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# Absorbing Markov Chain-based Roadside Units Deployment

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**Abstract**

Roadside Units (RSUs) are a device that can transmit and receive information between vehicles, an essential component for the environment of Vehicular Ad hoc Network (VANET). To determine the location of RSU based on real traffic data, we redefined the concept of intersection influence, and based on this proposed an approach determining the location of RSU and its coverage by using Absorbing Markov Chain. Our experimental results showed that our approach had high performance compared to existing graph transition probability-based Markov Clustering algorithm and K-Means-based algorithm.

**Keywords**: Absorbing Markov Chain, VANET, RSU deployment

## 1. Introduction

Recent technological advances in IT have led smart vehicles to be autonomous, learning, and evolving [1]. Concerning VANET, wireless communication environment between smart vehicles, a number of research works have been performed to prevent, avoid, or recognize vehicle accidents, and the RSUs under such a VANET condition serve as a static transmitting-receiving device like a base station that can transmit and receive information between vehicles, and accordingly they are mostly installed at intersections where many vehicles come into contact with one another [2].

The majority of existing research works related to RSU deployment have focused

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on the number of RSU required to cover the entire intersection [2], or collecting and delivering vehicular information by deploying the RSU on the intersection under either low or high traffic volume [3]. Although the methods are being suggested considering the probability connecting with the RSU based on recent moving information of vehicles [4,5], they only use limited road information such as bus service routes, or target at simple network of roads based on grid cell. In [6,7], although problems are solved by Markov Clustering Algorithm (MCL), graph-based clustering algorithm, as the number of intersections is higher, a problem arises from that it is more difficult to converge them into a specific intersection, and the number of iterative calculation of transition matrix is higher.

Thus, in this paper, we introduce Absorbing Markov Chain-based approach that can solve problems without iterative transition matrices. Our approach is based on the concept that the RSU is ruled out from calculating the probability of transition matrix as the RSU is in an absorbing state that does not have to be no more transient to a final destination of information transmission.

The rest of paper is organized as follows: Section 2 reviews some related research works, and Section 3 describes intersection influence and RSU priority required for our RSU deployment policy. In section 4 we explain the suggested approaches in detail, and Section 5 analyzes the experimental results derived from suggested techniques. Finally, our conclusion is drawn in Section 6.

## 2. Related works

Recent works related to RSU deployment can be classified into the 3 following categories. The first one was generated by a method that divides road network, expressing roads with grid cell in [3], and suggesting a method allocating RSU by using the probability information of vehicles migrating to adjacent cells. Nevertheless, adjacently located intersections do not necessarily mean there is connectivity between intersections, as although they are located adjacently, roads may not be connected between intersections. The second one is a method using network-based distribution, and in [4], an RSU deployment method is suggested so that vehicle communication can be performed within 2 hops in bus transport networks. However, this method is difficult to apply to roads where many vehicles move as it only considers vehicle communication between buses. The third one is a method using density-based distribution, and in [5], to minimize the RSU installation cost, suggested is that a large number of RSUs are installed in low traffic density, whereas a small number of RSUs are installed in high traffic density. However, this method only considers vehicle density but does not consider that vehicles can deliver information to be carried-and-forwarded to adjacent intersections. In [6, 7] closely related to this paper, the RSU is deployed by using MCL based on network and density. However, as the number of intersections is higher, it is more difficult to converge into a specific intersection, and the number of iterative transition is also higher.

Therefore, in this paper, we herein suggest RSU deploy methods appropriate for urban areas with complex road networks having real moving vehicle information and many intersections.

## 3. Assumptions and Definitions

In this section, we define the concept of intersection influence and RSU priority serving as an important role in determining the RSU. Table 1 shows notations used throughout this paper.

Table 1. Notations

| Notation | Description |
|---|---|
| $I$ | A set of all intersections |
| $I_i$ | The $i^{th}$ intersection in $I$ |
| $N_{i,j}$ | The $j^{th}$ intersection adjacent to $I_i$, where $j=\{1,2...n\}$ |
| $RS$ | A set of RSU |
| $RC$ | A set of RUS candidates |
| $CI_i$ | A set of intersection covered by $i^{th}$ RSU candidate |
| $PI(i)$ | The priority of $i^{th}$ intersection |
| $PR_i$ | The priority of $i^{th}$ RSU candidates |
| $II_{i,j}$ | The intersection influence from $I_i$ to $N_{i,j}$ |
| $sp_{i,j}$ | The limit speed from $I_i$ to $N_{i,j}$ |

### 3.1 Intersection Influence

Intersection influence $II_{i,j}$ indicates influence that $I_i$ has on adjacent intersection $N_{i,j}$. We define intersection influence by using the traffic volume measured at an intersection, distance between intersections, and time for passing intersections, and can obtain it as equation 1.

$$II_{i,j} = \alpha_{i,j} \times d_{i,j} \times t_{i,j} \quad (1)$$

Where, $\alpha_{i,j}$ indicates traffic influence, and can be obtained as equation 2 by using the linear regression equation defined in [6] based on traffic information collected at an intersection.

$$\alpha_{i,j} = \frac{n \sum_{t=1}^{n} x_{i,j}^t y_i^t - \sum_{t=1}^{n} x_{i,j}^t \sum_{t=1}^{n} y_i^t}{n \sum_{t=1}^{n} (x_{i,j}^t)^2 - \left(\sum_{t=1}^{n} x_{i,j}^t\right)^2} \quad (2)$$

Further, $d_{i,j}$ indicates the ratio of geographical distance from $I_i$ to $N_{i,j}$, and can be obtained as equation 3 based on the shortest distance amongst distances between adjacent intersections. Where, $Dis_i(N_{i,j})$ indicates a distance from $I_i$ to $N_{i,j}$, whereas $DMin(i)$ indicates the shortest distance amongst distances between $I_i$ and $N_{i,j}$.

$$d_{i,j} = \frac{DMin(i)}{Dis_i(N_{i,j})} \quad (3)$$

In addition, $t_{i,j}$ indicates the ratio of time taken to reach $N_{i,j}$, from $I_i$, which is different from distance between intersections for a different speed limit of each road. It can be obtained by equation 4, and $TTime_i(N_{i,j})$ indicates time taken from $I_i$ to $N_{i,j}$, and can be obtained by $Dis_i(N_{i,j})*60/sp_{i,j}$, whereas $TMin(i)$ indicates the shortest time amongst times taken from $I_i$ to $N_{i,j}$.

$$t_{i,j} = \frac{TMin(i)}{TTime_i(N_{i,j})} \tag{4}$$

### 3.2 RSU Priority

To select selected RSU candidates according to priority order, we determined RSU priority as what is shown as equation 5.

$$PR_i = avg(PI(CI_i)) \tag{5}$$

In other words, we determined average priorities of intersections that RSU candidates cover as RSU priority. This is because, in case the priority of RSU candidate intersections is high because adjacent intersections are accident-prone areas or attractions despite their low priority, the RSU that can cover the intersection should reflect its priority. Where, $PI(i)$ priority of each intersection is referred to [2].

## 4. Absorbing Markov Chain-based RSU deployment

In this section, we describe RSU deploy methods suggested in this paper in detail. The suggested methods consist of two steps. In the first step, the RSU candidate set is determined based on Absorbing Markov Chain, and in the second step, the location of RSU is determined based on priorities and RSU coverage amongst RSU candidates.

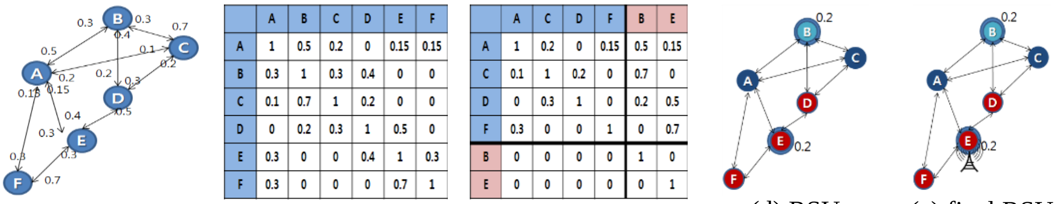
### 4.1 RSU Candidate Selection based on Absorbing Markov Chain

We solved problems arising from RSU deployment by using Absorbing Markov Chain. As vehicles are highly likely to pass a place where the influence between intersections is high, in order to determine an absorbing state, we selected an intersection that is the highest in the influence amongst adjacent intersections that have their influence over threshold, and also selected intersections that have no absorbing relationship as RSU candidate RC, as what is defined as equation 6.

$$RC = \{I_j \mid diffSet(\{I_j\} - \{I_i\})\} \tag{6}$$

$$where\ [I_i, I_j] = \{ max(II_{i,j=1:n}) > \theta \}$$

Figure 1(a) shows influence between intersections, whereas Figure 1(b) shows transient probability matrices on this. If the threshold is 0.5, the influence except for itself is absorbed by the intersection over 0.5, and accordingly, the absorption relationship is generated as $A \rightarrow B$, $C \rightarrow B$, $D \rightarrow E$, and $F \rightarrow E$, wherein B and E not transmitted to other intersections are selected as an absorbing state.



(b) Transition Matrix, *M*

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| A | 1 | 0.5 | 0.2 | 0 | 0.15 | 0.15 |
| B | 0.3 | 1 | 0.3 | 0.4 | 0 | 0 |
| C | 0.1 | 0.7 | 1 | 0.2 | 0 | 0 |
| D | 0 | 0.2 | 0.3 | 1 | 0.5 | 0 |
| E | 0.3 | 0 | 0 | 0.4 | 1 | 0.3 |
| F | 0.3 | 0 | 0 | 0 | 0.7 | 1 |

(c) Canonical form, *P*

| | A | C | D | F | B | E |
|---|---|---|---|---|---|---|
| A | 1 | 0.2 | 0 | 0.15 | 0.5 | 0.15 |
| C | 0.1 | 1 | 0.2 | 0 | 0.7 | 0 |
| D | 0 | 0.3 | 1 | 0 | 0.2 | 0.5 |
| F | 0.3 | 0 | 0 | 1 | 0 | 0.7 |
| B | 0 | 0 | 0 | 0 | 1 | 0 |
| E | 0 | 0 | 0 | 0 | 0 | 1 |

(a)Intersection Influence (b)Transition Matrix, *M* (c) Canonical form, *P* (d) RSU candidate B,E (e) final RSU allocation

Figure 1. Examples of Absorbing State Selection

If an absorbing state is determined, the probability can be obtained that can reach each absorbing state by using Absorbing Markov Chain. To accomplish this, transition matrix *M* on absorbing chain can be prepared again with canonical form *P* as equation 7.

$$P = \begin{bmatrix} Q & R \\ O & I_r \end{bmatrix} \quad (7)$$

Where, *Q* consists of transition probability matrices from non-absorbing states to non-absorbing states, whereas *R* consists of transition probability matrices from non-absorbing states to absorbing states. *O* consists of zeros matrices, which stands for no more transition in absorbing states, whereas $I_r$ consists of identity matrices. Figure 1 (C) shows canonical form *P* on transition matrix *M* of Figure 1 (b). The probability that transits from intersection $I_i$ to $I_j$ after *n* steps can be represented as equation 8.

$$p_{i,j}^{n} = \begin{bmatrix} Q^n & R \\ O & I_r \end{bmatrix} \quad (8)$$

Hence, in case of n=∞, the probability of being absorbed from intersection $I_i$ to RSU candidate $RC_j$ can be obtained as equation 9 [8], and the probability of being absorbed to $RC_j$ by using equation 10 can obtain $CI_j$ with over threshold value *Θ*.

$$B = NR, \quad where\ N = \sum_{k=0}^{\infty} Q^n = (I_r - Q)^{-1} \quad (9)$$

$$CI_j = \{I_i | max(B(i,j)_{j=1:n}) > \theta\} \quad (10)$$

### 4.2 RSU Allocation

When RSU candidate set *RC* and coverage *CI* of *RC* are determined, Top K is selected according to the size of cluster and priorities using algorithm TopK Size&Priority in [7]. As Figure 1(d) shows clustering results on transition results, {B} and {D,E,F} consisted of clusters. If Top 1 is selected, as B and E are RSU candidates, and their priority is 0.2 and the same, and E having big size of cluster is given weighted value derived from the size of cluster, the RSU is finally allocated in E.

## 5 Experimental Results

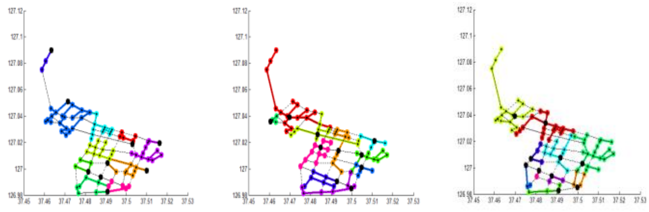
To evaluate suggested algorithms, we experimented on 89 intersections at Seocho-gu in Seoul based on data set collected on a daily basis. To accomplish this, we conducted comparative evaluation of K-Means distance-based clustering technique, and graph clustering algorithm MCL with the proposed method AMC. We generated connectivity data set ***D*** between intersections with waiting time 1 second at intersections based on connectivity information between intersections based on Possion distribution suggested in [6].

### 5.1 RSU Connectivity

In case the location of RSU is determined by the suggested algorithm, we defined the concept of the connectivity of RSU to the extent that the RSU can collect information of the entire intersection. Namely, to obtain the probability $Cost_{i,j}$ to be connected from intersection $I_i$ to $RS_j$, we used Dijkstra algorithm to find the shortest path between $I_i$ and $RS_j$, and used the connectivity information of intersections that exist in path forming the shortest path to calculate the final connection probability.

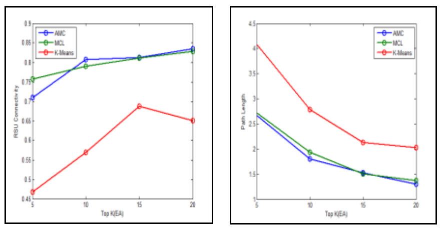
$$Cost_{i,j} = \left(\prod_{k=i}^{j-1} D_{k,k+1}\right) \quad (11)$$

Figure 2(a)-(c) used Dijkstra algorithms to demonstrate results obtained from connection path to the RSU selected by each algorithm at each intersection. Based on the connection information obtained, we conducted performance analysis.



(a) K-Means (b) MCL (c)A-Markov Chain

Figure 2. Path Search by using Dijkstra Algorithm



(a)R-Connectivity (b) Path Length

Figure 3. Simulation Results

### 5.2 Analysis of Simulation Results

Figure 3 shows experimental results. As what is shown in experimental results, AMC and MCL suggested in this paper were performed based on transition probability between intersections, RSU connectivity rises up to about 80%, showing relatively high performance, whereas K-Means algorithm performing distance-based clustering rises up to about 60%, showing relatively low performance. Also in the path distance from intersections to the RSU, AMC and MCL showed 1.8 whereas K-Means showed 2.7, relatively long. This indicates that the longer a path distance is, the higher the probability of lowering RSU connectivity is higher.

Especially, AMC and MCL showed similar performance, and it is of great significance in that MCL determines the RSU with $M^n$ as a result of conducting iteration until MCL collects the entire transition matrix $M$ into a specific state, whereas AMC is a result of simply conducting based on the transition probability on $M$-$|RC|$.

## 6. Conclusion

In this paper, we suggested RSU deployment method based on Absorbing Markov Chain. To achieve this, we redefined Intersection Influence by considering distance and time information with traffic influence, and based on this selected Absorbing State. Based on selected absorbing state, selected was the RC high in the probability by intersection by converting transition matrix to canonical form. Afterwards, the RSU were selected based on RC priority and coverage. We experimented based on real traffic volume data of Seocho-gu, Seoul, and showed high performance by comparing existing MCL with K-Means.

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