

A Graph-based Model for RSUs Deployment in Vehicular Networks by Considering Urban and Network Limitations and QoS Requirements of Service Advertisement and Discovery

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Abstract

The efficient send and receive of information in VANET improves the efficiency of the safety and traffic services advertisement and discovery. However, if the V2V is the only communication system used, the restrictions of the urban environment and network drop the performance of VANET. In order to improve the performance of the network, it is necessary to use V2I communication as well as V2V communication. Therefore, RSUs must be placed in the environment. However due to the high costs of placement, the full coverage of the environment would not be possible. Therefore, it is necessary to optimally install a limited number of RSUs in the environment.

In this article a graph-based model is presented to find optimal location of RSUs in the urban scenario. All the urban and VANETs limitations have been applied to the graph in form of weight. Solving the Steiner tree problem leads to find optimal places to install RSUs. In the following, the presented model extends to support QoS requirement of service advertisement and discovery. The simulation results, based on real traces, shows an improvement in performance of the given model in comparison with the other scenarios of RSUs placement.

Keywords: Vehicular networks, RSU placement, Steiner tree, QoS requirements, Urban and network restrictions

1. Introduction

Vehicular Networks have captured the attention of industry and academic centers by presenting a wide range of safety, comfort and traffic services [1,2,3]. In order to present such services, it is necessary to have efficient mechanisms of advertisement and discovery. However, due to issues such as high mobility of nodes, high topology changes and network partitioning, the service discovery mechanisms do not have proper performance [4,5]. The network connectivity should be improved in order to use service discovery and advertisement efficiently. Network connectivity is improved through enabling V2I communications alongside V2V communications [6,7,8,9]. In this condition V2I communication helps to overcome connectivity problems in low density areas [7,10].

Achieving V2I communications via RSU installation requires a high expenditure [11]. The high cost of the process is not affordable at the initial stage [12]. For that purpose the least number of RSUs should be installed in the environment. Due to the limited number of RSUs, one of the main challenges in the vehicular networks field is to place RSUs optimally in a way which can have a great impact on the VANET performance. The limitations of urban and vehicular communication should be considered during the searches to find the right locations for the RSU placement. By assessing some traffic traces [13], in this article a series of restrictions in the urban environment and vehicular communications has been extracted in which the major ones are as follows:

The traffic flow between the areas: There is a permanent traffic flow between some areas in the urban environment. Hence, the nodes which are located in these areas can make V2V communications through single hop or multi hop eliminating the need to install RSU for communication in such areas. Therefore these areas have lower importance in the RSU placement.

Server distribution: The distribution of servers in the urban environment is not uniform as some areas involve more servers than others. Due to the fact that servers bear a huge part of sending traffic packets (for instance the traffic messages which are sent by traffic control centres as one of the servers), the presence of the RSUs next to the servers causes the sending traffic of servers via RSUs to enter the infrastructures with no need of multi hop communications and through the infrastructure packets are sent to the other nodes in the network. Access to the infrastructure through fewer hops incredibly reduces the receiving time of server's sending messages to the other nodes. Hence, areas in which the RSUs placement covers more servers will have more impact on the RSUs installation.

Urban environment constraints: Urban environment has its own specific impact on RSU placement and deployment. Among those limitations the following points are worth mentioning:

- ❖ *Inappropriate locations for the RSUs placement:* According to the area's conditions, such as distance from the internet infrastructure, the cost of RSU installation in some areas is high. Therefore, those areas choose to install RSUs which have lower installation and maintenance costs as the expenditures can be reduced. Such conditions must be considered in the RSU deployment to avoid selecting those areas.
- ❖ *The areas where there is no need of coverage:* In the urban environment there are many areas which do not need to be covered by RSUs. Most of the places where there is no vehicular traffic, like parks and green areas, have these characteristics. The RSU deployment should be applied in a way that these areas are not in the coverage priority.

In this article, the RSU installation has been formulated to a graph by applying the urban area's constraints and requirements of the user applications. All the environmental constraints and necessities of the user application in form of weight have been applied to the graph. The contributions of the article are: 1) The RSU installation issue for the urban environment has been studied by considering these factors: urban characteristics and constraints such as presence of traffic flow, lack of necessity to cover the areas, inappropriate locations for RSU placement and limitations of the vehicular networks including VANET's low capacity in high density areas. 2) Optimal placement of RSUs has been formulated to a weight graph by considering urban and VANET constraints. At the end by solving the Steiner tree problem the optimal locations for RSU placement can be obtained. 3) The last presented model has been extended by adding QOS requirements as it guarantees the fact that the amount of delay in sending and receiving messages between vehicles does not exceed a certain threshold among any two subjected areas.

The following part of the article has been categorized as follows: In part 2, the related work regarding RSU placement and maintenance is presented. In part 3, the issue is modelled in the form of a weight graph. The simulation results are presented in part 4 through a series of real traces. Finally, the conclusion is presented in part 5.

2. Related Work

In recent years considerable attention has been paid to vehicle to infrastructure (V2I) communications and optimal RSU placement issues [14,15]. Hence, the RSU placement issue for the highway and urban environments has been studied by authors. The highway environment because of its simplicity has drawn more attention as most of the presented work have studied the highway environment. However, many of the presented models are not applicable to urban environments. Moreover, the works presented for urban environments did not consider the restrictions of the urban environment and VANET as well as ignored the requirements of the application in RSU placement.

Some of the most important works in this scope can be mentioned as follows: Reis and colleagues [7], by considering the environment density as a key factor in RSU placement showed that the performance of VANET will improve through installing RSUs in low density areas as well as improvement of VANET connectivity. Another noted work is Zhuang and Abdrabu [16] study. The authors gave an analytic model based on queuing theory for RSU deployment in the highway environments. The presented model provides the ability to determine the maximum distance between two RSUs in a way that the final delay for the packet delivery via V2V does not exceed a certain bound. One drawback of this method is the assumption of constant density which is not acceptable for all environment conditions especially urban environments and is not applicable to the urban environment. The other study regarding highway environment is Sou and Tonguz's work [6]. The authors by evaluating the effects of the RSUs installation on the highway environment noticed that RSU placement will considerably increase the VANT connectivity and will reduce the amount of message delay in the highway environments. The goal of Zou and Aslam [17] was to collect information from vehicles to the RSUs in the shortest period of time. They formulated the RSU placement issue to an optimization model. The objective function of the given model was to minimize the data collection time from the all possible locations to the RSUs. Also, they presented a heuristic method named balloon optimization based on dynamic programming in order to find optimal locations in the highways to install RSUs.

Table 1. The comparison of the mentioned works in terms of parameters which are applied in the RSU deployment

	Highway/ Urban	Model/Simulation	Inappropriate areas	No need of coverage	Considering the position of servers	Considering the	The area density	Traffic flow	Multi hop communication	The necessities of the application(QoS Requirement)	The type of given traces in the evaluation
Aslam [18,17]	Both	Model	x	x	x	✓	x	x	x	x	Random
Abdrabou [16]	Highway	Both	x	x	x	✓	x	x	✓	✓	Random
Wang [19]	Urban	Both	x	x	x	✓	x	x	x	x	Random
Reis [7]	Highway	Model	x	x	x	✓	✓	x	x	x	-
Trullols [20]	urban	Both	x	x	x	✓	x	x	x	x	Real
Liang [21]	Urban	Model	x	x	x	✓	x	x	x	x	-
Barrachina [8]	Urban	simulation	x	x	x	✓	✓	x	x	x	Random

Liang and colleagues [21] are among those who had worked in urban environment area. They had formulated RSU placement and configuration to the form of linear programming. One of the most important characteristics of this model is finding a trade-off between installation costs and the user required coverage. Zou and Aslam [18] have developed the last given model for highways in a way that match the urban environment to reduce data collection time from the urban area. The study of Brrachina and his colleagues [8] was based on simulation of the urban environment. A method known as D-RSU considered the area's density in order to install RSUs in the environment. The D-RSU objective is to minimize the number of RSUs as they report emergency situations which are occurring in the environment such as accidents. A summary of works which have been done is given in **Table 1**.

According to **Table 1**, some of the given methods are specific to the highway environment and are not capable of developing to match the urban area which is one of the limitations of the mentioned works. Moreover, the efficiency of some of the methods has been evaluated only through simulation and with the help of some random traces which are not precise and proper evaluations to show the efficiency of the presented mechanisms. However, the RSU placement model presented in this article evaluated the efficiency of the model through simulation and a series of real traces. As shown, one of the main objectives of the presented methods is to reduce the RSU's installation and maintenance costs. Also, in some limited works the environment density and presence of multi hop communications in the deployment issue had been considered. The requirements of the application such as the maximum bearable delay have been only considered in the Abdrabou [16] model. According to the most recent studies, the other parameters in **Table 1** were not considered by any of the mentioned methods. The

presented method in this article is the first model which has considered all the properties and constraints which are mentioned above in form of a graph based model for the RSU placement.

3. Problem Statement and Pre-Processing Stage

The urban environment has drawn the attention of a few experts due to its unique characteristics. The fact which is clear to everyone is the importance of the communication between the nodes in the urban environment and exploitation of that communication in order to decrease traffic jam, avoid accidents, shorten the travel time and the other related services [22,23]. Due to the specific characteristic of the vehicular environment such as high mobility of nodes and as a consequence the high VANET topology changes, the V2V communication especially in low density areas is one of the crucial challenges [24]. They attempted to install RSUs to solve the VANET partitioning problem which is occurring during topology changes. However, many authors did not consider the urban environment restrictions and its specific conditions in the RSU deployment or assumed the vehicular specific conditions as simple as possible. In this article the RSU's optimal installation issue is formulated to a graph based problem. The VANET and urban environment restrictions are applied to the graph in the form of weight. The presented procedures in Fig. 1 are followed to formulate the RSU's optimal installation issue to a graph problem.

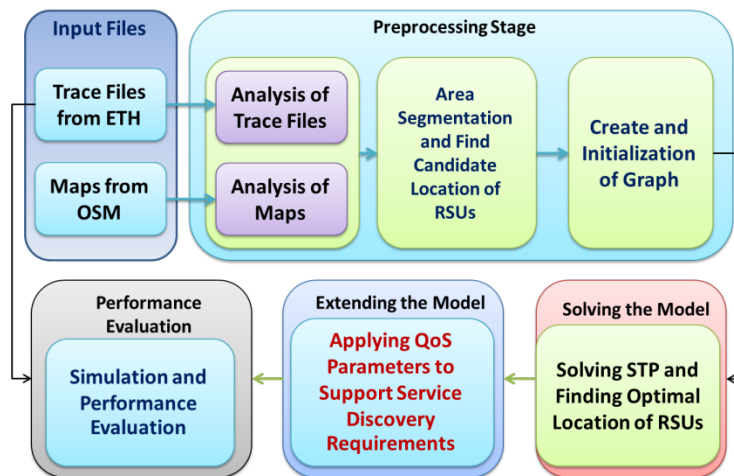


Fig. 1. The RSU placement procedures and model evaluation

As shown, the given solution to the optimal RSU placement included four phases as follows: pre-processing stage, solving the Steiner tree problem, extending the graph model as it can protect the quality of service requirements of applications to guarantee efficient service advertisement and discovery, and presenting a model based on integer programming and evaluation of the model. The noted stages in Fig. 1 have been passed through in sequence to formulate the optimal RSU deployment into a Steiner Tree Problem(STP) and finally its efficiency is evaluated. In the following the processes are clarified.

3.1. Pre-processing stage

Recently, real trace generation and use has attracted attention as a method to evaluate the presented protocols inside the VANET field [13]. In this part a series [25] of online real traces and a series of synthesized generated traces were introduced which can be used in the

evaluation of VANETs protocols. The authors are focused more on the series of Zurich traces than other available series. Hence, in this article Zurich traces are also analyzed and evaluated to present the model for the RSU placement. The urban environment segmentation has been done through analyzing the Zurich traces and OSM map. Size of the zones and candidate locations for the RSU installation are determined as any RSU, in terms of range, can cover maximum four zones. Density of different zones can be measured according to the accomplished segmentations and trace file analysis. Moreover, it can be determined between which created zones there is traffic flow. **Fig. 2** shows part of the urban areas with only main routes and the side streets have been eliminated. It is assumed that places such as car parks, health centers and garages are part of comfort servers and places like traffic control services are part of traffic servers. All of these comfort servers are reporting their own status to the environment and the other nodes are going to find their required services out of the received information from the servers. As can be seen in **Fig. 2** the distribution of the servers in the environment is not uniform. By RSU placement in some specific areas, more servers can be covered. For that reason the presented model tried to place RSUs in the locations where they can cover more servers. **Fig. 3** is the same as **Fig. 2**, except that only the main routes are shown and it is generated through Netconvert program.



Fig. 2. The urban segmentation

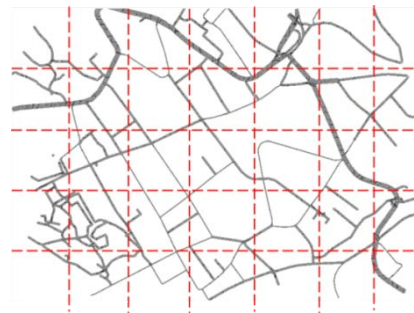


Fig. 3. The segmentation via NetConvert



Fig. 4. Traffic flow between different zones

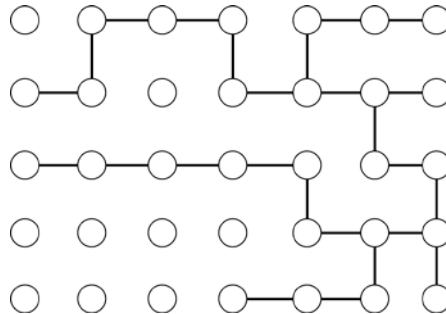


Fig. 5. The initial graph

One of the most striking features of urban environment which has been ignored in most of the previous works is the presence of traffic flow in the environment. An evaluation of the trace files has shown that there is always a traffic flow among some zones in the environment. In **Fig. 4**, the present of traffic flow between different zones is shown as dotted lines. Also, in **Fig. 5**, the graph is corresponded to **Fig. 4**. Any area in the graph has a corresponding vertex and if there is any traffic flow between the zones, an edge has been created between the corresponding vertexes.

Determination of the candidate locations: if the RSU is placed in the junction point of the four areas, it will cover all those areas, though it depends on the area's width and RSU's range. For that purpose, those locations are candidate for the RSU placement which are nearest to the junction point of the all four areas. Fig. 6 shows the candidate locations for the RSU installations. You can see these points in bold in Fig. 6.

3.2. Weighting the graph: A graph is created as a result of the accomplished actions. The vertexes of this graph are zones and locations which make it a candidate for RSU installation. According to Fig. 6 the created graph is not a connected graph. Moreover, the weight of the graph's edges situation is not clear. The graph should be weighted in order to formulate the RSU placement problem into the Steiner tree problem.

In this part, the key parameters which have been used in weighting a graph are defined as follow:

Density of road segment: in this parameter, the density shows the number of vehicles. Therefore, the density of each segment equals the average number of available vehicles in that area. This number can be dynamically determined according to the received messages from the vehicles. Also, the number of available vehicles inside an area can be computed after area segmentation and trace files evaluation.

Density of a zone: same as previous definition, the number of available vehicles in an environment is the density of that zone.

Road segment capacity: in this status, it will be evaluated to see maximum how many vehicles should be driven in this specific segment based on the size of segment, size of each vehicle and the minimum gap between vehicles. Therefore, segment capacity is the max number of vehicles which can move in that segment.

Zone capacity: zone capacity is defined the same as segment capacity which means the max number of vehicles that can move inside the zone.

The weight assigned to the edges of the graph will be done according to the following procedures:

A) Weighting the vertexes which are peer to the zones: important parameters in weighting the vertexes as they can be peer to the zones including the density of each zone as well as the need of area to coverage.

1- Needs of the area to be covered: in this stage it evaluates if the zone needs to be covered by RSU or not. In case that a zone is a traffic free zone such as green spaces and parks which have no need of coverage, the peer vertex is eliminated from the graph. This act is the first step of graph Pruning.

2- Density of the area: Every area includes several road segments. Any route which is located between two junctions is known as a road segment. In order to estimate the density of each area the following must be applied:

The density of any road segment is measured in different intervals and by averaging various densities, the mean density of any road segment is obtained. Sum of road segments densities shows the mean density of each zone.

$$\rho_{Z_i} = \sum_{j \in Z_i} \rho_{RS_j} \quad (1)$$

where ρ_{Z_i} is equal to the mean of the i'th zone density and the ρ_{RS_j} is the mean of the j'th road segment density. Based on its width and its number of road segments any zone in the environment can have the maximum vehicle capacity which can be measured as below. As each area includes several road segments, the capacity of every area is equal to the sum of all the road segment capacities inside the area. However, every road segment according to its

length involves the maximum vehicle capacity which can be measured through Equation 2.

$$C_{RS_i} = \frac{Length_{RS_i}}{VehAvgLength + min\ Gap} \tag{2}$$

where $Length_{RS_i}$ is the length of road segment and the $VehAvgLength$ is the average size of the vehicles and $min\ Gap$ is the minimum distance between every two vehicles which are moving in tandem. Now, the zone’s capacity equals the total capacity of the road segments inside the zone.

$$C_{Z_i} = \sum_{j \in Z_i} C_{RS_j} \tag{3}$$

Now, T_h and T_l parameters are respectively defined as high and low density thresholds. The amount of $\alpha_{Z_i} = \frac{\rho_{Z_i}}{C_{Z_i}}$ which shows the vehicular density of each zone is calculated for every single zone. By comparing α_{Z_i} with the high and low density thresholds it can be determined which area has a high density and in which area this amount is low or medium.

$$\alpha_{Z_i} \begin{cases} < T_l & \text{areas with low density} \\ > T_h & \text{Congested areas} \\ \text{else} & \text{areas with moderate density} \end{cases} \tag{4}$$

The most appropriate method in determining the high and low thresholds is to consider theoretical traffic equations. The goal of traffic theory is to maximize the traffic flow in the routes. However, the amount of traffic flow depends on the density and speed of vehicles. According to Fig. 7 [26] traffic flow in the areas with low density which are less crowded show minimal amount.

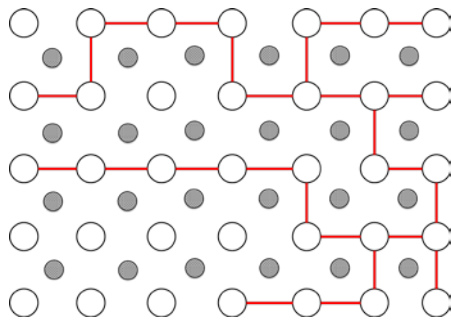


Fig. 6. The candidate locations for RSU placement

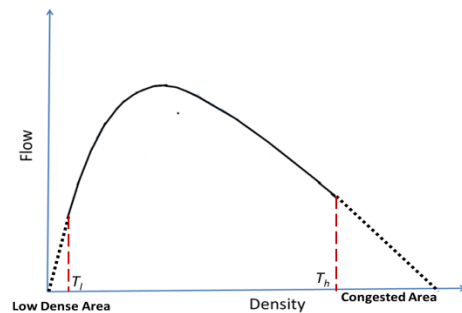


Fig. 7. The density and flow relationship

The presence of the proper traffic flow in the zones can be determined according to Fig. 7. In these zones there is less need to install RSUs. However, the zones with the less traffic flow would not help the V2V traffic information exchanges. These zones have been shown as dotted points in Fig. 7. The partitioning problem in the low density zones and the congestion and network insufficient capacity in the high density zones will hinder efficient vehicular communications. Therefore, the low and high threshold limits should be determined according to Fig. 7. Hence, T_h determines the low limit of the crowded area and T_l is set as the high limit of the less crowded zones. Now, according to the amount of α in each zone, it can be determined which zone has a high, low or medium density. By determining the density of each

zone, the RSUs can be installed in the low and the high density zones. In order to install RSUs in the low or high density zones, a minimum cost is assigned to these zones. As there is a higher possibility of vehicular communications in the medium density zones, there is no need to install RSUs in those zones. Also, larger penalty costs are assigned to these zones in order to reduce the chance of RSU placement in them and to reduce the total installation costs.

$$P_{Z_i} = \begin{cases} p_l, & \alpha_{Z_i} < T_l \\ p_h, & \alpha_{Z_i} > T_h \\ p_m, & \text{else} \end{cases} \quad (5)$$

B) Weighing the vertexes which are peer to the candidate locations: most constraints of the urban environment are applied to the vertexes in the form of weight. However, it evaluates to check the possibility of the RSU placements in the candidate zones before weighting the vertexes. If installation in a candidate location leads to the coverage of a restricted zone, this candidate location is eliminated. In fact, this action is the second step of graph pruning. In the weighting candidate locations, we considered the limitations of the urban environment. The most important parameters in weighting and determining the costs of candidate locations are as below:

- a. The fixed costs of RSU placements and maintenance in the candidate locations (P_c).
- b. The costs of suitability of candidate locations. If the candidate locations were not suitable for RSU placement, a large number is assigned to the location representing the costs of that specific location. (p_n)
- c. The number of covered servers: the installation of RSU causes that some number of available servers in all four zones to be covered by this RSU. The greater the number of covered servers in the zone is, the more important the location for the RSU placement will be and the lower the costs that will be assigned to the area will be (b_s)
- d. The number of low density areas which have been covered: it may be possible that by RSU placement in a candidate point, more low density areas can be covered. In this condition the mentioned location will have a higher installation importance. In fact, the number of low density covered zones and the amount of assigned cost have a reverse ratio. (b_l)

$$C_{R_i} = \frac{(p_c * p_n)}{(b_s * b_l)} \quad (6)$$

This simple equation is defined according to the direct or inverse proportion of the defined parameters to the weight amount which should be attributed to any candidate point.

C. Weighting the graph's edge

The aim of valuating the graph vertexes is to determine the costs of the graph edges. Now according to the values of the graph vertexes the amount of each edge is calculated as follows: State 1: if the available edges connect two areas with traffic flow between them, the costs peer to this edge is equal to zero.

State 2: if the edges connect two areas which are traffic free zones, the costs of edge would be a function of the costs of the two heads of the edge as well as the connectivity probability of the two zones which is usually a big number.

State 3: if the edge connects an area to a candidate point, the costs of the edge would be equal to the total costs of the two vertexes at the two heads of the edge. Hence, the costs of edge e (C_e) will be calculated according to Equation 7.

$$C_e = \begin{cases} 0, & e \text{ connect } z_i, z_j \text{ and there is a flow between them} \\ f(P_{z_i}, P_{z_j}, p), & e \text{ connect } z_i, z_j \text{ and there is not a flow between them} \\ P_{z_i} + C_{r_j}, & e \text{ connect } z_i, r_j \end{cases} \quad (7)$$

At the end of the pre-processing stage, a weighted graph is created which includes several vertexes. The objective is to make communication between the vertexes which are peer to the zones. For this purpose, if the normal communication between the vertexes is not possible, installing RSUs in some of the candidate zones would make it possible. The objective of this issue is to determine a subset of candidate points as it can point to the possibility of communication among the available areas in the environment. The necessary solution to achieve this goal will be presented in the next section. The final created graph in the pre-processing stage is shown in Fig. 8.

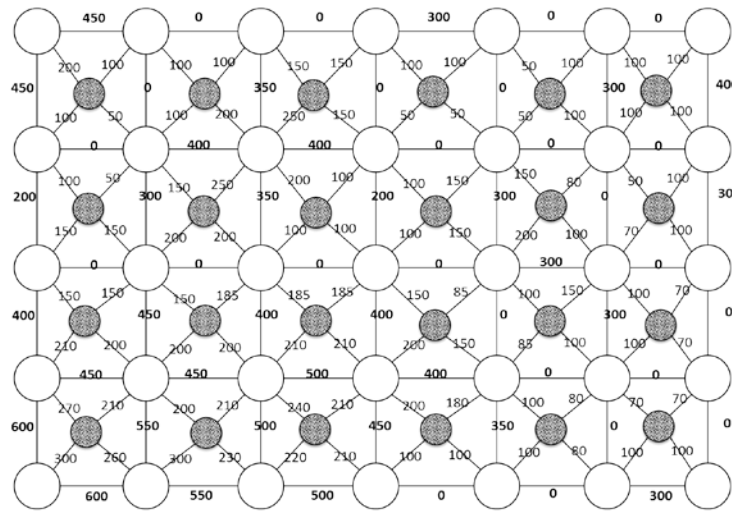


Fig. 8. The final created graph in pre-processing stage

4. Optimization Stage

A weighted graph is created in the pre-processing stage which includes some vertexes and edges with specific weights. The graph involves two different vertexes. Some of the vertexes are peer to the created zones in the environment and as the objective to have possible communication between different zones, a spanning tree should be established in order to involve these points. The other type of vertexes are the candidate locations to install RSUs. The objective is to install the minimum number of RSUs in the environment in order to provide the possibility of information exchange among the available vehicles in the zones. In fact, this issue is known as the Steiner tree problem. Hence, the RSU's optimal placement issue formulates to the Steiner Tree problem.

The Steiner Tree problem: The Steiner Tree problem on the $G(V,E)$ graph consists of finding a tree with the minimum weight which includes the subset T of the set V . If necessary, the other vertexes of set V can be used. In this definition V is the set of vertexes and $E \subseteq V * V$ is the set of the graph edges. The cost of C_e assigns to any $e=\{i,j\}$ edge in the graph. Two

subdivisions of the vertexes which are called $T \subseteq V$ and $S \subseteq V$ are defined as set of terminals and set of Steiner points. The objective of the Steiner tree is to find a tree which includes all sets of terminals and if necessary uses the Steiner points while its cost is minimum [27,28]. Hence, we have:

$$T \subseteq V, S \subseteq V, \{S \cup T\} = V, \{S \cap T\} = \emptyset, S := V \setminus T$$

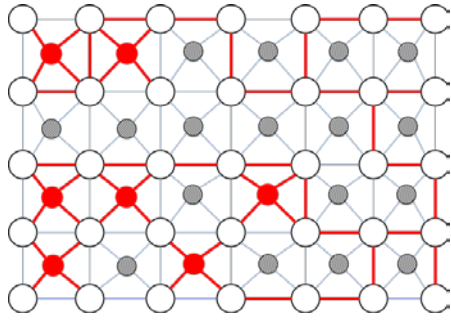


Fig. 9. Solution of the Steiner Tree problem

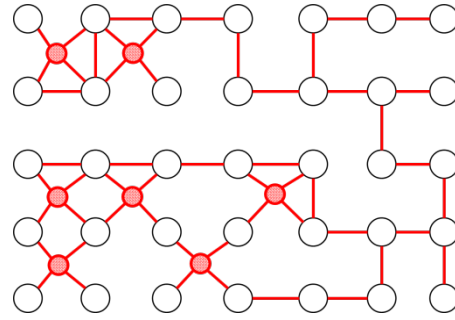


Fig. 10. Connectivity graph

According to **Fig. 9**, out of 24 candidate locations only 7 are selected to communicate between all the areas in the environment. By choosing these 7 locations among all the other candidate points, communication between all areas is possible. In order to make the graph clearer the values of the edges are omitted, the selected points are shown in bold and the non-selected locations are filled in crosshatch. **Fig. 10** shows the connectivity tree between the areas and the candidate points. The graph in **Fig. 10** shows how to make connections among the available nodes in the areas through multi-hop communications or V2I via RSUs. Hence, for the areas which have low vehicular densities and it is impossible to exchange the information via single/multi hop communications, this possibility will be provided for the nodes through the RSU installation.

4.1. The optimization models based on Mixed Integer Programming

In the previous section the problem of RSU placement in the urban environment is formulated to the Steiner tree problem. The objective of this section is to present an optimal model based on MIP (Mixed Integer Programming) to solve the Steiner tree problem. As a large number of optimal models has been presented to solve the Steiner tree problem [29,30,31], in this part an optimal MIP-based model has been presented and revised which is based on the available models and branch and cut solutions to solve the Steiner tree problem. For that purpose, at the beginning the problem has been formulated to an undirected graph then to a directed graph and in the following, the presented model for the directed graph is developed as it can protect the quality of service parameters inside VANET for efficient service advertisement and discovery. The undirected graph $G=(V, E)$ and the series $T \subset V$ which is called the terminal collection, are presented. The peered Steiner tree is defined as a subdivision of $E' \subset E$ edges as for any two vertexes of t_1 and $t_2 \in T$, there is a route from t_1 to t_2 in $(V(E'), E')$. The $V(E')$ involves a series of vertexes which belong to the edge set of E' .

C_e is considered as costs of the edge for any available edge in the graph. Also, the value of the binary variable of X_e would be equal to one if there is an edge e in the tree; otherwise it would be equal to zero.

The mixed integer programming model is presented as below to solve the Steiner tree in the undirected graph according to the symbols in **Table 2** and [30]. By solving the optimization model which is presented in Equation 8, the RSU installation locations in the environment can

be determined among the total candidate locations.

Table 2. List of used symbols in the MIP models

Parameter	Description	Parameter	Description
G	Undirected Graph	V	Total number of vertexes
E	Total number of edges	T	Total number of terminal vertexes
S	Steiner tree	C_e	Cost of the edge e
X_e	The Boolean variable to check availability of the edge in the tree	$\delta(W)$	a series of the edges that one head of them has been located at W
D	Directed graph	A	Series of directed edges (Arcs)
y_a	Boolean variable to determine the direction of the edge a in Steiner Abr.	$\delta^+(W)$	a set of edges that their tail is in the W and their head has been located at the W supplement
x_a^t	the Boolean variable which is shown if there is an edge a on the way from the root to the terminal t or not?		

The presented model will be solved through branch and cut solution [32].

$$\begin{aligned}
 & \min \sum_{e \in E} C_e X_e \\
 & \sum_{e \in \delta(W)} X_e \geq 1, \text{ for all } W \subset V, W \cap T \neq \emptyset, (V \setminus W) \cap T \neq \emptyset \\
 & X_e \in \{0,1\}
 \end{aligned} \tag{8}$$

4.2. Extending the presented model in order to guarantee service discovery and advertisement requirement

The importance of VANET is to send the safety and traffic information to the vehicles on time as the available vehicles can avoid accidents in the environment through receiving the updated information. Therefore, the VANETs should guarantee that the necessary information for the vehicles is sent to them on the certain bound. For that purpose, in the RSU deployment in addition to the considered factors in the previous sections, service discovery and advertisement parameters such as delays in sending the information will be added as it can be guaranteed that the information would be exchanged during a specific period of time through established RSU placement.

There are usually a number of servers in the urban area. Servers in the urban environment are known as sources of send/receipt of traffic information responsible for huge volumes of traffic information continuously sent from these nodes to the other nodes in the environment. Due to the limited validity time of the traffic information in the environment, it should be guaranteed that these information is sent to other vehicles in other zones at certain times. Otherwise, the available vehicles in the environment cannot use the received information from the servers in order to make their decisions such as choosing the best direction, or in case of using this information the correctness of the made decisions cannot be guaranteed.

Moreover, some areas in the environment are known as high risk areas as they always have high traffic congestion or safety incidents such as accidents. Therefore, it is necessary that other related nodes receive the information in the shortest time in order to prevent the safety dangers in the environment. For that purpose, it is necessary to make arrangements for the

zones which involve the servers or these zones must be recognised as high risk zones as the information related to these zones can be received by the other nodes at a certain time. The following actions are performed in order to apply the delay constraints to the initial model which is presented in Equation 8.

Solving the Steiner tree problem for the directed graph: Another solution to the Steiner tree problem which is necessary for solving developed model is to use the directed Steiner tree. For that purpose, in the first step the given graph will be converted to a directed graph. For achieving that, two edges (u, v) and (v, u) will be substituted for the $\{u, v\} \in E$. Collection A involves a series of the directed edges. Therefore, the created directed graph consists of: $D = (V, A)$. Some of the available vertexes are called the $r \in T$ root. A Steiner Arborescence with root r consists of a subdivision of Arcs (directed edges) as $A' \subset A$ and $(V(A'), A')$ for any vertex $t \in T \setminus \{r\}$ including a directed route from r to t . Also, the variable y_a is valued as below: for any directed edge $a \in A$ if a is located in Steiner Arborescence, then $y_a = 1$ otherwise y_a would be valued at zero.

Now, according to the definition of the given variables Equation 8 for the directed graph is revised as below:

$$\begin{aligned} & \min \sum_{a \in A} C_a y_a \\ & \sum_{a \in \delta^+(W)} y_a \geq 1 \text{ for all } W \subset V, r \in W, (V \setminus W) \cap T \neq \emptyset \\ & y_a \in \{0, 1\} \\ & \delta^+(W) = \{(u, v) \in A \mid u \in W, v \in V \setminus W\} \text{ for } W \subset V \end{aligned} \quad (9)$$

Adding the delay constraint to the presented model for the directed tree: similar to the previous statement, a numeric cost is given to each edge and this parameter is called C_a . Moreover, it is necessary to apply the delay constraint to the tree. For that purpose, another parameter is assigned to the edge. The second parameter can be the number of allowed hops between the root vertex and the terminal in the multi-hop communications or it can be the maximum allowed delay time for sending the information from the origin area to the other areas of the terminal. This parameter is called d_a and is specified to any directed edge of the graph. Now, by considering the delay constraint, the Steiner problem is defined as follows [31,33]:

There is a tree with minimum weight which is connecting the origin r to the all the vertexes in the terminal. Also, the total delay will not exceed a certain amount for any available route between the root and terminal vertexes.

$$\begin{aligned} & \min \sum_{a \in A} C_a y_a \\ & \sum_{a \in \delta^+(W)} x_a^t \geq 1 \text{ for all } t \in T, W \subset V, w \in W, t \in \{V \setminus W\} \\ & 0 \leq x_a^t \leq y_a \text{ for all } a \in A, t \in T \\ & \sum_{a \in A} d_a x_a^t \leq \alpha \\ & y_a \in \{0, 1\} \end{aligned} \quad (10)$$

Hence, by considering the delay parameters the RSU installation issue will be formulated to the specific Steiner tree problem that the delay constraint has been applied to. In the mentioned problem, the high risk areas and the areas which involve the servers are considered as the root,

and the other areas are considered as terminal vertexes. By solving the optimal problem which has been presented in Equation 10, the RSU installation places are determined and it will be guaranteed that the amount of delay in sending the traffic information between the selected areas and the other areas will not exceed certain bounds.

5. Performance Evaluation and Simulation Results

In this section we address the evaluation of presented models for the RSU deployment. The given solution is compared and evaluated in comparison with the other solutions and mechanisms regarding RSU placement. And finally, the impact of the urban RSU deployment on the efficiency of VANET and advertising time of occurred incidents in the environment is measured.

Five different scenarios have been considered for evaluation as follows: 1) only V2V communications are used 2) the uniform RSU deployment in the urban environment: in this condition the RSUs are distributed in the environment without considering any constraints 3) RSU deployment by applying density parameter: in this condition RSUs are installed in the areas which are suffering from partitioning problem to improve the VANET connectivity 4) RSU deployment by considering initial model which is presented in this article: in this condition as well as costs and density parameters, the other urban constraints are applied in the RSU deployment 5) the RSU deployment based on time constraints(QoS parameter) which is presented in this article. The evaluation of different mechanisms is done in two stages. In the first stage, the given models are compared in terms of the number of necessary RSUs for the vehicular environment coverage. Also, the impacts of increasing the number of areas in the number of RSUs is evaluated. Moreover, the effects of the maximum number of allowed hops in multi hop communications is evaluated in the number of necessary RSUs. Finally, the impact of density on the number of necessary RSUs is assessed.

It is determined in [Fig. 11](#) that any RSU placement and deployment model needs several RSUs in order to cover the environments with different number of areas. As expected the RSU's uniform deployment needs more RSUs to cover the environment as in this method none of the limitations of the VANET has been applied in the model. Many parameters regarding RSU deployment are considered in the Steiner tree method therefore in this method the number of necessary RSUs for the environment coverage will be reduced. However, in the QoS-based model, by applying the maximum allowed hops, the number of installed RSUs is slightly increased though it will guaranteed that the maximum delay between the areas will not exceed a certain threshold.

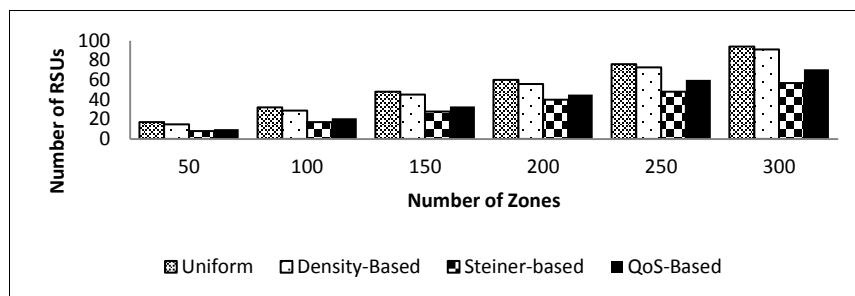


Fig. 11. The number of necessary RSUs for environment coverage by considering the different areas

One of the most important factors in number of necessary RSUs for environment coverage is the maximum number of allowed hops in the multi hop communications. It is obvious that the number of necessary RSUs is reduced by increasing the number of allowed hops. **Fig. 12** shows the effects of the number of allowed hops on the number of necessary RSUs.

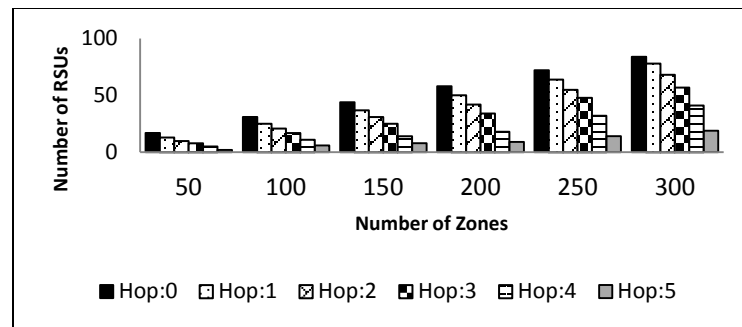


Fig. 12. The number of allowed hop effects on the number of necessary RSUs

On the one hand the impact of increasing the number of the areas on the number of necessary RSUs for environmental coverage are measured and on the other hand the maximum number of allowed hops on the number of necessary RSUs are evaluated. According to **Fig. 12**, by increasing the number of allowed hops, the number of necessary RSUs is not linearly reduced but it is reduced exponentially. In addition to the number of hops in the multi hop communications, there is another important parameter on the number of environmental necessary RSUs which is the environment density. The number of RSUs required to cover the environment has a direct relationship with the number of low density areas which are facing partitioning problems. Hence, in this part the effects of density on the number of necessary RSUs are evaluated. For that purpose three different conditions are considered: 1) most areas in the environment have low environmental density (state L: almost 75% of the areas have low density), 2) most areas have medium environmental density (state M: almost 75% of the areas have good density), 3) most of areas have vehicular congestion (state H: nearly 75% of the areas face congestion). It is determined how many RSUs are needed for each of the above states.

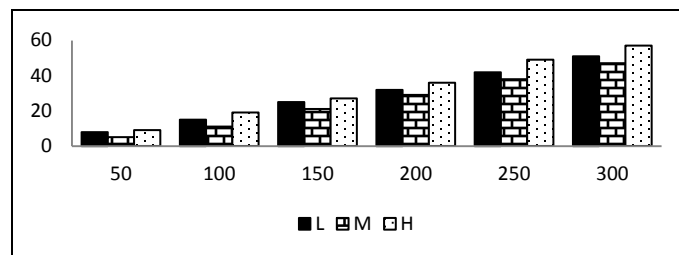


Fig. 13. The impact of density on the number of necessary RSUs in the environment

In **Fig. 13** the effects of density on the number of necessary RSUs are shown. As can be seen in **Fig. 13**, by increasing the number of low density areas in the environment the number of needed RSUs for the environmental coverage will be increased. However, where most areas have proper and good density, there is less need for RSUs to cover the environment as there is the possibility of multi-hop communications in that condition. However, there are low capacity problems in the condition that most areas face congestion. Therefore, in order to avoid capacity problems, it is necessary to install more than one RSU in some areas. Hence,

more RSUs are required in this condition.

In order to compare the various scenarios, the specific number of RSUs regarding each scenario is installed in the environment. Then, according to the availability of the RSUs in the environment, their impact on VANET efficiency in different conditions are evaluated. The used simulation parameters in the evaluation of the methods are presented in [Table 3](#).

Table 3. Environment and simulation assumptions

Parameter	Value
RSU's Transmission Range	200 meters
The number of covered zones by each RSU	4
Size of each zone in urban scenario	200 * 200 square meter
Size of environment in urban scenario	3000 * 3000 square meter
Traffic Simulator	SUMO [34]
Network Simulator	OMNET [35]
Vehicular Network simulation framework	Veins 2 [36]

At the end, the impact of RSU placements on the parameter of 'message advertisement time from the servers or safety servers to the other nodes' will be assessed through simulation. For this purpose, in case of using the QoS-based model, the high traffic points and the areas which involve the servers will be considered as the root of Steiner tree and therefore it will guaranteed that the number of hops between these points and other available points (terminals) in the Steiner tree would not exceed a certain amount. In this condition, it is supposed that the servers related messages or safety messages in the high risk areas have been sent from the origin points periodically and at a certain rate. After that, the receiving time of the messages by the other available nodes will be measured. The results of the simulation and the service advertisement time in these two conditions are shown in [Table 4](#).

It can be seen that by RSU placement in the environment the VANET efficiency increases as the service advertisement time is incredibly improved compared to the condition in which only V2V communications are used. In the uniform scheme, if the areas which have low density or congestion issues are not common, they would be able to announce the messages at a certain time. However, most of the areas that have high or low densities would not have necessary efficiencies as the RSUs have been placed regardless of the environment density. In the density based method, as the RSUs have been installed according to the density of the areas, it will lead to the proper coverage of the low density areas and for that reason it is a more efficient model regarding the service advertisement in comparison with the uniform method. However, in this method the only key applied parameter is the environment density while the other environmental and VANET constraints have no role in the RSU placement. But in the two presented methods in this article, in addition to the density condition the other mentioned constraints in [Table 1](#) have been applied in the RSU placement, therefore it will be more efficient in the service advertisement. The QoS-based model has better service advertisement time in comparison with the other methods as it will guarantee that by RSU placement the amount of receiving delay with the messages for the users will not exceed a certain bound.

Similar to the service advertisement time parameter, in the following the parameter of the service discovery time is assessed. For that purpose it is assumed that the traffic conditions of the areas is preserved in the nodes and the related aggregated data is stored in the server nodes. By sending messages the available nodes are trying to get the traffic information from the areas that they are going to move towards. Hence, the messages will be sent to the environment in order to inform the other nodes of the available traffic conditions. The nodes which are

preserving the information about those areas are responding to these messages. The time it takes for an applicant node to be informed of the area's traffic information is called service discovery time. In fact via the explained method, the service discovery time will consist of the search and response times as one of them is sending a request from the nodes and the other is answering from the node which has the information.

According to **Table 4**, in Steiner based model the amount of announcement time and service discovery compared to the infrastructure-less, uniform and density-based, has been improved up to 31%, 23% and 17 % respectively. Also, in QoS based method, the amount of announcement time and discovery service in comparison to the infrastructure-less, uniform and density based models has been improved up to 33.2%, 29%, 21.8 % respectively.

Table 4. The service discovery and advertised time

	Infrastructure-less			Uniform			Density-based			Steiner-based			QoS-based			no of RSUs
	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	
Avg. Advertisement Time	0.352	0.232	0.516	0.246	0.158	0.431	0.210	0.157	0.415	0.203	0.132	0.373	0.195	0.130	0.366	5
				0.168	0.136	0.228	0.156	0.128	0.217	0.105	0.092	0.155	0.101	0.090	0.151	10
				0.134	0.093	0.195	0.119	0.082	0.194	0.092	0.052	0.149	0.088	0.049	0.144	15
Avg. Discovery Time	0.691	0.414	1.00	0.563	0.306	0.846	0.529	0.294	0.791	0.489	0.252	0.744	0.414	0.244	0.709	5
				0.360	0.271	0.458	0.299	0.251	0.355	0.274	0.190	0.344	0.240	0.169	0.303	10
				0.286	0.193	0.391	0.228	0.159	0.310	0.205	0.109	0.298	0.176	0.094	0.278	15

6. Conclusion

This article focused on the urban environment and VANET and urban constraints extracted from real traces for RSUs deployment. By considering the urban and network limitations, a graph based model is presented for the optimal RSU placement in the urban area. The limitations are applied to the graph in form of weight and the optimal locations for the RSU placement had been achieved by solving the Steiner tree problem. In this model the number of necessary RSUs for area coverage has been reduced in comparison with the other models owing to the pre-processing stage which has been done on the graph. At the end the QoS requirement of service advertisement and discovery IS applied to the model and this condition IS formulated to a Steiner tree problem with delay constraint. However, by doing the last step the number of RSUs IS slightly more than the initial presented model but it guarantees that the information exchanging time will not exceed a certain bound.

In the end, through RSU deployment in the environment and simulation, it has been concluded that via performing the RSU placement based on our models, VANET efficiency improves by considering the urban restrictions and VANET limitations.

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