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Optimal RoadSide Units Distribution Approach in Vehicular Ad hoc Network

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ABSTRACT

A vehicular ad hoc network is a particular type of ad hoc mobile network. It is characterized by high mobility and frequent disconnection between vehicles. For this, the roadside units (RSUs) deployment permits to enhance the network connectivity. The objective of this work is to provide an optimized RSUs placement for enhancing the network connectivity and maximizing the accident coverage with reducing the deployment cost. In this paper, we propose our approach called Optimized RoadSide units Deployment (ORSD). The proposed approach comprises a two-step, in the first step, ORSD finds the RSUs candidate locations based on network density and connectivity. We calculated the connectivity of each segment based on speed and arrival information's. The second step permit to find the optimal solution of our proposed objective function. The objective function permits to enhance the network connectivity and maximizing the accident coverage. To find the optimal solution of our objective function is an NP-complete problem of order $o(n^2)$. Therefore, we propose to solve this problem in two phases, so that it becomes a simple linear problem to solve. The ORSD is proposed for urban and high way scenarios. The extensive simulation study is conducted in order to assess the effectiveness of the proposed approach. We use the Simulator of Urban MObility (SUMO) for generating different traffic scenarios. We develop scripts to extract different information as density, speed and travel time in each segment. Then, we develop an algorithm to calculate connectivity probability for each segment. Then, we implement our objective function to finds optimal RSUs positions in terms of connectivity, accident cover and cost.

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1. INTRODUCTION

With the rapid progress in the field of intelligent transportation systems [1], the concept of vehicular ad hoc network (VANET) [2] is created. VANET permit to exchange the different type of information on roads using smart vehicles [3]. The VANET topology is frequently dynamic with not steady connectivity. So, the establishment of the stable route between vehicles, vehicle to vehicle communication (V2V), is challenge due the high mobility of vehicles. Therefore, the vehicle to infrastructure (V2I) is necessary to enhance the connectivity and coverage of VANET network. The V2I communication is assured by deployment the roadside units (RSUs) in the network. The RSUs represents wireless access point. Due their deployment cost, the RSUs placement must be optimal [4]. Therefore, the main objective of this work is to provide an optimized RSUs position to enhance network connectivity and coverage accident area.

In this paper, we propose a novel approach called ORSD (Optimized RoadSide Units Deployment). ORSD is a solution that optimizes RSUs deployment for vehicular ad hoc network improving the accident area coverage where there is low connectivity.

In the first step, we calculate the connectivity probability in each segment using the traffic information (arrival rate, density, speed). The second step, we select RSUs candidate positions in segments with low connectivity probability because with high connectivity probability the information is circulated using V2V communication. Then, we select the optimal RSUs positions for final installation based on accident area.

The article is organized as follows. Section 2 presents and discusses important related works on the deployment of roadside units. In section 3, we present the model of the system. Section 4 details the ORSD algorithm and the proposed objective function to maximize both network connectivity and accident area. Finally, Section 5 discusses the simulation results. Section 6 presents the conclusion of this research work.

2. RELATED WORKS

In order to improve the deployment of RoadSide Units (RSUs), many works have been developed by the academic community. In [5][6], the authors were addicted to finding the optimal positions to maximize the coverage area, in order to improve connectivity and reduce the delay and messages transmission.. They consider intersections to be best candidate positions for urban scenarios.

In [7], they use two optimization methods: Analytical Binary Integer Programming (BIP) and Balloon Expansion Heuristic (BEH), but they only consider urban environments without considering the density of vehicles and use only the intersections as candidates’ positions.

In [8] the authors concluded that putting RSUs in intersections does not improve the connectivity of isolated vehicles since the density in intersections is usually higher. They consider communication coverage and vehicles density to study the distribution of isolated nodes.

By cons, the authors in [9] propose to distribute the RSUs along the route, equidistantly. The objective is to study the differences between (RSU) to improve the collection and delivery of data on highway. This proposition is located in highway case and uses the V2I communication only.

On the other hand, in [10] the authors take in consideration both urban and highway scenarios and two types of communication V2V and V2I. To enhance delay-sensitive applications in vehicular network, the authors propose using genetic algorithms to find best positions in order to minimize the transmission delay of safety messages based on information of traffic as speed and density, the algorithm complexity is O(n2).

In [11] and [12], the authors use the genetic algorithm to optimize RSUs placement to enhance the reception of basic safety message (BSM) delivered from the vehicles. From the related work, many works use only V2I communication to communicate.

The authors choose to use intersections in the case of urban scenario and uniform distribution in the case of highway scenario, which are not best RSUs positions. Consequently, in our work, we propose the ORSD (Optimized RoadSide units Deployment) approach in both urban and highway scenarios and we use V2I and V2V (V2X) communications to reduce unnecessary infrastructures and guarantee better coverage of high accident risk areas. Table 1 presents a comparative study between the different approaches.

Table 1. Comparative study

Study reference	Scenario	Connexion mode	RSU connectivity	Initial localisation
[5]	Urban	V2I	Yes	Intersection
[9]	Highway	V2I	Yes	Equidistant
[6]	Urban	V2I	Yes	Intersection
[10]	Urban & highway	V2X	Yes	Intersection, random or uniform
[11]	Urban & highway	V2X	Yes	Intersection, random or uniform

3. PROPOSED SYSTEM MODEL

In our proposed system model, as shown in figure 1, we consider a set of road segments in the studied area Si={S1, S2,…,SN} where each Segment Si is characterized by density Di , speed Vi and number of accidents ACi . Each segment has a length equal 2*r where r represents the radio range of vehicle. Also, Pz represent the population size in the studied area.

Let CP={1,…,m} be the set of candidate positions to install RSUs.

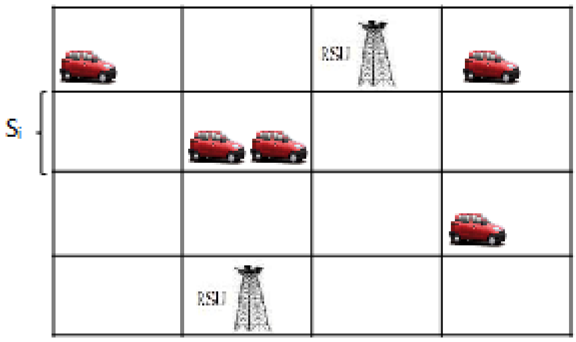


Figure 1. System model

These variables are summarized in Table 2.

Table 2. Notation

Variable	Notation
Segment i	S_i
Density in segment i	D_i
Speed in segment i	V_i
Length of segment	L
Radio range of vehicle	r
Population size	Pz
Accidents number in segment i	AC_i
Decision variable to use or not the RSU_i	y_i
Number of RSU candidate positions	m
Road segment number	n
Number of RSUs to deploy	NRSU

In our system, we take into account V2X communication. We assume that all RSUs are connected through wired links. We detail in the following the different steps of proposed ORSD approach.

4. ORSD STEPS

The aim of paper is to find the best RSUs locations in urban and highway scenarios. The challenges consist to ensure maximum accidents coverage in the segments with low connectivity. In fact, our objective is to find the best RSUs placement and to enhance the connectivity of the system while minimizing the number of RSUs.

4.1. Problem modelling

We model our problem by the objective function to maximize the accidents coverage and system connectivity. So, we use equation (1) to (6) to represent our problem modelling. Equation (1) represents the objective function.

$$F = F1 + F2 \qquad (1)$$

Objective function is composed of two sub-functions. *F1* represents the system connectivity i.e. the connectivity average in all segments and *F2* represents the accidents coverage.

$$F1 = \sum_{i=1}^{n} Pc_i\, Y_i \Big/ number\ of\ segment \tag{2}$$

$$\begin{cases} Pc_i = Pc_i & if\ Pc_i > threshold \\ Pc_i = 1 & if\ Pc_i \leq threshold \end{cases} \tag{3}$$

$$if\ Pc_i \leq threshold \rightarrow RSU_{candidate} = +1 \tag{4}$$

Where Pc_i is connectivity probability of segment i will be detailed in section 4.2.

$$F2 = max \sum_{i=1}^{m} AC_i\, Y_i \tag{5}$$

with

$$\begin{cases} \mathrm{Y_i} \in \{\mathrm{RSU_{candidate}}\} & (a) \\ \sum_{i=1}^{m} \mathrm{Y_i} \leq \mathrm{NRSU} & (b) \\ \mathrm{Y_i} \epsilon \{0,1\} & (c) \end{cases} \tag{6}$$

This set of equations is the continuation of the function F2 described by equation 5, with :
(a): Selected positions (Optimal) by F2 are candidate positions (results of the objective function F1)
(b): Number of selected positions (Optimal) by F2 below the threshold (the number of RSUs to deploy)
(c): if Y_i=0 is indicate the RSU (i) is not deployed. if Y_i=1 is indicate the RSU (i) is deployed

The solution feasibility must respect the constraints described by (6) to ensure that the number of RSU used is lower than a given RSUs threshold (NRSU). Y_i is the variable that indicates if the RSU *(i)* is deployed or not.

In our work, the objective is to find the optimal positions to deployed RSUs. To do that, we propose two processing steps as depicted in figure 2.

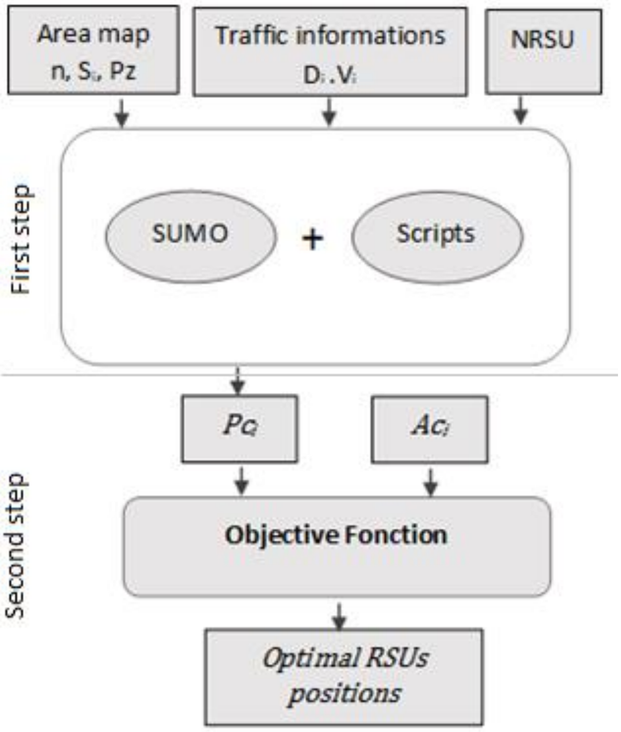


Figure 2. Proposed ORSD approach

The first step allows to calculate the connectivity probability Pci of each segment. The second step permit to find the optimal solution of our objective function (eq. 1).

To find the optimal solution of our objective function is an NP-complete problem [10] of order o(n²). Therefore, we propose to solve this problem in two phases, so that it becomes a simple linear problem to solve.

4.2. First phase: Connectivity probability calculation

To apply O*RSD*, we need to calculate the connectivity probability (*Pc)* used by equation (2). *Pc* is the probability that there is a sequence of connected nodes in the road segment. So, we use the Simulator of Urban MObility (SUMO) [13] for extracting information about density and speed in each segment to calculate vehicle arrival rate named λ_i. according to equation (eq.7). Vehicle arrivals can locally see as a Poisson process of intensity *D*.

$$\lambda_i = \frac{2D_i}{\bar{v}} \tag{7}$$

Where $\bar{v}$ represent the average speed in the segment and the factor 2 due to the number lane of the segment.

We can be computed the connectivity probability from Theorem 1 in [14].

$$Pc_i = \sum_{i=0}^{\left[\frac{L}{r}\right]+1} \frac{\left(-\lambda\, e^{-\lambda r}\,(L-(i-1)r)\right)^i}{i!} - \lambda\, e^{-\lambda r} \sum_{i=0}^{\left[\frac{L}{r}\right]} \frac{\left(-\lambda\, e^{-\lambda r}\,(L-ir)\right)^i}{i!} \tag{8}$$

With

Pc_i : represent the connectivity probability of segment i.

L : represent segment length.

r : represent vehicle radio range .

Pc_i equal 1 if every pair of vehicle in segment i are connected, as shown in figure 3.

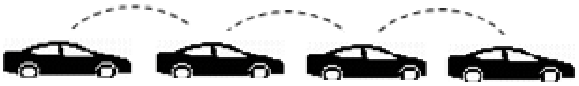


Figure 3. Example of connected vehicles

4.3. Second phase: RSUs candidate and optimal positions

To explain the different steps, we use a scenario of 12 segments and 9 intersections using SUMO as shown in figure 4.

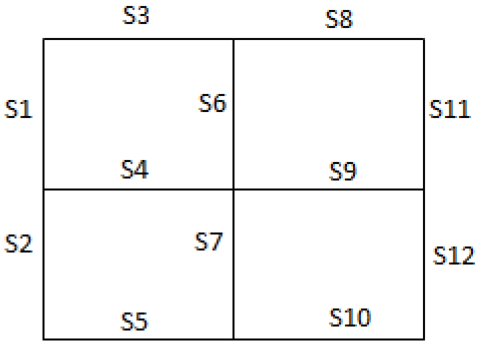


Figure 4. Scenario with 12 segments and 9 intersections

4.3.1. Select RSUs candidate positions based on the connectivity probability

In the first, we choose the candidate positions based on information of connectivity probability. We use the equations (2), (3) and (4) to maximize the system connectivity probability where the system connectivity probability is average of connectivity probability (eq. 9) of all segments in the area studied.

$$PS = (Pc1 + Pc2 + \cdots + Pcn)/n \tag{9}$$

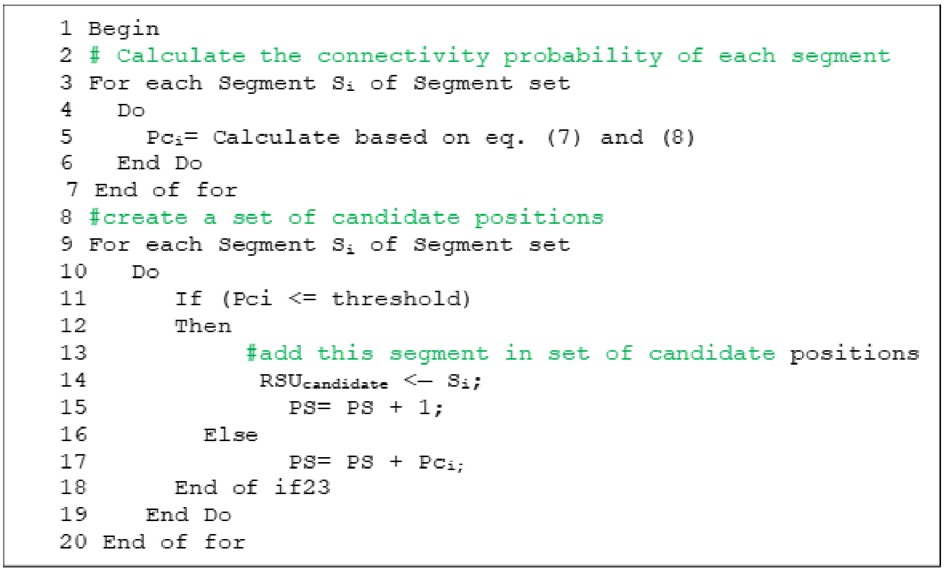
Where n represent number of segments in the area studied.

In the first, we compute the connectivity probability of each segment (Pci) based on eq. (7) and (8). Figure 5 and table 3 illustrate the obtained values for each segment such as Pc1=0.2885, Pc2=0.1035, Pc3=0.3795, Pc4=0.4917, Pc5=0.2301, Pc6=0.4829, Pc7=0.4723, Pc8=0.2949, Pc9=0.4906, Pc10=0.1123, Pc11=0.2044 and Pc12=0.1626. So, the system connectivity probability $PS = 0.3094$.

Table 3. Connectivity probability of segment and system

Segment	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	PS
Pci	0.2885	0.1035	0.3795	0.4917	0.2301	0.4829	0.4723	0.2949	0.4906	0.1123	0.2044	0.1626	0.3094

Then, we set the threshold of connectivity probability to determine the candidate positions according to follow algorithm:



```
Begin
# Calculate the connectivity probability of each segment
For each Segment $S_i$ of Segment set
  Do
    $Pc_i$= Calculate based on eq. (7) and (8)
  End Do
End of for
#create a set of candidate positions
For each Segment $S_i$ of Segment set
   Do
      If (Pci <= threshold)
      Then
           #add this segment in set of candidate positions
            $RSU_{candidate}$ <— $S_i$;
              PS= PS + 1;
        Else
              PS= PS + $Pc_i$;
      End of if23
    End Do
End of for
```

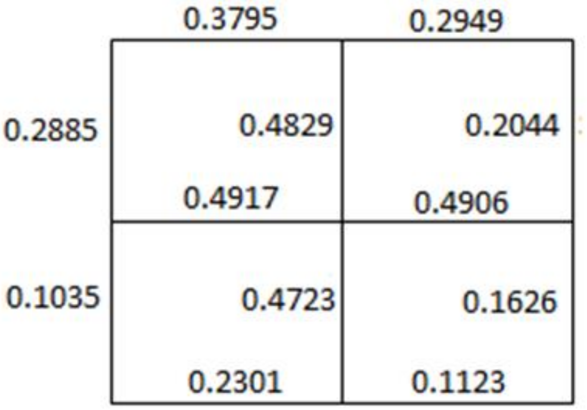


Figure 5. connectivity probability of each segment

If we set the threshold equal to 0.25, the system connectivity probability becomes $PS = 0.5942$ and there are four candidates position to deploy RSUs as figure 6 shows (red point represent candidate positions). So, the result is the set of candidate positions *m*.

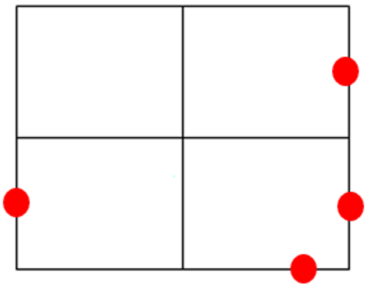
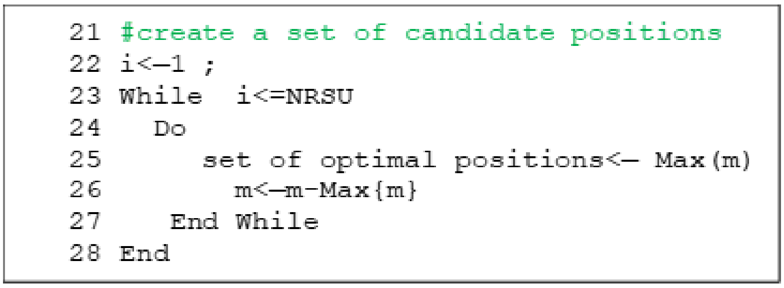


Figure 6. candidate positions

4.3.2. Selection of optimal positions of RSU based on the accident number

In this section, we use the equations (5) and (6) to select optimal positions among set of candidate positions $\{m\}$. We choose the segments with higher accident number as best optimal positions following this algorithm:



```
#create a set of candidate positions
i<-1 ;
While  i<=NRSU
  Do
     set of optimal positions<- Max(m)
       m<-m-Max{m}
    End While
End
```

If we set 2 at the threshold of RSU (NRSU), therefore, the two segments which have the maximum number of accidents among the set of candidate positions will be selected as the optimal positions as figure 7 illustrate.

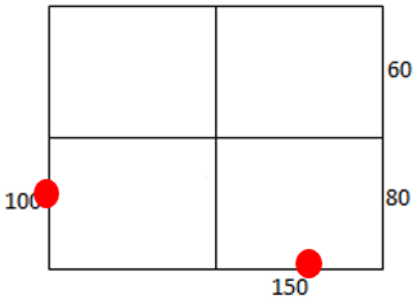


Figure 7. optimal positions

5. RESULTS AND PERFORMANCE

In this section, we present simulation results of proposed ORSD approach with different scenarios. We use the simulator of urban mobility (SUMO) for generating different traffic scenarios. We develop scripts to extract different information as density, speed and travel time in each segment. Then, we develop ORSD algorithm to calculate connectivity probability for each segment and selects optimal RSUs positions using C++ programming language. Table 4 gives the simulation parameters.

Table 4. Simulation parameters

Variable	Value
Number of segments	100
Segment density (vehicle/km)	1 to 25
Average Speed	15 to70
Segment Length	500
Radio range of vehicle	250
Population size	20000
Number of accidents in segment	1 to 20
Threshold of connectivity probability	0.1 to 0.9

To evaluate our solution’s performances, we valuate two criteria’s:

- The number of necessary RSUs to guarantee threshold of connectivity probability,
- The coverage rate of accident area.

Our objective, we do not need to cover the all area studied but we use only some RSUs candidates. In figure 8, we plot RSUs candidates’ positions depending on the threshold of connectivity probability average (*PS*) in the all area. To get *PS* = {0.1,0.2} we do not need any RSUs. By cons, to get *PS*=0.7, there are 17 RSUs candidates’ positions by applying the equation (2). We notice high connectivity probability, we must use more RSUs.

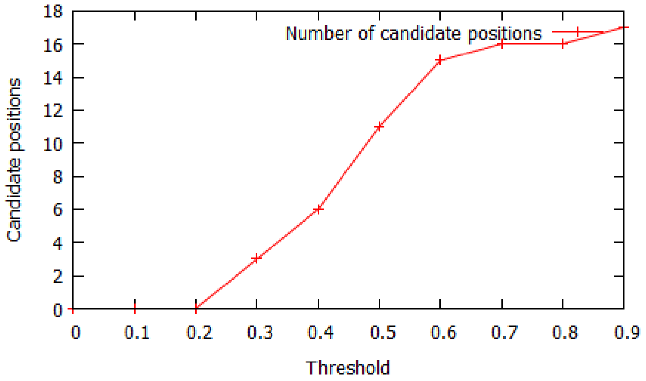


Figure 8. Connectivity probability vs. RSUs candidate positions

Then, we introduce the accident in each segment to compare between RSUs candidates’ positions and optimal positions as figure 9 shows. We note that among 11 positions candidates we use only 7 as optimal positions i.e. to coverage max accident area in the segment with low connectivity, we use 7 RSUs Positions as optimal positions among 11 candidates’ positions.

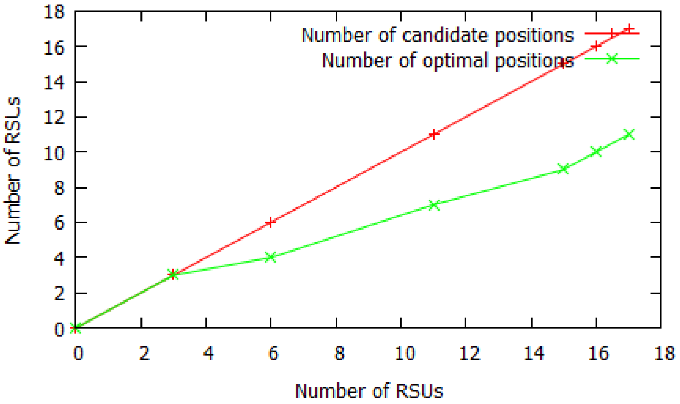


Figure 9. RSUs candidates positions vs. Optimal positions

As table 5 shows, the coverage AC rate could reach 100% (scenario 3), if number of deployed RSUs close to the number of RSUs candidates as scenario 2 and 6 show. By cons, the rate of coverage AC is low when we use less RSUs than RSUs candidates' positions as scenarios 4 and 7 show.

Table 5. Results

Scenarios	Threshold	RSUs	RSUs candidate	Accidents number	Coverage AC number	Coverage AC rate
1	0.3	2	5	644	355	55.10%
2	0.3	4	5	444	437	98,42%
3	0.3	5	5	560	560	100%
4	0.5	2	13	813	308	37,88%
5	0.5	6	13	1176	897	76,27%
6	0.5	9	13	1234	1132	91.73%
7	0.7	2	20	2086	370	17,73%
8	0.7	8	20	1917	1246	64,50%
9	0.7	12	20	1879	1681	89,45%

Our objective is to find better coverage accident area in segment with low connectivity for a given number of RSUs

6. CONCLUSION

In this work, we aim to maximize the coverage accident in isolated segments. To do that, we propose a mathematical modelling of system and we propose ORSD approach (Optimized RoadSide units Deployment). In this proposed approach, we calculate the connectivity probability for each segment based on the traffic information in the studied area. We select the RSUs candidates' positions based on the information of connectivity in each segment. Afterward, we select the optimal positions based on proposed objective function to maximise the coverage of accident zones. Proposed ORSD approach is used in different scenarios urban and highway. We used scenarios with around one hundred segments. The results obtained show the convergence of the proposed solution towards a better coverage of accidents zones in segments with low connectivity and with a reduced number of RSUs.

In general, the proposed solutions optimize the deployment of RSUs in high-density areas. We have offered coverage of areas with high accident risk and low vehicle density. Currently we are working on a solution based on a bio-inspired approach. And we test proposed ORSD approach on real areas.

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