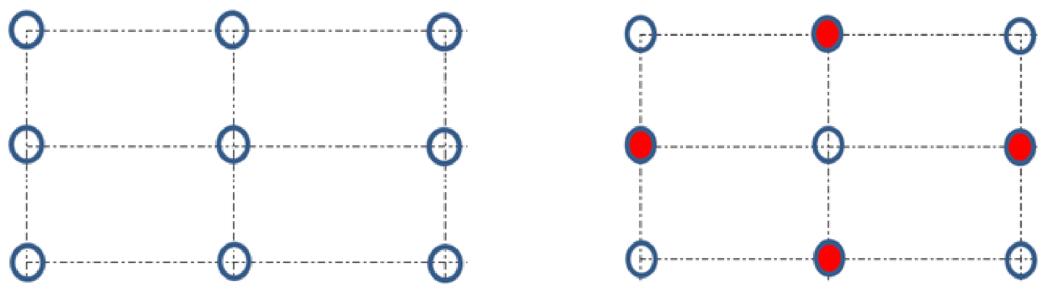
**Definition V.3 (Intersection-coverage [8])** *An intersection $I_j$ is covered by a RSU placed at an intersection $I_i$ if $I_j$ is located within the transmission range $R$ of this RSU.*

$$\text{So, } \forall\, I_i \in RSET, \forall\, I_j \in \{I \backslash RSET\}$$
$$(d_{ij} \leq R) \iff I_j \in CSET$$

*In this case, intersection $I_i$ covers the intersection $I_j$.*

As shown in Figure V.1, a RSU coverage of a road trace $G = (I, E)$ consists of finding a subset $RSET \subseteq I$ of all road intersections, where $|RSET| \leq K$ is the optimal subset of intersections that are selected for RSU deployment, satisfying the following conditions:

$$\begin{cases} RSET \cap CSET = \emptyset \\ \quad\quad and \\ RSET \cup CSET = I \end{cases}$$



(a) Input graph. (b) The intersection in red are the RSET set

Figure V.1: Example of the intersection coverage problem.

For each intersection $I_i$, we have a decision variable:

$$x_i = \begin{cases} 1, & \text{if a RSU is placed at the i-th intersection} \\ 0, & \text{otherwise} \end{cases}$$

In our model, the vehicles must be connected with neighboring RSUs, and so the goal is to deploy RSUs at high priority intersections aiming to maximize the coverage for vehicles within a monitored area.

According to this goal, a linear programming formulation for our problem can be provided as follows:

$$\text{Maximize} \quad \frac{\sum_{I_i \in I} p_i \times x_i}{\sum_{I_i \in I} x_i} \tag{V.3}$$

$$\text{Subject to:} \quad \sum_{I_i \in I} x_i \leq k \tag{V.4}$$

$$d_{ij} \geq 2.R \quad \forall (I_i, I_j) \in RSET \tag{V.5}$$

$$x_i \in \{0, 1\} \quad \forall I_i \in I \tag{V.6}$$

The objective function (V.3) favors more the intersections with high priority, while minimizing the number of these intersections. $p_i$ denotes the priority of the $i - th$ intersection. Constraint (V.4) ensures that the coverage of all the road segments by the RSUs does not exceed a maximum threshold $k$. In order to avoid overlapping coverage cases, the distance between two neighboring RSUs installed in adjacent intersections $I_i$ and $I_j$ will account for the transmission range of the RSUs. To achieve this, we introduce two sets denoted as RSET and CSET. RSET includes all intersections where RSUs are placed, while CSET contains all intersections covered by the RSUs included in RSET. This constraint is defined in (V.5). Constraint (V.6) defines the integrality constraints.

### V.2.2 Heuristic genetic algorithm

In this section, we propose an enhancement of GICA algorithm presented in the chapter IV called Heuristic Genetic Algorithm (HGA), it has a standard structure of genetic algorithm except the initial population. Random initialization technique leads to a very slow convergence to the optimal solution, to speed up the research process to the global optimum, a new initial population method has been suggested in this algorithm, named Greedy Heuristic Initialization (GHI), GHI represents an original population initialization that increases the quality of initial population. So, HGA algorithm replaces line 5 of the GICA algorithm cited in chapter IV by the algorithm 3:

**Algorithm 3** *GHI*

**Input** $p_i, i = \{1, \dots, n\}$
**Output** $P$ // Initial population
Sort $I$ with $p_i$ in a descending order of priority
$P \leftarrow 0$
**for** j:=0 to T **do**
    Select $I_i \in I$ where $i = rand(0 : n/4)$
    $P_{ji} \leftarrow 1$
    $I \leftarrow \{I \backslash S_i\}$ // $S_i$ the coverage of RSU located at $I_i$
    $i \leftarrow i + 1$
    **while** ( $I \neq \emptyset$ ) **do**
        Choose $I_i \in I$ where $p_i$ the highest is
        $P_{ji} \leftarrow 1$
        $I \leftarrow \{I \backslash S_i\}$
        $i \leftarrow i + 1$
    **end while**
**end for**
**return** $P$

## V.3 ACO for the RSU deployment problem

In this section, we present the proposed Ant Colony System (ACS), which is one of the ACO variants [57]. First, we will provide a brief introduction on the principles underlying the ACS algorithm, and then we will present the details of the AC-RDV to optimize RSU deployment.

### V.3.1 Ant colony system

In an Ant Colony System (ACS) a set of agents (called artificial ants) cooperate in finding good solutions to combinatorial optimization problems. This approach, proposed by Dorigo [57], is inspired by the collective behavior of ants that communicate with each other indirectly via a chemical substance known as the pheromone, allowing the ants to establish an optimal path between their nest and the food source. In the following we discuss the formulation of AC-RDV algorithm for RSUs deployment problem. It consists of the different stages: state transition rule, the global updating rule and the local updating rule. In the following, we will give details of these steps for the RSUs deployment problem.

### V.3.2 AC-RDV approach

Since the RSU deployment is a discrete optimization problem [58], the Ant Colony System (ACS) emerges as an efficient approach for solving this kind of problems [57]. Generally, the research process of ACS is composed of two loops that are interrelated. The first one is the research cycle of individual ants, which finishes when the ant happens to cover all the graph edges. The second one consists of combining the individual results of all the ants to make a global solution to the problem (see AC-RDV algorithm). At the beginning of algorithm, m ants are released and randomly choose their starting intersection; then, each of them starts to make a solution to the problem by filling on a list with one intersection at each step until it can cover all the graph edges (road segments). During the research process, an ant l chooses the following intersection by counting the combination of the pheromone trail values and the heuristic information. Then, it privileges the intersection characterized by a higher probabilistic value (see equation V.7). Every ant will have memory regarding the intersections it has already selected in order to guarantee the validity of the constructed list. Figure V.2 represents the ant decision depending on both the pheromone trail $\tau_j$ and the heuristic information $\eta_j$ gathered, where $j \in \{C, D, E\}$. The decision to pick an intersection $j$ when the ant is at intersection $i$ for time step $(t)$ is obtained as follows:

$$a_{ij}(t) = \frac{\tau_j.(\eta_j)^{\alpha}}{\sum\limits_{k \in A^l} \tau_k.(\eta_{kt})^{\alpha}} \tag{V.7}$$

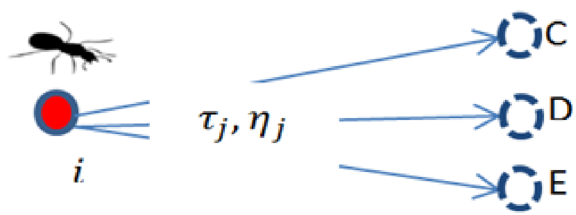



Figure V.2: Ant decision depending on $\tau_j$ and $\eta_j$.

In ACS, a new state transition rule called pseudo-random-proportional is introduced [59]. Depending on the pheromone trail and the heuristic information, the ant $l$ located at an intersection $I_i$ chooses the intersection $I_j$ as its next intersection to be visited according to two parameters: $q_0$ and $q$. Let $q_0 \in [0, 1]$, which is the parameter specifying the compromise between exploitation of the recent solution and exploration of other unvisited or relatively unexplored search space regions, and $q$ is a random variable uniformly distributed over $[0, 1]$.The pseudo-random-proportional transition rule is given as follows:

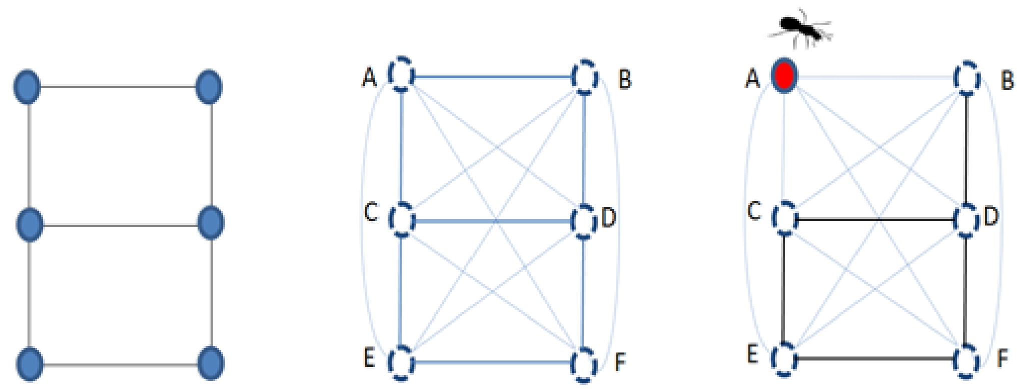
$$P_{ij}^{l}(t) = \begin{cases} 1, & if\ q > q_0\ and\ j = Argmax(a_{ij})\ \forall j \in A^i \\ 0, & if\ q > q_0\ and\ j \neq Argmax(a_{ij})\ \forall j \in A^i \\ a_{ij}(t) = \frac{\tau_j.(\eta_j)^{\alpha}}{\sum\limits_{k \in A^l} \tau_k.(\eta_{kt})^{\alpha}} & if\ q \leq q_0 \end{cases} \tag{V.8}$$

Concerning the performance of AC-RDV algorithm, the heuristic information $\eta_j$ plays an important role; it takes the objective function into consideration in the process of finding a solution. However, there can be two ways to define heuristic information: static or dynamic [60]. Here, we devise a dynamic heuristic to reflect the reality that the number of road segments that are not yet covered will change whenever an RSU is deployed.

***Dynamic heuristics and graph updating***

The heuristic function is the ratio between the temporary degrees of an intersection and intersection priority. The temporary degree of an intersection $I_j$ is defined as the number of road segments covered by intersection $I_j$, but not covered by any intersection $I_i \in RSET_{k-1}$, where $RSET_{k-1}$ is the partial solution in step $k-1$ (before adding intersection $I_j$ to the solution). In other words, an intersection $I_i$ is covered by a RSU placed at intersection $I_j$ if the distance between $I_i$ and $I_j$ is less than or equal to $2R$. Let $S_j$ be the coverage of RSU located at $I_i$ (intersection-coverage of $I_i$), that includes all intersections within the transmission range of this RSU. To model the coverage of an intersection i with another $I_j$, it is natural to use a strongly connected graph $G_c = (I, E_c)$ derived from graph $G$. So, the temporary degree is given by the decision variable $\gamma_k(i,j)$. When an intersection $I_i$ is covered by an intersection $I_i \in RSET_{k-1}$, $\gamma_k(i,j) = 1$ ; otherwise, $\gamma_k(i,j) = 0$. Where $(i,j)$ is the link between the two intersections $I_i$ and $I_j$ . This $G_c$

graph must be updated once a new intersection $I_j$ is introduced to RSET, i.e. all intersections belong $S_i$ are excluded from the deployment candidate set of intersections; therefore, the temporary degree changes. The graph updating is shown in Figure V.3.




(a) Original graph G. (b) Derived graph $G_c$ (c) Update graph $G_c$

Figure V.3: The coverage updating graph.

So, the heuristic function will be dynamically evaluated and calculated as follows:

$$\eta_{jk} = \frac{\sum_{(i,j)\in E_c} \gamma_k(i,j)}{p_j} \tag{V.9}$$

Where $k$ is the number of added interactions, $\sum_{(i,j)\in E_c} \gamma_k(i,j)$ is the temporary degree of intersection$I_j$, and $p_j$ is the priority associated to intersection $I_j$. The selection of those intersections $RSET \subseteq I$ denotes the optimal location for the RSU deployment and the road segments that should be covered.

### *Pheromone updating*

In the AC-RDV algorithm, pheromone updating consists of two rules: local update and global update. The local pheromone update is defined when an ant l

**Algorithm 4** $AC - RDV$

**Input** $G = (I, E), D, p_i, i = \{1, \ldots, n\}$

**Output** Neighborhood map of RSUs based on intersection priority $p_i$

Initialize parameters $\rho, \tau_{ij}, \tau_0, \varphi$

Initialize the ants number $l$ ;

Best solution: $RSET = \emptyset$

**while** (ending condition is not met) **do**

    Construct a complete graph $G_c = (I, E_c)$

    **for** (all ant from : 1 to l) **do**

        Get the initial graph $G$

        **repeat**

            Compute $\eta_j$ based on (9)

            For each ant choose the next intersection using (8)

            Apply the local pheromone update rule based on (10)

            Update graph $G_c = (I, E_c)$

        **until** (no intersection visited)

    **end for**

    Apply the global pheromone update rule according to (11)

    **return** the solution of each ant (RSET and CSET)

    Calculate the overlap area of each ant

**end while**

**return** best solution $RSET^{(best)}$

at an intersection $i$ chooses a new intersection $I_j$ to its partial solution $S^l$. Ant $l$ updates the amount of pheromone $\tau_i$ according to the following formula:

$$\tau_i = (1-\varphi).\tau_i + \varphi.\tau_0 \tag{V.10}$$

Where $0 \leq \varphi \leq 1$ is a parameter used to specify the strength of the local update rule. Once all the ants have made their solutions, the pheromone traces are updated as follows:

$$\tau_i(t+1) = (1-\rho).\tau_i(t) + \rho.\Delta\tau_i \tag{V.11}$$

Where, $\rho \in [0,1]$ is the coefficient that will define the rate of evaporation of the pheromone on the intersection between iterations $t$ and $(t+1)$ . Regarding $\Delta\tau_i$, it provides the quality of the best subset $I_i$ which contains intersection $I^{'}$:

$$\Delta\tau_i = \begin{cases} \frac{1}{\sum\limits_{j\in I^{'}} p_j} & if\ i \in I^{'} \\ 0, & otherwise \end{cases} \tag{V.12}$$

The stop criterion of our algorithm is the reaching of the maximum number of iterations.

### V.3.3 Computational complexity analysis

Usually, the computational complexity of any algorithm is measured in worst-case complexity; it is denoted in asymptotic notation that is indicated the longest running time performed by an algorithm given any input of size $n$.

Computing the computational complexity of any algorithm involves the estimation of the number of elementary steps performed to finish execution. According to this proposal, from step 9 to 13, denote the solution cycle, the ants make (in worst case) $\boldsymbol{n}$ visits to build solution. For the $l$ ants, the computational complexity is estimated as $\boldsymbol{O(l.n^2)}$. Since, it is a complete graph, the complexity in step 5 is given by, where $n$ is the graph order (the number of vertices).

From step 15 to 17 the complexity is $O(2n + l)$. Finally, the computational complexity of one iteration of the proposed AC-RDV algorithm. Therefore, it becomes: $O((l+1).n^2 + 2.n + l)$. As $l < n$, we have:

$$O((l+1).n^2 + 2.n + l) \simeq O(n^3)^1.$$

For a maximum number $NC_{max}$ of iterations, the general complexity of the algorithm is: $NC_{max}.n^3$, where $NC_{max}$ is a constant belonging to N. On the basis of this complexity function, our algorithm can give better near-optimal solutions in polynomial time.

## V.4 Performance evaluation

In this section, we evaluate the performance of the proposed optimization strategy and present the results obtained. We analyze how our algorithm works differently according to the different characteristic of road networks and finds the optimal number and locations of the RSUs deployed in such areas. For this purpose, we developed a simulator using C++ programming language and conducted a series of experiments. Therefore, we use three random topologies classes including 67 intersections, 72 intersections and 224 intersections. However, each topology makes a variation of the number of road segments to build three different instance classes of network topologies. The network topologies have been generated randomly including the positions of intersections. In order to measure the priority of each intersection, two traffic factors are taken into account: regarding (1) the density of vehicles and (2) the intersection popularity. Table V.1 details the three

[1]The Big-O Asymptotic Notation gives us the upper bound idea, mathematically described below: $f(n) = O(g(n))$ if $\exists\ n_0 \in \mathbb{N}^*$ and $c > 0$, such that $f(n) \leq c.g(n)\ \forall n \geq n_0$ .

network topologies used during the evaluation process in terms of number of roads and intersections parameters.

Table V.1: Test Dataset based on random street topologies.

| Topologies | | | Density | | Popularity | | Distance | |
|---|---|---|---|---|---|---|---|---|
| | *n* | *m* | *max* | *min* | *max* | *min* | *max* | *min* |
| Map1 | | 50 | 342 | 1393 | 0 | 6 | 410 | 996 |
| Map2 | 67 | 100 | 399 | 1388 | 0 | 9 | 433 | 939 |
| Map3 | | 250 | 360 | 1391 | 0 | 12 | 411 | 995 |
| Map4 | | 500 | 380 | 1301 | 0 | 18 | 422 | 944 |
| Map5 | | 350 | 560 | 1363 | 3 | 8 | 320 | 617 |
| Map6 | 72 | 500 | 580 | 2388 | 3 | 11 | 346 | 577 |
| Map7 | | 600 | 610 | 2691 | 3 | 19 | 328 | 616 |
| Map8 | | 800 | 900 | 3600 | 3 | 35 | 337 | 580 |
| Map9 | | 600 | 1500 | 3393 | 5 | 18 | 360 | 697 |
| Map10 | 224 | 750 | 1800 | 4000 | 5 | 24 | 389 | 657 |
| Map11 | | 900 | 1200 | 5000 | 5 | 30 | 369 | 696 |
| Map12 | | 100 | 1500 | 7000 | 5 | 42 | 379 | 660 |

The vehicles density refers to the volume of traffic at each intersection, while the intersection popularity describes the geographical interest of the intersection. Hence, the popularity of an intersection is measured by the different bus lines passing through it; a popular intersection is an intersection crossed by an number of bus lines. These parameters are obtained randomly with respect to a uniform distribution, either from the interval based on the traffic data provided in [8].

### V.4.1 Baseline and evaluation metrics

For evaluating the effectiveness of our algorithm, we use four performance metrics: the number of RSUs, the average area coverage $(Cov)$ by the RSUs, the average connectivity $(c_n)$ and the overlapping ratio $(\delta)$. The average area coverage by the RSUs indicates the ratio of road segments coverage in the network. The average connectivity $(c_n)$ refers to the ratio of the intersections $I_i \in CEST$ and the total number of intersections. The average connectivity is denoted as:

$$c_n = \frac{1}{n} \sum_{i=1}^{n} \frac{|S_i|}{n} \tag{V.13}$$

Where $S_i$ denotes the intersections set belonging to transmission range of the RSU installed at $i - the$ intersection. The overlapping area of the $i - th$ RSU is denoted as:

$$\delta_i = \sum_{I_j \in RSET} (2.R - d_{ij}) \tag{V.14}$$

Where $d_{ij} \leq 2.R$ . The overlapping ratio is denoted as:

$$\delta = \frac{1}{n} \sum_{i=1}^{|RSET|} \sum_{j=i+1}^{|RSET|} \frac{(2.R - d_{ij})}{R} \tag{V.15}$$

Considering that the two parameters have different units of measurement, to remove this effect, we use minimum–maximum normalization [61] to transform data of different units into a value with a range from 0 to 1, in accordance with the flowing equation:

$$f'_{ij} = \frac{f_{ij} - min(F_j)}{Max(F_j) - min(F_j)} \tag{V.16}$$

Let $f_{ij}$ is the original value obtained by the $j-th$ parameter at the $i-th$ intersection, then $F_j$ is a set of $f_{ij}$ for $i = \{1, 2, \ldots, M\}$ that contains all values obtained by the $j-th$ parameter at all intersections. Finally, $f^{'}_{ij}$ is the normalization value of the $j-th$ parameter. So, after filling-in both traffic parameters, the weight of each traffic parameters is distributed on the interval $[0, 1]$. Once this is done, the intersection priority in each location is determined. In order to show how the proposed algorithm works under different urban scenarios and to find the optimal number of RSUs in such areas, we compare the results obtained by our algorithm against three approaches. The first one is the greedy approach proposed by Chi et al. [8]. The second approach is a genetic intersection coverage algorithm (GICA) developed in our previous work [6]. The third one is a Heuristic Genetic Algorithm (HGA) proposed in section V.2.2.

In each test, we have used an Ant colony consisting of 10 ants. The exploration rate was $q_0 = 0.1$, and the evaporation rates were $\varphi = 0.1$ and $\rho = 0.1$. For the influence factor of the heuristic, we used $\alpha = 5$ . The initial value of the pheromone trail is $\tau = 0.6$. Overall, 100 iterations were performed for each of the test sets associated to each road topology. For all topologies, we run the (GICA) and (HGA) algorithms with the following parameters:

$T = 100, p_{Cros} = 0.9, p_{Mut} = 0.01, \varrho = 80\%, \psi = 20\%, t = 100$ iterations

We also analyzed the effect that different RSU transmission ranges and weights of the two traffic factors have on the network performance. In order to evaluate the effect of each traffic factor, we have distributed the weights of the two traffic factors contain: vehicle density $w_1$ and location popularity $w_2$ in an interval $[0, 1]$. Table V.2 illustrates the parameter settings of our experiments.

Table V.2: Parameter settings and values.

| Topologies | Values |
|---|---|
| RSU Transmission Range $(R)$ | $\{250m, 350m, 450m, 550m\}$ |
| Weights of factors $(w_1, w_2)$ | $(1,0)/(0.7,0.3)/(0.5,0.5)/(0.3,0.7)/(0,1)$ |

## V.4.2 Experimental results

Now, we present a set of experiments comparing the performance of the greedy algorithm proposed [8], GICA [6] and HGA algorithms against our proposed AC-RDV algorithm, considering the three classes of urban topologies defined earlier. Our goal is to quantify the impact of the transmission range, RSU deployment budget and traffic weight parameter through the coverage area $Cov$, average connectivity $c_n$, and overlapping area $\delta$ matrices. Therefore, we keep the total cost of RSU deployment under a predefined budget (number) and vary this budget in intervals $[10\%, k]$.

***Impact of the RSU transmission range***

First, we have evaluated the total number of RSUs located, coverage area $Cov$, average connectivity $c_n$, and overlapping area $\delta$ for all topologies under test according to the RSU transmission range. The overlapping area is required to analyze the redundant duplicated traffic messages generated by the neighboring RSUs. For all instances, we have used the traffic parameters weight as $(w_1, w_2) = (0.7, 0.3)$.

In the proposed system, the best possible solution is mentioned as $RSET^{Best}$ (see line 19 of algorithm 3), $RSET^{Best}$ describes the good ant in the colony (i.e. the best RSU deployment in VANET), which is represented by the best vector of RSUs places found according to both intersection coverage and intersection priority. For all numerical results depicted in Tables V.3 to V.6, the best found solution for the proposed system is denoted in bold font as: $(Best)$. Each data point is the average of 10 runs, while the error bars represent a 89% confidence interval.

In Table V.3, for a transmission area range equals to 250 m, we observe that AC-RDV is still better than the other algorithms in both the RSUs number and solution quality $(Cov, c_n, \delta)$. We observe that the HGA gives better results compared to GICA, that means the heuristic initialization strategy (HGA) performs better than the random initialization strategy (GICA), this is because HGA starts with a population containing good solutions generated by a greedy approach.

Table V.3: The numerical results for transmission range R=250 m .

| Map | RSUs number | | | | Average Coverage (%) | | | | Average connectivity (%) | | | | Overlap Rate (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV |
| 1 | 51 | 43 | 39 | **39** | 43.4 | 48.90 | 51.64 | **52.55** | 35.94 | 41.65 | 50.45 | **51.65** | 4.73 | 4.54 | 0.7 | **0.4** |
| 2 | 57 | 47 | 43 | **41** | 46.7 | 53.89 | 57.97 | **58.99** | 33.48 | 40.08 | 44.18 | **47.33** | 5.2 | 4.33 | 2.3 | **1.2** |
| 3 | 61 | 49 | 48 | **45** | 51.6 | 56.99 | 60.96 | **62.03** | 37.41 | 45.20 | 47.38 | **50.71** | 6.34 | 6.22 | 3.2 | **2.62** |
| 4 | 63 | 57 | 54 | **49** | 54.0 | 62.45 | 68.27 | **68.47** | 39.24 | 46.63 | 48.47 | **53.20** | 5.42 | 5.2 | 4.01 | **3.66** |
| 5 | 56 | 50 | 47 | **42** | 46.86 | 55.92 | 59.28 | **62.81** | 33.27 | 39.31 | 43.24 | **48.00** | 9.00 | 7.38 | 4.89 | **2.05** |
| 6 | 59 | 52 | 50 | **46** | 44.45 | 53.02 | 56.40 | **59.68** | 35.33 | 40.81 | 45.58 | **49.92** | 11.4 | 6.26 | 3.87 | **1.96** |
| 7 | 62 | 55 | 52 | **47** | 50.26 | 59.50 | 63.23 | **66.47** | 36.30 | 43.68 | 47.77 | **51.34** | 9.00 | 7.51 | 5.01 | **3.52** |
| 8 | 66 | 58 | 55 | **50** | 54.55 | 63.63 | 67.11 | **72.04** | 38.68 | 46.02 | 50.20 | **55.76** | 10.21 | 8.75 | 7.81 | **3.11** |
| 9 | 143 | 121 | 107 | **98** | 50.54 | 58.07 | 62.74 | **65.16** | 34.04 | 39.47 | 44.19 | **49.34** | 12.16 | 9.29 | 7.91 | **4.07** |
| 10 | 157 | 129 | 119 | **104** | 53.69 | 60.74 | 65.14 | **67.28** | 36.26 | 41.37 | 45.37 | **50.49** | 9.30 | 11.3 | 6.53 | **4.48** |
| 11 | 171 | 143 | 136 | **111** | 56.30 | 64.23 | 66.85 | **69.77** | 35.11 | 41.94 | 46.76 | **51.24** | 12.97 | 11 | 9.18 | **6.03** |
| 12 | 207 | 156 | 148 | **131** | 61.07 | 65.90 | 69.85 | **72.73** | 39.29 | 46.95 | 52.76 | **57.20** | 13.89 | 9.16 | 8.04 | **7.31** |

When the RSUs' transmission range is 350 m (see table V.4), the difference between AC-RDV based coverage and HGA coverage becomes very small in first topology class. We can observe that HGA achieves a higher coverage than GA, and it is slightly upper that the coverage obtained by the GA algorithm. This can be explained by the characteristics of this traffic, which has less dense.

Table V.4: The numerical results for transmission range R=350 m .

| Map | RSUs number | | | | Average Coverage (%) | | | | Average connectivity (%) | | | | Overlap Rate (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV |
| 1 | 42 | 35 | 33 | **27** | 45.60 | 51.35 | 54.22 | **55.18** | 48.69 | 53.60 | 56.46 | **62.11** | 8.72 | 6.80 | 5.98 | **3.59** |
| 2 | 51 | 40 | 36 | **31** | 49.11 | 56.58 | 60.87 | **61.94** | 45.35 | 46.24 | 50.36 | **55.40** | 8.39 | 6.54 | 5.76 | **3.46** |
| 3 | 55 | 43 | 40 | **35** | 54.19 | 59.84 | 64.01 | **65.13** | 50.67 | 56.27 | 59.60 | **65.56** | 11.41 | 8.90 | 7.83 | **4.70** |
| 4 | 57 | 48 | 46 | **38** | 56.77 | 65.57 | 71.68 | **71.89** | 53.16 | 60.14 | 63.15 | **69.47** | 9.79 | 7.64 | 6.72 | **4.03** |
| 5 | 50 | 4 | 40 | **23** | 49.20 | 58.72 | 62.24 | **65.95** | 45.07 | 51.54 | 55.69 | **61.26** | 12.94 | 10.09 | 8.88 | **4.95** |
| 6 | 53 | 47 | 43 | **35** | 46.67 | 55.67 | 59.22 | **62.66** | 47.86 | 50.50 | 55.55 | **61.11** | 15.25 | 11.90 | 10.47 | **5.83** |
| 7 | 56 | 46 | 44 | **36** | 52.77 | 62.48 | 66.39 | **69.79** | 49.18 | 57.26 | 62.99 | **69.29** | 12.21 | 9.52 | 8.38 | **4.67** |
| 8 | 60 | 51 | 47 | **39** | 57.28 | 66.81 | 70.47 | **75.64** | 52.39 | 58.33 | 63.16 | **69.48** | 16.60 | 12.95 | 11.40 | **6.35** |
| 9 | 129 | 107 | 100 | **77** | 53.07 | 60.97 | 65.88 | **68.42** | 46.12 | 51.76 | 56.94 | **62.63** | 19.25 | 15.02 | 13.22 | **6.93** |
| 10 | 141 | 115 | 102 | **80** | 56.37 | 63.78 | 68.40 | **70.64** | 49.12 | 53.24 | 58.56 | **64.42** | 18.09 | 14.11 | 12.42 | **7.46** |
| 11 | 154 | 128 | 117 | **87** | 59.12 | 67.44 | 70.19 | **73.26** | 47.56 | 51.99 | 57.19 | **62.91** | 21.97 | 17.14 | 15.08 | **9.05** |
| 12 | 186 | 140 | 125 | **102** | 64.12 | 69.20 | 73.34 | **76.37** | 53.21 | 57.68 | 62.45 | **68.70** | 19.04 | 14.85 | 13.07 | **7.85** |

If we increase the extended range of RSU as R= 450 m (see table V.5), our algorithm covers far more area and makes good network connectivity for a given number of RSUs compared to other approaches. It is obvious that increasing the wireless transmission range will have a significant impact on the average connectivity.

Table V.5: The numerical results for transmission range R=450 m .

| Map | RSUs number | | | | Average Coverage (%) | | | | Average connectivity (%) | | | | Overlap Rate (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV |
| 1 | 38 | 31 | 29 | **24** | 47.96 | 56.72 | 58.06 | **69.68** | 53.91 | 60.28 | 67.62 | **73.34** | 11.34 | 8.16 | 7.34 | **5.51** |
| 2 | 46 | 36 | 32 | **28** | 53.85 | 62.52 | 65.18 | **65.09** | 50.22 | 56.56 | 64.31 | **67.19** | 10.91 | 7.85 | 7.07 | **5.30** |
| 3 | 49 | 39 | 36 | **31** | 56.62 | 66.10 | 68.54 | **68.45** | 56.12 | 65.43 | 68.98 | **72.00** | 14.83 | 10.68 | 9.61 | **7.21** |
| 4 | 51 | 43 | 41 | **34** | 63.42 | 72.44 | 76.76 | **75.55** | 58.87 | 67.50 | 70.56 | **75.53** | 12.73 | 9.17 | 8.25 | **6.19** |
| 5 | 45 | 38 | 36 | **29** | 55.06 | 64.87 | 66.65 | **69.31** | 49.92 | 56.90 | 62.94 | **68.15** | 16.82 | 12.11 | 10.90 | **8.18** |
| 6 | 48 | 42 | 39 | **31** | 52.38 | 61.50 | 63.42 | **65.86** | 53.01 | 59.07 | 66.36 | **70.87** | 19.83 | 14.28 | 12.85 | **9.64** |
| 7 | 50 | 41 | 40 | **32** | 58.73 | 69.02 | 71.09 | **73.34** | 54.46 | 63.22 | 69.54 | **72.89** | 15.87 | 11.42 | 13.28 | **9.96** |
| 8 | 54 | 46 | 42 | **35** | 62.34 | 73.81 | 75.46 | **79.49** | 58.03 | 66.61 | 73.08 | **79.17** | 21.58 | 15.54 | 13.99 | **10.49** |
| 9 | 116 | 96 | 90 | **69** | 58.28 | 67.36 | 70.55 | **71.90** | 51.07 | 57.13 | 64.33 | **70.05** | 25.03 | 18.02 | 16.22 | **12.17** |
| 10 | 127 | 103 | 91 | **72** | 60.50 | 70.46 | 73.24 | **74.24** | 54.40 | 59.87 | 66.04 | **71.68** | 23.52 | 16.93 | 15.24 | **11.43** |
| 11 | 138 | 115 | 105 | **78** | 62.10 | 74.51 | 75.16 | **76.99** | 52.67 | 60.71 | 68.07 | **72.75** | 26.56 | 18.57 | 16.71 | **12.53** |
| 12 | 167 | 126 | 112 | **92** | 64.88 | 76.44 | 78.54 | **80.26** | 58.94 | 67.96 | 76.80 | **81.21** | 24.75 | 17.82 | 16.04 | **12.03** |

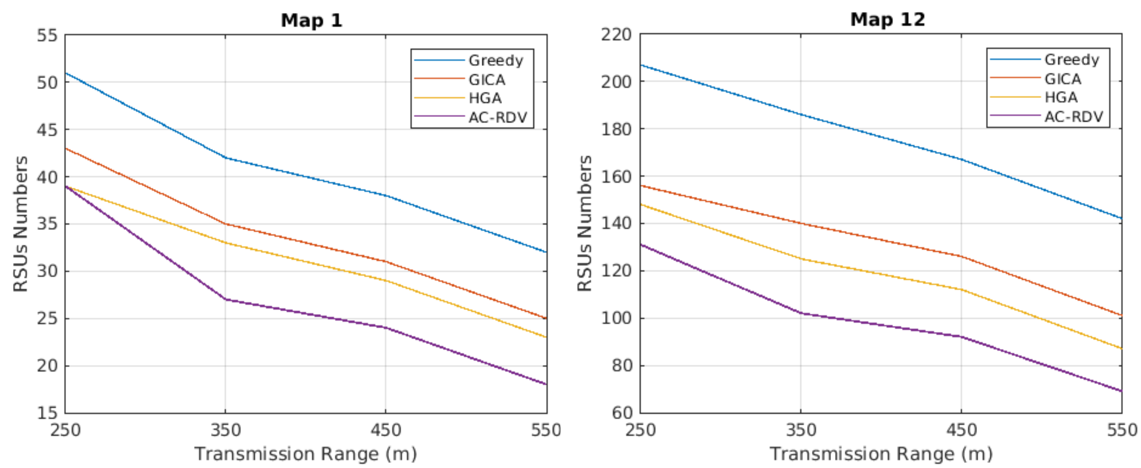
If we extend range the RSU as R= 550 m (see table V.6), our algorithm covers much more area and makes good network connectivity for a given number of RSUs compared to other approaches.

Table V.6: The numerical results for transmission range R=550 m .

| Map | RSUs number | | | | Average Coverage (%) | | | | Average connectivity (%) | | | | Overlap Rate (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV | GA | GICA | HGA | AC-RDV |
| 1 | 32 | 25 | 23 | **18** | 51.80 | 62.96 | 65.03 | **80.13** | 62.54 | 75.35 | 83.17 | **88.74** | 21.48 | 17.18 | 13.40 | **11.39** |
| 2 | 39 | 29 | 25 | **21** | 58.16 | 69.40 | 73.00 | **74.85** | 58.26 | 70.70 | 79.10 | **81.30** | 19.47 | 15.58 | 12.15 | **10.33** |
| 3 | 42 | 31 | 28 | **23** | 61.15 | 73.37 | 76.76 | **78.72** | 65.10 | 81.79 | 84.85 | **87.12** | 20.7 | 16.61 | 12.96 | **11.02** |
| 4 | 43 | 34 | 32 | **26** | 68.49 | 80.41 | 85.97 | **86.88** | 68.29 | 84.38 | 86.79 | **91.39** | 17.82 | 14.26 | 11.12 | **9.45** |
| 5 | 38 | 30 | 28 | **22** | 59.46 | 72.01 | 74.65 | **79.71** | 57.91 | 71.13 | 77.42 | **82.46** | 23.55 | 18.84 | 14.70 | **12.50** |
| 6 | 41 | 34 | 30 | **23** | 56.57 | 68.27 | 71.03 | **75.74** | 61.49 | 73.84 | 81.62 | **85.75** | 27.76 | 22.21 | 17.32 | **14.72** |
| 7 | 42 | 33 | 31 | **24** | 63.43 | 76.61 | 79.62 | **84.34** | 63.17 | 79.03 | 85.53 | **88.20** | 22.22 | 17.78 | 13.87 | **11.79** |
| 8 | 46 | 37 | 33 | **26** | 67.33 | 81.93 | 84.52 | **91.41** | 67.31 | 83.26 | 89.89 | **93.80** | 24.61 | 19.69 | 15.36 | **13.06** |
| 9 | 99 | 77 | 70 | **52** | 62.94 | 74.77 | 79.02 | **82.69** | 59.24 | 71.41 | 79.13 | **84.76** | 35.04 | 28.03 | 21.86 | **18.58** |
| 10 | 108 | 82 | 71 | **54** | 65.34 | 78.21 | 82.03 | **85.38** | 63.10 | 74.84 | 81.23 | **86.73** | 32.93 | 26.34 | 20.55 | **17.47** |
| 11 | 117 | 92 | 82 | **59** | 67.07 | 82.71 | 84.18 | **88.54** | 61.10 | 75.89 | 83.73 | **88.03** | 37.18 | 29.74 | 23.20 | **19.72** |
| 12 | 142 | 101 | 87 | **69** | 70.07 | 84.85 | 87.96 | **92.30** | 68.37 | 84.95 | 87.46 | **95.26** | 34.65 | 27.72 | 21.62 | **18.38** |

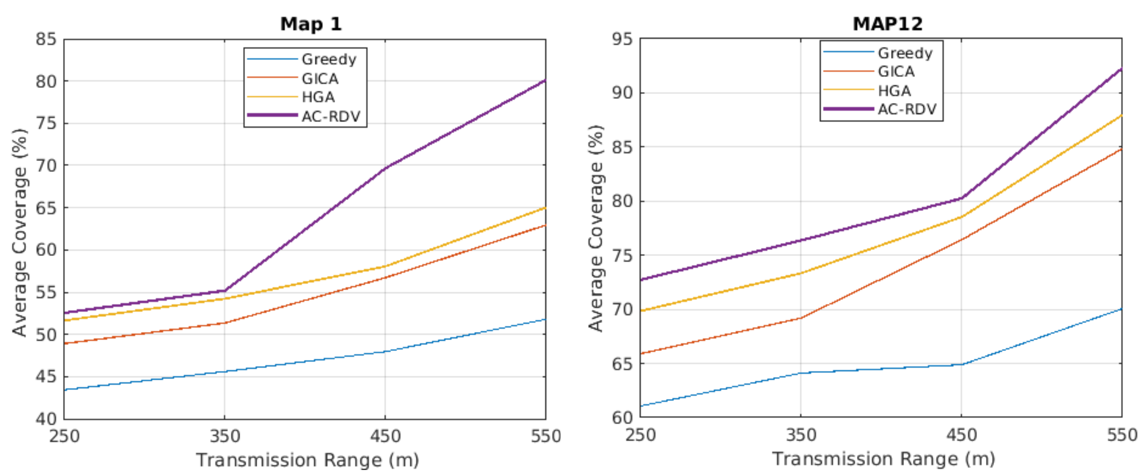
From the all results, we find that the average connectivity increases with the growth of vehicles density. Reducing the transmission range leads to keep only the vehicles behind the interaction connected in one big network partition that contains the majority of vehicles. This clearly shows that our algorithm requires less number of RSUs for a given area, which makes the solution more economically reliable compared to the other approaches.

As it can be seen in Figure V.4, increasing the RSU transmission range decreases the deployment cost. For the Map 1 where the number of RSUs $n = 67$ and the number of road segments $m = 50$, for $R = 250$ m to 550 m, the number of RSUs decreases into 31.34% in AC-RDV. While, the map 12 contains 222 intersections and 1000 road segments, the number of RSUs decreases to 27.93% in AC-RDV.




(a) Map 1. (b) Map 12

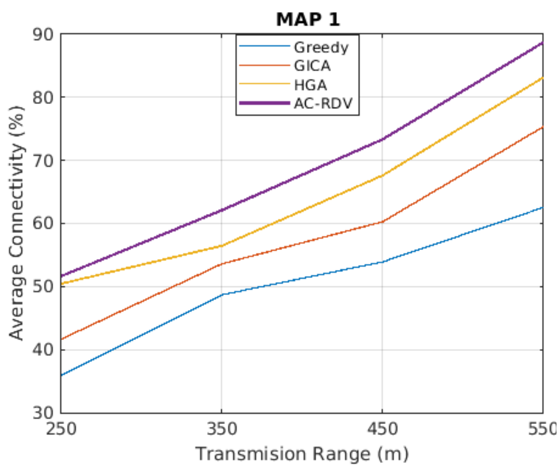
Figure V.4: Number of RSUs required depending on the transmission range.



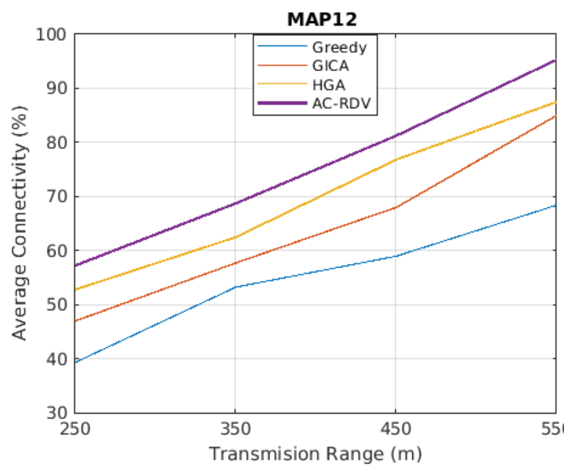

(a) Map 1. (b) Map 12

Figure V.5: Average Coverage according to the RSU transmission range variation.

As shown in Figure V. 5, AC-RDV provides a good coverage average as the transmission range grows from 250 m to 550 m. In the map 1 the average area coverage increases to 27.58%, while the average area coverage in map 12 increases to 19.67 %. This is due to the distance between deployed RSUs, which is shorter than transmission area, which allows disseminating the message to RSUs. As for the 250 m transmission range, AC-RDV based coverage also performs better than GA algorithm and GICA. Moreover, AC-RDV and HGA give the similar results for the map 1. As for the 250 m transmission range, AC-RDV based coverage also performs better than GA algorithm and GICA. Moreover, AC-RDV and HGA give similar results as in map 1. This can suggest that, the effectiveness of our algorithm appeared especially in the large-scale deployment. We have also investigated the impact of the transmission range on the connected intersections; we utilized the average connectivity as a metric.




(a) Map 1.




(b) Map 12

Figure V.6: Average connectivity according to the RSU transmission range.

In Figure V.6, AC-RDV remarkable the average connectivity is achieved though the transmission area is larger. Therefore, high transmission range is still needed to keep the network connected.

Similarly, Figure V.7 shows that the overlapping ratio ($\delta$) of each region, when using the AC-RDV algorithm, is quite lower than all other approaches. In this figures, we display the relationship between overlapping ratio ($\delta$) and RSU transmission range of RSU $(R)$. For $450 \leq R \leq 550$ m, we observe an increase of the overlapping ratio for the two neighboring intersections (see Figure V.7), showing a proportionality relation between $R$ and $(\delta)$.

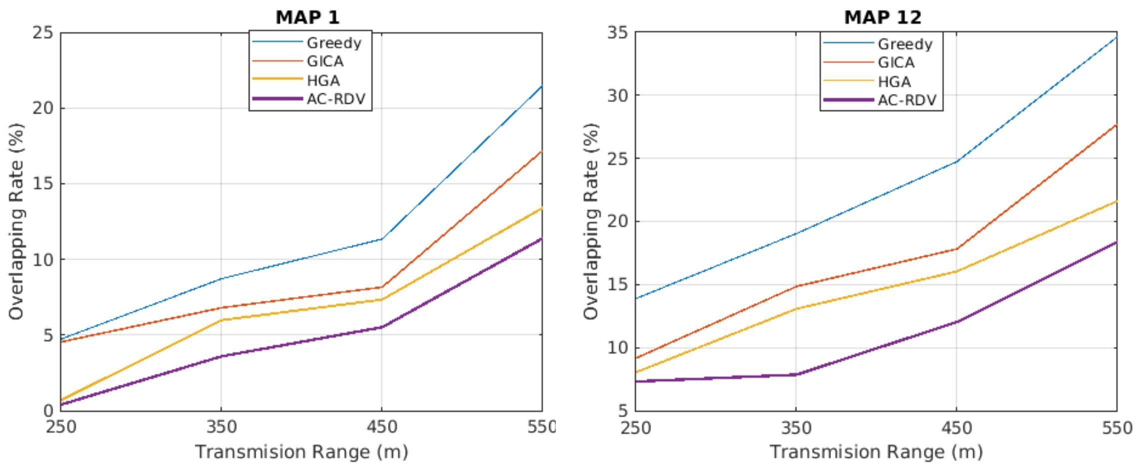



Figure V.7: Overlapping rate when varying the RSU transmission range.

Since the length of the road segments connecting two intersections $I_i$ and $I_j$ in all our topologies is in the range $401 \leq d_{ij} \leq 996$ m, the distance from the intersection i to intersection j is $d_{i,j} = 2.R$, and $450 \leq R \leq 550$ m, which explains the increase of the overlapping ratio for the two neighboring intersections (see Figure V.7). This situation explains that the transmission range of the RSU is proportional to overlapping ratio when $450 \leq R \leq 550$ m.

### *Impact of the RSUs number*

In order to know how well these RSUs are able to cover the network area, we fixed the deployment budget under to predefined number $(K)$ of RSU. This $k$ value can be measured as 30% of the number of intersections. In the considered topologies, thereafter, we test the variations in terms of coverage area, average connectivity, and the duplicate message transmission in each scenario. Indeed, we vary this number as the set 10%, 15%, 25%, 30%. Figures V.8, V.9, V.10 summarizes the results for the Map 10 using $R = 450$ m. Figure V.8, as shwed, as the number of RSUs increases, so does the percentage of covered areas.

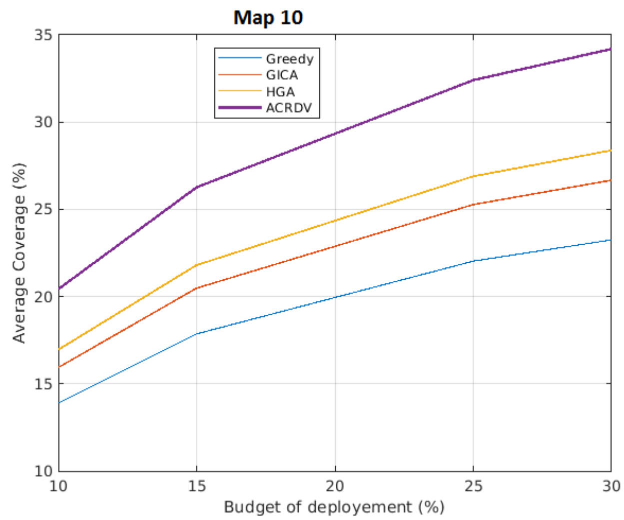



Figure V.8: Average Coverage rate when varying the RSU number.

Compared to the other approaches, AC-RDV improves the coverage area of RSUs under to less number of RSUs, which makes the solution more economically reliable. As for budget of deployment equals to 30 %, AC-RDV outperforms GA, GICA and HGA in terms of the average coverage by up to 34.9 %, 24.3 %, and 15.7%, respectively. It is obvious that increasing the deployment budget will have a significant impact on the average connectivity. From figure V.8, it can be seen that the more the number of RSUs increases, although coverage covers larger area of a road, which leads to large number of connected vehicles. We select a value k= 30 % since the connectivity has been more affected by this number of RSUs. As can be seen in figure V. 9, the average connectivity provided by AC-RDV Algorithm for k=30 % is more than a double of that insured by GA.

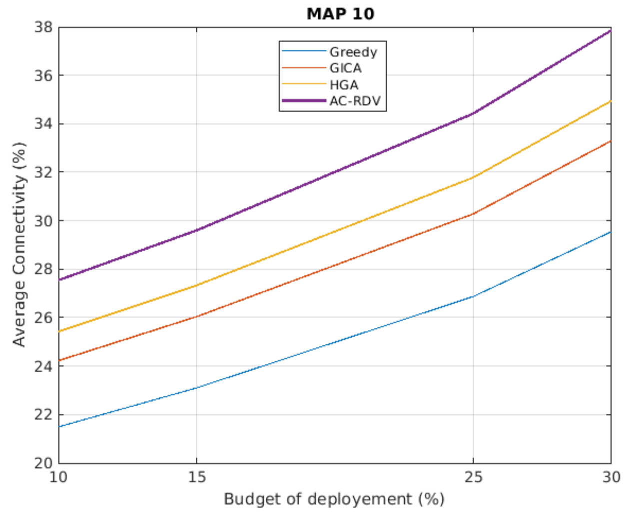



Figure V.9: Average Connectivity according to the RSU number variation.

Also, AC-RDV outperforms GICA, HGA by up to 22.9 % and 15.57 %, respectively. We select a value k= 30 % RSUs since the message coverage has been more affected by this number of RSUs.

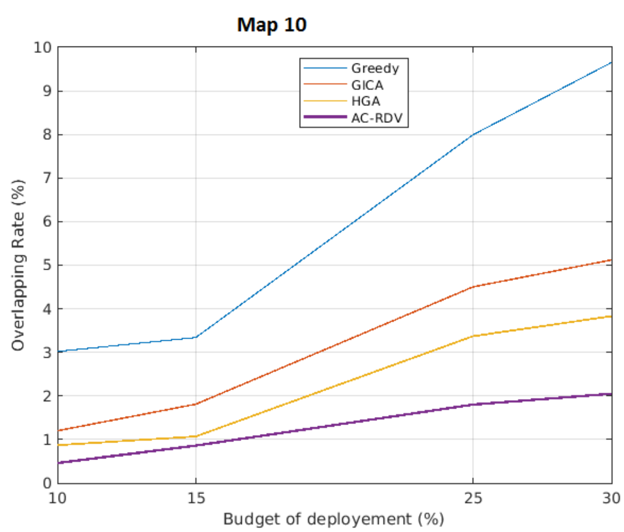



Figure V.10: Overlapping rate when varying the RSU number.

To decrease the redundant duplicated traffic messages generated by vehicles, it is required to analyze the overlapped area covered by two neighboring RSUs. However, aggressive retransmission may cause severe collisions. The results shown in figure V.10, as the number of RSUs increases the overlapping rate increases. For a deployment cost from 10 % to 30 %, the overlapping rate increases to 3.82 % (AC-RDV), 7.83 % (HGA) , 8.60 % (GICA), and 9.40 % (GA).

### *Impact of weights on the traffic factors*

One says that an approach is stable if we can apply it using different criteria.

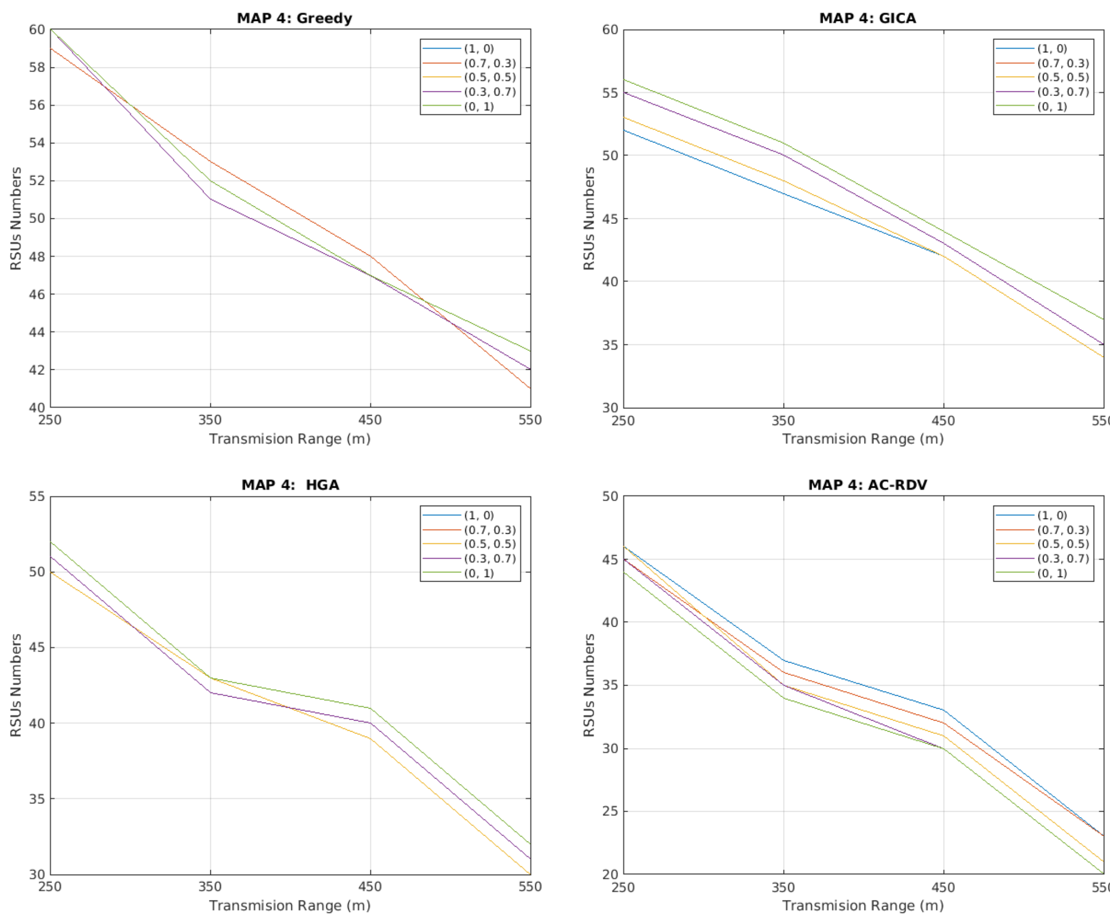



Figure V.11: Impact of weights on the traffic factors on the RSU deployment

To obtain the knowledge on how much the AC-RDV approach can be influenced by the weighs of the traffic factors, a set of tests were made where we changed the weights of the traffic factors (see Table V.2). As shown in Figure V. 11, the results of applying the four algorithms (GA, GICA, HGA and AC-RDV algorithm) on Map 4 prove that the greedy algorithm is more stable than the AC-RDV approach. This can be explained by the probabilistic aspect of our approach, since, in order to generate the solution, we use a stochastic transition rule. As a result, we can say that the change of weights does not influence our approach.

From this simulation study, we can conclude that our AC-RDV approach is a much better placement strategy than the greedy algorithm for urban vehicular networks in terms of the number of RSUs required and the area coverage achieved. To sum up, our approach is suitable for different traffic schemes for it significantly boosts the quality of communications in vehicular environments.

## V.5 Conclusion

Dealing with the problem of RSU deployment in VANETs, we introduced in this study a new bio-inspired RSU placement system called "Ant colony optimization system for RSU deployment in VANET (AC-RDV)". AC-RDV is an intersection-coverage approach based on intersection priority to deploy RSUs at the intersections having a higher impact on the efficiency of vehicular networks. Furthermore, AC-RDV provides a new dynamic heuristic function performed by considering the density of vehicles included in each time. For a more practical RSU deployment, based on graph model, we propose a vehicular network updating every time a new RSU is deployed. This could be achieved by removing the candidate intersections adjacent to the RSU when these intersections are located within its transmission range. We validated AC-RDC with extensive tests using different road topologies created randomly on various urban areas. Compared to the three approaches: GA, GICA, HGA, the reached results display that our scheme shows better performances in terms of reduced number of deployed RSUs and the overlapping ratio as well as maximizing the coverage area and connectivity network.

# CHAPTER VI

# CONCLUSION AND FUTURE WORKS

Vehicular ad hoc networking is a key enabling technology for future intelligent transportation systems (ITS) such as traffic safety and efficiency and comfort services. Maintaining transmission coverage of network is considered as one of the most active areas of research in vehicular ad hoc network (VANETs). However, the high speed of the vehicles along with the availability of choices of multiple paths defines the dynamic topology of VANETs. Tackling the coverage problem, though, RSUs deployment is a main solution, which enables the VANET to ensure a good connectivity. This thesis focuses on methods that improve the transmission coverage and the connectivity of vehicular networks with Roadside Units. By reviewing the recent proposed approaches in this context, we examined the reached results and their evaluation methods. Our main objective is to study the RSUs deployment optimization including their performances. The RSUs deployment is mainly influenced by several factors, such as vehicle mobility (density, speed), vehicles location, complex roadways, routing protocols, and QoS settings, etc. Depending to the mobility of vehicles, the strategy of RSUs location in the geographic areas, we classified the state of the art of the RSU placement strategies into two main categories namely, static and dynamic deployment. In the static category, the RSUs are always deployed in a static point on the relevant geographical areas such as uniform distribution, logical coverage area, intersection point, segments centers, and hotspot regions. On the other side, the RSUs placement by the dynamic deploying may also decrease the deployment cost. We have surveyed the published techniques for optimization of RSUs deploying and compared them depending to their objectives, placement and applications. In addition, we contested that static deployment are more practical and robust when the deployment cost is taken into consideration. To deal with the limitations of the reviewed studies proposed in the litteratre, we have proposed two contributions:

***GICA: an evolutionary strategy for roadside units deployment in vehicular networks***. It is based on the intersection-priority concept to deploy RSUs at the intersections having a higher impact on the efficiency of the vehicular networks. To achieve this, we have formulated this problem as a multi-objective optimization problem in order to maximize the intersection coverage while minimizing the number of RSUs required and the overlapping. The performance of this proposal has been shown by a set of simulations and comparisons with the greedy algorithm.

The latter, is a ***AC-RDV: A novel ant colony system for roadside units deploy-***

***ment in vehicular ad hoc networks***. This study focuses on the issue of deploying a set of RSUs that is able to maximize network coverage with a reduced cost. However, we propose a new formulation of RSUs deployment issue as a maximum intersection coverage problem through a graph-based modeling. AC-RDV is based on the idea of placing RSUs at the intersections having a higher impact on the efficiency of vehicular networks. Since RSU deployment problem is considered as NP-Hard, AC-RDV is inspired by the foraging behavior of real ant colonies to discover the minimum number of RSU intersections that ensures the maximum network connectivity. We validated AC-RDC with extensive tests using different road topologies created randomly on various urban areas. Compared to the three approaches: GA, GICA, HGA, the results obtained showed the effectiveness of the proposed AC-RDV in terms of number of RSUs placed, the average area coverage, the average connectivity and the overlapping ratio.

## Future works and perspective

Before giving directions for future research of relevance to the work shown in this dissertation, we present some VANET limitations related to this network deployment:

- VANET consists of group of vehicles and only RSU as infrastructure entities, then only V2V or V2I communications are offered in a VANET.
- The high advance of personal devices makes challenge to these devices to communicate with VANETs because of the incompatible network architecture.
- VANETs architecture missing intelligent decisions because the restrictions

of computing and storage well as the absence of cloud computing services at vehicles.

- The high mobility of vehicles causes the loss of bandwidth. With growing connected vehicles, the traditional Vehicular Ad-hoc Network (VANET) is changed to Internet of Vehicles (IoVs) because of its constraints including limitation in processing, analyzing, evaluation of different information gathered by vehicles, the connection and disconnection of vehicles in or out the coverage area and the entrusted Internet services which do not offer different applications.

After all these limitations of VANET and with the emergence of Internet of vehicles (IoV), based on profound investigations and considerations, the possible directions are as follows:

- The IoV offers to vehicles an easily connection to any objects in order to enhance traffic safety and to improve driver comfort. Consequently, the nodes participating in an IoV area are highly heterogeneous in nature and different modes of communications (as Vehicles-to-Vehicles (V2V), Vehicles-to-Infrastructure (V2I), Vehicles-to-Roadside units (V2R), Vehicles-to-Sensors (V2S), Vehicles-to-Personal devices (V2P)). It is worth noting that handling such variety of networks, nodes and diverse communication modes requires the proposal of new deployment strategy of RSUs.
- Extend our work in order to make an intelligence deployment based on the Internet of vehicles. For example, the RSU can change the traffic lights when the emergency vehicles are passed and inform other vehicles on this kind of emergency vehicles.

- Due to the high mobility of vehicles and the heterogeneity of devices deployed on roads, and to take up the challenge of ensuring data transmission (QoS ), we intend to deploy the RSUs based on 5G-IoV proposed in [62]. The 5G based on the IEEE802.11 ac standard will offer higher speed and more coverage than the present 4G.

[1] World health organization, global status report on road safety 2018.

[2] Felipe Domingos Da Cunha, Azzedine Boukerche, Leandro Villas, Aline Carneiro Viana, and Antonio AF Loureiro. Data communication in vanets: a survey, challenges and applications. 2014.

[3] Uichin Lee and Mario Gerla. A survey of urban vehicular sensing platforms. *Computer Networks*, 54(4):527–544, 2010.

[4] Mohamed Nidhal Mejri, Jalel Ben-Othman, and Mohamed Hamdi. Survey on vanet security challenges and possible cryptographic solutions. *Vehicular Communications*, 1(2):53–66, 2014.

[5] Huanhuan Yang, Zongpu Jia, and Guojun Xie. Delay-bounded and cost-limited rsu deployment in urban vehicular ad hoc networks. *Sensors*, 18(9):2764, 2018.

[6] Abderrahim Guerna and Salim Bitam. Gica: An evolutionary strategy for roadside units deployment in vehicular networks. In *2019 International Conference on Networking and Advanced Systems (ICNAS)*, pages 1–6. IEEE, 2019.

[7] Abderrahim Guerna, Salim Bitam, and Carlos T Calafate. Ac-rdv: a novel ant colony system for roadside units deployment in vehicular ad hoc networks. *Peer-to-Peer Networking and Applications*, pages 1–17, 2020.

[8] Jeonghee Chi, Yeongwon Jo, Hyunsun Park, and Soyoung Park. Intersection-priority based optimal rsu allocation for vanet. In *2013 Fifth International Conference on Ubiquitous and Future Networks (ICUFN)*, pages 350–355. IEEE, 2013.

[9] Eghbal Heidari, Alexander Gladisch, Behzad Moshiri, and Djamshid Tavangarian. Survey on location information services for vehicular communication networks. *Wireless networks*, 20(5):1085–1105, 2014.

[10] Maryam Rashidi, Iulian Batros, Tatiana K Madsen, Muhammad T Riaz, and Thomas Paulin. Placement of road side units for floating car data collection in highway scenario. In *2012 IV International Congress on Ultra Modern Telecommunications and Control Systems*, pages 114–118. IEEE, 2012.

[11] Jaehoon Jeong, Shuo Guo, Yu Gu, Tian He, and David Du. Tbd: Trajectory-based data forwarding for light-traffic vehicular networks. In *2009 29th IEEE International Conference on Distributed Computing Systems*, pages 231–238. IEEE, 2009.

[12] Baber Aslam, Faisal Amjad, and Cliff C Zou. Optimal roadside units placement in urban areas for vehicular networks. In *2012 IEEE Symposium on Computers and Communications (ISCC)*, pages 000423–000429. IEEE, 2012.

[13] Fayaz Ali, Faisal Karim Shaikh, Abdul Qadir Ansari, Naeem Ahmed Mahoto, and Emad Felemban. Comparative analysis of vanet routing protocols: on road side unit placement strategies. *Wireless Personal Communications*, 85(2):393–406, 2015.

[14] Jean-Pierre Hubaux, Srdjan Capkun, and Jun Luo. The security and privacy of smart vehicles. *IEEE Security & Privacy*, 2(3):49–55, 2004.

[15] Reza Ghebleh. A comparative classification of information dissemination approaches in vehicular ad hoc networks from distinctive viewpoints: A survey. *Computer Networks*, 131:15–37, 2018.

[16] Saif Al-Sultan, Moath M Al-Doori, Ali H Al-Bayatti, and Hussien Zedan. A comprehensive survey on vehicular ad hoc network. *Journal of network and computer applications*, 37:380–392, 2014.

[17] Sherali Zeadally, Ray Hunt, Yuh-Shyan Chen, Angela Irwin, and Aamir Hassan. Vehicular ad hoc networks (vanets): status, results, and challenges. *Telecommunication Systems*, 50(4):217–241, 2012.

[18] Salim Bitam, Mohamed Batouche, and Abdelhamid Mellouk. Qosbeemanet: A new qos multipath routing protocol for mobile ad-hoc networks. In *2010 IEEE Globecom Workshops*, pages 1648–1652. IEEE, 2010.

[19] Khalid Abdel Hafeez, Lian Zhao, Zaiyi Liao, and Bobby Ngok-Wah Ma. Impact of mobility on vanets' safety applications. In *2010 IEEE Global Telecommunications Conference GLOBECOM 2010*, pages 1–5. IEEE, 2010.

[20] Kevin C Lee, Uichin Lee, and Mario Gerla. Survey of routing protocols in vehicular ad hoc networks. In *Advances in vehicular ad-hoc networks: Developments and challenges*, pages 149–170. IGI Global, 2010.

[21] Guang Yu Li. *Adaptive and opportunistic QoS-based routing protocol in VANETs*. PhD thesis, Paris 11, 2015.

[22] Dsrc.http://grouper.ieee.org/groups/scc32/dsrc/.

[23] IEEE 802.11 p Working Group et al. 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. *IEEE Std*, 802, 2010.

[24] Kashif Dar, Mohamed Bakhouya, Jaafar Gaber, Maxime Wack, and Pascal Lorenz. Wireless communication technologies for its applications [topics in automotive networking]. *IEEE Communications Magazine*, 48(5):156–162, 2010.

[25] Uichin Lee and Mario Gerla. A survey of urban vehicular sensing platforms. *Computer Networks*, 54(4):527–544, 2010.

[26] Adebola O Adebowale. *Wireless Access in Vehicular Environments (WAVE)*. Department of Electrical and Electronic Engineering, University of Bristol, 2011.

[27] Christian Lochert, Björn Scheuermann, Christian Wewetzer, Andreas Luebke, and Martin Mauve. Data aggregation and roadside unit placement for a vanet traffic information system. In *Proceedings of the fifth ACM international workshop on VehiculAr Inter-NETworking*, pages 58–65, 2008.

[28] Cristiano M Silva, Andre LL Aquino, and Wagner Meira Jr. Deployment of roadside units based on partial mobility information. *Computer Communications*, 60:28–39, 2015.

[29] Chunyan Liu, Hejiao Huang, Hongwei Du, and Xiaohua Jia. Optimal rsus placement with delay bounded message dissemination in vehicular networks. *Journal of Combinatorial Optimization*, 33(4):1276–1299, 2017.

[30] Chunyan Liu, Hejiao Huang, and Hongwei Du. Optimal rsus deployment with delay bound along highways in vanet. *Journal of Combinatorial Optimization*, 33(4):1168–1182, 2017.

[31] Atef Abdrabou and Weihua Zhuang. Probabilistic delay control and road side unit placement for vehicular ad hoc networks with disrupted connectivity. *IEEE Journal on Selected Areas in Communications*, 29(1):129–139, 2010.

[32] Dongxiu Ou, Yuchen Yang, Lixia Xue, and Decun Dong. Optimal connectivity-based deployment of roadside units for vehicular networks in urban areas. *Transportation Research Record*, 2559(1):46–56, 2016.

[33] Prithviraj Patil and Aniruddha Gokhale. Voronoi-based placement of roadside units to improve dynamic resource management in vehicular ad hoc networks. In *2013 International Conference on Collaboration Technologies and Systems (CTS)*, pages 389–396. IEEE, 2013.

[34] Xu Liya, Huang Chuanhe, Li Peng, and Zhu Junyu. A randomized algorithm for roadside units placement in vehicular ad hoc network. In *2013 IEEE 9th International Conference on Mobile Ad-hoc and Sensor Networks*, pages 193–197. IEEE, 2013.

[35] Baber Aslam, Faisal Amjad, and Cliff C Zou. Optimal roadside units placement in urban areas for vehicular networks. In *2012 IEEE Symposium on Computers and Communications (ISCC)*, pages 000423–000429. IEEE, 2012.

[36] Chinmoy Ghorai and Indrajit Banerjee. A constrained delaunay triangulation based rsus deployment strategy to cover a convex region with obstacles for maximizing communications probability between v2i. *Vehicular Communications*, 13:89–103, 2018.

[37] Huang Cheng, Xin Fei, Azzedine Boukerche, and Mohammed Almulla. Geocover: An efficient sparse coverage protocol for rsu deployment over urban vanets. *Ad Hoc Networks*, 24:85–102, 2015.

[38] Younghwa Jo and Jaehoon Jeong. Rpa: Road-side units placement algorithm for multihop data delivery in vehicular networks. In *2016 30th International Conference on Advanced Information Networking and Applications Workshops (WAINA)*, pages 262–266. IEEE, 2016.

[39] Evellyn S Cavalcante, André LL Aquino, Gisele L Pappa, and Antonio AF Loureiro. Roadside unit deployment for information dissemination in a vanet: An evolutionary approach. In *Proceedings of the 14th annual conference companion on Genetic and evolutionary computation*, pages 27–34, 2012.

[40] Oscar Trullols, Marco Fiore, Claudio Casetti, Carla-Fabiana Chiasserini, and JM Barcelo Ordinas. Planning roadside infrastructure for information dissemination in intelligent transportation systems. *Computer Communications*, 33(4):432–442, 2010.

[41] Jun Tao, Limin Zhu, Xiaoxiao Wang, Jian He, and Ying Liu. Rsu deployment scheme with power control for highway message propagation in vanets. In *2014 IEEE Global Communications Conference*, pages 169–174. IEEE, 2014.

[42] Ali Jalooli, Min Song, and Xiaohua Xu. Delay efficient disconnected rsu placement algorithm for vanet safety applications. In *2017 IEEE Wireless Communications and Networking Conference (WCNC)*, pages 1–6. IEEE, 2017.

[43] Joao FM Sarubbi, Taís R Silva, Flávio VC Martins, Elizabeth F Wanner, and Cristiano M Silva. A grasp based heuristic for deployment roadside units in vanets. In *2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM)*, pages 369–376. IEEE, 2017.

[44] Joao FM Sarubbi, Flavio VC Martins, and Cristiano M Silva. A genetic algorithm for deploying roadside units in vanets. In *2016 IEEE Congress on Evolutionary Computation (CEC)*, pages 2090–2097. IEEE, 2016.

[45] Tsung-Jung Wu, Wanjiun Liao, and Chung-Ju Chang. A cost-effective strategy for road-side unit placement in vehicular networks. *IEEE Transactions on Communications*, 60(8):2295–2303, 2012.

[46] Ozan K Tonguz and Wantanee Viriyasitavat. Cars as roadside units: a self-organizing network solution. *IEEE Communications Magazine*, 51(12):112–120, 2013.

[47] Ozan K Tonguz et al. Biologically inspired solutions to fundamental transportation problems. *IEEE Communications Magazine*, 49(11):106–115, 2011.

[48] Christoph Sommer, David Eckhoff, and Falko Dressler. Ivc in cities: Signal attenuation by buildings and how parked cars can improve the situation. *IEEE Transactions on Mobile Computing*, 13(8):1733–1745, 2013.

[49] Andre B Reis and Susana Sargento. Leveraging parked cars as urban self-organizing road-side units. In *2015 IEEE 82nd Vehicular Technology Conference (VTC2015-Fall)*, pages 1–5. IEEE, 2015.

[50] Andre B Reis, Susana Sargento, and Ozan K Tonguz. Parked cars are excellent roadside units. *IEEE Transactions on Intelligent Transportation Systems*, 18(9):2490–2502, 2017.

[51] Xiaoxiao Jiang and David HC Du. Bus-vanet: A bus vehicular network integrated with traffic infrastructure. *IEEE Intelligent Transportation Systems Magazine*, 7(2):47–57, 2015.

[52] Donghyun Kim, Yesenia Velasco, Wei Wang, RN Uma, Rasheed Hussain, and Sejin Lee. A new comprehensive rsu installation strategy for cost-efficient vanet deployment. *IEEE Transactions on Vehicular Technology*, 66(5):4200–4211, 2016.

[53] Lawrence Davis. Handbook of genetic algorithms. 1991.

[54] Melanie Mitchell. *An introduction to genetic algorithms*. MIT press, 1998.

[55] Zhenyu Wang, Jun Zheng, Yuying Wu, and Nathalie Mitton. A centrality-based rsu deployment approach for vehicular ad hoc networks. In *2017 IEEE International Conference on Communications (ICC)*, pages 1–5. IEEE, 2017.

[56] Irit Dinur and Samuel Safra. On the hardness of approximating minimum vertex cover. *Annals of mathematics*, pages 439–485, 2005.

[57] Marco Dorigo, Mauro Birattari, and Thomas Stutzle. Ant colony optimization. *IEEE computational intelligence magazine*, 1(4):28–39, 2006.

[58] Andre B Reis, Susana Sargento, Filipe Neves, and Ozan K Tonguz. Deploying roadside units in sparse vehicular networks: What really works and what does not. *IEEE transactions on vehicular technology*, 63(6):2794–2806, 2013.

[59] Marco Dorigo, Luca Maria Gambardella, Mauro Birattari, Alcherio Martinoli, Riccardo Poli, and Thomas Stützle. *Ant Colony Optimization and Swarm Intelligence: 5th International Workshop, ANTS 2006, Brussels, Belgium, September 4-7, 2006, Proceedings*, volume 4150. Springer, 2006.

[60] B Chandra Mohan and R Baskaran. A survey: Ant colony optimization based recent research and implementation on several engineering domain. *Expert Systems with Applications*, 39(4):4618–4627, 2012.

[61] Mohammed J Zaki, Wagner Meira Jr, and Wagner Meira. *Data mining and analysis: fundamental concepts and algorithms*. Cambridge University Press, 2014.

[62] Elhadja Benalia, Salim Bitam, and Abdelhamid Mellouk. Data dissemination for internet of vehicle based on 5g communications: A survey. *Transactions on Emerging Telecommunications Technologies*, 31(5):e3881, 2020.