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Enhancing VANET Connectivity through a Realistic Model for RSU Deployment on Highway

Roaa Jasim Mousa[1], Árpád Huszák[2], Mahdi Abed Salman[1]

[1] Department of Computer Science, University of Babylon, Iraq

[2] Budapest University of Technology and Economics Budapest, Hungary

Roaa_jasim@yahoo.com
Huszak @hit.bme.hu
mahdi.salman@uobabylon.edu.iq

Abstract. This study proposes a cost-effective deployment of the RSUs, aiming to improve the connectivity of VANET in highway scenarios. Based on real data, we present a general model that provides minimum number of candidate RSUs with their required positions to keep a given segment of highway always connected. The model employs some concepts of graph theory to test the connectivity in addition to stochastic (but based on realistic data) positioning of vehicles in a simulated environment The provided results show the efficiency of RSU deployment for any segment of a highway when real data is available in order to cover all vehicles on the highway.

Keywords. Vehicular Ad hoc Networks VANET, Road Side Unit, Graph theory, connected components, gap.

1. Introduction

Nowadays, with the improvement of the vehicle industry and the technology of wireless communication, vehicular ad hoc networks (VANET) are becoming one of the most critical study areas because of their significant contribution to the development of intelligent transportation system ITS [1].

VANET apply dedicated short-range communication (DSRC) based on IEEE 802.11p wireless technology, which is a multi-hop communication scheme using geographic position, enabling exchange information between network nodes [2] .

These two kinds of communications are carried out with help of vehicular Onboard Units OBU and Road Side Units RSUs.

On-board unit (OBU) is a device supplied to the vehicles. OBU provides information gathered from supporting sensors deployed in vehicle such as the position and speed of vehicles in addition to communication with OBUs in neighbor vehicles creating Vehicle to Vehicle communication (V2V).

The road side units (RSUs) are towers deployed alongside the road acting as an access points and/or routers with long range signal coverage. RSU may have a dedicated link with datacenters or Internet to serve vehicles and pedestrians with information creating what known as a vehicle-to-infrastructure (V2I) communications [3] [4].

This paper provides the following contributions 1) increases the connectivity of VANENT through deploying minimal number of RSUs on the highway efficiently. 2) presents a general method that determines the best locations for deploying candidate RSUs on highway segment.

The rest of the paper is organized as follows, section two surveys the related works. The proposed model is presented in section three. Section four presents simulation results, while section five conclude the study.

2. Related works

Most VANET research has suggested many solutions for improving VANET in different road environments.

Authors in [5] modified mathematical models based on clustering to study communication in highway scenarios when RSUs regarded as relay nodes. They use the data from PeMS[1] and RSUs deployed uniformly in the road.

In [6], authors identified an approach for RSU deployment in urban scenarios with real data called a density-based method. The RSU deployed in traffic lights according to high density of the area. Kim et al [7], offered a model for deploys RSUs in the urban scenario with real data. The downtown map was converted to a grid graph. The RSU is fixed in on the center of the grid cell. Every RSUs are weighted according to the density. In [8] , the authors developed an RSU deployment scheme based on the graph theory of real data in the urban scenario. The nodes of the graph represent the traffic signal controllers that regarded as a candidate location for the RSU. It takes the RSU interconnectivity, the number of links covered by each RSU and the RSU installation cost into consideration .In [9], authors suggested finding an optimal location to deploys the RSUs in urban scenarios with real data. In their study, they proposed using the intersection as a candidate location to deploy RSUs. The graph theory has been used to represent he network of the road. In [10], the authors trying to find the best position when deploying uniform RSUs on urban scenario that are bounded with limited budget and the set delay. They used genetic algorithm to maximize the number of roads covered by deploying RSUs. In [11] the authors offered a model to solve the problem of a Maximum Coverage with Time Threshold to improve the deployment of roadside units in urban scenario with minimum number of RSU. In their model, the road network represented as graph. The road intersection considered as RSU location candidate when creation the graph. In [12] , authors proposed a model to study and analysis the connectivity probability of vehicles traveling on highway scenario with one entry and exit, and multiple RSUs where these RSUs are connected via optical fibers. They used a dataset that is generated randomly. The highway is divided into the segment according to the number of RSUs every segment has two RSUs deployed at both ends where entry and exit is uniformly distributed along the road.

3. Proposed model for RSUs deployment.

VANET connectivity is enhanced when RSU bridge the disconnected area. Based on real data set from PeMS the model has its reality.

Model starts with modeling the highway. Based on PeMS dataset, the selected segment of the highway has a set of sensing stations denoted as $S = \{s_1,\ldots, s_k\}$, where k is the number of stations. Each station is previously installed on the road at specified geographical location. They measure the traffic flow and speed at its position and send readings to known datacenter. A sub-segment is bounded by two neighbor stations s_i, s_{i+1}.

We operate on these states to find where frequently gaps appear. Then, these gaps are filled with RSUs using one of two methods. The general model consists from several steps as it presented in the following:

For given segment of a highway road do:

1. Compute traffic measures for different times of the day.
2. Initialize the RSU list,

[1] Real data from California transportation.

3. For each time of the day do:
   a. Distribute vehicles in the given segment to rebuild the highway state to create a virtual snapshot. Store vehicle positions in list V.
   b. Represent V2V network as graph using list V (vehicles the nodes/communication possibility the edges).
   c. If the resulted graph is not connected, then
   - Locate gaps in the road.
   - Distribute RSUs within each gap.
   - Add new RSU to global list.
4. If not stop condition is met goto step 3
5. Drop redundant RCUs from global list.
6. Check the connectivity for whole day using remaining RSUs many times.
7. Compute the successful rate by dividing the number of connected graphs by total number of checks.

Using global list of RSU, and dropping redundant. We take the average of the number of RSUs deployed in a predefined number of iterations. It uses a predefined number of iterations *n* to determine the number of vehicle distributions.

Each step of the model is discussed in detail in the following:

3.1. Vehicles distribution in highway

Based on real measures, several distribution of vehicles positions in a highway produces different road snapshots. It also provides us with most possibilities for vehicle positions in given highway segment.

Vehicles distribution in each sub-segment is done according to its density. The number of vehicles to be distributed within a sub-segment, v_i, is calculated as the density measured at its first station, s_i, multiplied by the length of the sub-segment as shown in formula 1.

$$v_i = density_{s_i} \times geodic\langle s_i | s_{i+1}\rangle \qquad (1)$$

v_i vehicles are placed within each sub-segment normally at random. Each vehicle is assigned geodic coordinates (x_p, y_p) i.e. latitude and longitude. They are computed as following:

let $s_i=(x_i,y_i)$, $s_{i+1}=(x_{i+1},y_{i+1})$ be the coordinates of stations *i* and *i+1* respectively of sub-segment *i*.

The latitude coordinate x_p of a vehicle is bounded between (x_i, x_{i+1}). It is sampled normally at random as shown in formula 2.

$$x_p = \min x_i, x_{i+1} + random \times (\max x_i, x_{i+1-} \min x_i, x_{i+1}) \qquad (2)$$

The longitude coordinate y_p is calculated through linear interpolation according to the formula 3.

$$y_p = y_i + \left(x_p - x_i\right)\frac{(y_i - y_{i+1})}{(x_i - x_{i+1})} \qquad (3)$$

Repeats the same steps above to all the sub-segments in the selected highway segment.

The coordinates of all vehicles of all sub-segments are collected in one list that is denoted as $V = \bigcup_{i=0}^{i<s} v_i$, where *s* is the number of sub-segment.

3.2. Build connectivity graph

This work considers IEEE802.11p technology to create V2V connections. The VANET is modeled as graph G = (V, E) where V = {v_1, v_2,…,v_h} is the set vertices (or vehicles) distributed in the previous step. E is the set of links between vertices. A link (v_i, v_j) is existing in the E, if vehicles v_i and v_j are laying within the transmission range *r* of each other.

The purpose of the creating graph is to determine where the graph is disconnected, we call it gap. It is computed through finding the graph components.

3.3. Locating gaps

Using the number of components from previous step, we find where these gaps are, through the following:

Find the first and last vehicles in each component through computing the distance of each of its composing vehicles to nearest leading station.

Sort components according to their location on the highway based on the location of their first vehicle.

Determine the gaps boundaries based on the location of the last vehicle of component *i* and the first vehicle of the component *i+1*.

In this study, for simplicity, isolated nodes are deleted from the graph. As a result we obtain a set of gaps G with each has two boundaries points $g_i(x_1,y_1)$ and $g_i(x_2,y_2)$.

3.4. Deploying RSUs within gaps

RSU is deployed in the middle of the gap if the length of the gap was less than or equals to the double transmission range, otherwise, enough number of RSUs must be found through dividing the gap length by r according to the equation 4.

$$count_{rsu} = \frac{length_{gap}}{r} \qquad (4)$$

The position of first RSU is placed far by distance r meters from the $g_i(x_1,y_1)$. The RSU coordinates (latitude and longitude), are calculated as follow:

The longitude for first RSU is calculated by

$$x_{rsu\,1} = x_{1\,gi} + r (5)$$

where $x1_{gi}$ is the latitude of the gap beginning coordinate $g_i(x_1,y_1)$.

The latitude of the remaining RSUs

$$x_{rsu_{i+1}} = x_{rsu_i + 2r - \varepsilon} \qquad (6)$$

Where ε is the overlap parameter that allow two neighbor RSU to interconnected. Then longitude of all RSUs is calculated using linear interpolation as made with vehicle distribution in section 3.1. At the end, the locations coordinate of the RSUs is collected in a list for the selected road segment.

3.5. Dropping redundant RSUs

At the end of each iteration, RSUs are then reduced by taking the average number of them between any two neighbor.

3.6. Check the connectivity to whole the day

To test the efficiency of the candidates RSUs of the proposed model, it is checked if they provide coverage for the whole day even when the measure varying from hour to another.

3.7. Performance measure

The performance measure is used to assess the efficiency of the proposed method. To know if the candidate RSUs play a key role on producing connected VANET, we distribute vehicle in the road segment for different day times for several iterations K. Then, we compute, k, the number of connected graph resulting from vehicle distribution with candidate RSUs provide. To have an indication for successful rate, it is computed as

$$performance\ rate\% = {}^{k}/_{K} \times 100 \quad (7)$$

4. Results

To evaluate the performance of the proposed model, the python language is used to build a custom simulator. A selected segment from the freeway SR52-E, district 11, in San Diego city of California. Figure 1 and 2 show the data description of selected highway.

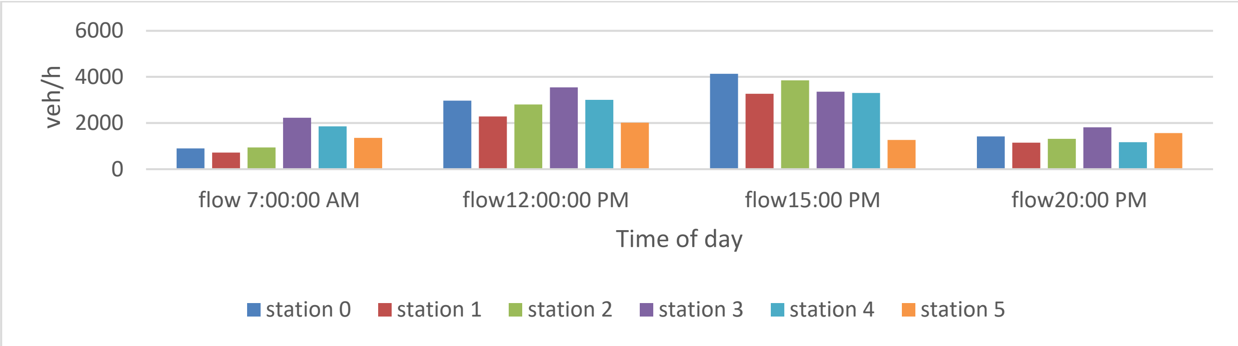

Figure 1. Traffic flow collected from SR52-E on Friday march, 1 2019

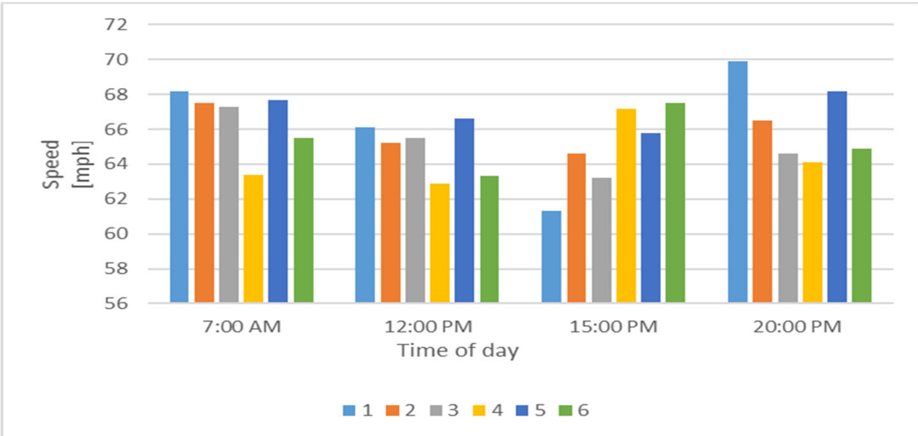

Figure 2. Vehicles' speed extracted from the PEMS on SR52-E Friday March,1 2019

4.1. Parameter setting

The street consists of multiple stations (Individual sensor point), multiple lanes, every lane have different flow and speed and the area between every two station has different lanes. In this work we use street about 10.5 km that have 6 station The simulation is performed with four different periods with each time lasting for 1 hour. The times are 7 am, 12 pm, 15, and 20. Transmission range is taken 300 meter as it in most literature. The overlap between any two neighbor RSUs is a circle with 100-meter diameter. i.e. the distance between them is 500 meter. The number of iterations is equal to 150.

The road is divided into five sub-segments. Each sub-segment uses the density of its leading station to calculated expected number of vehicle to distribute within its boundaries. The density for each station is computed in the table 1

Table 1: The density for every segment during four different time

Time of day	**Density 7:00 AM**	**Density12:00 PM**	**Density at 15:00**	**Density at 20:00**
Station 1	12.79472	44.78153	67.17229	20.79142
Station 2	10.055	31.60143	44.52929	15.80072
Station 3	36.20989	108.6297	152.8862	52.30318
Station 4	46.00015	73.18206	64.81839	37.63649
Station 5	27.43699	45.19033	50.03215	17.75334

The result of vehicle distribution for the given highway segment is shown in figure 3.

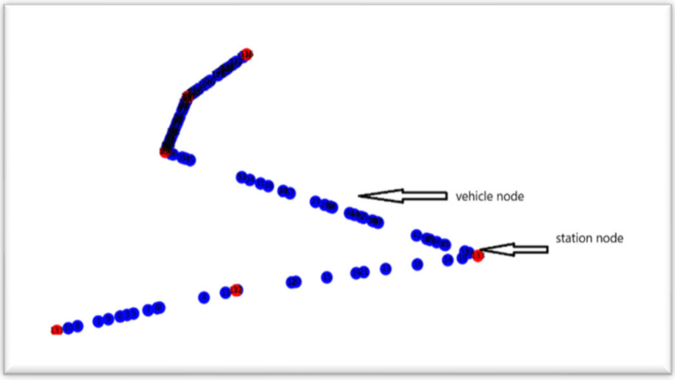

Figure 3. Vehicle distribution

The gap is the area with no link between two vehicle figure 4 show the gap in the road

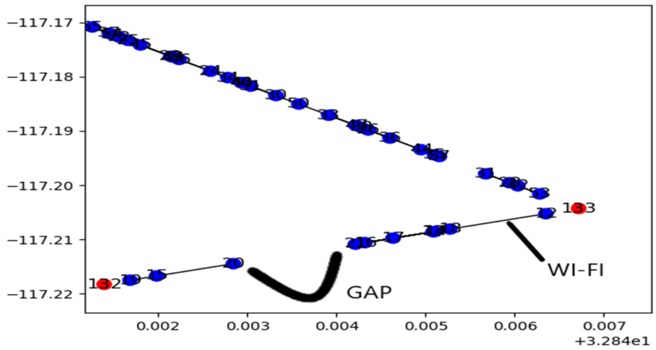

Figure 4. Road gaps

The rate of connectivity graph is checked. It represents an indication of the higher connected times, the right positions of RSUs that provide connectivity for the road throughout the whole day.

Figure 6 represents the connectivity rate before and after deployment RSUs in different time of day.

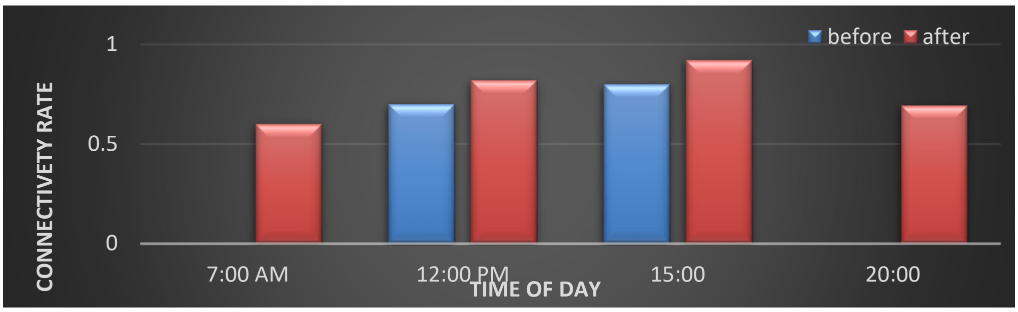

Figure 5. successful rate before and after deployment RSUs

We can see that the connectivity rate equals zero before deployment of the RSUs on the road at time 7:00 am and 20:00. And it about 70% and 80% for times 12 pm and 15 am respectively.

After deployment of the RSUs, the connectivity rate increased to only little. While it is increased dramatically for time 7:00 am and 20:00 to over 50%.

Table 2 shows the connectivity rate for our deployment. We can observe from the Table 2 that the provides a higher connectivity rate when increase the N. Also, this method required 9 RSUs to give 0.682 of connectivity rate so we need to increase the iteration counter to reach full coverage.

Table 2. connectivity rate for average based method

N	Connectivity rate for average based method
20	0.35
50	0.42
100	0.571
150	0.682

5. Conclusions

We study the problem of vehicular connectivity in the highway scenario at different times of the day. We present a model to propose a candidate positions of RSUs used enhance network connectivity. Based on the graph components we find the best positions for RSUs deployment. Average based method provides coverage with a good connectivity rate. It is simple and straightforward. Its success depends on the estimation of a suitable iteration counter. The result of our simulation shows candidate RSU can be used for ensuring information delivering in a frequently fragmented VANET. The dense zone in a road can play an essential role in minimizing the number of RSUs required to cover the road. The highway is filling with RSUs based on the transmission rate only may not a cost-effective solution. Several virtual deployments (projections) for vehicles in the road model based on real data show a sufficient replacement for dynamic models. In the future work, it would be important to find a way to include a buffering mechanism in the proposed model. load-balancing for RSUs could also be improved by using one type of centrality measurement.

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