Safety Message Dissemination in NLOS Environments of Intersection using TV White Space

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Abstract*— Safety message dissemination is a key mechanism for preventing intersection collisions. Normally, the dissemination is based on vehicular communications, of which the de-facto standard is Dedicated Short Range Communications (DSRC). However, due to DSRC high operation frequency, a signal suffers from serious attenuation when being propagated in Non Light-Of-Sight (NLOS) conditions. Previous works have leveraged the use of relay units (e.g., repeaters installed on traffic lights) that enabled a safety message to detour large obstacles. However, one cannot guarantee that vehicles find the relay units at every intersection. To solve this problem, in this paper we propose a novel scheme that enables reliable dissemination in NLOS conditions by exploiting a TVWS band. Specifically, the proposed scheme leverages the excellent propagation characteristics of a TVWS signal even without relays. To increase the benefit of a TVWS band, the proposed scheme employs an efficient retransmission protocol, the Repetitive Retransmission via Spatial Diversity (RRSD). The above method ensures the safe message dissemination even in very harsh NLOS conditions. Moreover, the proposed scheme reduces network congestion via a cluster approach that uses both DSRC and TVWS bands. To the best of our knowledge, this is the first attempt to propose a reliable dissemination scheme that supports intersection safety services without special relaying units in NLOS conditions. Simulation studies show that the proposed scheme outperforms the previous scheme in the delivery ratio of a safety message by 25%.

I. Introduction

In 2009, the U.S. government reported that more than 33,800 people were killed and more than two million people were injured from vehicle accidents [1]. Of those reported vehicle accidents, a large fraction of the accidents happened in intersections (specially, 26% of all crashes and 25% of fatal crashes in the United States) [2]. In an attempt to reduce the accidents in intersections, many automotive companies and research institutes developed intersection safety systems, which inform drivers of the possibility of vehicle accidents.

Vehicular communications are the basis for establishing intersection safety systems. Specifically, vehicles notice the possibility of accidents by exchanging their status information (e.g., a position, a velocity, and an acceleration) and disseminating safety messages via vehicular communications. As intersection safety systems are critical to saving life, the safety message dissemination must satisfy low latency and high delivery ratio requirements. For example, in the Intersection Collision Warning (ICW) system, a safety message must be delivered to vehicles that are located in a 300m range from the center of an intersection within 100ms [3].

The Dedicated Short-Range Communication (DSRC) is a dominant standard for vehicular communications, which uses 5.9 GHz licensed band [4]. In a DSRC band, however, a signal cannot pass through large-size obstacles (e.g. buildings or trees), which induce severe signal distortion at receivers in None Line-Of-Sight (NLOS) conditions. Unfortunately, in urban intersections, it is difficult to guarantee Line-Of-Sight (LOS) between vehicles that are located in different road segments. Thus, a vehicle usually fails in delivering safety messages to vehicles in different segments with direct communications in a DSRC band [5]. Measurement campaign in [6] showed the difficulty in successful reception when a sender and a receiver are located in different road segments. More specifically, Packet Error Rate (PER) is close to 100% when a sender and a receiver are apart from the center of intersection by 60m and 80m, respectively. However, most intersection safety services require their dissemination ranges larger than 250m [3]. Thus, we cannot realize intersection safety systems with direct DSRC communications.

There have been previous approaches that enabled message delivery in NLOS conditions by exploiting relaying vehicles ([7] [8]) or centralized units ([9] [10]). In [7], a sender selects vehicles that have LOS to the sender for relaying messages. However, when the vehicle density is low, vehicles might not find relay nodes [8]. In [8], the authors exploited parked vehicles for relaying messages to vehicles in other segments. However, we cannot guarantee the existence of parked vehicles that have LOS with a sender and a receiver[1]. In [9], each vehicle sends its safety message to Road Side Unit (RSU) and RSU disseminates the message to vehicles around the intersection. However, implementing RSUs in all intersections represents a significant money and time investment. In [10], the authors proposed a cluster-based mechanism that exploited two radio interfaces, one for inter-cluster communications in a LTE band and the other for intra-cluster communications in an ISM band. However, the use of a LTE band is not free, the band is often congested due to smart phone traffic and the delays are high.

So, we must raise an important question: "can a vehicle disseminate a safety message in NLOS conditions around an intersection, regardless of the existence of centralized units or relaying vehicles?". To meet this challenge, we require a link with good signal propagation characteristics in NLOS conditions for reliable Inter-Vehicle Communication (IVC). It is well-known that a signal propagates better (e.g., small path loss and penetration loss) in NLOS conditions as the operation frequency becomes lower [11]. Recently, the Federal Communications Commission (FCC) allowed unlicensed users to access the TV White Space (TVWS) band if there are no activities of licensed users [12]. Thus, in this paper, we propose a novel scheme that depends on a TVWS band for leveraging its good propagation characteristics. To further improve the delivery ratio at the corner of an intersection, the proposed scheme adopts a novel retransmission mechanism called RRSD (Repetitive Retransmissions via Spatial Diversity), ensuring that a vehicle that is supposed to deliver most reliably is selected as a sender in each retransmission attempt.

The good propagation characteristics of a TVWS band lead to a large interference range. Thus, if all vehicles use a TVWS band for their transmissions, network congestion becomes serious. The proposed scheme meets this challenge via a cluster approach that exploits a TVWS band for inter-cluster communications, and a DSRC band for intra-cluster communications and cluster managements.

Intensive simulation studies show that our scheme outperforms [10] by 25% in urban intersection scenarios. In summary, the

[1]Parked vehicles are likely to have LOS with a sender and a receiver when being located close to the center of an intersection. However, in most intersections of America, parking is prohibited nearby the center of an intersection.

contributions of this paper are as follows:

- Propose a novel safety message dissemination scheme that does not depend on special relaying units (e.g., RSU, LTE Base Station, moving or parked vehicles) in NLOS conditions around an intersection.
- Propose an efficient retransmission mechanism that exploits spatial diversity for reliable dissemination in NLOS conditions.
- Show that the proposed scheme is feasible to safety applications in an intersection

The remainder of this paper is organized as follows. In section II, we propose a scheme that enables reliable safety message dissemination in NLOS conditions. In section III, we evaluate the proposed scheme. This paper is concluded in section IV.

II. Proposed Scheme

A. System Model

In the proposed scheme, all vehicles have two radio interfaces, one for a DSRC band (DSRC radio) and the other for a TVWS band (TVWS radio)[2]. A DSRC radio employs an IEEE 802.11p protocol [4] with 10 MHz bandwidth and is always located on a DSRC Control Channel (CCH). On the other hand, a TVWS radio adopts an IEEE 802.11af protocol with 5 MHz bandwidth [11] and selects its channel among multiple TVWS channels. In addition to vehicles, there are TV broadcasting towers as Primary Users (PU) in a TVWS band.

A vehicle transmits two types of messages, a **Periodic Beacon Message (PBM)** and an **Emergency Message (EM)**. Every vehicle periodically broadcasts a PBM that contains vehicle's local parameters (e.g., position, velocity, and acceleration), while a vehicle disseminates an EM to warn other vehicles when detecting the possibility of accidents (e.g., locating vehicles in a "dilemma" zone [13]). In the proposed scheme, the EM has higher priority than the PBM and has to be disseminated to vehicles within a service range with stringent delay requirement. Thus, in this paper, we focus on a reliable EM dissemination.

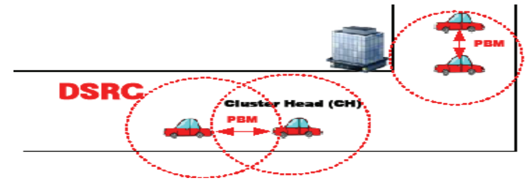
B. Assumptions

In the proposed scheme, we make assumptions as follows. First, all vehicles have map information and Global Positioning Systems (GPS). With this assumption, vehicles achieve time synchronization; they get their geographical coordinates (e.g., latitude and longitude) and relative locations at intersections (e.g., current road segments info). This assumption is reasonable since most drivers have navigators or smart phones with GPS antenna and map information (e.g., google MAP). Second, in a TVWS band, vehicles can distinguish a vehicle signal from other signals (e.g., signals from TV broadcasting towers). For detecting a vehicle signal, our scheme depends on a preamble detection that compares the received signal with the pre-defined preamble sequence for a vehicle [14]. Fortunately, a previous work showed that a mobile device could accurately detect a protocol signal even in noisy channel via preamble detection in IEEE 802.11 [16]. Third, we assume that an EM can be generated only within a safety region. Here, the safety region refers to a road segment that covers the ranges of safety services and is defined in each direction of an intersection. This makes sense since vehicles outside the safety region (e.g., 300m from the center of intersection for ICW) rarely cause accidents at the center of an intersection within delay requirements (e.g., 100ms for ICW).

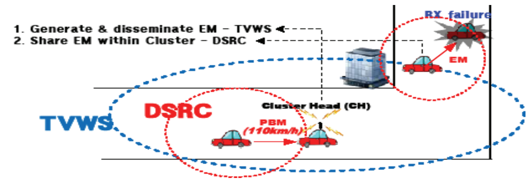
C. Overview of the Proposed Scheme

Fig.1 illustrates overall operations of the proposed scheme. When approaching an intersection, vehicles in the same road segment form a cluster. All vehicles periodically exchange PBMs via a DSRC radio; the cluster head keeps checking the possibility of accidents based on the received PBMs (Fig.1(a)). When detecting

[2]Cost of a radio interface is much smaller than that of a vehicle.



(a) Normal operation



(b) Emergency situation

Fig. 1. Overall operations: (a) normal operation and (b) emergency situation

the possibility of accidents (i.e., within 300m from intersection), the cluster head generates and disseminates an EM within a service range via a TVWS radio (Fig.1(b)). If at least one vehicle receives the EM, the vehicles share the EM within a cluster via a DSRC radio[3]. However, the use of a TVWS band for reliable safety message dissemination raises two technical challenges: 1) finding available TV channels and 2) rendezvous among vehicles at the same TV channel.

Vehicles obtain available TVWS channels by searching a pre-computed spectrum map [14][4]. More specifically, vehicles establish a local spectrum map indexed by positions of a driving route via accessing a centralized database, and obtain available TVWS channels by table look-up, using positions as an index at run-time. This approach is reasonable since the activity of a primary user does not change frequently, thereby an updating interval of the database is long. (e.g., one day in FCC [15]).

As available channels may be different according to a position, vehicles need to make rendezvous at the same TVWS channel. For this purpose, our scheme employs a rendezvous mechanism similar to [14]. Specifically, a vehicle determines a transmission channel when generating an EM and transmits a harbinger signal before sending an EM; neighbor vehicles tune their TVWS radios to the channel. Each vehicle selects the lowest channel of its available channels for its transmission since a signal propagates well in a low frequency band. Then, neighbor vehicles tune their TVWS radios to the channel as follows. As the first step, each neighbor vehicle gathers all available channels by table look-up within its service area In the second step, the neighbor vehicle periodically scans the channels that are gathered in step 1. Finally, when detecting the harbinger signal in one of channels, the vehicle tunes a TVWS radio to the channel and receives the EM [14].

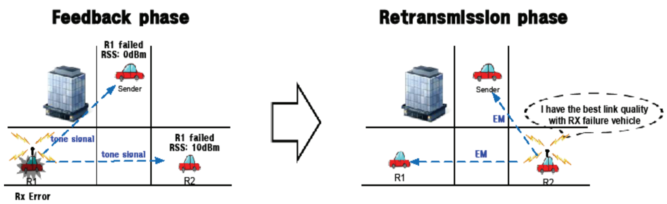
Recall that our scheme leverages good signal propagation characteristics of a TVWS band for reliable safety message dissemination. The benefit of using low frequency band can be augmented when integrated with an efficient retransmission mechanism. This is because safety message might not be delivered reliably just with direct communications in harsh NLOS conditions (e.g., the corner of urban intersections). Specifically, in the urban intersections, large obstacles could be so densely deployed around the corner that communication links in TVWS band may be unreliable. For example, an experimental study in [18] showed that 80% PER occurred when there were tall buildings at the corner, and a sender and a receiver in different segments are 150m away from the corner. Accordingly, the delivery ratio of a safety message is so low that the proposed scheme cannot satisfy the communication

[3]For simplicity, we adopt a flooding with time-to-live (TTL) one, which can be replaced with other efficient mechanisms. However, finding the best forwarding mechanism is not our main scope.

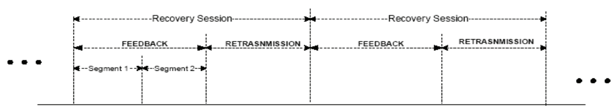
[4]In most urban areas, there are more than one available TV channels when we search available TVWS channels for portable devices in [17].

requirements of the safety services. To address this problem, we propose a Repetitive Retransmission via Spatial Diversity (RRSD) that selects a sender that has the best TVWS link quality with the cluster (TVWS sender) in each retransmission attempt. The detailed design of RRSD will be explained in subsection II-D.

In urban intersections, the overhead for managing a cluster can be large since a topology of a vehicular network frequently changes. More specifically, vehicles join a cluster when approaching an intersection and leave the cluster when crossing an intersection, which happen very frequently in urban intersections. The join and leave processes in the previous mechanisms cause huge network overhead [19]. Hence, our scheme requires a clustering mechanism with low clustering overhead. However, due to page limitation, we omit the details of the clustering mechanism, which can be found in the full paper [20].



(a) Tone-based feedback



(b) Structure of RRSD

Fig. 2. Repetitive Retransmission via Spatial Diversity (RRSD): (a) Tone-based feedback and (b) Structure

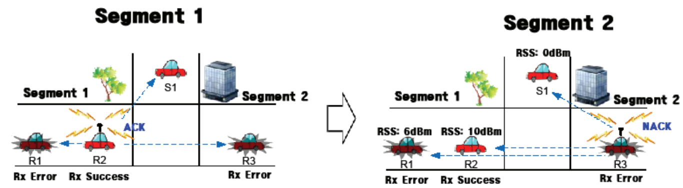
D. Repetitive Retransmission via Spatial Diversity (RRSD)

Repetitive Retransmission via Spatial Diversity (RRSD) relies on spatial diversity to increase a delivery ratio of an EM in each retransmission attempt. Specifically, we select a vehicle that is supposed to deliver an EM most reliably (TVWS sender) in each attempt. This is because link qualities are location-dependent and vary from vehicle to vehicle and with time. For this purpose, RRSD must overcome two challenges: 1) reliable acknowledgement in NLOS conditions and 2) link measurements with several vehicles.

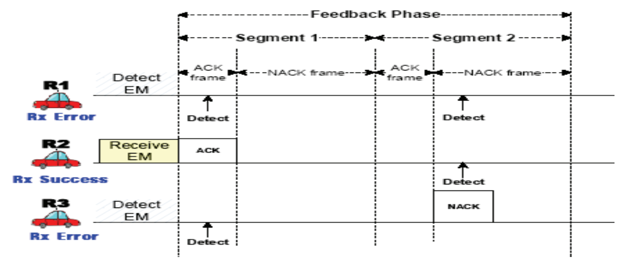
As shown in Fig.2(a), RRSD meets these challenges via a tone-based feedback mechanism. Here, a tone signal consists of a PN sequence that is encoded with a simple on-off keying and decoded via cross-correlation with a known sequence set. It is well-known that an on-off keying and a cross-correlation mapping are robust to signal distortion, thereby leading to reliable acknowledgement in NLOS conditions. Moreover, vehicles estimate link qualities for an EM retransmission from received tone signals due to channel reciprocity [21].

Fig.2(b) illustrates a time structure in a RRSD. A vehicle initiates a RRSD when detecting an EM via a TVWS radio and terminates the RRSD when recognizing that all vehicles have received the EM or the lifetime of the EM expired. A RRSD consists of 'recovery session', which is composed of two phases: 1) a feedback phase and 2) a retransmission phase.

1) Feedback phase: In a feedback phase, each vehicle transmits an ACK (NACK) tone signal via a TVWS radio to advertise the success (failure) of an EM reception within a service area. In RRSD, whenever detecting the tone signal, vehicles need to figure out 1) type of the signal (i.e., ACK or NACK) and 2) the road segment ID that the signal comes from[5]. For this purpose, vehicles



(a) Operations



(b) Time diagram that describes vehicle activities in a feedback phase

Fig. 3. Feedback phase in RRSD: (a) operations and (b) a time diagram

identify the tone signal with a signal detection time, which can be realized by adopting a Time Division Multiple Access (TDMA)[6]. Specifically, a feedback phase is divided into time blocks for each cluster (i.e., the segment ID); each time block consists of ACK and NACK frames (i.e., the type), as depicted in Fig.3(b)[7].

In an ACK frame, a vehicle that has received an EM (e.g., R2 in Fig.3(a) and Fig.3(b)) transmits an ACK tone signal. When detecting the signal, vehicles in the same cluster (e.g., R1 in Fig.3(a) and Fig.3(b)) notice that more than one vehicle have received an EM within a cluster. In this case, even if failing in an EM reception, the vehicles do not send any NACK tone signal in the following NACK frame since they can easily share the EM within a cluster via a DSRC forwarding (e.g., see no NACK tone in the NACK frame of segment 1 in Fig.3(b)). However, if an ACK tone signal is not detected, vehicles recognize that there are no vehicles that have received the EM within a cluster (e.g., see no ACK tone in the ACK frame of segment 2 in Fig.3(b)). In this case, the vehicles in the cluster transmits NACK tone signals (e.g., R3 in Fig.3(a) and Fig.3(b)).

When receiving a NACK tone signal, vehicles estimate link quality with a NACK sender by measuring Received Signal Strength (RSS)[8]. For example, as depicted in Fig.3(a), S1, R1, and R2 can estimate the link qualities with R3 by measuring RSS of the NACK tone signal from R3, respectively.

Concurrent NACK transmissions by multiple vehicles may lead to an error in estimating a link quality. Thus, we divide the NACK frame into multiple time slots and each cluster member transmits a NACK tone signal in its own time slot.In this paper, we will not explain the details of a slot assignment due to page limitation.

2) Retransmission phase: In a retransmission phase, a vehicle retransmits an EM via a TVWS radio, which follows a three-step procedure. First, to give access priority according to link quality, each vehicle determines its Contention Window (CW) size based on its measured value.Second, each vehicle checks whether it has the EM in its buffer. Third, a vehicle retransmits the EM based on CW if it has received the EM.

It is noted that multiple vehicles may attempt to retransmit the same EM in a retransmission phase, which can cause huge network congestion. To reduce the number of transmitters, we employ a suppression mechanism with CSMA/CA. Specifically, if detecting an EM signal via a preamble detection, other vehicles

[5]In RRSD, the retransmission is optimized for maximizing the number of clusters that at least one member have received an EM. This is because the vehicles in the same segment usually have LOS conditions, thereby being able to easily share the EM via a DSRC radio.

[6]When detecting an EM, vehicle reserves a TVWS band during a feedback phase

[7]We can assign a time block to each cluster via MAP info (e.g., N:1st, S:2nd). However, the assignment mechanism is not our main scope.

[8]RSS has large correlation with PDR if the transmission rate is small [22].

TABLE I
DEFAULT SIMULATION PARAMETERS

Radius of safety region	300m
Delay bound of EM	100ms
Generation interval of PBM	100ms
Data rate of a TVWS radio	1.5Mbps
Data rate of a DSRC radio	3Mbps
Minimum Contention Window	15
Number of iteration	10

suppress their transmission attempts.

3) Discussion: In RRSD, a tone signal can be identified only when at most one EM is generated at a time. To validate the identification of the tone signal, we analyze a distribution of an EM generation via a trace-based analysis. We obtain the mobility traces of vehicles using SUMO [23]. Specifically, we acquire a tiger MAP on an urban area (Fairfax ave & Beverly BLVD in Los Angeles)and use the MAP for SUMO simulation. We assume that an emergency event happens when a vehicle violates the speed limit and an EM is generated every 100ms by aggregating all emergency events in each cluster. From the mobility trace, we count the number of an EM generation and the number of emergency events every 100ms.

From the trace-based analysis, we found that less than one EM is generated at a time, thus the identification method in RRSD is feasible. Specifically, only one event happens in 91% of all epochs with event generation. Even if more than two events happen with 9%, such concurrent events happen in the same road segment, which means that the events can be included in a single EM. Thus, we can validate the identification method through this trace-based analysis.

III. PERFORMANCE EVALUATION

A. Simulation Setup

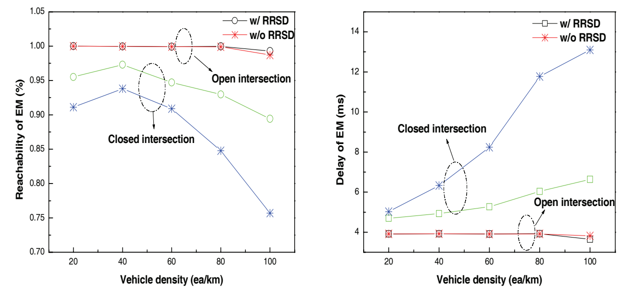
As discussed in section II-D, concurrent EM generations do not happen in an urban area. Thus, we focus on 2x2 Manhattan Grid (i.e., a single intersection) with two lanes where vehicles move in both directions. At the corner of an intersection, large size buildings can be located. To model vehicle mobility, we use a car-following model that was developed by Gipps.

We summarize default simulation parameters in Table.1. In this simulation, a cluster head generates an EM when finding vehicles located in dilemma zone [13]; the cluster head should disseminate the EM within 300m from the center of an intersection with a 100ms lifetime [3]. Similar to [14], all vehicles generate PBMs every 100ms.

In MAC layer settings, we use CSMA/CA for both DSRC and TVWS radios.In physical layer settings, both TVWS and DSRC radios follow a IEEE 802.11 communication system with the lowest transmission rate (i.e., 3Mbps for a DSRC radio and 1.5Mbps for a TVWS radio). For realistic signal propagation at the corner, we adopt CORNER as a path loss model [25]. However, CORNER assumes that large-size buildings are located at every corner of an intersection; a pair of vehicles in different road segments around the corner always suffer from large signal attenuation caused by the buildings. However, in practical situations, a building may not exist at certain corners. Hence, we consider a NLOS path loss model of CORNER only when a building is deployed at the corresponding corner. In addition, we consider a Rayleigh fading model to consider statistical propagation characteristics of vehicular communications.

B. Impact of the Vehicle Density

In this subsection, we investigate the performance of the proposed scheme according to the vehicle density. To see the importance of selecting a TVWS sender, we consider two configurations in the proposed scheme: 1) 'w/ RRSD' where a TVWS sender is selected for each retransmission attempt and 2) 'w/o RRSD' where only an EM generating vehicle can retransmit the EM. Moreover, we consider two different intersections: 1)'closed intersection' where there are large obstacles at all corners, and 2) 'open intersection' where there are no obstacles at the corner.



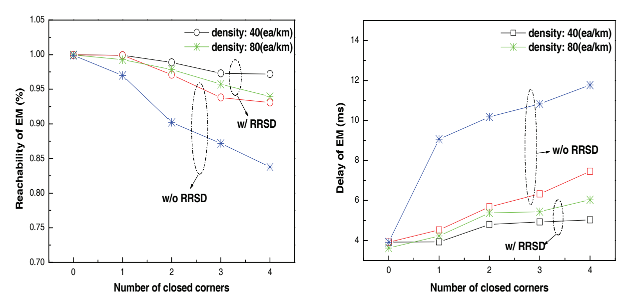
(a) Reachability of EM (b) Delay of EM

Fig. 4. System performances according to the vehicle density: (a) reachability of an EM and (b) delay of an EM

In Fig.4(a), we observe that reachability in both configurations (e.g., 'w/ and w/o RRSD') is close to one in an open intersection. This is because an EM retransmission rarely happens in an open intersection. Specifically, LOS can be guaranteed between vehicles in the different road segments, thus, vehicles in other road segments are likely to succeed in an EM reception at the first EM transmission attempt. The results in Fig.4(b) prove this conjecture, where delay in an open intersection is very short in both configurations.

However, in a closed intersection, the reachability with 'w/ RRSD' is higher than that with 'w/o RRSD' as depicted in Fig.4(a). This is because an EM generator is unlikely to have good link qualities with other vehicles in the closed intersection (i.e., w/o RRSD). Hence, repetitive retransmissions by the same vehicle (i.e., EM generator) is not efficient for a successful delivery. However, if we select a vehicle with better link qualities for retransmission (i.e., w/ RRSD), an EM retransmission is more likely to succeed. This argument is supported by the results in Fig.4(b). Specifically, a delay with 'w/ RRSD' is shorter than that with 'w/o RRSD', which implies that the number of recovery session until successful delivery is reduced with 'w/ RRSD' configuration.

C. Impact of the Closed Corner in an Intersection



(a) Reachability of EM (b) Delay of EM

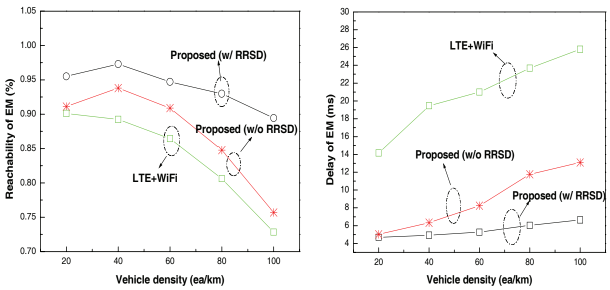
Fig. 5. System performances according to the number of closed corners in an intersection: (a) reachability of an EM and (b) delay of an EM

In this subsection, we analyze the performance of proposed scheme according to the number of closed corners in an intersection. Here, a closed corner refers to a corner where a large-size building is deployed. Similar to section III-B, we consider two configurations of the proposed scheme: 'w/ RRSD' and 'w/o RRSD'.

As shown in Fig.5(a), we observe that the reachability of an EM is rarely affected by the number of closed corners when the proposed scheme has 'w/ RRSD' configuration. This is because we select a vehicle with better link qualities for each retransmission attempt in this configuration. Thus, an EM retransmission succeeds with high probability even if most of corners are closed. We can prove this conjecture in Fig.5(b), where delays are short in ‘w/ RRSD’ configuration.

However, in ‘w/o RRSD’ configuration, the reachability is affected by the number of closed corners as illustrated in Fig.5(a). This is because the same vehicle retransmits an EM repetitively, even though it has the bad link qualities with the failed vehicles. Thus, an EM retransmission is not successful with high probability, leading to the low reachability. This conjecture can be proved by the results in Fig.5(b), where we can find that delay increases as the number of closed corners rise. The increase in delay implies that more recovery sessions are necessary for an EM delivery. Thus, an EM may not be delivered successfully until the lifetime expires, especially when many corners are closed.

D. Improvement over Previous Work



(a) Reachability of EM (b) Delay of EM

Fig. 6. Comparison of system performances between the proposed scheme and [10] according to the vehicle density: (a) reachability of an EM and (b) delay of an EM

In this subsection, we compare the proposed scheme with a clustering scheme that employs two radio interfaces, one for the LTE and the other for the Wi-Fi [10]. We use two configuration settings in the proposed scheme: ‘w/ RRSD’ and ‘w/o RRSD’[9]. To consider realistic LTE scenario, we set Inter-Site Distance (ISD) to 1.7km, which is normally recommended by [26]. From the ISD value, we calculate the average distance between LTE Base Station (BS) and center of intersection to 425m.

In Fig.6(a), we observe that the proposed scheme outperforms the previous scheme. In particular, the proposed scheme with ‘w/ RRSD’ configuration improves the reachability over [10] by up to 25%. This improvement comes from two reasons. First, LTE transmission for inter-vehicle communications is not efficient. More specifically, even if an inter-vehicle distance is short, a vehicle transmits the EM to far away BS first, and then BS forwards the EM to the Gateway. The gateway then transmits the EM to the affected intersection cluster heads on separate LTE band. Thus, low BS-station link quality and Inter-Cell Interference (ICI) reduces a delivery ratio of the EM. Second, [10] relies on a single cluster-head for inter-cluster communications. More specifically, to reduce the cost of using LTE, only cluster-heads have connections with BS and are capable to communicate with the BS. Hence, [10] produces low delivery ratio when the link quality between BS and the cluster head is low. In contrast, our scheme leverages spatial diversity, as one of its main contribution. Specifically, to improve a delivery success, multiple receivers can receive an EM. Therefore, even if a cluster head fails in receiving the EM, other vehicles can compensate for the reception failure.

Fig.6(b) shows that a delay of [10] is longer than that of proposed schemes by up to 150%. This is because the scheduling mechanism of the LTE data channel usually induces a large delay when the LTE band is crowded by typical background smart-phone traffics. In contrast, the proposed scheme depends on CSMA/CA, which produces good performance when the network is not crowded. Fortunately, the proposed scheme exploits a TVWS band, which is used by only a few vehicles (e.g., a cluster head or a TVWS sender).

[9]For fair comparison, even if [10] depends on multiple Wi-Fi channels, we only use one Wi-Fi channel, but without interference.

IV. Conclusion

We proposed and analyzed a reliable dissemination scheme in NLOS conditions around an intersection without special relaying nodes. To leverage the good propagation characteristics, the proposed scheme depended on a TVWS band for EM dissemination in NLOS conditions. More specifically, vehicles in the same road segment form a cluster. Vehicles exploited TVWS band for inter-cluster communications, and DSRC band for intra-cluster communications and cluster managements. To further enhance the delivery ratio at the corner, the proposed system features a RRSD retransmission scheme that exploits a spatial diversity. The simulation results showed that the proposed scheme outperformed a previous cluster-oriented scheme based on LTE instead of TVWS for inter-cluster communications.

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