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Roadside Units Deployment for Efficient Short-time Certificate Updating in VANETs

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Abstract— **Roadside Units (RSUs) aided distributed certificate service is a promising approach for ensuring security and privacy preservation in vehicular ad hoc networks (VANETs), where the existence of RSUs is critical for such a scheme in order to allow On-Board Units (OBUs) to update their short-time certificates on time. However, RSUs may only be deployed at some critical points along roads due to the cost. In this paper, we propose a cost-efficient RSUs deployment scheme to guarantee that OBUs at any place could communicate with RSUs in certain driving time (DT), and the extra overhead time (ET) of adjusting routes to update short-time certificate is small. Based on a real-world map, several deployment examples are given illustrating the influence of key factors in RSUs deployment such as wireless communication range, DT and ET. Furthermore, extensive analysis demonstrates that our RSUs deployment scheme can meet the required design goals.**

Keywords – **Vehicular communications; Privacy preservation; Certificate updating; RSUs deployment**

I. INTRODUCTION

Vehicular ad hoc networks (VANETs) are special instantiations of mobile ad-hoc networks, and mainly consist of On-Board Units (OBUs) and Roadside Units (RSUs) [1]. OBUs are installed on vehicles to provide wireless communication capability, and RSUs are deployed and managed by the trust authority (TA). VANETs are expected to improve road safety and optimize traffic management,etc. However, there are also many challenges such as information security and privacy preservation [2]–[5]. For example, vehicles need to exchange speed and location information in the driving assistance and accident warning applications. The authentication for such life-critical information is essential, which can make sure that any received message is indeed sent by a legitimate user and has not been altered. Meanwhile, some drivers don't want to disclose their privacy information including speed and position, which could be utilized for tracking the locations of specific OBUs, and obtaining their moving patterns. Therefore, the identities of message senders should not be revealed to other OBUs.

Recently, pseudonymous authentication scheme is considered to be a promising approach to address the security and privacy issues in VANETs [3], [6]–[8]. Raya et al. [3] present the basic idea of pseudonymous scheme that each OBU stores a large set of certificates and randomly chooses one of the available certificates for signing a message at one time. However, when one vehicle is revoked, all the available certificates, i.e., 43,800 of them in [3], would be added to Certificate Revocation List (CRL). The CRL increases quickly so that it is difficult to be distributed in a timely fashion. To decrease the CRL size, RSUs aided distributed certificate service has been proposed in [6]–[8]. Lu et al. [6] present that the OBUs update short-time certificates from the RSUs. In this way, it becomes unnecessary for the OBUs to have a copy of CRL. Instead, the RSUs receive CRL from TA, and issue short-time certificates for the legitimate OBUs that are not in CRL. This scheme has advantages in reducing the cost of updating, storing and checking CRL for the OBUs, while there is a challenge for certificate updating. As illustrated in Fig.1, an OBU O_1 obtains a short-time certificate from an RSU R_1. If O_1 can not contact with another RSU no matter its destination is store A or store B before this certificate expires, it would be unable to disseminate its traffic messages. Moreover, passing by certain RSU may lead the OBU giving up the convenient and fast route. Although erecting RSUs at all intersections is the most common solution [5], it's impractical due to the huge cost. There are several research works considering the immobile units deployment issue in VANETs for different

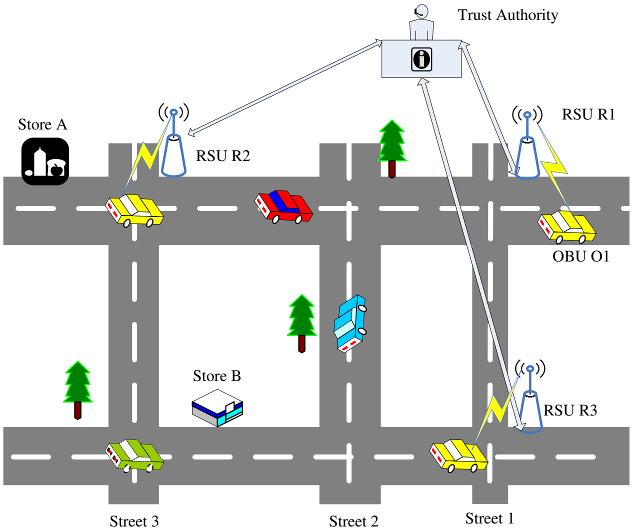


Fig. 1. System model

application purposes. Lochert et al. [9] present a genetic algorithm to achieve better placement for supporting units in a VANET-based traffic information system which could help a vehicle to find the shortest path to its destination and save the driving time. In [10], Agarwal et al. propose to deploy access points at regular intervals along roads and model the delay in messaging from a vehicle to an access point. However, how to deploy a proper number of RSUs for certificate updating is still an open issue.

To solve this issue, one approach is to guarantee OBUs at any place communicate with RSUs in certain driving time (DT), and the extra overhead time (ET) of adjusting routes to update short-time certificates is small. In this way, TA can set the certificate validity period according to DT, and then an OBU is able to update certificate before the last one expires. To deploy the minimum RSUs for this prospective goal, we define the optimal RSUs deployment problem constrained by DT and ET. It is proved to be equivalent to the set-covering problem, which is NP-hard and could be solved by a classical approximation algorithm. Simulations demonstrate the influence of key factors in RSUs deployment such as wireless communication range, DT, and ET, and the RSUs deployment plan generated by our scheme can guarantee most OBUs update certificates on time.

The remainder of the paper is organized as follows. In section II, we present the system model and problem formalization. In section III, DT and ET constraint problem is defined for achieving the design goal and solved by a classical approximation algorithm. Section IV gives some examples for the RSUs deployment in real world map when the constraint factors vary. Finally, we conclude the paper in section V.

II. PROBLEM FORMALIZATION

In this section, the system model and problem formalization are presented. The notations used throughout the paper are given in Table I.

TABLE I

NOTATIONS

Symbol	Notation
R	the wireless communication range of RSU
N	the total number of intersections
I_i	the i-th intersections
TS_i	the traffic signal period at I_i
$W_{i,j}$	the road between neighboring intersections I_i and I_j
$Vel_{i,j}$	the expectant velocity of OBUs on the road $W_{i,j}$
$RSU(i)$	a bool that 1 means there is an RSU at I_i
$Cov_R(i)$	a bool that 1 means I_i is in the communication coverage of RSUs, given the communication range is R
$CS(i)$	an intersection set in the communication coverage of the RSU in I_i.
$SP_{i,j}$	the shortest path between vertexes V_i and V_j in direction graph $G(V, E)$
$ET_{i,j,k}$	the extra overhead that driving from I_i to I_j passing by I_k
$\|.\|$	the path length

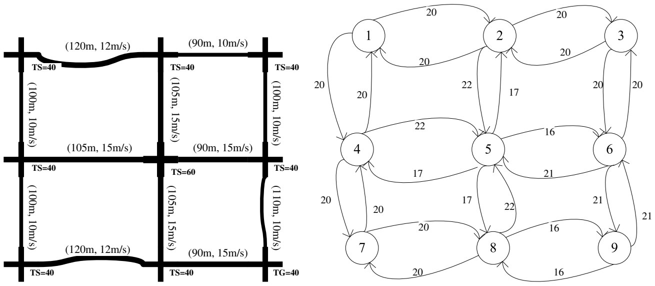
A. System Model

As illustrated in Fig. 1, a typical VANET consists of three entities in city scenarios: the top TA, the fixed RSUs along the road side, and the mobile OBUs equipped on the running vehicles.

- *TA:* TA is in charge of the registration of the RSUs and OBUs. TA can reveal the real OBU identity of a safety message and publishes the CRL periodically to the RSUs. Moreover, TA can be a road authority, such as the government. It has the basic information about streets and traffic statistics, and proposes the RSUs deployment plan according to the tradeoff between the requirements of most OBUs and the investment budget.
- *RSU:* RSUs are erected at intersections for the considerations of power and management. RSUs use the same communication technology and the deployment cost is constant at any intersections. RSUs connect with TA by wired links [1], and act as certificate proxies of TA. An RSU can issue short-time certificates for the OBUs with valid membership.
- *OBU:* Each OBU has a long-term unique identity. OBUs mainly communicate with each other for sharing local traffic information, and with the RSUs for updating the short-time certificates. Digital maps are available for the OBUs. It provides the street-level map, the communication coverage of RSUs and the traffic statistics such as vehicle speed on roads, and traffic signal schedule at intersections [11].

B. Problem Formalization

Due to the cost, the RSUs can not cover everywhere so that the OBUs can not update certificate anytime, anywhere. However, it can guarantee most OBUs have valid certificates if the RSUs deployment satisfies two requirements. First, the certificate validity period matches with the distribution of RSUs. As shown in Fig.1, the OBU O_1 should arrive the RSU R_2 (R_3) before its certificate issued by the RSU R_1 expires if it drives to store A (B). Second, selecting the route to update certificate should not cause significant burden to the OBUs. Suppose driving to store B from R_1 through street 2 is faster than the route through street 1, it means that O_1 pays extra time and cost for driving through R_3. This kind of overhead should be small. Otherwise, some OBUs may give up updating certificates. In this paper, we aims to deploy a number of RSUs under these requirements in a city scenario with thousands of intersections.



(a) Street map Map_9 (b) $G_9(V, E)$

Fig. 2. Constructing direction graph for a street map

Without loss of generality, an OBU prefers the shortest path to its destination. For simplicity, both of the departure place and destination of an OBU are marked by the nearest intersections, and we transform a road map to a directed graph for intersections. Traffic information is known such as N intersections, $\{I_i\}$, traffic signal period, $\{TS_i\}$, sections of roads between neighboring intersections, $\{W_{i,j}\}$, and expectant velocity on each road, $\{Vel_{i,j}\}$. Suppose both the traffic signal period for red light and green light at I_i equal TS_i, and an OBU arrives at I_i at anytime, so the expectant pausing time of the OBU at I_i is TS_i/4. Based on these information, TA constructs a direction graph $G(V,E)$. Each intersection I_i has a mapping vertex (denoted as V_i) in V, while the image of road $W_{i,j}$ in edge set E is $E_{i,j}$. The length of $E_{i,j}$ is corresponding to the estimated time from the moment that an OBU leaves from I_i to the moment that it passes through I_j, where $|E_{i,j}|$ = $|W_{i,j}|$/$Vel_{i,j}$ + TS_j/4. As shown in Fig. 2, a direction graph is constructed for an instance of street map with 9 intersections (denoted as Map_9). Let $SP_{i,j}$ denote the shortest path between vertexes V_i and V_j, and $DT_{i,j,k}$ denote the shortest path through vertex V_k between vertexes V_i and V_j. Obviously, $|DT_{i,j,k}|$ = $|SP_{i,k}|$ + $|SP_{k,j}|$. Let $ET_{i,j,k}$ denote the extra overhead that selecting $DT_{i,j,k}$ instead of $SP_{i,j}$, where $ET_{i,j,k}$ = $|DT_{i,j,k}|$ - $|SP_{i,j}|$.

Wireless communication range (denoted as R) is an important parameter for roadside-to-vehicle communications (RVC), and affects the communication bandwidth and the coverage areas of RSUs. It can confirm the communication coverage if the locations of RSUs are known, and set $Cov_R(j)$ =1 if I_j is in the communication coverage of an RSU with a given R. Moreover, let $CS(i)$ denote a set of intersections that in the communication coverage of the RSU in I_i, and $CS^{-1}(i)$ denote the contrary mapping set, where $CS(i)$={j | $Cov_R(j) = 1$ if $RSU(i)$=1 & $RSU(k)$=0 ($k \neq i$)} and $CS^{-1}(i)$={j | i ∈ $CS(j)$}.

Before seeking RSUs deployment plan, TA selects suitable parameters DT and ET. Small DT is favorite for privacy sensitive users to change certificates frequently, and small ET could reduce interferences for the driving of the OBUs. However, the investment budget must be considered in the RSUs deployment. TA could make the tradeoff between the requirement of most OBUs and the engineering cost.

Finally, we formalize the requirements for the RSUs deployment as following.

***Definition** 1 (DT and ET Constraints):* For any OBU driving from an intersection I_i to another intersection I_j, if $|SP_{i,j}| > DT$, then there exists an intersection I_k on the way to I_j at which OBUs could communicate with RSUs, i.e., $Cov_R(k)$=1, such that $|SP_{k,j}| < |SP_{i,j}|$, $|SP_{i,k}| \leq DT$, and the overhead of passing by I_k is small, i.e., $ET_{i,j,k} \leq ET$. In this way, the intersection pair (I_i,I_j) satisfies DT and ET constraints. If all the intersection pairs in certain area satisfy DT and ET constraints, it says the area satisfies this DT and ET constraints.

Then, we will find out the most cost-efficient deployment for certain DT and ET constraints in the following section.

III. RSUs DEPLOYMENT

Given an intersection set $Z \in \{I_i\}$, we recognize Z as a viable RSUs deployment plan if DT and ET constraints are satisfied in case of that erecting an RSU at every intersection in Z, i.e., ∀ k ∈ Z, $RSU(k)$ = 1. Furthermore, we define the optimal problem as follows.

***Definition** 2 (DT and ET constraint problem):* DT and ET constraint problem is stated to find a minimum-size Z from all the viable deployment plans. Z is called the optimal RSUs deployment plan.

To solve a DT and ET constraint problem, we transform it into the classical set-covering problem. An instance (X,F) of the set-covering problem consists of a finite set X and a family F of subsets of X, such that every element of X belongs to at least one subset in F: $X = \bigcup_{S \in F} S$. It says F covers X [14].

***Definition** 3 (Set-covering problem):* Set-covering problem is stated to find a minimum-size subset $C \subseteq F$ whose members cover all of X: $X = \bigcup_{S \in C} S$.

As shown in Algorithm A1, we can get an instance $(X^{'},F^{'})$ of the set-covering problem from the DT and ET constraint problem. An element $x_{i*N+j} \in X^{'}$ means the intersection pair (I_i, I_j) satisfying $SP_{i,j} > DT$, while $S_k \in F^{'}$ is mapping with the intersection I_k. If $x_{i*N+j} \in S_k$, it means that erecting an RSU at I_k could guarantee (I_i, I_j) satisfy DT and ET Constraint. For example, we generate an instance $(X^{'},F_9^{'})$ from the graph $G_9(V,E)$ shown in Fig. 2(b). Suppose DT = 65, ET= 0, and R is too small that an RSU could just cover the intersection where it is. It can be seen that $SP_{1,9}$= 75 > DT, then $x_{1*9+9} \in X^{'}$. Moreover, deploying RSUs at I_2 can make (I_1, I_9) satisfy DT and ET Constraint, so set $x_{18} \in S_2$. Similarly, we observe that $X^{'}$ = { x_{18}, x_{34}, x_{66}, x_{82}}, and $F_9^{'}$ = { S_2={x_{18}, x_{82}}, S_5={x_{18}, x_{82}}, S_6={x_{34}, x_{66}}, S_8={x_{18}, x_{34}, x_{66}, x_{82}}, S_9={x_{34}, x_{66}} }.

Given a subset $C \subseteq F^{'}$, define a function $H(C)$= { I_i | S_i ∈ C }. Obviously, $|H(C)|$ = $|C|$. Let $H^{-}()$ denote the reverse mapping function of $H()$. From Theorem 1 given below, we can achieve the optimal deployment plan if the set-covering problem of $(X^{'},F^{'})$ is solved.

***Theorem** 1:* The set-covering problem of the instance $(X^{'},F^{'})$ and the DT and ET constraint problem are equivalent.

Proof. Given Z is the optimal deployment plan for DT and ET constraint problem and C satisfies the set-covering problem of $(X^{'},F^{'})$. Then, according to the transforming procedure in Algorithm A1, $H^{-}(Z)$ covers $X^{'}$. So $|H^{-}(Z)| \geq |C|$; Moreover, because C covers $X^{'}$, $H(C)$ satisfies the DT and ET constraints, so $|H(C)| \geq |Z|$; Finally, since $|H(C)|$ = $|C|$, and $|H^{-}(Z)|$= $|Z|$, then $|H(C)| = |Z|$. As a result, both two problems are equivalent. □

Because the set-covering problem is NP-hard [14], the DT and ET constraint problem is also NP-hard. We will use the classical polynomial-time approximation algorithm, called GREED_SET_COVER(X,F) [14], to solve $(X^{'},F^{'})$, then $H(C)$ would be the optimal deployment under the DT and

Algorithm 1: **[A1] Problem Transforming**

```
   Data: Basic traffic information such as the intersection number
         N, $G(V,E)$, $\{Cov_R(i)\}$ and $\{CS^{-1}(i)\}$, and the
         deployment constrain ($DT$,$ET$)
   Result: Generate an instance ($X^{'}$,$F^{'}$).
1  begin
2      Compute each $SP_{i,j}$ in $G$ by Floyd algorithm
3      for each $i \leq N$ do
4          Set $S_i$=∅
5      end
6      Set $X^{'}$= ∅;
7      for each pairs $i$, $j \leq N$ do
8          if $|SP_{i,j}| > DT$ then
9              Set $x_{i*N+j} = i*N+j$
10             Set $X^{'}$= $X^{'} \cup \{x_{i*N+j}\}$
11             for each $k \leq N$ & $k \neq i$ do
12                 if $SP_{k,j} \leq SP_{i,j}$ & $SP_{i,k} \leq DT$ & $ET_{i,j,k}$
                   $\leq ET$ then
13                     for each $q \in CS^{-1}(k)$ do
14                         $S_q = S_q \cup \{x_{i*N+j}\ \}$
15                     end
16                 end
17             end
18         end
19     end
20     Set $F^{'}$=$\{S_i \mid S_i \neq \varnothing\ \}$
21     return ($X^{'}$,$F^{'}$)
22 end
```

ET constraints. Solving the instance ($X^{'}$,$F_9^{'}$), we have $\{S_8\}$. It means that we should deploy an RSU at I_8.

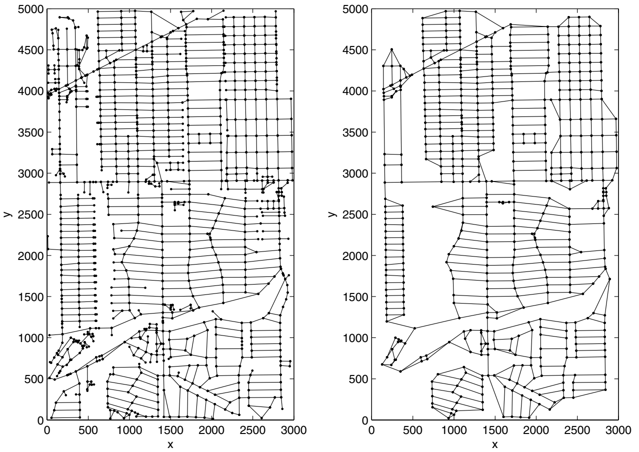
Algorithm 2: **[A2] GREED_SET_COVER(X,F) [14]**

```
Data: $X$ and $F$
Result: a subset $C$ that covers $X$ .
begin
    $U \leftarrow X$
    $C \leftarrow \varnothing$
    while $U \neq \varnothing$ do
        select an $S \in F$ that maximizes | $S \bigcup U$ |
        $U \leftarrow U$ - $S$
        $C \leftarrow C \bigcup S$
    end
    return ($C$)
end
```

Notice that, the cost of solving the DT and ET constraint problem includes two parts: the problem transforming cost in algorithm A1 and the cost of set-covering problem by the algorithm GREED_SET_COVER (X,F). In algorithm A1, Floyd algorithm to solve all-pair shortest-paths problem takes O(N^3) [14]. Moreover, there are 3 level loops in lines 7-19. N^2 intersection pairs present in line 7. Meanwhile, each iteration in both two loops in line 11 and 13 is less than N, thus, the whole loops run in O(N^4). Therefore the cost of algorithm A1 is O(N^4). According to [14], GREED_SET_COVER(X, F) runs in O($|X|*|F|*\min(|X|,|F|)$), where $|X|$ and $|F|$ denote the number of items in X and F respectively. In the set-covering instance ($X^{'}$,$F^{'}$), $|X^{'}| \leq N$ and $|F^{'}| \leq N$. So solving ($X^{'}$,$F^{'}$) takes O(N^3) by the algorithm GREED_SET_COVER(X,F). In conclusion, solving DT and ET constraint problem takes O(N^4). Suppose these works for RSUs deployment could get ample computation resources, our scheme may work well even when the aiming area is large.

IV. PERFORMANCE EVALUATION

To evaluate the performance of our scheme, we select the map of the West University Place and Braeswood Place, Houston, TX, USA from the publicly available TIGER (Topologically Integrated Geographic Encoding and Referencing) database of the U.S. Census Bureau [15]. Excluding few highways in this 3km*5km area, there are 1027 intersections (denoted as Map_{1027}), as shown in Fig. 3(a). For simplicity, we recursively omit the intersections where less than 3 roads are connected. As shown in Fig. 3(b), there are 581 intersections left after the predigestion. Moreover, for each intersection, set TS_i = 30s and for each road, set $Vel_{i,j}$ = 15m/s. Recently most researchers use 5.9 GHz Dedicated Short Range communication (DSRC) for roadside-to-vehicle communications [12], while R is supposed to be 300m. However, R may be restricted in actual applications because using poor link quality in the outboard of RSU's coverage area reduces the system throughput [13]. Therefore, we set R = 100m, 200m or 300m, respectively. If an intersection I_i is in the coverage of an RSU, the OBUs are supposed to update certificates at I_i successfully.

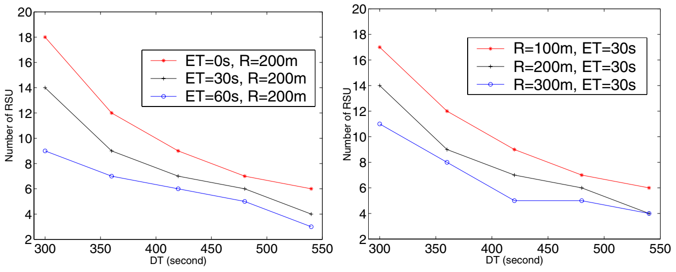


(a) Map_{1027} with 1027 intersections (b) Map_{581} with 581 intersections

Fig. 3. West University Place and Braeswood Place, Houston, 3km∗5km

R, DT, and ET are three key factors for RSUs deployment. Then, let DEP(DT, ET, R) denote the deployment plan for Map_{581}. In Fig. 4(a), the numbers of RSUs in DEP({300s, 360s, 420s, 480s, 540s}, {0s, 30s, 60s}, {200m}) are given. Obviously, the number of RSUs decreases when DT and ET increase. A similar trend is observed when DT and R increase, as shown in Fig. 4(b).

In an RSUs aided distributed certificate service scheme, if an OBU can not update its certificate on time, it will be unable to disseminate its traffic messages so that there is



(a) ET, R=200m (b) ET=30s, R

Fig. 4. Deployment examples when $DT \in \{300s, 360s, 420s, 480s, 540s\}$

a risk for the driver safety. We define the silence ratio as the ratio between the cumulative time that an OBU doesn't have the valid certificate during the simulation and the total simulation time. The small silence ratio means an OBU most likely can update its certificate on time when it is on the road. From Map_{1027}, suppose an OBU at location A drives to destination B, and it can request a certificate with the validity period DT from RSUs. The locations are randomly chosen in our simulation. On the way to B, if the OBU finds out an RSU at intersection I_k satisfying DT and ET constraints, it will select the route passing through I_k. Otherwise, it prefers the shortest path to B. After arriving at B, the OBU will select another destination until the end of the simulation. The traffic lights in intersections exchange lights every 30s, and the vehicle velocity varies within the range of 15m/s ± 20%. The simulation lasts 90 minutes. Let U_β denote the uniform deployment plan that β RSUs are erected uniformly in the Map_{1027}. Given ET = 30s, R = 200m, and DT = 300s or 360s, Fig. 5 shows the average silence ratio of 10^4 OBUs under different RSUs deployment plans DEP(300, 30s, 200m), DEP(360, 30s, 200m), U_9, and U_{15}. It can be seen that our RSUs deployment plans achieve the lower silence ratio than the uniform deployment plans. Moreover, it is worth noting that there are 14 RSUs in DEP(300, 30s, 200m), 9 RSUs in DEP(360, 30s, 200m). Although U_{15} has 15 RSUs, its silence ratio is larger. Therefore, our scheme can achieve the cost-efficient RSUs deployment to guarantee most OBUs update their certificates on time.

V. CONCLUSIONS

In this paper, we have formalized the DT and ET constraints for certificate updating and presented a scheme to achieve the most cost-efficient deployment of RSUs. For future work, we will study how to set the certificate validity period according to the real time traffic information in a given RSUs deployment plan.

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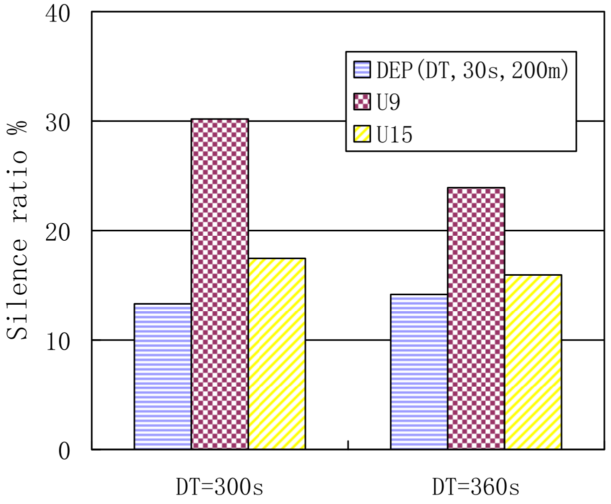

Fig. 5. The silence ratio under different RSUs deployment plans

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