An Accurate Vehicle-to-Vehicle Instant Alert System Using Directional Antennas

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***Abstract*—With the maturity of 5G networks and V2X technologies, utilizing V2X to increase driving safety becomes feasible. Road side units (RSU) recognize dangerous events and notify the related vehicles using 5G V2X communications. The alert latency between RSUs and related vehicles may cause car accidents. Besides, the V2X emergency alarms are broadcasted by dipole antennas. Many unrelated vehicles will receive unnecessary alerts and distract drivers. This paper proposes an accurate vehicle-to-vehicle instant alert system (V2V-IAS) to detect potential dangerous events and alert target vehicles by directional antennas to reduce transmission delay and interference. In V2V-IAS, a vehicle can fuse camera information and cooperative awareness messages (CAM) messages from surrounding vehicles carried to predict dangerous events without relying on RSUs. Once an event is detected, the vehicle will send an alert to specific cars in real time using directional antennas to increase the transmission success rate and reduce disturbing unrelated vehicles. We also use two sets of Qualcomm MDM9150 to conduct real road tests and simulate multi-vehicle environments on Matlab to validate our idea. From experiments, directional antennas can reduce the possibility of packet collisions up to 21% and transmit at the same distance with less output power compared to dipole antennas.**

***Index Terms*—Driving safety, V2X communication, dipole antenna, directional antenna, patch antenna, dual antenna system.**

I. Introduction

Vehicle-to-everything (V2X) communication is one of the essential applications for 5G systems. Currently, a driver notifies an alert by horning. As a result, target vehicles may not be notified, but many unrelated vehicles may be disturbed. It is expected that V2X communications can help improve road safety and traffic efficiency [1]–[3].

To guarantee road safety, [4] utilized road side units (RSUs) to combine camera and profile data of vehicles, identify potential danger events, and notify related vehicles via vehicle-to-infrastructure (V2I) communications. The RSUs involved in the whole process, including observing the environment by cameras, identifying vehicles, and sending out alerts to specific vehicles. However, the computation latency of video processing and transmission delay may exceed 100 milliseconds, which is the requirement in the 3GPP standard [5].

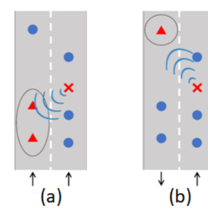

Fig. 1. Notification scenario for lane change (a) and overtaking (b).

In addition, the current V2X emergency alarms are broadcasted by dipole antennas. Many unrelated vehicles will receive unnecessary alerts and distract drivers. Sudden brake, lane change, single carriageway, and intersection are four common cases that require alerts [4]. In Fig. 1(a), when car x wants to change the lane, the two triangle cars are the warning targets. The signal should be sent in that direction, and vehicles at other directions should not be interfered by the signal. Fig. 1(b) is an overtaking case in a single carriageway. When car x intends to pass the car in front of it, x should alert the triangle car.

In this paper, we propose an accurate vehicle-to-vehicle instant alert system (V2V-IAS) to detect dangerous events and send instant warnings to related vehicles without the help of RSU. V2V-IAS consists of a vehicle identification (VID) module, a vehicle status analysis (VSA) module, an alert packet transmission (APT) module, and an antenna adjustment (AAM) module. VID and VSA modules identify vehicles and monitor dangerous events. APT module is in charge of sending out instant warning messages to the specified vehicles. In order to transmit warning messages more accurately, we use AAM to switch dipole antennas and directional antennas. To evaluate V2V-IAS, we use two sets of Qualcomm MDM9150 to conduct road tests and simulate multi-vehicle environments on Matlab.

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From experiments, when the target vehicle is in the same direction as the directional antenna, the transmission distance of the directional antenna is 1.5 times that of the dipole antenna. In the multi-vehicle experiments, the probability of packet collisions of V2V-IAS can be reduced by up to 21%. Through the assistance of V2X communications and directional antennas, V2V-IAS can avoid dangerous events and reduce interference for unrelated vehicles.

The contributions of this work are summarized as follows:

- V2V-IAS only utilizes camera images and the CAM messages from surrounding vehicles to detect dangerous events without the help of RSU. The alert latency can be intensively reduced.
- Directional antennas are applied in V2V-IAS to increase the transmission success rate and reduce interference to other unrelated vehicles.
- Road tests and simulated multi-vehicle environments are established to demonstrate the practicality of V2V-IAS.

II. Related Work

With the advancement of 5G networks and V2X technologies, many traffic accidents can be reduced. In [4], RSUs combined CAM information sent by the vehicles and the video data to establish the spatial relationship of surrounding vehicles and detect potential road hazards. RSUs sent alerts to target drivers by decentralized environment notification message (DEAM) if a dangerous event is detected. [6] proposed a MEC-based collision avoidance system, in which vehicles and users sent basic safety messages (BSM) to a centralized collision detector by CV2X and smartphones. When a potential collision was detected, a warning message was sent to the target object. However, the collision detectors described in [4] and [6] were on RSU or cloud servers, which may cause delay beyond the 3GPP standard time for mutual vehicle awareness and road safety [5]. The vehicle side should do collision detection.

On the other hand, 3GPP supports direct V2X communications over the sidelink. The user equipment (UE) can independently broadcast an alert message even when it is beyond the coverage area of the base station. However, without the resource coordinating of the base stations, the UE cannot determine whether the resources have been claimed. Therefore, when the density of the UE increases, collisions are bound to occur. [7]–[9] asked TX to sense the channel first and then select appropriate resources to send the data. The collisions may be reduced but cause transmission delay. When the car was in a crowded environment, the delay became much longer. Thus, we will utilize a directional antenna, which can concentrate the energy to the specific area, to reduce delay and interference in V2X communication.

Identifying the location of vehicles is necessary to transmit alerts to the specified targets. [10] determined the 3D locations of vehicles by utilizing a convolutional neural network, ground plane estimation, and a new object tracklet smoothing method with common monocular cameras. [11] predicted the location of vehicles by fusing the information obtained from multiple on-board sources such as GPS receiver and automotive radar. [12], [13] combined LIDAR with the camera to achieve real-time 3D object detection. We will use the techniques of [10] to increase the accuracy of the locations of vehicles.

III. Vehicle-to-Vehicle Instant Alert System

We propose an accurate vehicle-to-vehicle instant alert system (V2V-IAS), as shown in Fig. 2. V2V-IAS consists of a vehicle identification (VID) module, vehicle status analysis (VSA) module, alert packet transmission (APT) module, and antenna adjustment (AAM) module.

A. VID Module

VID module collects the information of the surrounding vehicles of the host vehicle. The information of surrounding vehicles is transmitted by CAM message. For example, speed and the GPS location of the vehicles can be exchanged among neighboring vehicles. Due to the accuracy of GPS locations is around five meters, we utilize the object detection model of [10] to identify vehicles surrounding the host vehicle. We derive the location relative to the host vehicle and compare it with the information of CAM messages to obtain more accurate locations of surrounding vehicles. Let $V(t)$ be the set of locations of surrounding vehicles. $V(t) = \{v_1(t), v_2(t), ..., v_n(t)\}$, where n is the number of surrounding vehicles. The host vehicle can get its location $V_o(t)$ from its on-board global navigation satellite system (GNSS) receiver. $V(t)$ and $V_o(t)$ are sent to the VSA module for dangerous event detection. Besides, $V_o(t)$ will also be sent to the APT module for generating the broadcast CAM message.

B. VSA Module

VSA module identifies dangerous events and generates the decentralized environmental notification message (DENM) message to alert surrounding vehicles. The set of locations of surrounding vehicles $V(t)$ is maintained in the database. The database contains the IDs of vehicles, GPS location, the information of vehicles, and IPv6 address. VSA utilizes $V_o(t)$ and $V(t)$ to predict collisions. First, based on the speed and trajectory of the vehicle, we can predict its future trajectory. We also predict the future trajectory of the host vehicle. We compare these two trajectories. If a dangerous event happens, a warning DENM message $E(t)$ is generated. All DENM messages $E(t)$ are forwarded to the APT module for transmission.

C. APT Module

The APT module collects messages from VID and VSA and sends them out according to their types. The dipole antenna transmits CAM messages. The directional antenna delivers DENM messages since they need to reach specific vehicles. The module calculates the appropriate output power and the transmission direction for the directional antenna according to the locations of the target vehicles to increase the transmission success rate and reduce the interference.

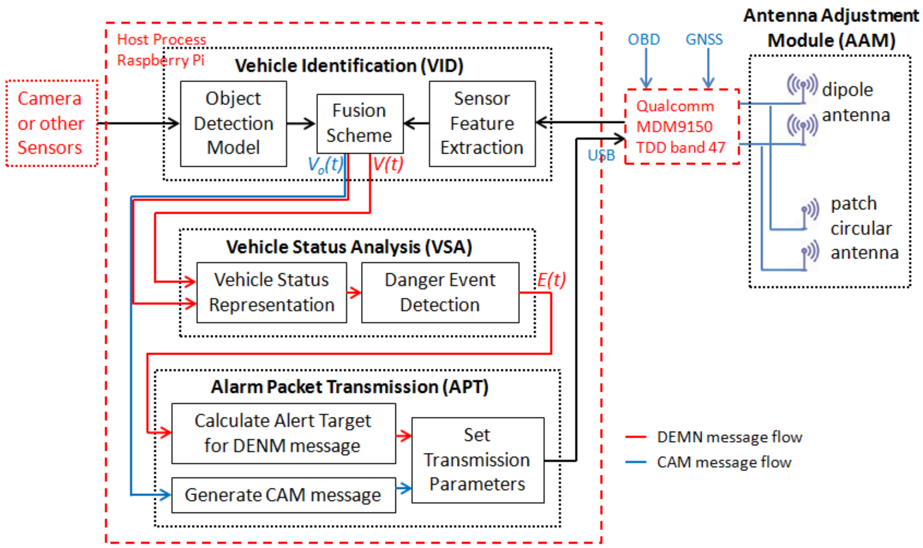

Fig. 2. System architecture.

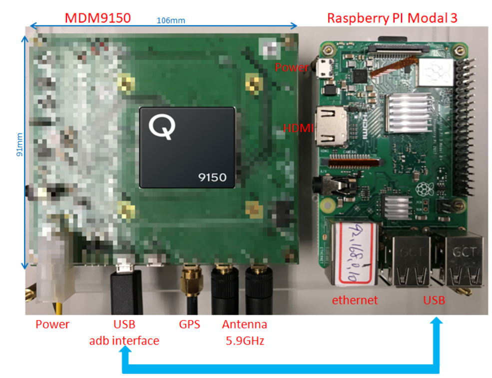

Fig. 3. Hardware platform : Raspberry Pi 3B and MDM9150.

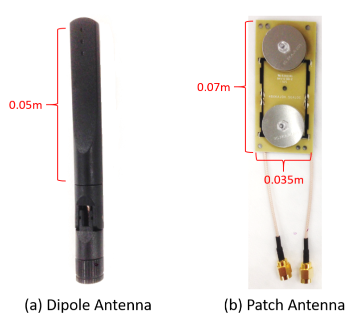

Fig. 4. Dipole and patch antennas.

D. AAM Module

AAM module switches between dipole antennas and directional antennas by general-purpose input/output (GPIO) from the host process. When the DENM messages are transmitted, the AAM module adjusts the transmission direction of the directional antenna.

IV. Experiments

In experiments, we use an MDM9150 and a Raspberry Pi 3B to build an evaluation platform, as shown in Fig. 3. VID, VSA, and APT modules are implemented on Raspberry Pi. AAM module includes a dipole antenna and a set of patch antennas in different directions. There are many types of directional antennas. A patch antenna is a semi-directional radiator with a flat metal strip mounted on a ground plane. The dipole antenna and patch antenna we adopted are shown in Fig. 4. AAM module will receive commands from Raspberry Pi to switch different antennas. The MDM9150 works at the ITS spectrum 5.9GHz and uses the PC5 interface to directly communicate with another UE over the direct channel without relying on base stations. Its radio signal is connected to the AAM module so that we can use Raspberry Pi to change the antenna for MDM9150. The frequency range for both antennas is from 5.15 GHz to 5.925 GHz. The peak gain of the dipole antenna is 2.84 dBi at 5.925 GHz, while the peak gain of the patch antenna is 8.76 dBi at 5.925 GHz. The peak gain of the patch antenna is 5.92 dBi higher than that of the dipole antenna. The front-to-back radiation ratio of the patch antenna is 16 dB. In the following experiments, we conduct road tests and simulate the multiple vehicle environments to evaluate V2V-IAS.

A. Field Test

We conduct road tests by using two sets of Qualcomm MDM9150 to measure transmission distance. One is set as the receiving device, and the other is set as the transmitting device. We move the transmitting device away from the receiving device and execute a test every 10 meters until no signal is received. We use both antennas to send 30 packets and record the reception status at the receiving end at each test point.

First, we perform a line-of-sight (LOS) test in the open area. Fig. 5 shows the packet receiving ratios at different distances. When the target vehicle is in the same direction

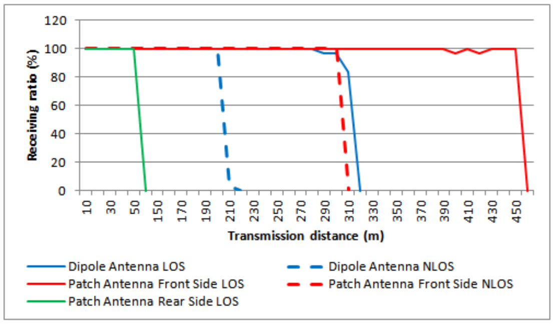

Fig. 5. Packet receiving ratio vs. transmission distance.

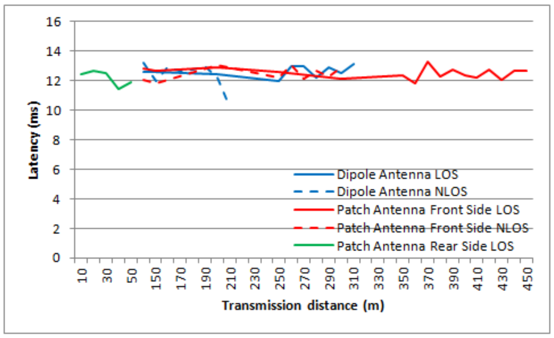

Fig. 6. Latency vs. transmission distance.

as the patch antenna, the transmission distance can reach 450 meters. On the other hand, the transmission distance in the opposite direction is only 60 meters. It is 250 meters shorter than that of the dipole antenna at LOS. In other words, there is less interference to the vehicles in the opposite direction for the case of patch antenna when vehicles in the opposite direction are not our target alerting vehicles.

We can use the Friis transmission equation to validate the result, as seen in Eq.(1). Friis transmission equation shows the relationship between the gain of different antennas and the transmission distance.

$$P_r = P_t + D_t + D_r + 20\log_{10}(\frac{\lambda}{4\pi d}), \quad (1)$$

where P_t is the power transmitted to the terminals of transmit antenna, and P_r is the power at the receive antenna. D_t and D_r are the antenna gain of transmitting antenna and receiving antenna. λ is the wavelength of the operating frequency. d is the distance between the transmitting antenna and the receiving antenna. The receiving device is using a dipole antenna, so the D_r is 2.84 dBi. We use both antennas on the transmitting device, so the D_t of the dipole antenna is 2.84 dBi, and the D_t of the patch antenna is 8.76 dBi. P_t is the output power of the transmitting device, currently set to 0 dBm. P_r is set to -90 dBm. By Eq. (1), we obtain the transmission distance d of the dipole antenna is 304 meters and the patch antenna is 478 meters. In addition, the gain on the back of the patch antenna is about -8 dBi. We can obtain the transmission distance in the opposite direction is only 69 meters. It shows that the experimental results are the same as theoretical calculations.

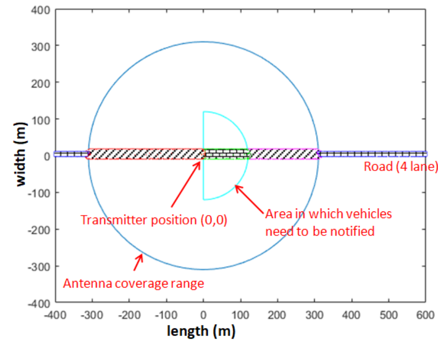

Fig. 7. Simulation of the multi-vehicle environment by Matlab.

Next, we conduct a non-line-of-sight (NLOS) test in a parking lot. In Fig. 5, if vehicles are blocking the signal between the sending and receiving devices, the transmission distances of the patch antenna and dipole antenna are decreased to 310 meters and 210 meters, respectively. Fig. 6 compares the transmission latency with the different distances of dipole antenna and patch antennas in LOS and NLOS. The latencies are all less than 15ms and remain constant.

B. Multi-vehicle Simulation

We evaluate V2V-IAS in multi-vehicle environments on Matlab, as shown in Fig. 7. The simulation area is a rectangular area with a width of 1,000 meters and a height of 800 meters. The target vehicle is located at coordinates $(0, 0)$. The road was 1,000 meters in length and comprised six lanes, three in either direction with a lane width of 3 meters. The distance between vehicles is calculated as 2.5 seconds multiplied by the vehicle speed. We set 40, 70, and 100 km/h as three vehicle speeds to simulate different congestion levels. We change the antenna coverage by adjusting output power according to the locations of target vehicles. That is, we tune the power to the minimum required level. Similarly, we use Eq.(1) to adjust the output power of the transmitting antenna.

Fig. 8 and Fig. 9 presents the simulation results at three different speeds. With higher power, inter-vehicle distance and transmission power are positively correlated. In Fig. 8, when the patch antenna is adopted, the output power required for reaching the same distance is lower than the dipole antenna. However, when an alert is sent to the target vehicles, the number of vehicles within the range of the patch antenna is significantly less than that of the dipole antenna, as indicated in Fig. 9. This is because the patch antenna could concentrate its energy in the target direction and reduce interference with other vehicles. According to our estimation, in a crowded environment, the probability of packet collisions can be reduced by up to 20.6%.

To increase the realism of the multi-vehicle environment, we simulate the an intersection and evaluate the coverage of different antennas. Fig. 10 reveals that when the distance between the vehicle and the intersection exceeds 200 meters, the coverage area of the patch antenna on the left and right

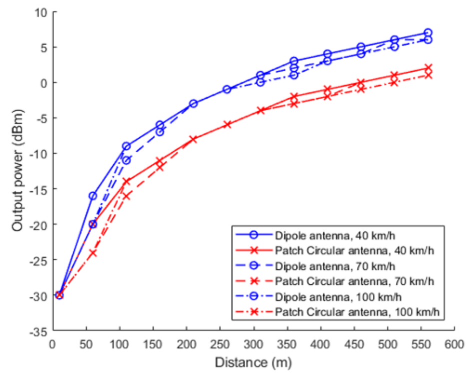

Fig. 8. Output power vs. distance.

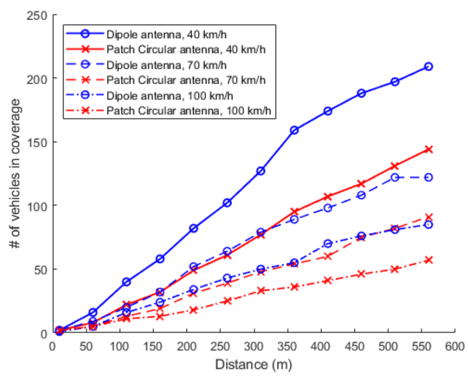

Fig. 9. Number of vehicles in radio coverage vs. distances.

sides is more significant than that of the dipole antenna. This indicates that the patch antenna is suitable for sending alert messages in this situation. When the distance between the host vehicle and the intersection is less than 200 meters, the coverage area of the dipole antenna on the left and right sides is more extensive than that of the patch antenna. Therefore, the dual antenna system we propose can switch between different antennas according to different usage scenarios, which is more flexible in use and can improve driving safety.

V. Conclusion

This paper proposed an accurate vehicle-to-vehicle instant alerts system (V2V-IAS) to detect potentially dangerous events in the vehicle side and send alerts by the directional antenna. V2V-IAS consisted of VID, VSA, APT, and AAM modules. VID module and VSA module identified vehicles and predicted dangerous events in real time. APT module adjusted transmission parameters, and the AAM module switched between two antennas. To evaluate V2V-IAS, we conduct actual road tests and simulate multi-vehicle environments on Matlab. In LOS road test, when the target vehicle is in the same direction as the patch antenna, the transmission distance of the patch antenna is 1.5 times that of the dipole antenna. The transmission distance of the patch antenna in the opposite direction is only 20% of the dipole antenna. In multi-vehicle

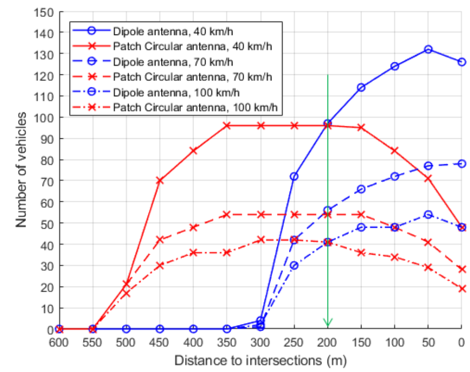

Fig. 10. Number of vehicles in radio coverage vs. distances to intersection.

experiments, when using V2V-IAS, the probability of packet collisions can be reduced by 21%. In conclusion, V2V-IAS can not only concentrate RF signal to the specific area through the directional antenna and adjusting output power but intensively reduce interference to other unrelated vehicles.

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