Abstract

Recent advanced transport technologies in vehicle-to-vehicle communications have paved the way for testing new solutions that would reduce congestion and prevent traffic incidents. The main objective of multiple transport agencies is to improve road safety by providing reliable and flexible solutions to all drivers on the roads. While significant efforts are put together for dealing with regulations and standard adoption, various questions regarding the practical performance and accuracy of such technologies are still to be tackled.

This paper presents the results obtained from an ongoing research investigation focusing on testing the capabilities of Dedicated Short Range Communications (DSRC) to meet critical levels of road safety in terms of positioning accuracy. After previous analysis of positioning accuracy of heavy vehicles on a 42 km test-bed in Illawarra, Australia, we now focus on testing the positioning accuracy as transmitted by two light vehicles, engaged in five different simulation experiments of potential traffic collisions. Firstly, as ground truth is not available, we conduct a comparative analysis of transmitted positioning through Basic Safety Messages by using both Open Street Map and Google Street Map as reference, and show the latter provides better accuracy in positioning error computation. Secondly, we present the results obtained when analyzing the collision alerts broadcasted during the incident demonstrations. The findings indicate that speed, breaking and DSRC installation might influence the successful transmission of collision alerts to the surrounding drivers and can be used as a guideline for future settings of using DSRC equipped vehicles in light vehicles.

KEYWORDS: DSRC, connected vehicles, positioning accuracy, collision alert investigation, road safety.

1. Introduction

Traffic congestion and road vehicle collisions are one of the most important problems in concentrated urban areas around the globe, leading to almost 1.24 million road traffic deaths per annum [1]. In order to address this issue, advanced transport technologies such as Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications are already being tested and recent studies show the benefits of adopting these technologies in terms of life-savings and economic impact [2].

Recent advancements in wireless communication technologies have led to the emergence of dedicated short-range communication (DSRC), which has been designed to support V2V communications, enhance mobility and improve road safety [3]. As vehicular communications need fast interoperability, U.S., Europe and Japan have assigned dedicated bandwidths for DSRC communications [4]. In order to assess the performance and safety benefits of DSRC, various projects and test bed initiatives have concentrated on: testing the effective communication range between two vehicles and security protocols [5], analysing the
probability of successful message reception [6], detecting collision situations and sending drivers early alerts [7], analysing collision timing [8], or investigating signal priority for connected vehicles (CV) at signalized intersections [9]. Despite a high DSRC reliability indicated by these studies, in 2014, the National Highway Transportation Safety Administration (NHTSA) published the need to further investigate open research problems before establishing rule-making for a deployment-level V2V communication system mandate [10].

One of the biggest problems to address when using DSRC for building safety applications such as proximity collision alerts, automated braking, intersection signal alerts, etc., is to have an accurate vehicle positioning capability. Current systems only use Global Navigation Satellite System (GNSS) [11]. Although in ideal operating conditions (clear sky, no obstructions), GNSS can usually meet the positioning accuracy for most DSRC applications, in dense urban areas, high multi-paths or tunnels the GNSS signal can be limited or contains inaccurate positioning [12]. Some CV applications need sub-meter accuracy at the lane level, especially for real-time situational awareness [13]. Bridging the gap between positioning accuracy and the necessary availability for CV applications represents an important challenge still to be tackled. In [14] the authors proposed a Bayesian approach for using received signal strength data from roadside equipment (RSE) to update and improve GPS positioning. While this approach can work well when RSE is available and ready to use, many test beds have insufficient RSE or they are located at sparse locations throughout the study network. Other studies propose integrating GNSS and navigation information such as map data [11, 15], which contains “metadata” for travellers. However, until such maps are developed and shared across a large fleet, the cost to maintain a huge map database can become prohibitive especially for rapidly growing cities.

The Cooperative Intelligent Transport Initiative (CITI) is a project currently undertaken by Transport for New South Wales (TfNSW), with the aim of building Australia’s first semi-permanent test-bed for testing the DSRC technology over an area of 917 km² in the Illawarra Region of NSW south of Sydney [16]. Currently, sixty vehicles (58 heavy vehicles and 2 light vehicles), three signalised intersections and one roadside location have been equipped with DSRC units. In order to ensure road safety, one of the main problems of the project is to address the generation of false collision alerts which might hinder driving and could result in a mistrust of the DSRC on-board-unit warning device. The first step to identify the possible cause of false alerts is to investigate and understand the accuracy of the transmitted positioning between the connected vehicles, as reported from Basic Safety Messages (BSMs). Our previous studies [17] on positioning accuracy for heavy vehicles, indicated that almost 37.89% of transmitted BSMs during a specific period of time were incomplete or empty, while some heavy vehicles presented various anomalies in positioning (for example, one of the most active trucks showed 9% of anomalies). While the transmission of DSRC BSMs should not be impacted by the structure of the vehicle (heavy or light) neither the DSRC installation process, one would need further investigations to acknowledge the difference in transmission between various types of DSRC-equipped vehicles. This work is therefore a continuation of previous results to test and detect if the same anomalous behaviour would appear in positioning or broadcasting collision alerts for light vehicles equipped with DSRC. The main objectives of this study are:

a) investigate the error (noise) in the transmitted GPS positioning for DSRC-equipped light vehicles,
b) analyse the transmission of collision alerts during experiments which simulate real-life incidents,
c) identify the factors that might hinder broadcasting collision alerts.

2. CITI project background

The Cooperative Intelligent Transport Initiative (CITI) is a project deployed by Transport for NSW (TfNSW) in partnership with Data61|CSIRO and the Australian Federal Government’s Heavy Vehicle Safety Productivity Program. The main goal of the project is to assess V2V/V2I communication technology that could reduce the number of road accidents, with a focus on the Illawarra region, on both urban and periferal traffic conditions. In order to address this problem and the high cost generated by truck accidents, CITI project aims at building a semi-permanent test bed for evaluating and further testing of the Cooperative Intelligent Transport Systems (CITS) technology, especially DSRC equipped vehicles.
2.1 Current deployment and location

During the first stage, the CITI project has installed DSRC devices in 58 heavy vehicles, 2 light vehicles, 3 signalized intersections (Figure 1b) and 1 roadside unit in the operating area marked in Figure 1a. CITI currently utilizes Cohda Wireless MK4 and MK5 DSRC units [18] running Cohda’s alert software in vehicles and roadside software for infrastructure deployment. Cohda’s DSRC systems are using the US standards of IEEE 1609 family, SAE J2735 and IEEE 802.11p standards. While the heavy vehicles have only GPS antennas, the light vehicles used for the current study have a combination of GPS/GLONASS, potentially providing more accurate positioning. Inside the vehicles, the DSRC unit is connected to a Nexus 7 tablet for audio and visual display of generated alerts, such as Forward Collision Warning (FCW), Intersection Collision Warning (ICW), Electronic Brake Light Warning (EBLW), as well as two custom alerts.

![Figure 1 a) CITI operating area with an example of daily trip: (150.558,-34.51) x (151.318,-34.109) (Google maps source). b) DSRC equipped intersections: (150.874,-34.447 x 150.889,-34.439) (Google maps source).](image)

2.2 Challenges

Vehicles in the trial are broadcasting their position 10 times a second in a message known as the Basic Safety Message (BSM). The positioning information in these messages is based on GPS measurements and if the GPS signal is lost then the position may be extrapolated from last known data in a process known as “dead reckoning” [19]. However, in CITI, no additional sensors are connected to the DSRC unit and dead reckoning is restricted to interpolations from last GPS locations. For the remainder of this article, reference to “GPS” is actually a reference to “GPS-based positioning information” as broadcasted by a vehicle in a BSM. Therefore, the accuracy of the “transmitted GPS positioning” is not independent of the DSRC unit, but is a mix of processing and transmission methods.

Large variations in the transmitted location to other connected vehicles can trigger false collision alerts, or hinder driver’s response to alerts. As road safety is the main focus of the CITI project, a major concern is to identify the risks that drivers face when being exposed to false alarms or when false and correct alarms cannot be distinguished. As our previous investigations on heavy vehicles revealed various anomalies in term of positioning accuracy while operating in some road sections of the test-field area, current analysis is focused on: a) assessing the accuracy transmitted by light vehicles in urban areas near Port Kembla b) investigating the successful transmission of collision alerts when simulating real-life incident scenarios. In terms of ground truth, this investigation uses the closest mapped road position from both Google Street Maps (GSM) and Open Street Map (OSM) to determine the “error” or noise in the DSRC transmitted GPS position. As well, the simulated incidents have been filmed in order to verify the lane positioning of the cars during the tests.
3. Positioning analysis for light vehicles

3.1 Context

Two light-vehicles belonging to RST and equipped with DSRC systems were involved in various test-case scenarios in which the DSRC system sent alert messages to the driver in order to avoid collision between the two cars. This demonstration took place in Wollongong, on the 8th of April 2016 at around 11 am local time for approximately one hour, and generated almost 35,000 BSMs for each vehicle, as represented in Table 1.

Table 1 Transmission times for collision scenarios.

<table>
<thead>
<tr>
<th>Car</th>
<th>Start time</th>
<th>End Time</th>
<th>BSM number</th>
</tr>
</thead>
</table>

Figure 2 shows the paths that the cars have taken during the experiment, covering a different range of roads from the city center to peripheral arterial roads.

Figure 2 Trajectory of two DSRC-equipped light vehicles (QGIS, Google Satellite).

The following driving scenarios were tested:

1. *Forward collision experiment* – testing the forward collision avoidance with successful generated collision alert message (first car decelerates, second car (following) receives alert messages);
2. *Forward collision experiment, reversed roles* – testing the forward collision avoidance with successful generated collision alert message when the roles of vehicles were reversed;
3. *Unmarked T-intersection experiment* – first test of collision avoidance at an unmarked T-intersection (low visibility) with failed collision alert message.
4. *Unmarked T-intersection experiment* – second test of collision avoidance at an unmarked T-intersection (low visibility) with successful generated collision alert message.
5. *Signal Phase and Timing (SPaT) Equipped intersections* demonstration – successful generation of red light alerts based on traffic signal messages received by both connected vehicles.
3.2 Data sources and noise processing

The data transmitted by the DSRC-equipped vehicles is automatically collected when vehicles are stopping near 2 equipped trailers in Port Kembla. It contains all transmitted and received DSRC messages, including BSMs. After initial data format reading and verification, we batch processed and extracted only the necessary messages and fields for data analysis. In our case, we processed the BSMs containing positioning, speed, heading, acceleration, brakes, elevation, timing, as well as the collision alert messages with exact timing and type of collision transmitted during the simulated incidents. The mean deviations or noise from the road center were computed by using the procedures previously proposed in [17], which consists of a map-matching procedure to identify the trajectory of the DSRC GPS positioning, followed by noise deviation computation for the trial experiments.

When analyzing the generated trajectories plotted on satellite imagery, the GPS location transmitted by light vehicles seems to be generally accurate, smooth, following the projection of the street, as shown in Figure 3a. However, the orange trace around the roundabout presents some jitter between consecutive GPS locations. A possible explanation for this phenomenon is related to the role of dead reckoning in the DSRC device. As BSMs are generated at regular intervals and not at every GPS position received, the BSMs are probably interpolated based on GPS updates. If GPS updates are less than 10 times a second, then interpolations may be imprecise, especially if the vehicle is changing direction, as occurs on a roundabout. Similar results have been previously observed for heavy vehicles engaging in turnings or roundabouts. By attentively analyzing the GPS location when vehicles are passing over the bridge, there is a difference of almost half lane width between the traces of the vehicles. While this could be a different GPS error, we suspect that it is an accurate reflection of a differently configured GPS antenna location in the vehicle, as will be confirmed in a subsequent section.

A particular behavior is observed when vehicles are stopped with their engines on while waiting for passengers (Figure 3b). While this behavior does not raise large problems when the vehicles are parked with the engine off, it might be important to analyze the impact of this behavior when the vehicles are stopped and waiting at red traffic lights. It may also be an indicator of typical drift in positioning that is harder to detect with data from a moving vehicle. A brief examination of the plot indicates different patterns in the drift of each vehicle but this may be due to the cars not being in those stationary positions at the same time.

![Figure 3a](image1.png) ![Figure 3b](image2.png)

**Figure 3a** Accurate transmission of GPS location for 2 light vehicles with DSRC **b** Variations of GPS signal while vehicles are waiting for passengers.
3.2 Noise analysis along the route

As ground truth map reference is not available for computing the noise (distance from the transmitted GPS locations to the center of the road), we use both Google Street Map (GSM) and Open Street Map (OSM) as pseudo “ground truths”. For a centralized comparison and analysis, statistical results are provided in Table 2. Results indicate an average noise for both cars below 5 meters when using both OSM and GSM. Knowing that the lane width in Australia is 3.5 meters and some of the roads present 2 lanes per direction, the noise remains in acceptable accuracy limits (below 5.25 meters). As well, one would observe better accuracy provided by GSM in terms of distance from the road center (24-36 cm), which is a similar result compared to our previous findings for the heavy vehicle positioning analysis. Higher noise levels have been obtained only in parking areas or U-turns which have been deliberately made during the experiments and which have not be taken into consideration for the present analysis. It would be also worth highlighting that some urban areas (in general roundabouts or various merging lanes) may be miss-represented in both OSM and GSM. Figure 4 shows the GPS locations transmitted by one light vehicle when passing through a roundabout (yellow). In this particular case, the GSM (violet line) seems to offer a better approximation of the path of the car when compared to OSM (blue line), which provides a rough approximation of the road shape. When the vehicle is entering the roundabout, noise levels obtained with OSM are higher than the ones provided by GSM due to a different geometry of the path representation. However once inside the roundabout, the OSM shape file seems to better fit the travel trajectory of the vehicle. Various similar examples can be found along the route. Therefore, in the next section, we focus on analyzing the noise mapping in the areas where the forward and intersection collision accidents were simulated, and use GSM as a main reference for noise computation.

| Table 2 Errors between GSM and OSM for light vehicles noise analysis. |
|---|---|---|---|---|
| GSM | OSM | Errors GSM- OSM |
| Average Noise [m] | Standard deviation [m] | Average Noise [m] | Standard deviation [m] | Average Noise [%] | Standard deviation [%] |
| Light Vehicle 1 | 4.3239 | 4.3641 | 4.6848 | 4.3360 | 7.7036 % | 0.6481 (0.02 m) |
| Light Vehicle 2 | 4.6595 | 4.4316 | 4.9032 | 4.3506 | 4.9702 % | 1.8618 (0.08 m) |

Figure 4 Example of roundabout representation in OSM, GSM and GPS locations from car 1.
3.2 Noise analysis in the collision area test bed

When analyzing noise evolution in the collision area test bed, we observe an average noise level of 3.86 meters for the first light vehicle, and 4.84 meters for the second, as represented in Figure 5a) and c). By taking into consideration U-turns and maneuvers to pull off the road and set up the initial positioning of the vehicles before the trial experiments, a good positioning accuracy can be assessed for noise levels in light vehicles. As an observation, a particular driver might have a bias for a different offset from the road center or configurations in the vehicle may have an incorrect offset which might impact the broadcasted BSM position and therefore noise. As well, the noise distributions of both cars indicate two peaks of 3, respectively 5 meters from the GSM road center, as represented in Figure 5b) and d), which relate to the true positioning of the vehicles during the experiments. But using the DSRC system for generating collision alerts when possible incidents can occur usually needs a higher precision and granularity in the noise and positioning calculation. In order to have a clear insight about the speed, noise and vehicle positioning during the collision experiments, in next sections we provide a more detailed analysis of the noise during the collision experiments.

![Figure 5](image_url)

Figure 5 a)-c) Noise evolution and b)-d) noise histogram for the two light vehicles in the collision areas.

4. Collision alert investigation

4.1 Forward collision demonstrations

The scope of the first experimentation scenario included a forward collision demonstration in which both vehicles were travelling on the same lane at regular speed; suddenly the leading vehicle breaks while the following vehicle receives a Forward Collision Alert notification which allowed the driver to avoid the collision. The second demonstration repeated the same setting but with vehicles in swapped positions. As both demonstrations had successful transmission of collision alerts with similar noise-speed behavior, in
the following we only provide our findings on the first one. Figure 6 presents the: a) a screenshot of the transmitted GPS location for both cars during the experiment, b) the registered noise (distance from the road center) and c) the speed evolution for both vehicles. The noise registered when the cars are travelling at higher speeds (40-50km/h) presents low values (between 1-2 meters from GSM road center) and follows the same evolution (as represented in Figure 6b), at time “11:06:20”). At lower speeds (<10 km/h), one vehicle presents higher noise levels, which can be explained by the turnings undertaken after the scenario ended. If this hypothesis is true, this would indicate GPS tracking is accurately reflecting vehicle movements rather than presenting true “noise”. The collision alert was generated at “11:06:27” which is indicated by a sudden deceleration in the speed profile of the light vehicle 2 (Figure 6b) followed by the same sudden deceleration of the vehicle 1 following behind. It is important to note that these observations are representative only for the current study, and cannot be generalized to other vehicles which might have different noise/alerting behavior.

4.2 Unmarked T-intersection collision demonstrations

An important demonstration scenario for testing the advantages of using DSRC equipped light vehicles is around signalized T-intersections, where visibility is low and the lack of traffic lights can lead to collision.
The main motivation behind these demonstrations comes after receiving feedback from drivers signalizing missing or false alerts which were generated in what one would describe as “safe driving conditions”. Receiving the collision alert in time would help reduce the risk of collision and improve road safety for all drivers. The first T-intersection collision test resulted in a fail of the DSRC system on vehicles to broadcast the “collision alert message” (Figure 7a), while the second test concluded with a successful transmission of the alert (Figure 7b).

Figure 7 GPS location, noise and speed evolution during both T-intersection collision tests with failed (a,c,e) and successful collision alert (b,d,f).

Figure 7 shows the mapping, positioning error (noise) and speed during the demonstration for both tests: subfigures a), c), e) for failed alert and b), d), f) for successful collision alert). The positioning error recorded during the first collision test registered low levels of almost 0 meters (Figure 7c) at the moment of potential collision - around 11:13:17 AM), indicating that both cars were circulating close to the road center (findings validated by video recording during the incident simulation). A good noise accuracy was recorded as well during the second collision test (below 2 meters at the moment of collision -11:14:59 AM). Analyzing the speed of vehicles in both experiments shows different breaking behaviors. If during the first collision experiment the light vehicle 1 presented a longer deceleration time interval from the moment of receiving the collision alert (see Figure 7e),11:13:17 to 11:13:21), in the second collision experiment one would observe a shorter deceleration time-interval (from 11:14:59 to 11:15:01). While this initial observation regarding breaking behavior and success/failure of transmitting collision alert is valid for the current study using light vehicles, further investigations and multiple demonstrations at a larger scale, with different road topologies and various traffic conditions would need to be tested before validating the finding at a larger scale.
4.3 SPaT in DSRC-equipped intersections demonstration

Figure 8 a) Positioning of vehicles before the signalized DSRC road-side unit b) noise and c) speed evolution before approaching the intersection and after.

The last demonstration was to test the reception of red light alerts when the two connected vehicles were approaching the 3 DSRC-equipped intersections. Figure 8 a) shows the positioning of the vehicles while approaching the TomThumb intersection before stopping at the red light and turn right. Both cars successfully received the red light alert while waiting to turn right before approaching DSRC-equipped TomThumb intersection. Figure 8b) shows the noise evolution of both cars which follow similar patterns before arriving at the intersection. Although both cars were waiting on the same lane (the road has 4 lanes in this area), there is a slight drift to the right from the road center which can be noticed for vehicle 1, as the noise reaches almost 8 meters from the road center before entering the intersection. This finding confirms that although the vehicles have been set up with same initial configurations of the DSRC system, vehicle 2 might need further tests in order to detect if the problem is related to a bad positioning of the DSRC system or other factors could interfere with the accuracy of the transmitted positioning: road geometry, speed, etc.
5. Conclusions

In this paper we presented the positioning accuracy of two light vehicles equipped with DSRC and investigated the incident analysis and detection through 5 demonstration experiments. While overall noise levels remain in acceptable limits (averages below 5 meters), a detailed analysis of positioning during the incident analysis revealed circumstances where the noise presented drifts that reaches maximum 8 meters from the road center.

During the demonstrations, one unmarked t-intersection experiment failed to send out the collision alert. To better understand the performance of collision alerts in DSRC-equipped vehicles, further analysis on speed, noise, generated alerts and GPS positioning could be conducted in order to help assess the road safety of such DSRC alert messaging.

The data derived for this study could also be used in lane-switching behavior, as well as studying the reaction of drivers to false alerts. Despite some issues with the GPS derived data and while lane accuracy is not possible on vehicles used in CITI due to privacy concerns, it is expected that lane movement analysis is possible. The recorded speed and acceleration of a vehicle is accurate enough to show immediate acceleration and deceleration of a vehicle. By correlating these reactions together with DSRC generated messages, it should be possible to build a generic profile of “reaction to alerts” from the drivers. As well, it is believed the distance between the cars, noise, elevation, as well as the speed profiles of the vehicles at the moment of a collision can provide meaningful insights which indicate when safety alerts are prone to fail.

Limitations

Due to the small number of incidents being analyzed, we cannot apply automatic statistical interpretation for incident detection during the light vehicle analysis. Compared to the heavy vehicles which operate daily and generate millions of BSMs, light vehicles which are currently DSRC-equipped are not involved in daily trips in CITI area. Ultimately, we believe that more data is needed to be analyzed in order to understand whether some changes in GPS noise as transmitted from BSMs indicate a change in driver’s reaction to collision alerts or there are sudden changes in GPS positioning (for example due to changes in accessible satellites) which may make the analysis more difficult in some cases.

Perspectives

Accelerometers are a primary measurement of acceleration (or force). Therefore, if acceleration was found to be an important measure to assess reactions to alerts (or for any other research purpose), more analysis is required. In particular, a comparison of data from accelerometers and BSM-based information should be made to fully assess whether BSMs are sufficient for studying driver’s behavior when using connected vehicles. At the moment of the tests, vehicles were not equipped with accelerometers. This work is an initial step in the positioning accuracy and incident alerts investigation for improving road safety. CITI is an ongoing project, with aims to investigate further DSRC use at signalized intersections, as well as improving road safety especially in high concern public areas (schools, kindergartens, etc.). More light vehicles are currently being installed with CITS and accelerometers, and some vehicles will have video recording features for validation of tests.

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