An Efficient Scheme for Tag Information Update in RFID Systems on Roads

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***Abstract*—RFID Systems on Roads (RSR) is a recently developed framework that focuses on enhancing transportation safety. In RSR, a large scale of passive RFID tags with road related information are deployed on road surfaces or roadside units. A vehicle with an onboard RFID reader can acquire the road information via reading from these RFID tags. As a result, it is critical to update the tags with the latest road information (especially, emergent alerts) in a timely manner in RSR. In this paper, we design a novel cluster based information diffusion scheme that aims to quickly and accurately update the contents of the RFID tags. To the best of our knowledge, our work is the first to focus on the problem of updating RFID tags in RSR. Our proposed scheme organizes RFID tags into clusters. The emergent information and update status of these clustered tags can be read by passing by vehicles. These vehicles can exchange such information with each other via vehicle-to-vehicle (or vehicle-to-infrastructure) communications. After synthesizing the received information, these vehicles can update the nearby tags and spread the information accordingly. Our extensive simulation results demonstrate that our proposed information diffusion scheme can effectively update the tags within certain time constraint under various scenarios.**

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I. Introduction

RFID technology has been widely used in our daily lives due to its convenience and low cost. There exist two types of vehicle network RFID applications, which can be classified by the locations of RFID tags and readers. To be specific, *Type-I* applications refer to the situation that RFID tags are attached to vehicles and the readers are installed at roadside units. An example of Type-I applications is Electronic Toll Collection (ETC). In Type-I applications, RFID tags store vehicle related information, and these information can be collected by RFID readers when vehicles pass by. On the contrary, *Type-II* applications mean that RFID tags are deployed on the road surface or roadside units, and the readers are mounted on vehicles. Type-II applications are designed to provide road related information to vehicles. Specifically, RFID tags store the road information, and vehicles acquire the information by reading the tags as they pass nearby. Type-II applications are considered to be useful for improving vehicle transportation safety and the efficiency of road travel.

The existing work on the system design for Type-II applications concentrates primarily on improving road safety and travel efficiency by reading tags. For example, the use of RFID tags on traffic signs to help vehicles correctly identify traffic signals and control their speeds is developed in [1]. Another example architecture adopts on-road RFID tags to help improve the vehicle localization accuracy [2]. However, there still lacks work on how to update on-road RFID tags with the emerging road information in a timely manner in the literature. It is a very challenging problem for the following reasons. An emergent event may happen at anywhere at a given time. The emergent event/information needs to be spread to all the RFID tags on a road segment as soon as possible. That means there may be a large number of tags (e.g., multi-lane roads) to be updated in a small amount of time. Yet, an RFID tag can only be updated by a vehicle that passes nearby and we do not have any control over the vehicle's trajectories or traffic conditions.

In this paper, we propose a novel cluster based information diffusion scheme for quickly and accurately updating on-road RFID tags with emergent road information. To the best of our knowledge, our work is the first to focus on the problem of updating RFID tags in RFID Systems on Roads (RSR) [3]. RSR is a recently developed platform for improving the transportation safety and efficiency. It can provide unique safety features for hazard driving environments (such as ice/snow covered roads, storm or fog), where other intelligent technologies cannot provide satisfactory road information. To be specific, our proposed scheme categorizes RFID tags into clusters, which define the groups of tags that may mutually help on their information updates. The emergent information and update status of these clustered tags can be read by a passing by vehicle. The vehicle can exchange these information with other vehicles via vehicle-to-vehicle (vehicle-to-infrastructure) communications. After synthesizing all the received information, a vehicle can update the nearby tags and spread the information accordingly. The size of a cluster will affect the information update speed and the communication overhead. Our extensive simulation results demonstrate that our proposed scheme can successfully update tags and vehicles with the emergent information in a timely fashion.

The rest of the paper is organized as follows. Section II summarizes the related work. In Section III, we introduce the background information and our assumptions. We detail the design of the our purposed system and tag updating algorithms in Section IV. Evaluation settings and results are presented in Sections V and VI. We conclude our paper in Section VII.

II. Related Work

There are two types of RFID application in vehicle networks. For Type-I applications, RFID readers are installed on road side units, and tags are mounted on vehicles. Example Type-I applications include Electronic Toll Collection (ETC), vehicle access control, and automatic vehicle identification [1], [2], [4], [5]. In Type-II applications, RFID readers are attached to vehicles, and RFID tags are deployed on road surfaces or road side units. A recent example of Type-II applications is RFID systems on roads (RSR) [3]. The feasibility of communications between readers and tags in high speed vehicle networks is analyzed in [6]. In addition, the tag reading latency of RFID readers installed on vehicles under a wide range of speeds is studied in [7]. [8] proposed a method that could be adopted to identify the defective tags in RSR. Yet, to the best of our knowledge, the problem of RFID tag update in RSR has not been studied in the literature. Our proposed tag update scheme is inspired by the information diffusion problem in social networks, and the information collection problem in wireless sensor networks (a reverse direction to the tag information update problem). Next, we summarize the work that is the most relevant to ours in these two areas.

There are many work that study the problem of information diffusion in social networks. The most relevant work that is related to ours is [9]. Specifically, the authors of this paper adopt the idea that information spreads much faster among a group of people with frequent interactions than that of a relatively isolated group. This work inspires the design of our proposed tag information update scheme. However, RFID tags are unlike people in that passive RFID tags cannot talk with each other directly. As a result, the existing information diffusion techniques for social networks cannot

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be directly applied to the tag update problem in RSR. We also consider the reverse data collection procedure in wireless sensor networks (i.e., sinks sending information to sensors) to be a similar to the tag information update problem. For example, the authors of [10] study the multiple-sink data collection problem in a large-scale sensor network and propose an approximation algorithm to minimize data collection latency. A novel approach to significantly improve the utilization of available network resources for information collection is proposed in [11]. Furthermore, flooding based algorithms that aim to transmit data from one source to all other nodes have been studied in [12]–[14]. Yet, the proposed information diffusion solutions to sensor network cannot be directly applied to our problem because tags, unlike sensors, need to rely on vehicles to relay and update the information.

III. Background

A. RFID Systems on Roads

RFID systems on roads (RSR) is a new platform that aims to provide accurate and timely road related information to drivers. Such information may be stored in passive RFID tags that are deployed in the center of a lane. A vehicle can acquire the information via a onboard RFID reader when the vehicle passes by the tags. Once the vehicle obtains the information, it spreads the information to other RFID tags in two different ways. First, the vehicle can directly update the RFID tags that do not contain the information and are within the s communication distance. Second, the vehicle can share the information among other vehicles via vehicle-to-vehicle (V2V) and/or vehicle-to-infrastructure (V2I) communications. Subsequently, the other vehicles can directly update their neighboring RFID tags using the first approach. An example RSR is illustrated in Fig. 1.

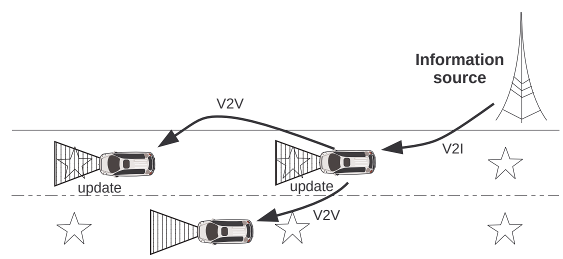

Fig. 1. An example RFID systems on road.

B. RFID Tag Storage Layout

We divide the RFID tag's storage space into the following five areas: (i) read-only; (ii) static information; (iii) update information; (iv) update status; and (v) digital signature. The read-only area may store permanent information such as factory number, tag configuration, and etc. The static information area can store information that typically does not change. Examples of such information include tag location, lane direction, and speed limits. The update information area is used to hold the information to be updated such as accidents and traffic congestions. The update status area may contain the statuses of the tag and its cluster. The digital signature area contains a digital signature to authenticate the communications between the tag and readers.

C. Assumptions

We make the following assumptions about the RSR platform under our consideration: i) RFID tags have enough storage space to store related information; ii) All vehicles are equipped with on-board RFID readers that can read from and write to RFID tags; iii) All vehicles are equipped with V2V/V2I communication components; and iv) The encounter time between a vehicle and a tag is sufficient to complete the process of authentication, reading, and writing.

IV. System Design

In this section, we describe our system design and our proposed algorithms for updating RFID tags in RSR. The primary objectives of our proposed system are to update all the tags as soon as possible while limiting the communication overhead.

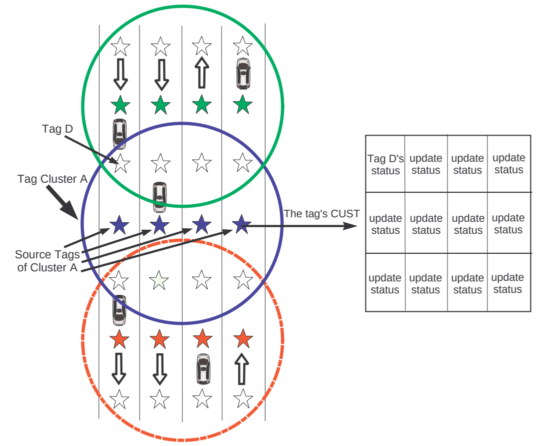

Fig. 2. RFID tag clustering.

A. Tag Clustering

To assist achieving the aforementioned primary design objectives, we first partition the RFID tags on a road into overlapped clusters. An example of tag clustering for a road with four lanes is presented in Fig. 2. In this example, each cluster (represented by a circle in the figure) includes three rows of tags. Note that the number of rows in each cluster can be any odd number in practice. We call the four tags in the center row of a cluster the source tags of the cluster. Each source tag maintains a Cluster Update Status Table (CUST) that contains the update status of the other tags in its cluster. Note that the update status in the CUST of a source tag may different from the one of another source tag. Specifically, if the source tag is not aware the update status of a tag (say tag *D*) in its cluster, the corresponding entry

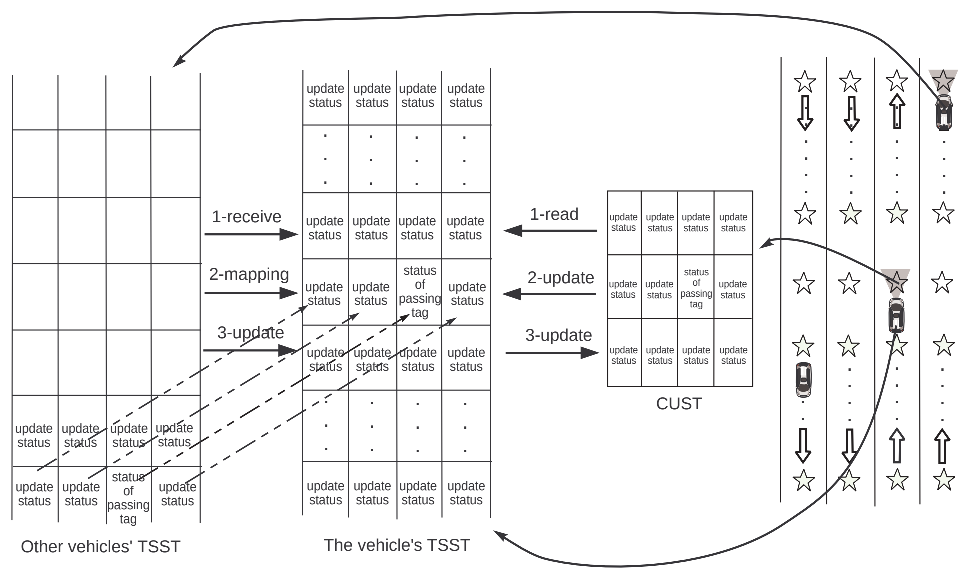

Fig. 3. CUST and TSST.

for tag D in the CUST is set to zero. If the source tag is notified that tag D has obtained the update information, there are two possible sets of actions. First, if tag D's cluster is still in the updating process (i.e., tag D's CUST has at least one entry whose value is zero), the corresponding entry for tag D in the source tag's CUST is set to one. Second, if tag D's cluster has finished the updating process (i.e., tag D's CUST has no zero valued entry), the corresponding entry for tag D in the source tag's CUST is set to two. When a vehicle passes a source tag and learns that the corresponding cluster has been fully updated, the vehicle will not broadcast update information. By doing so, the communication overhead can be significantly reduced.

B. Tag Updating

Since RFID tags cannot communicate directly with each other, a vehicle needs to function as a relay to update tags and their CUSTs. To make the tag updating process efficient, we introduce a Tag Status Synthesis Table (TSST) for each vehicle as shown in Fig. 3. This table includes an odd number of rows of tags. The size of TSST is typically larger than that of CUST. Each entry in TSST represents the update status of the corresponding tag.

When a vehicle passes a tag (say T), the vehicle reads the CUST of tag T. After reading the CUST, the vehicle first updates its TSST by adding the new row of tags and deleting

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the obsolete row of tags. Moreover, the vehicle updates its TSST entries by correlating the information obtained the tag's CUST using Algorithm 1 presented below. Specifically, there are following four possible cases for information correlation. We refer to an entry in the CUST as C_{kl}, and its corresponding TSST entry (if exists) as T_{ij}. In particular, $C_{k^*l^*}$ and $T_{i^*j^*}$ represent status of the tag that is currently being read (T in this example) in CUST and TSST, respectively.

1) *Neither the vehicle nor the tag has any emergent information*: In this case, there is no update necessary. In addition, the vehicle does not send its TSST to other vehicles.
2) *The vehicle has the emergent information, but not the tag (Algorithm 1: Line 2-7)*: The vehicle writes the emergent information to the tag and sets the tag in the update status (i.e., $C_{k^*l^*} = 1$). Moreover, the vehicle copies the values of the entries in its TSST to the corresponding entries in the tag's CUST. Lastly, the vehicle sets $T_{i^*j^*} = 1$ in its TSST.
3) *The tag has the emergent information, but not the vehicle (Algorithm 1: Line 9-11)*: In this case, the vehicle acquires the emergent information from the tag. Next, the vehicle copies the entries in the tag's

Algorithm 1 Tag Updating

1: // A vehicle has successfully read a tag.
2: **if** $C_{k^*l^*} == 0$ and the vehicle has the emergent information **then**
3:     Write the emergent information to the tag and set the tag as in update status.
4:     $T_{i^*j^*} = 1$;
5:     **for** each pair of C_{kl} and T_{ij} **do**
6:         $C_{kl} = T_{ij}$;
7:     **end for**
8: **else**
9:     **if** $T_{i^*j^*} == 0$ **then**
10:         Copy the emergent information from the tag to the vehicle;
11:     **end if**
12:     **for** each pair of C_{kl} and T_{ij} **do**
13:         **if** $C_{kl} > T_{ij}$ **then**
14:             $T_{ij} = C_{kl}$;
15:         **else**
16:             $C_{kl} = T_{ij}$;
17:         **end if**
18:     **end for**
19: **end if**
20: // Check tag statuses in CUST
21: **if** all $C_{kl} > 0$ & $C_{k^*l^*} < 2$ **then**
22:     $C_{k^*l^*} = 2$; $T_{i^*j^*} = 2$;
23:     Change the tag's status to normal;
24: **end if**
25: Write CUST to the tag if CUST has been updated;
26: Broadcast TSST if TSST has been updated;

CUST to the corresponding ones in its TSST.

4) *Both the vehicle and the tag have the emergent information (Algorithm 1: Line 12-18)*: We synchronize the elements in the CUST with the corresponding ones in the TSST in order to increase the vehicle's and the tag's awareness of the update status of the tags that are in both the TSST and the CUST.

Once all the actions of any of the four aforementioned cases complete, the vehicle needs to broadcast the updated TSST and the updated CUST. If there is no update, the vehicle does not broadcast these tables. In addition, if the tag's CUST indicates that all the tags have obtained the emergent information, the vehicle sets the tag's status back to normal.

C. Vehicle-to-Vehicle Information Exchange

To assist the information propagation and reduce the communication overhead, vehicles need to exchange the following information: (i) The current emergent information; (ii) The vehicle's current location (i.e., the location of the most recently read tag); (iii) The vehicle's current TSST; (iv) The set of tags that need to be updated with the emergent information. After receiving such information, vehicles synthesize these information to update their TSSTs using Algorithm 2 presented below.

Algorithm 2 V2V Information Exchange

//Vehicle v_m has received $TSST_n$.
if v_m does not have the emergent information **then**
  //v_n has the emergent information
  Copy the emergent information to v_m;
end if
for each pair of a_{ij}^m and a_{ij}^n **do**
  if $a_{ij}^m < a_{ij}^n$ **then**
    //v_n has the updated information for a_{ij}^n
    $a_{ij}^m = a_{ij}^n$;
  end if
end for
for each a_{ij}^m **do**
  if $a_{ij}^m == 2$ **then**
    Change the value of the entry in $CUST_{ij}^m \cap TSST_m$ to 1 if it was zero;
  else if $CUST_{ij}^m \subseteq TSST_m$ **then**
    //v_m has all the tags' information in $CUST_{ij}^m$
    if all the entries in $CUST_{ij}^m$ is non-zero **then**
      // all the tags in $CUST_{ij}^m$ have been informed
      $a_{ij}^m = 2$;
    end if
  end if
end for
Broadcast TSST if TSST has been updated;

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Next, we use an example scenario to explain the algorithm. Assume that a vehicle v_m receives the information from another vehicle v_n. We assume that an entry (say a_{ij}^m) in $TSST_m$ corresponds to the entry (say a_{ij}^n) in $TSST_n$ (if applicable). Based on the locations of v_m and v_n, and their heading directions, v_m finds the matching entries between the entries of $TSST_m$ and $TSST_n$. There are two possible situations: i) *v_m does not have the emergent information*: v_m first copies the emergent information. Next, v_m directly sets each a_{ij}^m to a_{ij}^n; ii) *Both v_m and v_n have the emergent information*: v_m updates each a_{ij}^m to a_{ij}^n if $a_{ij}^m < a_{ij}^n$. Furthermore, v_m can also read the CUST of each a_{ij}^m (denoted by $CUST_{ij}^m$). Specifically, v_m updates its $TSST_m$ under the following two scenarios: i) If $a_{ij}^m = 2$, each zero valued entry in $CUST_{ij}^m$ and $TSST_m$ should be set to 1 (Algorithm 2: Line 13-14); (ii) If all the entries in $CUST_{ij}^m$ are non-zero and $CUST_{ij}^m$ is completely included in $TSST_m$, a_{ij}^m should be set to 2 (Algorithm 2: Line 15-20). Finally, we broadcast the updated $TSST_m$ (Algorithm 2: Line 23).

Note that we assign a higher priority to communications between tags and vehicles than the communications between vehicles. This is because the contact time between a tag and a vehicle can be very short when the vehicle's speed is high. As a result, the vehicle may not have enough time to write the information to the tag.

V. Analysis and Evaluation Settings

A. Performance Measures

We first explain the measures used to evaluate the performance of our proposed algorithms below.

- *All-tag informed time*: the duration from the occurrence of the emergent information to the time that all the destination tags acquire the information. It means that all the destination tags have received the emergent information after the all-tag informed time. Yet, some of these tags may still be in the update status because they may not know the latest update status of other tags in their clusters.
- *All-tag updated time*: the interval between the occurrence of the emergent information and the time that all the destination tags return to the normal status after receiving the emergent information. It is common that the all-tag updated time is longer than the all-tag informed time.
- *Number of uninformed vehicles*: the number of vehicles that leave the information update area without receiving the emergent information.
- *Packet delivery ratio (PDR)*: the probability of successfully delivering a message to

its destination.

B. Performance Analysis

The all-tag informed time is determined by when the last tag is informed. For the easy of representation, we consider the performance analysis problem in a road segment that has 1 lane for each traffic direction and number of M tags on each lane. As a vehicle with updated information will update all its future reading tags, if the mth ($1 \leq i \leq M$) tag is updated by the vehicle, we can guarantee that the rest tags ($m+1, \cdots, M$) will all be informed after the vehicle's passing by. In the other words, it is for sure that all the tags will be informed if tag 1 has been updated. Therefore, the all-tag informed time is upper bounded by $T_{I_1} + l/v$, where T_{I_1} is the time when tag 1 is updated, l is the road length, and v is the vehicle's average speed. Then, the next step is to calculate T_{I_1}.

Without the loss of generality, we assume the mth tag is updated at time 0. In other words, the emergent information first appears at tag m. If m is 1, then $T_{I_1} = 0$. Otherwise, T_{I_1} is determined the by earliest time when new arriving vehicles (to the road segment) can receive the emergent information from other vehicles.

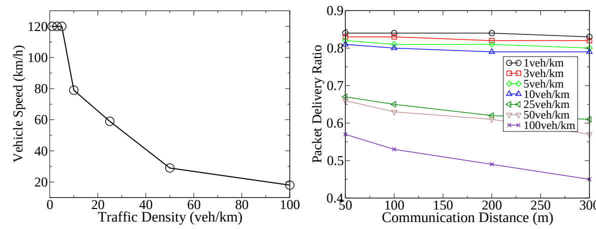
In general, the vehicle to vehicle communication range is larger than the lane width. It means that the vehicles on the reversed traffic lane can receive the emergent information from the vehicle that updated tag m. Similarly, they can forward the emergent information to new arriving vehicles. As a result, in the worst case where a vehicle cannot communicate with the vehicles behind itself (due the low traffic density), T_{I_1} is upper bounded by $T_{R_{meet0}} + T_{R_{travel}} + T_{R_{meet1}}$, where $T_{R_{meet0}}$ is the time when the vehicle R on reversed traffic lane meet the vehicle that updated tag m, $T_{R_{travel}}$ is how long vehicle R will take to travel to the starting point of the road segment (tag 1's location), and $T_{R_{meet1}}$ is when vehicle R can meet a new arriving vehicle after passing the starting point.

Assuming the average distance between two consecutive vehicles on each lane is D, $T_{R_{meet0}}$ is upper bounded by $D/2v$. Similarly, $T_{R_{meet1}}$ is also upper bounded by $D/2v$. $T_{R_{travel}}$ is upper bounded by $(lm/M + D/2)/v$, where $lm/M + D/2$ is the distance traveled by vehicle R to reach the starting point. In summary, the all-tag informed time is upper bounded by $\frac{3D+2l}{2v} + \frac{l}{Mv}m$. Therefore, in the worst case where $m = M$, the all-tag informed time is upper bounded by $\frac{3D+4l}{2v}$.

C. Simulation Environment and Parameters

We adopt the OMNeT++ 4.1 network simulator as our simulation platform. We develop a RFID deployment and reading/writing module for OMNeT++ so as to simulate RFID communications between tags deployed on roads and readers installed on the vehicles. We also implement the car-following model introduced in [15] in order to regulate vehicle movements. According to the car-following model, the traffic density determines the average speed of vehicles on the road. To be specific, the relationship between the vehicle speed and traffic density is shown in Fig. 4(a). Moreover, we utilize the UDP communication module in OMNeT++ to simulate the communications among vehicles. We set the packet loss probability of UDP communications to 15% according to [16]. Packet delivery ratio (PDR) is jointly determined by the packet loss probability, traffic density, and the communication distance. An increase of traffic density and communication distance can lead to more collisions, and thus, reduce the PDR as shown in Fig. 4(b). Note that the traffic density dictates PDR trends, while the communication distance has little impact on the PDR when traffic density is low (e.g., $< 25veh/km$, vehicle speed $> 50km/h$).

In our simulation, all the tags are deployed on a road of 500 meters in length, and 20 meters in width. We vary the traffic density and communication distance to simulate different scenarios. The to-be-updated information is randomly assigned to a vehicle on the road after an initialization period. The initialization period is 5 seconds for each simulation instance so that the network can reach a stable status. The detailed simulation parameters are listed in table V-C. Note that all the reported results are the average of 100 simulation runs.



(a) Vehicle speed vs. traffic density.

(b) Packet delivery ratio (PDR).

Fig. 4. Simulation parameters.

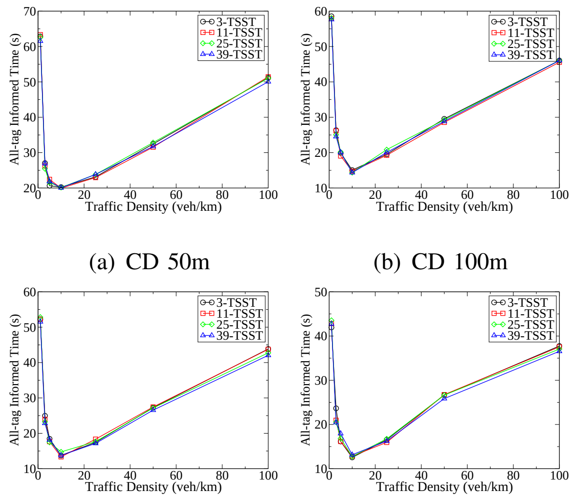
TABLE I
SIMULATION PARAMETERS

Road length	$500m$
Road width	$20m$
Number of lanes	4
Traffic density	$1, 3, 5, 10, 25, 50, 100veh/km$
Communication distance	$50, 100, 200, 300m$
Maximum speed	$120km/h$
Tag's interval	$10m$
MAC protocol	802.11
Packet loss probability	15%

VI. EVALUATION RESULTS

We illustrate our evaluation results in terms of all-tag informed time, all-tag updated time, and the number of uninformed vehicles as follows.

A. All-tag informed time



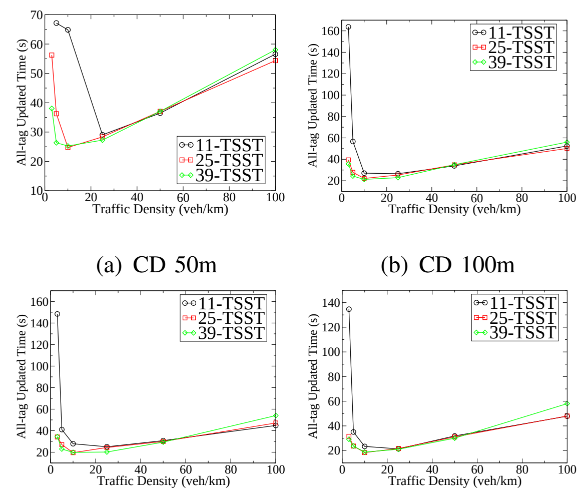
(a) CD 50m (b) CD 100m

(c) CD 200m (d) CD 300m

Fig. 5. All-tag informed time under various TSST sizes, traffic densities, and communication distance (CD).

The all-tag informed time measures the speed of information diffusion among tags. Fig. 5 reports the all-tag informed time for various TSST sizes and traffic densities. First of all, we can see that the all-tag informed time decreases when the communication distance increases. This is because more vehicles can be involved in the tag informing process under a longer communication distance. In addition, we can see that the size of TSST has a limited impact on the all-tag informed time when we fix the traffic density and communication distance. In contrast, the role of the traffic density on the all-tag informed time is mixed: i) When the traffic density is very low or very high, the all-tag informed time is long because either there are not enough vehicles to update the tags or there are too much collision due to excessive vehicle-to-vehicle communications; ii) When the traffic density is in a medium range (say 10-30 vel/km), the all-tag informed time is quite low (about 10 seconds).

B. All-tag Updated Time



(a) CD 50m (b) CD 100m

(c) CD 200m (d) CD 300m

Fig. 6. All-tag updated time under various TSST sizes, traffic densities, and communication distance (CD).

The all-tag updated time is usually longer than the all-tag informed time because the former includes the time to set tags back to the normal status. Fig. 6 shows the all-tag updated time for different TSST sizes and traffic densities. Note that the case of TSST size being 3 does not appear in the figures because the actual all-tag updated time of the case exceeds the maximum allowable time. In general, we observe that the TSST size, the traffic density and communication distance have a similar impact on the all-tag updated time compared to that of the case for the all-tag informed time. Specifically, it can be seen that a smaller TSST size (particularly, TSST =11) can lead to poor performance in low traffic density cases. With the increase of the TSST size, the all-tag updated time decreases as vehicles can obtain more tags update status exchange. However, if the TSST size grows too large (say 39), it can incur a higher all-tag updated time because of excessive communication overhead.

C. All-tag Updated Time with Active Request

We notice that our proposed algorithm suffers when the traffic density is low. To address this issue, we allow vehicles to actively send out requests to other vehicles so as to help update uninformed tags. Assume that a vehicle v_n has successfully finished updating a tag (i.e., after completing Algorithm 1). If v_n finds zero-valued entries in the tag's CUST, v_n broadcasts a request that includes the tag's location and its CUST. Assume that another vehicle v_m receives the request. If an entry in the CUST (say C_{kl}) corresponds to a non-zeroed entry in v_m's TSST (say T_{ij}^m), v_m runs the following algorithm to generate a response.

Algorithm 3 Respond to request

```
Vehicle v_m has received a request from v_n
for each of T_ij^m do
    if T_ij^m > 0 and C_kl == 0 then
        Broadcast v_m's TSST
    end if
end for
```

Via doing so, the update status of certain tags can be received by more vehicles in a wider range (i.e., the radius is twice that of the communication distance). Fig. 7 illustrates the all-tag updated time when the active request is utilized. We observe that the all-tag updated time can be reduced by at least 9% in low traffic density conditions with the adoption active requests. When the communication distance is 50 meters, the time is further reduced about 23%. Yet, adding active requests may increase the all-tag updated time in high traffic density scenarios because excessive communication overhead may congest the vehicle network.

D. Number of Uninformed Vehicles

The number of uninformed vehicles (i.e., those leave the road without obtaining the emergent information) is presented in Table II. We can see that the number of uninformed vehicles is always zero when the communication distance is larger than or equal to 200 meters and the traffic density is smaller than 50 veh/km. When the traffic density reaches 100

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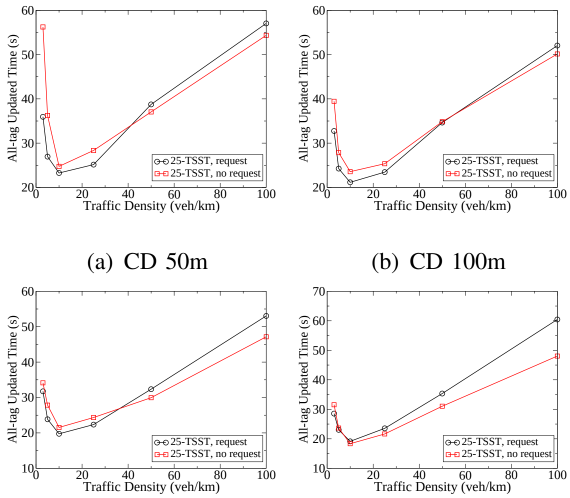


(a) CD 50m (b) CD 100m

(c) CD 200m (d) CD 300m

Fig. 7. All-tag updated time with active requests under various communication distance (CD).

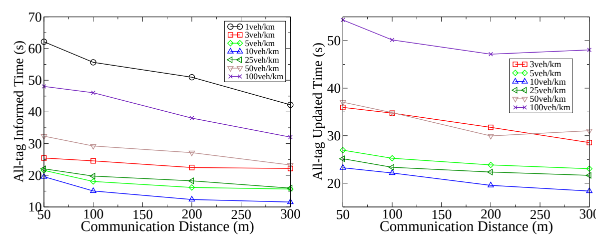
TABLE II
NUMBER OF UNINFORMED VEHICLES

Traffic Density	Communication Distance			
	50m	100m	200m	300m
1veh/km	0	0	0	0
3veh/km	0	0	0	0
5veh/km	4	2	0	0
8veh/km	4	2	0	0
10veh/km	6	2	0	0
25veh/km	7	2	0	0
50veh/km	8	2	0	0
100veh/km	16	10	6	2

veh/km, the number of uninformed vehicles is still very small (2-6). Note that our results are obtained when the road length is 500 meters. The results may vary under different road lengths.

E. The Impact of Communication Distance

Fig. 8 reports the all-tag informed time and all-tag updated time under different communication distance. We can see that the communication distance plays a less significant role compared to that of the traffic density. In general, increasing the communication distance to a certain level (e.g., less than 200m) can help reduce the all-tag informed/updated time because more vehicles can exchange their TSSTs with each other. Subsequently, more TSST exchanges can expedite the information diffusion process. However, when the communication range becomes large enough, it can lead to a higher collision probability that decreases the packet delivery ratio.



(a) All-tag informed time. (b) All-tag updated time.

Fig. 8. The impact of communication distance.

VII. CONCLUSION

In this paper, we propose a novel cluster based information diffusion scheme for quickly and accurately updating on-road RFID tags with emergent road information. To the best of our knowledge, our work is the first to focus on the problem of updating RFID tags in RSR. Our extensive simulation results demonstrate that our proposed scheme can successfully update tags and vehicles with the emergent information in a timely fashion. Note that, although the scheme is proposed for single event update, it can be extended to support multiple event update by adding a field into the tag's status for each event. In the future, we plan to implement the proposed scheme on a test-bed and examine its performance under more comprehensive road conditions.

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