Binary Programing Model to Optimize RSU Placement for Information Dissemination

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Abstract: Vehicular communication systems are developed not only to increase safety but also for mobility of road transportation. Roadside units (RSU) are the prominent elements of this technology. This equipment is installed on roadsides and at intersections to gather traffic information from vehicles and send messages and alarms to vehicles. Due to the costly implementation and maintenance of this equipment, determining the number of RSUs and their placement are the important problems. In this paper, we propose a novel binary programming (BP) model to the placement of RSUs beside a road to maximize information dissemination to vehicles. This approach makes decisions based on the number of curves, number of on-ramps, accident rate, weather condition, and cost limitations. The proposed model is applied on Tehran to Pardis Freeway. According to the computational experiments, four operational phases are obtained to equip the whole road for information dissemination.

1 INTRODUCTION

To begin with, vehicular communication system (VCS) is a one of the new technologies in transportation system for increasing safety and mobility. This technology includes two primary elements. Generally put, on-board units (OBUs) are installed in vehicles in order to gather sensor data, particularly vehicles' speed and position, and also send and receive messages to/from other elements. The next element is a roadside unit (RSU) which can be installed on roadsides. RSUs can act similar to a wireless LAN access point and provide communications with the infrastructure and OBUs of vehicles through dedicated short-range communication (DSRC). To elaborate on, RSUs have two main functionalities: analyzing traffic conditions based on data received from OBUs and disseminating travel and safety information to vehicles. We have appointed the name *information dissemination,* which includes the following information to drivers:

- Weather condition, in particular rainy, foggy, or slippery roads;
- Road speed limits in curves and intersections;
- Alerting vehicles for entering from an on-ramp;
- Alerting drivers for decreasing speed or changing path when an accident is occurring on a road.

The entire area of the road must be completely covered in order to take advantage of the highest level of safety in connecting vehicles until the position of the vehicle is accessible by infrastructure online. Nevertheless, due to the high cost of equipping the entire road, we can consider a step by step strategy according to the importance of each segment of the road. Because of the limitation of technology, RSU antennas cover 500m surrounding area. Therefore, RSUs must be installed every 1km to provide continuing coverage on a road. It is preferable to cover part of the road and select some appropriate locations for installing RSUs because of the high cost of implementation and lack of market penetration of vehicular communication system. Besides, appropriate locations are those with high potential for disseminating the above information at the right time (see Fig. 1).

As a case in point, suppose that there are 80 candidates for installing RSU on a freeway with the length of 80 km; if we want to install 10 RSUs on this road, then 3.5×10^8 different modes can be expected. The subject of this paper is to determine the optimal placement with the strategy of maximum nformation dissemination.

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Aslam (Aslam,2011) posed the problem by obtaining optimal placement of RSUs along freeways with the goal of minimizing the average time taken for a vehicle to report an event to a nearby RSU. Ignoring the importance of alert as well as lack of consideration of various RSUs in segments, in which the probability of accidents is higher, are the disadvantages of this work.

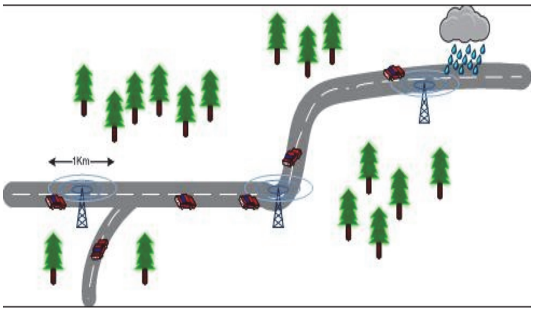

Figure 1: RSUs placement schema.

Cavalcante et al. (Cavalcante,2012) followed the issue with utilizing genetic and greedy algorithms and determined the placement of RSUs in urban areas with the maximum coverage of circulating vehicles.

Rashidi (Rashidi,2012) proposed a method to calculate the distance between RSUs (gap) on a freeway based on the data delivery ratio, data collection update interval, and size of measured data.

Indeed, in these studies, no limitations are considered for cost; furthermore, the number and location of RSUs have been calculated on the basis of limited data buffering. Similar works for the location and placement can be pointed out for the determination of locations for RSUs in a city. The main difference between these works is the dependence of placement on traffic and network topology.

Rizk (Rizk,2014) presented a greedy method for RSU placement in urban and rural roads, which covered the whole road districts and minimized the overlap between RSUs.

When all parts of the road are covered by RSUs, it is possible to inform any vehicles in all parts, which is called *full information dissemination*. The aim of this research is to obtain a greater level of information dissemination to vehicles according to the restrictions on the cost of equipment and importance of segments. The main contribution of this paper is to propose a novel binary programming model for the placement of optimal roadside units beside freeways to maximize information dissemination of the road based on cost constraint and segment characteristics. In Section 2, the proposed model is fully introduced. The computational results and discussion of the model's performance are presented in Section 3. In the last section, some conclusions from the research output and their limitations are reported.

2 MATHEMATICAL MODEL

Informed vehicles that are on the border of coverage and moving toward the scene of accident act as temporary RSUs for a certain period of time. These vehicles make a brief stop and periodically rebroadcast the safety message to mimic the function of the conventional roadside units (Mehar,2015). When an accident occurs, wireless technologies enable vehicles to share warning messages with other vehicles using vehicle to vehicle (V2V) communications. Since RSUs are usually very expensive to install, authorities limit their number, especially in the suburbs and areas with large population, making RSUs a priceless resource in vehicular environments. Additionally, opting locations near on-ramps, curves, and hazardous segments could have more benefits.

In this section, first, a BP model is introduced for optimizing RSU placement for information dissemination. In this mathematical model, the selected locations should have a greater impact on the objective function optimization. If each RSU covers within the radius of r and L is the length of the road, therefore $L = N/(2*r)$ represents the locations or segments which are candidates for installing RSUs and, in fact, some of them should be selected with regard to the financial restrictions. The proposed model for RSU placement can be expressed as follows:

$$Max \sum_{i\in I} (C_i+W_i)y_i \tag{1}$$

Subject to

$$W_i = W_{z_{j+1}} \prod_k (1-y_k)\ ,\ k<i,\ \ y_k \in z_j,\ \forall i \in I,\ \forall j \in J; \tag{2}$$

$$C_i = A_i + R_i + T_i\ ,\quad \forall i \in I; \tag{3}$$

$$\eta . \sum_{i\in I} y_i \le F_{Total}\ , \tag{4}$$

$$y_i \in \{0,1\}\ ,\ \forall i \in I; \tag{5}$$

where y_i is a decision variable for installing RSUs. It is equal to one if RSU is installed in the i^{th} segment; otherwise, it is zero — each road is divided into N

segments and each segment is equal to 1 km. Meanwhile, i indicates the segment $i \in I$; $I = \{1, \dots, m\}$ and j shows weather zone $j \in J$; $J = \{1, \dots, n\}$, in which $m \leq n$; A_i shows the accident rate of the i^{th} segment that should be normalized, W_i represents the weather indicator of the i^{th} segment, R_i implies the number of the on-ramp in the i^{th} segment; T_i represents the number of road curves in the i^{th} segment; Q_i is the number of all accidents occurring in the i^{th} segment once a year; V_i suggests the volume of annual average of daily traffic (AADT); Z_j reveals a set of segments located in the j^{th} weather zone of a road; and W_{z_j} represents the weather indicator of the j^{th} zone, which is between zero and one ($W_{z_j} \in [0\ 1]$). Moreover, some other parameters are defined as follows: F_{Total}: Total financial budget for implementing the whole project; ŋ: Implementation cost for an RSU; r: Radius of an RSU coverage area; L: Length of the road; and N: Number of candidate RSU locations. Additionally, by defining accident rate — the average number of accidents per 1.000.000 km of driving in each segment, according to (Golembiewski,2011)we conclude that:

$$A_i = \frac{Q_i \times 1{,}000{,}000}{V_i \times 365 \times 2 \times r} \tag{6}$$

Furthermore, objective function (1) optimizes the location of RSUs, in which maximum information dissemination to vehicles is achieved. Constraint (2) reflects that there is just one weather indicator value for all segments, in particular $j \in J$ zone. Besides, sending weather condition information is sufficient just by one RSU to the next zone $(j+1)$. Consequently, the influence of one of them is considered in the objective function. In other words, the effect of weather indicator should not be calculated in the segments under one zone. $y_k \in z_j$ includes segments within the j^{th} zone. The coefficient of y_i in objective function includes a number of the on-ramps, curves, and accident rate in the i^{th} segment which is considered in constraint (3). Constraint (4) ensures that financial limitation is met and constraint (5) defines the decision variables only for the segments in which the RSU can be installed.

3 COMPUTATIONAL EXPERIMENTS

To analyze the impact of the proposed model on information dissemination, a real case study — Tehran to Pardis Freeway (see Fig. 2) — with 11 curves, 13 ramps of about 20 km with 0.37 total average accident rate, and 4 zones were considered, the full description of which is presented in Table 1.

In general, for normalizing the accident rates, we divided each accident rate into the segments on the maximum value of all accident rates. In addition, the history of the road for determination weather indicator during a year was investigated and a number between 0 and 1 was assigned to each segment; 1 represents an unfavorable weather, such as foggy or rainy realm on most days or slipping road condition during cold days, and 0 indicates pleasant weather as well as road surface condition in that area during a year. Weather conditions are the same in a number of adjacent segments (because of the segment size). Besides, we considered weather zones (z_j) and assigned segments within the respective zone. Considering an RSU throughout a zone was adequate to warn drivers.

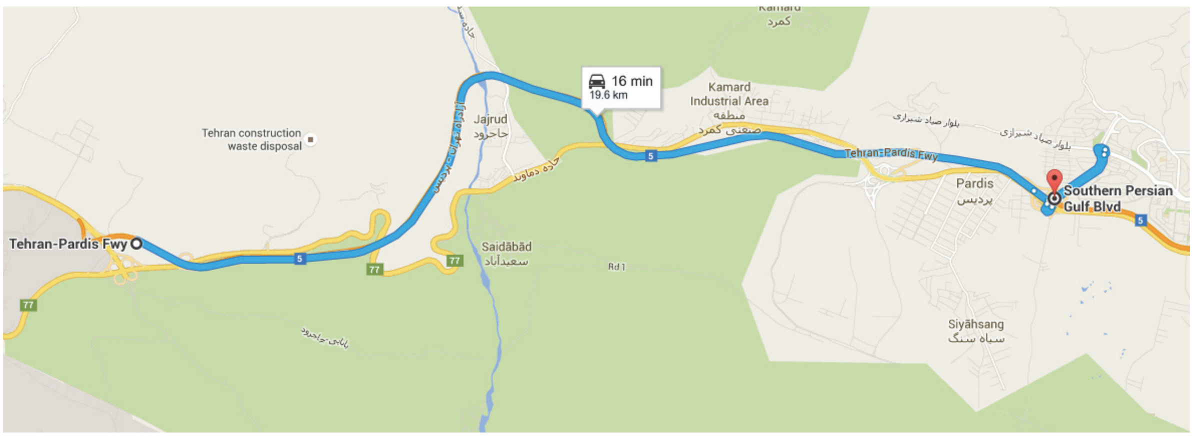

Figure 2: The map of Tehran to Pardis Freeway.

Table 1: Detail of Tehran to Pardis Freeway case study.

Segments (i)	T_i	(R_i)	(A_i)	(z_j)	(W_{z_j})
1	1	1	0.41	z_1	0.2
2	1	1	0.45	z_1	0.2
3	0	2	0.63	z_1	0.2
4	1	0	0.3	z_1	0.2
5	0	0	0.24	z_1	0.2
6	2	1	0.81	z_2	0.3
7	1	0	0.4	z_2	0.3
8	0	0	0.16	z_2	0.3
9	1	0	0.24	z_2	0.3
10	0	2	0.67	z_2	0.3
11	0	0	0.19	z_3	0.7
12	1	0	0.39	z_3	0.7
13	0	1	0.27	z_3	0.7
14	1	0	0.3	z_4	0.5
15	1	2	0.79	z_4	0.5
16	0	1	0.1	z_4	0.5
17	0	0	0.1	z_4	0.5
18	0	1	0.21	z_4	0.5
19	1	1	0.55	z_4	0.5

Additionally, even though the objective function (1) includes binary variables, constraint (2) is not a linear equation. Ergo, to transform this constraint into a linear one, some new binary variables are defined (Chen,2010). For example, for z_3, we can define $u_{k,j}$, which is equivalent to the multiplication of two binary variables and related constraints as follows. These constraint ensure that variable $u_{k,j}$ is 1 if and only if the related two variables are equal to 1; otherwise, it is zero. For further details, see the related book (Chen,2010), page 66. As a case in point, if weather zone z_3 includes y_1, y_2, and y_3 segments, constraint (2) can be transformed into the following constraints by defining $u_{11,12} = y_{11}.y_{12}$:

$$W_{11}=W_{z_3} \tag{7}$$

$$W_{12}=W_{z_3}.(1-y_{11}) \tag{8}$$

$$W_{13}=W_{z_3}.(1-y_{11}-y_{12}+u_{11,12}) \tag{9}$$

$$2u_{11,12}\le y_{11}+y_{12} \quad , \quad y_{11}+y_{12}\le 1+u_{11,12} \tag{10}$$

$$u_{11,12}\in\{0,1\} \tag{11}$$

where the values of $w_{11}, w_{12}, and\ w_{13}$ are the coefficients of $y_{11}, y_{12}, and\ y_{13}$ in the objective function (1); using the modified variables repeatedly, the model could turn into a BP model. Considering

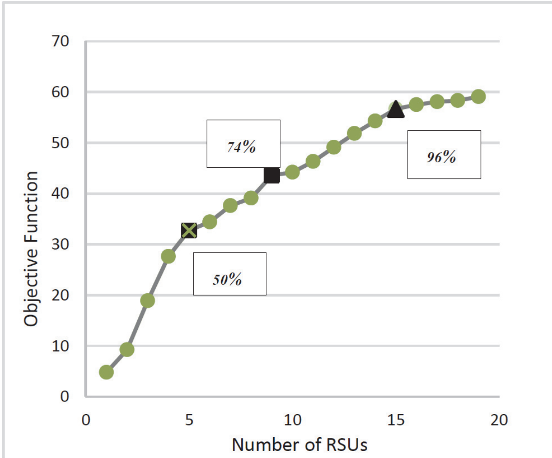

Figure 3. The trend of the objective function.

this matter, the model is a binary programming (BP) problem and can be solved using common solvers. If the segments have great length, the number of auxiliary variables will increase for solving the problem. As a case in point, if a segment has 20 RSU, we need 19 auxiliary variables for linearization in addition to the 20 binary variables. The simple case study was solved by the binary programming solver CPLEX 12.3 with AIMMS 3.12 software. We used the default parameters of CPLEX. Experiments were carried out on an MSI laptop, 4GB of RAM memory, a 2.2-GHz processor. Fig. 1 shows the situations in which the number of RSUs was increased from 1 to full coverage of freeway (19 RSUs). When all parts of the road were covered by RSUs, it is possible to inform any vehicles in all parts; then, we can achieve full information dissemination. The aim of this research is to obtain a greater level of information dissemination to vehicles according to the restrictions on the cost of equipment and importance of segments. Results show that, with the placement of 5 RSUs, we can achieve more than 50 percent of full information dissemination. Moreover, sensitivity analysis on the number of RSUS indicates that more than 15 RSUs beside the road do not have a significant effect on the objective function.

The effect of adding each RSU to the objective function is shown in Fig 2. According to Fig 2, major changes can be seen after the ninth RSU, when 74 percent of full information dissemination is achieved.

According to the results, investors can present a pattern for funding and phasing the project, as one of the best characteristics of the proposed model. Hence, freeway equipment can be done in four phases. The first phase, placement of 5 RSUs, is equivalent to

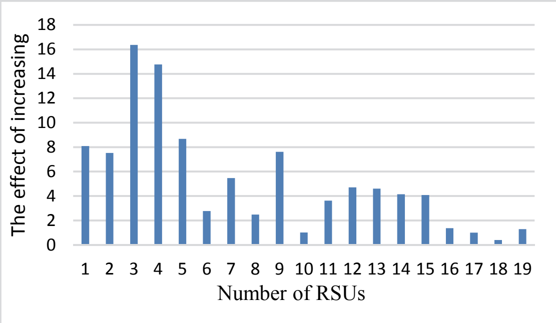

Figure 4: The effect of increasing each RSU on objective function.

achieving more than 50 percent of full information dissemination. The second phase, placement of 4 next RSUs, is equivalent to fulfilling almost 74 percent of full information dissemination (totally 9 RSUs). The third phase, placement of 6 other RSUs, achieves 96 percent and, in the last phase, 4 final RSUs have slight effect on the objective function.

4 CONCLUSION AND FUTURE WORK

By the same token, Roadside unit (RSU) is one of the substantial elements in vehicular communication systems. This equipment could be installed around a road and send messages to vehicles. These messages such as weather condition, limit speed warning, and accident warning alerts are important for drivers in order to have safe and efficient driving. Also, it is ideal to cover the whole road by RSUs; nonetheless, it is not a cost-effective solution due to the costly implementation and maintenance of this equipment and lack of market penetration of vehicular communication system. In this paper, a BP optimization model was proposed to choose an appropriate placement for RSUs. This approach made decisions based on the number of curves, number of on-ramps, accident rate, weather condition, and cost limitations. The proposed model was applied to one of the suburbs of Tehran freeway ─Tehran to Pardis. This model was solved precisely using CPLEX 12.3. We would like to point out that the results indicated that, with the placement of 5 out of 19 RSUs, more than 50 percent of full information dissemination can be achieved. Furthermore, equipping the freeway can be classified in four phase operational budget. The first phase, placement of 5 RSUs, is equivalent to achieving more than 50 percent of full information dissemination. The second phase, placement of 4 next RSUs, is equivalent to fulfilling almost 74 percent of full information dissemination (totally 9 RSU). The third phase, placement of 6 other RSUs, achieves 96 percent and, in the last phase, 4 final RSUs have alight effect on the objective function. In future works, in addition to the listed parameters, the parameters regarding volume of traffics can be applied.

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