Report on
C-V2X Technology Trial
Version 1.4

Date: 15 Mar 2018
# Executive Summary

This report presents an overview of the recent C-V2X Technology Trial, including background and objectives, introduction to the technology demo, preparation and setup for the trial, trial results, and conclusions. The report is structured to provide a comprehensive understanding of the trial's objectives, methodology, and outcomes.

## Abbreviations and Acronyms

C-V2X: Connected Vehicles to Everything

## Background & Objectives

The primary objective of the C-V2X Technology Trial is to evaluate the effectiveness of vehicle-to-everything (V2X) communication in enhancing road safety and improving transportation efficiency. The trial aims to demonstrate the capability of V2X technology to provide real-time communication between vehicles and other road users, improving situational awareness and reaction times.

## Introduction on C-V2X Technology Demo

### 2.1 Introduction

This section introduces the concepts of C-V2X technology and its potential applications in enhancing transportation systems.

### 2.2 Overview of End-to-End C-V2X Network Architecture

The network architecture is described, including the roles of different entities in the V2X communication system.

## Preparation & Setup for the Technology Trial

### 3.1 Introduction

This section provides an overview of the preparation and setup process for the technology trial.

### 3.2 Trial Site, Route and Plan

#### 3.2.1 Overview of Trial Site - Hong Kong Science Park

Details about the location of the trial site and its significance.

#### 3.2.2 Trial Route and Rundown

A detailed rundown of the trial route is provided, including specific points and timings.

### 3.3 Trial Network

#### 3.3.1 Overview of Trial Network Architecture

The architecture of the trial network is described, highlighting the key components and their interconnections.

#### 3.3.2 Test Setup – In-Car System Setup

Details about the in-car system setup, including hardware and software configurations.

## C-V2X Technology Trial Results

### 4.1 Road Safety Use Cases & Trial Results

#### 4.1.1 Use Case: V2V Do Not Pass Alarm

Results obtained from the V2V Do Not Pass Alarm use case are discussed, highlighting any identified issues or improvements.

#### 4.1.2 Use Case: V2V Blind Spot Warning (BSW)

Results from the V2V Blind Spot Warning use case are presented, focusing on the effectiveness of the system in real-world conditions.

#### 4.1.3 Use Case: V2I Emergency Stop Warning

Evaluation of the V2I Emergency Stop Warning use case, including any observed improvements or challenges.

#### 4.1.4 Use Case: V2P Vulnerable Road Users (VRU)

Results from the V2P VRU use case, emphasizing the impact on vulnerable road users.

#### 4.1.5 Use Case: V2I Blind Intersection Alarm

Outcome analysis of the V2I Blind Intersection Alarm use case, discussing any notable findings or areas for improvement.

## Conclusion of the Technology Trial

The trial results are summarized, highlighting the achievements and lessons learned, and suggesting areas for future development.

## Appendix

### A Equipment List & Testing Parameters

A comprehensive list of equipment used during the trial, along with relevant testing parameters.
Executive Summary

This document specifies the report for Technology Trial of C-V2X in Hong Kong Science Park, conducted by Smart Mobility Consortium (SMC).

In May 2017, HKT has applied from OFCA the below 3 temporary operating permits for the purpose of technical trial of C-V2X technology:

<table>
<thead>
<tr>
<th>Permit No</th>
<th>Frequency specified</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>T00544</td>
<td>5850 - 5860 MHz</td>
<td>8 May to 31 Oct, 2017</td>
</tr>
<tr>
<td>T00550</td>
<td>2655 - 2665 MHz</td>
<td>22 May to 31 Oct, 2017</td>
</tr>
<tr>
<td>T00551</td>
<td>2665 - 2670 MHz</td>
<td>24 May to 30 Jun, 2017</td>
</tr>
</tbody>
</table>

With these temporary assignments, HKT has successfully conducted the C-V2X Technology Trial in Science Park at end June, 2017.
## Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>HV</td>
<td>Host Vehicle</td>
</tr>
<tr>
<td>RV</td>
<td>Remote Vehicle</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transport System</td>
</tr>
<tr>
<td>IoV</td>
<td>Internet-of-Vehicles</td>
</tr>
<tr>
<td>C-V2X</td>
<td>Cellular-Vehicle-To-Everything</td>
</tr>
<tr>
<td>V2X</td>
<td>Vehicle-to-Everything (V2V + V2I)</td>
</tr>
<tr>
<td>V2V</td>
<td>Vehicle-to-Vehicle</td>
</tr>
<tr>
<td>V2I</td>
<td>Vehicle-to-Infrastructure</td>
</tr>
<tr>
<td>V2N</td>
<td>Vehicle-to-Network</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network</td>
</tr>
<tr>
<td>OBD</td>
<td>On-Board Diagnostics</td>
</tr>
<tr>
<td>ECU</td>
<td>Electronic Control Units</td>
</tr>
<tr>
<td>RSU</td>
<td>Road Side Unit</td>
</tr>
<tr>
<td>VRU</td>
<td>Vulnerable Road User</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HTTP</td>
<td>Hypertext Transfer Protocol</td>
</tr>
<tr>
<td>REST</td>
<td>Representational State Transfer</td>
</tr>
<tr>
<td>NCE</td>
<td>Network Co-operation Engine</td>
</tr>
<tr>
<td>ICGW</td>
<td>In-Car Gateway</td>
</tr>
<tr>
<td>EGW</td>
<td>Edge Gateway</td>
</tr>
<tr>
<td>EPC</td>
<td>Evolved Packet Core</td>
</tr>
<tr>
<td>OBDii</td>
<td>On Board Diagnostics 2</td>
</tr>
<tr>
<td>RTK</td>
<td>Real Time Kinetic</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transportation System</td>
</tr>
</tbody>
</table>
1 Background & Objectives

In Hong Kong, over 60% of all road accidents involve vehicle-to-vehicle (V2V) or vehicle-to-pedestrian (V2P) collision. Over 40% of cyclist casualties involve accidents on or around carriageways. Some of the most common contributors to traffic accidents include stationary or parked vehicles on busy roads, driving too close to the vehicle in front, inappropriate changing of lanes, careless cycling, jaywalking by pedestrians, and drivers losing control of their vehicles.

A C-V2X powered smart mobility system not only allows vehicles to connect to the cloud, but also enables vehicles to communicate with one another as well as with pedestrians, and to synchronize with infrastructure. With C-V2X, "co-operative awareness" between vehicles, pedestrians and the road environment makes it possible to realize mobility safety as well as autonomous driving. Furthermore, it can also support law enforcers, traffic and urban management institutions, and transportation companies to plan and monitor the safety and efficiency of traffic movements.

C-V2X technologies, based upon the 3rd Generation Partnership Project (3GPP) release 14 specification, operates through both network-based communications on commercial cellular infrastructure, as well as direct communications over the 5.9GHz band.

In order to look closer to the benefits of C-V2X, in Mar 2017, ASTRI, HKT, Huawei and Qualcomm have jointly formed the Smart Mobility Consortium (SMC).

The Consortium aims to use C-V2X to introduce a series of Intelligent Transport Services (ITS) in Hong Kong including a warning mechanism for collision and control, assistance for cruise control and parking, and alert systems for speed and lane violations. In addition, it will help drivers and traffic administrators to identify potential loopholes and risks in aspects like road intersections, pedestrian crossings and traffic queues.

The Consortium plans to work alongside the Government, automobile industry, and other relevant industry stakeholders to make this happen. Upon successful completion and rollout, the project is expected to lead to further opportunities for related sectors including shipment, ridesharing, home-delivery, insurance, infotainment, and mobile healthcare, etc.

To begin with, the Consortium has conducted the 1\textsuperscript{st} C-V2X technology trial at Science Park, during the ITS AP Forum 2017 (www.itsap2017.com) at end June of 2017.
2 Introduction on C-V2X Technology Demo

2.1 Introduction

2.2 Overview of End-to-End C-V2X Network Architecture

As from the definitions of 3GPP Release 14 (TR22-885 V14.0.0) as shown in Figure 1, Vehicle-to-Everything (V2X) communications consists of:

- Vehicle-to-Vehicle (V2V) Communications
- Vehicle-to-Infrastructure (V2I) Communications
- Vehicle-to-Pedestrian (V2P) Communications
- Vehicle-to-Network (V2N) Communications

Figure 1. Vehicle-to-Everything (V2X) Communications.

Figure 2 shows the end-to-end V2X network architecture. It mainly consists of V2X device equipped in the vehicles to enable direct Vehicle-to-Vehicle (V2V) communications between vehicles, which is the PC5 communications channel of LTE-Direct mode as defined in R12 of 3GPP standard. Similarly, the V2X device in vehicle also communicates with V2X device of road users (like pedestrians), and enables the Vehicle-to-Pedestrian (V2P) communications, also via the PC5 communications channel. The V2X devices of vehicles are also connected to the network infrastructure, enabling Vehicle-to-Infrastructure (V2I) communications via the Uu communications channel, with is indeed the 3GPP LTE air interface, by using Road Side Units (RSUs). For the backend, there is also a V2X application and management server, which enables different V2X use cases and applications for road safety and traffic management etc.
In Hong Kong, “Vehicle-to-Vehicle” and “Vehicle-to-Pedestrian” are the two major types of traffic accident which contribute to the majority of the traffic accidents. The consortium therefore selected from the set of 3GPP defined road safety use cases, the following 5 user cases which are relevant to the Hong Kong situation for technology trial:

- V2V Do Not Pass Alarm
- V2V Blind Spot Warning (BSW)
- V2I Emergency Stop Warning
- V2P Vulnerable Road Users (VRU)
- V2I Blind Intersection Alarm

Details about each use case can be found in the Appendix A.
3 Preparation & Setup for the Technology Trial

3.1 Introduction
In this section, the C-V2X trial preparation and setup will be discussed. The overview for the selected trial site, trial route and the corresponding plan and schedule will also be discussed. Prior to the road tests in trial site in Hong Kong Science Park, the project team also performed preliminary tests for use case functional and LTE-V connectivity tests in Huawei Xian test site as well. The corresponding findings and results will be discussed as well. After that, the project team carried out trial network installation and extensive road tests, with trial network and system setup, trial network RF coverage and latency measurement, RTK-GPS integration test, network optimization and enhancement, road safety use case functional tests, advanced V2X software function development for performance enhancements. During the road test period, the project team also experienced various challenging environment limitations in trial site and severe weather conditions. The final rehearsal was also performed with extensive trial runs according to planned schedule and rundown as final preparation for the ITS AP forum trials.

3.2 Trial Site, Route and Plan

3.2.1 Overview of Trial Site - Hong Kong Science Park

Figure 3. Map View of Trial Site in Hong Kong Science Park.
The selected trial site is at Hong Kong Science Park, mainly in the area in front of the Photonics Building, and in the area around the SAE and Philips Buildings, along the Science Park West Avenue as indicated in Figure 3. The test route of the test was conducted in area marked by the red line.

### 3.2.2 Trial Route and Rundown

There are total five use cases to be performed for three laps of trial route, with one or two use cases per lap, as shown in Figure 4. The total duration is estimated around 20 mins. There are total 3 vehicles and 1 pedestrian needed in this trial. The estimated speed is around 20 to 30 km/h within speed limit inside Hong Kong Science Park. The rundown is in the order of (1) Do Not Pass Warning (DNPW), (2) V2I Emergency Stop, (3) Blind Spot Warning (BSW), (4) V2P Vulnerable Road Users (VRU), and (5) V2I Intersection Collision Warning.
3.3 Trial Network

3.3.1 Overview of Trial Network Architecture

Figure 5 shows the end-to-end trial network architecture. It mainly consists of in-car V2X system with In-Car Gateway (ICGW), pedestrian V2X system with Pedestrian Gateway (PGW), LTE eNB (both BBU and RRU) for Road Side Unit (RSU) with local Edge Gateway (EGW), LTE core network with EPC, and Central V2X management system. The V2X application is also developed and run to realize different road safety use cases for road users. In addition, the high precision GPS system (namely RTK GPS), with reference station and mobile terminal are also integrated in the in-car V2X system for high precision positioning purpose. After the logistics and delivery of C-V2X equipment, the project team started working on the trial network installation and integration.

In the technology trial, two (2) V2X communication channels were used between the V2X system and the in-vehicle unit, as well as, between in-vehicle units, with the use of frequency as follow:

<table>
<thead>
<tr>
<th>V2X Communication Channel</th>
<th>Description</th>
<th>Frequency (MHz)</th>
<th>Band Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2V</td>
<td>LTE PC5</td>
<td>5850-5860</td>
<td>FSS/ISM 5.9GHz</td>
</tr>
<tr>
<td>V2I</td>
<td>LTE Uu</td>
<td>2665-2670</td>
<td>3GPP Band 41</td>
</tr>
</tbody>
</table>
For the technical trial, a TDD-LTE base station (eNB and antenna) was installed on the roof-top of Photonics Building in Hong Kong Science Park (the start showed in Figure 3). The baseband unit (BBU) of the eNB and the EPC were installed in the ASTRI’s server room as well, located on the 3rd floor of the same building. There is a fiber connection established between the roof-top and the server room. Figure 6 below show the setup of the equipment.

![Setup of V2X test equipment](image)

**Figure 6 Setup of V2X test equipment**

### 3.3.2 Test Setup – In-Car System Setup

To conduct the road tests, in-car V2X system is installed inside each of the tested vehicles with all necessary equipment, including C-V2X UE terminal, In-Car Gateway (ICGW), RTK GPS terminal, and corresponding antennas, OBD adaptor, router, battery and tablets for alarm display etc. Figure 7 shows the highlights of in-car V2X system setup in tested vehicles.
Further, the in-car V2X system architecture is shown in Figure 8. The In-Car Gateway (ICGW) is integrated with the RTK GPS terminal. It is also connected to the OBDii adaptor via in-car Wi-Fi network. The ICGW is also integrated with C-V2X UE terminal as the communications interface with other vehicles (via V2V PC5 communications channels), and with the RSU (via V2I Uu communications channel). The V2X mobile app running on the tablets provides the alarm notifications to the drivers for different road safety use cases.
4 C-V2X Technology Trial Results

In this section, the results for the C-V2X technology trial will be discussed. It includes the results and outcomes for the five road safety use cases trials.

4.1 Road Safety Use Cases & Trial Results

As in 3GPP Release 14 (TR22-885 V14.0.0), there are different defined V2X use cases, which cover all different V2X communications and use case scenarios, i.e. Vehicle-to-Pedestrian (V2P), Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) with RSU, Vehicle-to-Network (V2N). In this trial, the project team mainly focuses on road safety V2X use cases, which are more specific to the environment and deployment considerations in Hong Kong.

- V2V Emergency Stop Warning
- V2V Blind Spot Warning (BSW)
- V2I Emergency Stop Warning
- V2P Vulnerable Road Users (VRU) Warning
- V2I Blind Intersection Alarm

The project team successfully demonstrated five road safety use cases, in more than 20 sessions on the three trial days of ITS AP Forum, and achieved 100% success rate with zero failure and false alarm case.

- V2V Do Not Pass Alarm
- V2V Blind Spot Warning (BSW)
- V2I Emergency Stop Warning
- V2P Vulnerable Road Users (VRU)
- V2I Blind Intersection Alarm

The use case trial results have been recorded and please refer to the video link – https://www.youtube.com/watch?v=ZrBM8cSQz-M
4.1.1 Use Case: V2V Do Not Pass Alarm

Descriptions
Do Not Pass Warning (DNPW) warns the driver not to overtake a slower moving vehicle when a vehicle in the opposite lane is approaching.

Pre-conditions
- The Host Vehicle (HV) is equipped with UE supporting V2V Service.
- There are several cars (including Remote Vehicles RV-1 and RV-2) in HV vicinity also equipped with UEs supporting V2V Service.

Service Flow

1. Host Vehicle (HV)’s ICGW broadcasts its message via V2V channel (with LTE-V2X UE) containing its current status, (e.g., GPS location, speed, & trajectory etc.).
2. Remote Vehicle 1 (RV-1)’s ICGW also broadcasts its message via V2V channel (with LTE-V2X UE) containing its current status, (e.g., GPS location, speed, & trajectory etc.).
3. HV’s ICGW receives messages from RV-1’s V2X device (via V2V channel); it then determines whether to trigger “Do not Pass Warning” to notify its driver.
4. The decision of alarm triggering on HV’s ICGW will be made based on distance (measured by high precision GPS), direction (determined whether RV-1 is in adjacent lane, moving in reverse direction), and whether turning signal of HV is on, indicating the driver of HV has intention to pass (optional) etc.

Post-conditions
- The driver of Host Vehicle is alerted (with the Remote Vehicle RV-1 coming) with a “Do Not Pass” warning, who can take appropriate action.
RSU & V2X UEs
- RSU is NOT required
- V2X UEs support PC5
- V2X application for this use case

Other requirements
- User Interface, and GPS at V2X UE
- In-Car Gateway (ICGW), Edge Gateway (EGW), and IoV Management System

Procedure
- Car 1 is moving slowing on the road. Car 2 follows Car 1.
- The driver in Car 2 wants to overtake Car 1 via the opposite lane, while Car 3 is approaching from the opposite lane.

Test Results:
- Do Not Pass Warning was promptly shown on the on-board media pad to warn the driver not to overtake a slower moving vehicle.
Figure 12. Trial for V2V Do Not Pass Alarm.

Figure 13. Trial for V2V Do Not Pass Alarm.
4.1.2 Use Case: V2V Blind Spot Warning (BSW)

Descriptions
During a lane change attempt, the Blind Spot Warning (BSW) or Lane Change Warning (LCW) application will warn the driver of the host vehicle if the blind spot zone into which the host vehicle intends to switch, is occupied by another vehicle traveling in the same direction. This use case provides advisory information to the driver whenever a vehicle in an adjacent lane is positioned in a blind spot zone of the host vehicle.

This use case also addresses the frequent road accidents occurred in Hong Kong, when head vehicles on inner lane want to exit the roundabout, and hit by the rear vehicles on the outer adjacent lane, or careless lane changing.

Pre-conditions
- The Host Vehicle (HV) is equipped with UE supporting V2V Service.
- There are several cars (including Remote Vehicle RV) in HV vicinity also equipped with UEs supporting V2V Service.

Service Flow

1. Host Vehicle (HV)’s ICGW broadcasts its message via V2V channel (with LTE-V2X UE) containing its current status, (e.g., GPS location, speed, & trajectory etc.).
2. Remote Vehicle 1 (RV-1)’s ICGW also broadcasts its message via V2V channel (with LTE-V2X UE) containing its current status, (e.g., GPS location, speed, & trajectory etc.).
3. HV’s ICGW receives messages from RV-1’s V2X device (via V2V channel); it then determines whether to trigger “Blind Spot Warning” or “Lane Change Warning” to notify its driver.
4. The decision of alarm triggering on HV’s ICGW will be made based on distance (measured by high precision GPS), direction (determined whether RV-1 is in adjacent lane, moving in same
direction), and whether turning signal of HV is on, indicating the driver of HV has intention to change lane (optional) etc.

![Diagram](image)

**Figure 15. Service Flow for Use Case: V2I Blind Spot Warning**

**Post-conditions**
- The driver of Host Vehicle is alerted (with the Blind spot vehicle coming), who can take appropriate action.

**RSU & V2X UEs**
- RSU is NOT required
- V2X UEs support PC5
- V2X application for this use case

**Other requirements**
- User Interface, and GPS at V2X UE
- In-Car Gateway (ICGW), Edge Gateway (EGW) and IoV Management System

**Procedure**
- The driver in Car 2 wants to change lane.
- Car 3 is traveling on the lane that the driver in Car 2 wants to change to. And, Car 3 is approaching but it is within the “Blind Spot Zone” of Car 2.
Test Results:

- Blind Spot Warning was promptly shown on the on-board media pad to warn the driver not to change lane.
4.1.3 Use Case: V2I Emergency Stop Warning

**Descriptions**
This use case describes V2I communication where a RSU notifies vehicles in vicinity in case of emergency stop to trigger safer behavior. This use case also addresses the frequent road accidents occurred in Hong Kong that when the vehicles turn at the intersection point, it cannot see the stopped vehicle or even the pedestrian suddenly crossing the road behind the stopped vehicle, and as a result hitting them.

**Pre-conditions**
- The driver is driving the Vehicle A on the street. The Vehicle A is equipped with V2X UE supporting V2I service.
- There are several Service RSUs in his vicinity equipped with UEs supporting V2I Service.

**Service Flow**
1. Vehicle A malfunctions and stops near a road intersection/junction. The vehicle A generates a “Stationary vehicle warning” DENM message to the nearby RSU.
2. A RSU in the vicinity of vehicle A is able to receive the “Stationary vehicle warning” DENM message.
3. The RSU relays the message to its surrounding vehicles.
4. All vehicles within the transmission range from the RSU receive the message.

**Post-conditions**
- Vehicles (which are in the vicinity of the RSU) deliver the information to the nearby RSU for further relaying the message to drivers travelling in the vicinity for taking appropriate action where necessary.

**RSU & V2X UEs**
- RSU supports Uu
- V2X UEs support both Uu and PC5
Other requirements

- User Interface, and GPS at V2X UE
- In-Car Gateway (ICGW), Edge Gateway (EGW) and IoV Management System

Procedure

- Car 2 has stopped on a road.
- Car 3 is approaching Car 2, but Car 2 is not within the line of sight (LOS) of the driver in Car 3.

Test Results:

- V2I Emergency Stop Warning was promptly shown on the on-board media pad to warn the driver that another vehicle has stopped nearby.
Figure 22. Trial for V2I Emergency Stop Warning.

4.1.4 Use Case: V2P Vulnerable Road Users (VRU)

Descriptions

This use case describes the vehicle and pedestrian are in non-line-of-sight situation, and both equipped with V2P communications. The vehicle detects the pedestrian's presence in “danger zone” and alerts the driver with “Pedestrian Crossing Warning”. This capability extends the safety benefit of V2X to pedestrians and other vulnerable road users, e.g. bicyclists etc. The statistics shown in 2015 that Vehicle to Pedestrian collision is one of the major types of Road accidents (~20%) in Hong Kong like careless bicyclists, among vehicle-to-vehicle collision accidents (~44%) and other types. [http://www.td.gov.hk/en/road_safety/road_traffic_accident_statistics/2015/index.html](http://www.td.gov.hk/en/road_safety/road_traffic_accident_statistics/2015/index.html)

Pre-conditions

- Vehicle A and VRU B’s smartphone are supporting V2P Service
- Vehicle A and VRU B are in proximity (within each other's V2P communication range)

Service Flow

Figure 23. Use Case: V2P Vulnerable Road Users (VRU).
1. Vehicle A broadcasts a message containing its current status, e.g., location, speed, acceleration and trajectory;
2. VRU B's handheld device determines whether it is in a vulnerable situation with potential traffic hazard, e.g., by checking user outdoor/indoor status, proximity to Vehicle A, user activity state, e.g., texting, looking at the screen, listening to music;
3. VRU B's handheld device broadcasts a pedestrian message containing its status, e.g. location, speed, acceleration and optionally user behaviour state;
4. Vehicle A receives messages from VRU B’s handheld device and determines that it needs to notify its driver of potential pedestrian conflicts at least [4] seconds of Time-To-Collision (TTC).

![Figure 24. Service Flow for Use Case: V2P Vulnerable Road Users (VRU) Warning.](image)

**Pre-conditions**
- The driver of Vehicle A is informed of the potential hazard, and can take necessary actions.

**RSU & V2X UEs**
- RSU is NOT required
- V2X UE and VRU UE both supports PC5
- V2X application for this use case

**Other requirements**
- User Interface, and GPS at V2X UE & VRU UE
- In-Car Gateway (ICGW) and IoV Management System

**Procedure**
- Car 1 has stopped on the right lane of a road.
- Car 2 travels on the left lane of the same road.
- A negligent pedestrian is crossing the road in front of Car 1.
- The pedestrian is not within the line of sight (LOS) of the driver in Car 2 because Car 1 has blocked the view.
Test Results:

- V2P Vulnerable Road Users (VRU) Warning was promptly shown on the on-board media pad to warn the driver when a negligent pedestrian is crossing the road.
Figure 26. Trial for V2P Vulnerable Road Users (VRU).

Figure 27. Trial for V2P Vulnerable Road Users (VRU).

4.1.5 Use Case: V2I Blind Intersection Alarm

Descriptions

- When Vehicle A and Vehicle B, C are approaching the intersection point, in where, the V2V communications is out of coverage, or the vehicles are in non-line-of-sight situation. Then RSU is in place to relay the vehicles’ messages via V2I communications channel, and the application processing could also be done by Edge Gateway (EGW), in order to trigger “Intersection Collision Warning” to alerts all the vehicles drivers in potential hazard of collision happening.

- This use case also addresses the frequent road accidents occurred in Hong Kong that when the vehicles do not follow the traffic signal and rules at the intersection point, and go out without seeing the vehicles from other lanes, and cause the accidents.

- Technically, V2X messages are delivered from one UE supporting V2I Service to other UEs supporting V2I Service via an RSU. The RSU receives V2X messages transmitted from UEs supporting V2I Service and transmits the received V2X messages to UEs within a local area. A UE receives V2X messages transmitted by the RSU. After processing the received V2X messages, the UE notifies the driver of relevant information.
Pre-conditions

- The driver is driving the Vehicle A on the street. The Vehicle A is equipped with UE supporting V2I Service.
- There are several Service RSUs in his vicinity equipped with UEs supporting V2I Service.

Service Flow

**NLOS Situation**

![Diagram of NLOS Situation](image)

Figure 28. Use Case: V2I Blind Intersection Collision Alarm.

1. Vehicle A and Vehicle B’s UEs determine a cell which is controlled by an eNB operating as an RSU for active road safety services.
2. Vehicle A’s UE triggers transmission of a V2X message periodically or based on a certain event that happens at the vehicle, e.g. collision risk warning.
3. The RSU receives one or more V2X messages from one or more vehicles including Vehicle A’s UE.
4. The RSU may or may not filter out some V2X messages received from some UEs.
5. The RSU distributes a V2X message at the cell.
6. Vehicle B’s UE monitors transmission of the V2I messages and receives the V2I message at the cell.
Figure 29. Service Flow for Use Case: V2I Emergency Stop Alarm.

**Post-conditions**
- Vehicles (which are in the vicinity of the RSU) deliver the information to the nearby RSU for further relaying the message to drivers travelling in the vicinity for taking appropriate action where necessary.

**RSU & V2X UEs**
- RSU supports Uu
- V2X UEs support both Uu and PC5
- V2X application for this use case

**Other requirements**
- User Interface & GPS at V2X UE
- In-Car Gateway (ICGW), Edge Gateway (EGW) and IoV Management System

**Procedure**
- Car 2 has stopped at a road intersection, and is about to cross the intersection.
- Car 3 is approaching the same road intersection, but Car 3 is not within line of sight (LOS) of the driver in Car 2.
Figure 30. Demo Location for Use Case – V2I Intersection Collision Warning.

Test Results:
- V2I Blind Intersection Warning was promptly shown on the on-board media pad to warn the driver when another vehicle is approaching the road intersection.

Figure 31. Trial for V2I Blind Intersection Alarm.
5 Conclusion of the Technology Trial

Throughout the 3-days trial event, SMC has successfully showcased C-V2X to the ITS & transport industry and other relevant parties for the readiness of the technology.

Figure 32. Trial for V2I Blind Intersection Alarm.
## Appendix A – Equipment List & Testing Parameters

### Equipment List

<table>
<thead>
<tr>
<th>Equipment Name</th>
<th>Model No.</th>
<th>Supplier</th>
<th>Major Function(s)</th>
<th>Technical Standard (if applicable)</th>
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<tbody>
<tr>
<td>eNodeB Main Control Board</td>
<td>UMPTb4</td>
<td>Huawei</td>
<td>Main Control Function for eNodeB</td>
<td>3GPP Rel12</td>
</tr>
<tr>
<td>eNodeB Baseband Board</td>
<td>LBBPd4</td>
<td>Huawei</td>
<td>Baseband processing for eNodeB</td>
<td>3GPP Rel12</td>
</tr>
<tr>
<td>eNodeB Remote Radio Unit</td>
<td>RRU3256</td>
<td>Huawei</td>
<td>Radio Unit for eNodeB</td>
<td>3GPP Rel12</td>
</tr>
<tr>
<td>TUE</td>
<td>TUE2.0</td>
<td>Huawei</td>
<td>Prototype Terminal for PC5 and Uu communication</td>
<td>3GPP Rel13</td>
</tr>
<tr>
<td>GNSS-INS Navigation System</td>
<td>KY-ins100</td>
<td>BDStar</td>
<td>High Resolution Position\inertial Navigation</td>
<td>N/A</td>
</tr>
<tr>
<td>ICGW</td>
<td>RASPBERRYPI3-M ODB-1GB</td>
<td>ASTRI</td>
<td>In Car Gateway (ICGW) for V2X applications</td>
<td>N/A</td>
</tr>
<tr>
<td>Server</td>
<td>Intel® NUC Kit NUC5i7RYH</td>
<td>Jumbo</td>
<td>Data collector and analysis for V2X management</td>
<td>N/A</td>
</tr>
<tr>
<td>Media Pad</td>
<td>Huawei Mediapad M3</td>
<td>Huawei</td>
<td>Mobile app for V2X alarm display</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Notes:
- TUE – Test UE
- ICGW – In Car Gateway
### Testing Parameters

<table>
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<tr>
<th>Parameter Name</th>
<th>Parameter Descriptions</th>
<th>Parameter Values</th>
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<tr>
<td>Operating frequencies &amp; BW- Uu</td>
<td>UL&amp;DL Operating frequencies &amp; BW- Uu</td>
<td>2665~2670MHz &amp; 5MHz</td>
</tr>
<tr>
<td>Operating frequencies &amp; BW- PC5</td>
<td>Operating frequencies &amp; BW- PC5</td>
<td>5850~5860MHz &amp; 10MHz</td>
</tr>
<tr>
<td>eNodeB Tx power - Uu</td>
<td>eNodeB Transmitter Power of PDSCH</td>
<td>20dBm</td>
</tr>
<tr>
<td>TUE Tx Power - Uu</td>
<td>Terminal Transmitter Power of PUSCH</td>
<td>23dBm(Max)</td>
</tr>
<tr>
<td>TUE Tx power - PC5</td>
<td>Terminal Transmitter Power of PC5 PSSCH</td>
<td>23dBm(Max)</td>
</tr>
<tr>
<td>TUE Antenna Gain</td>
<td>Terminal Antenna Gain of PC5</td>
<td>2dBi</td>
</tr>
<tr>
<td>TUE Modulation Scheme</td>
<td>Terminal Modulation Scheme of PSSCH</td>
<td>QPSK/16QAM</td>
</tr>
</tbody>
</table>
| KY-ins100 Receiver Frequency Range   | Frequency Range of GPS system, GLONASS system,Beidou system | GPS L1: 1575.42 MHz
|                                       |                                                             | GPS L2: 1227.60 MHz                                   |
|                                       |                                                             | GLONASS L1: 1593-1610 MHz                             |
|                                       |                                                             | GLONASS L2: 1237-1253 MHz                             |
|                                       |                                                             | BeiDou B1: 1561.098 MHz                               |
|                                       |                                                             | BeiDou B2: 1207.14 MHz                                |
| KY-ins100 Receive Power Range         | Receiver range of GPS system, GLONASS system,Beidou system | L1: -122 to -87 (signal) dBm, -161 to -141 (noise) dBm/Hz |
|                                       |                                                             | L2: -126 to -93 (signal) dBm, -161 to -141 (noise) dBm/Hz |

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