Report on
C-V2X Technology Trial for Autonomous Vehicle at Hong Kong International Airport

Version 1.1

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Executive Summary

This document includes the report for Technology Trial of C-V2X in Hong Kong International Airport, conducted by HKT, ASTRI and Hong Kong Airport Authority.

In May 2019, HKT has applied from OFCA the below temporary operating permit for the purpose of technical trial of C-V2X technology:

Permit No	Frequency specified	Period
T00656	5905 - 5925 MHz	20 May to 19 Nov, 2019

With the temporary assignment, HKT has successfully conducted the C-V2X Technology Trial in Hong Kong International Airport at end Nov, 2019.

For the whole technology trial period, the joint team (HKT, ASTRI, HKAA, C-V2X solution vendor Huawei and Autonomous Tractor vendor) had made great efforts to design the solution, prepare and facilitate the installation, install and integrate the equipment and End-to-End C-V2X system and complete various performance tests.

Abbreviations and Acronyms

3GPP	3rd Generation Partnership Project
HKIA	Hong Kong International Airport
HKAA	Hong Kong Airport Authority
PoC	Proof-of-Concept
NR	New Radio
ITS	Intelligent Transport System
C-V2X	Cellular-Vehicle-To-Everything
V2X	Vehicle-to-Everything
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
RSU	Road Side Unit
OBU	On-Board Unit
DCU	Driving Control Unit
ICGW	In-Car Gateway
AV	Autonomous Vehicle
PoE	Power-over-Ethernet

1 Background & Objectives

Vehicle-to-Everything (V2X) has grabbed the world's attention in the past decade due to its limitless application and importance it will bring in the future. Throughout the period, one of international standard that may boost the development of V2X is named C-V2X from 3rd Generation Partnership Project (3GPP). C-V2X relies on cellular network to transmit information, using LTE as a medium currently and New Radio (NR) in the future.

According to the past research and study on this monumental technology, the ability of C-V2X to connect all the vehicles on the road, roadside infrastructures such as Roadside unit (RSU), even pedestrians on the road has unlocked plenty of future applications and benefits, in particular the huge improvement in road safety by eliminating road accidents and more importantly boosts the "co-operative awareness". This new concept could also facilitate the transportation to become more safely and efficiently by reducing user's overall travelling journey time, since C-V2X is capable of determining the road occupancy and thus seeking the fastest route to the destination.

In Nov 2018, HKT and ASTRI have formed the Smart City Joint Laboratory to explore new applications of Smart City Infrastructure and Smart Mobility, including the C-V2X technologies.

http://hkt.com/About+HKT/Press+information/Press%20Information%20Detail?pop=Y&guid=1d4dc4d69ff37610VgnVCM1000006a8ba8c0____&language=en_US

Based on the insights from advantages of C-V2X, HKT and ASTRI invited Hong Kong Airport Authority (HKAA) and Huawei to launch a Proof-of-Concept (PoC) C-V2X project inside the airfield. In fact, Hong Kong International Airport has an urgent need to consolidate its famous reputation so as to prevent other airports threaten their world-leading position, especially the top place in cargo traffic for consecutive 9 years and the third place in international passenger traffic in the world. Besides, in order to reduce the impact of shortage in tractor drivers and enhance the daily airfield operation efficiency, autonomous vehicle (AV) comes in handy and becomes a viable solution to tackle the insufficiency of tractor drivers. Upon successful completion, rollout and favorable result collection, the project scale is expected to enlarge to the entire airfield.

Since the C-V2X technology provides an alert system for speed and lane violation between the vehicles, it could facilitate the driverless vehicles by getting more real-time updates on road conditions that affect their routes. Therefore, this PoC aims to test the C-V2X technology deployed in the AV application

2 Introduction for C-V2X Technology Demo

The C-V2X project at Hong Kong International Airport mainly focuses on the V2I and V2N communications. In the entire system, it consists of several components and they are the On-Board Unit (OBU), RSU and a backend server.

The OBU is placed inside the autonomous vehicle and all inbound and outbound messages are processed at this module. The RSU contains 2 pairs of antennas, which is designed for C-V2X 5.9GHz and LTE spectrum.

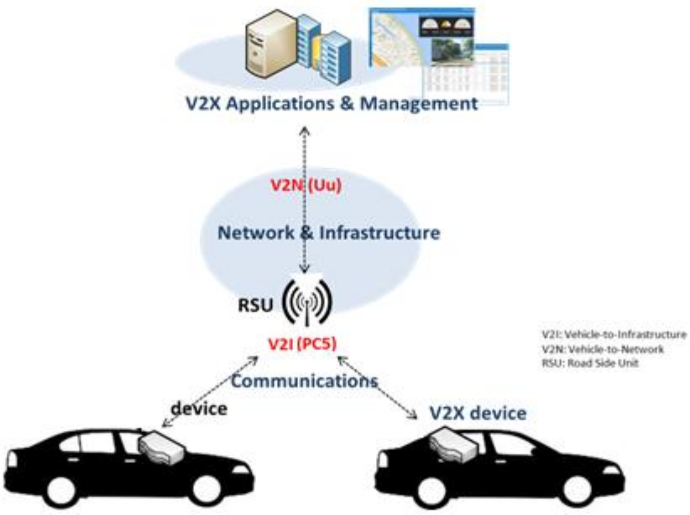


Figure 2. End-to-End Vehicle-to-Everything (C-V2X) Network Architecture

For the V2I communication, the OBU communicates with the RSU through the PC5 communications channel as defined in Release 15 of 3GPP standard. For the V2N communications, the data in RSU is sent to the C-V2X backend system via the Uu communications channel, which is indeed the 3GPP LTE air interface. In the backend system, it is responsible to conclude an appropriate response based on all collected data and send to the equipped vehicle so as to prevent any danger. Afterwards, the result is conveyed to all RSUs and eventually to the OBU, and thus the OBU triggers the equipped vehicle to take action.

3 Preparation & Setup for the Technology Trial

3.1 Introduction

In this section, the C-V2X trial preparation for autonomous vehicle applications and setup will be discussed. The overview for the selected trial site, trial route and the corresponding plan will also be discussed. After the trial network and equipment installation in trial site in the Hong Kong International Airport (HKIA), the project team carried out functional tests for dedicated equipment, including the Video Analytics, communication using C-V2X spectrum, and simulated different use cases with Autonomous Vehicle. During the road test period, the project team also experienced various challenging environment limitations in trial site such as severe weather conditions.

3.2 Trial Site, Route and Plan

3.2.1 Overview of Trial Site – Bonded Road (Cheong Wing Road) in HKIA

Figure 3. Map View of Trial Site in HKIA

As indicated in Figure 3, Cheong Wing Road inside the airport restricted area is selected as the trial site for the C-V2X system and part of the road is a bidirectional single-lane road which requires coordination between each road driver in reality. The test route of the test was conducted in area marked by the red line.

3.2.2 Trial Route and Rundown

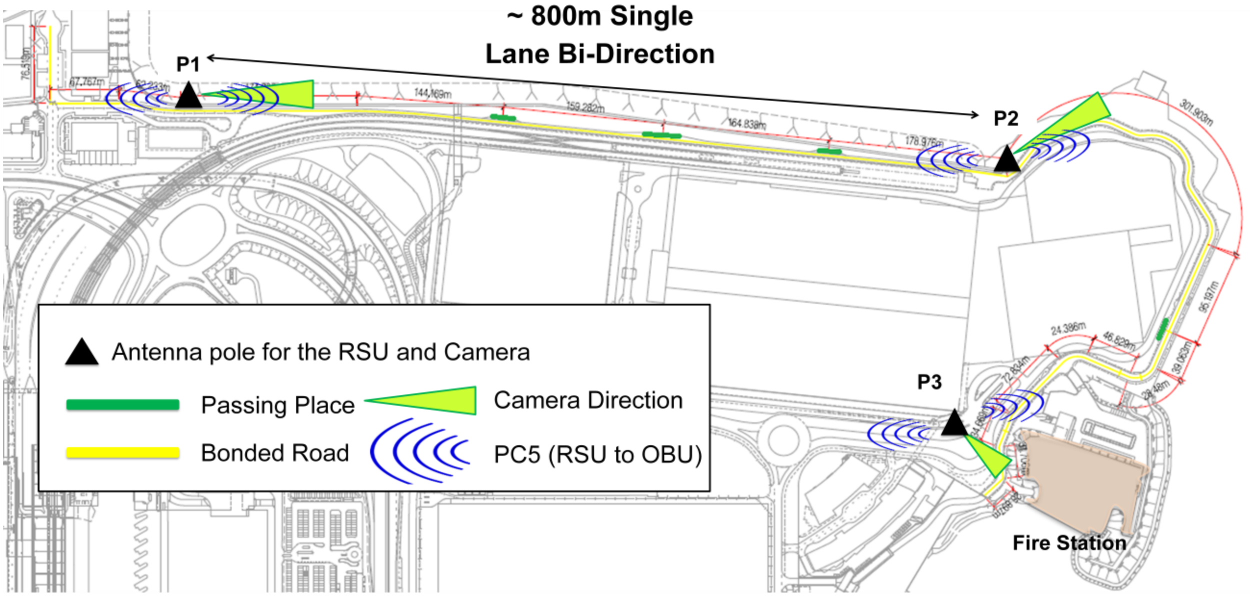


Figure 4. Trial Route and Rundown.

There are in total three use cases simulations to be performed for the trial route. All cases require an Autonomous Vehicle equipped with OBU and a normal vehicle as prerequisites. The target when designing those use case is to test the functionality of the RSU and ensure its connectivity to V2X server and the Autonomous Vehicle, no matter under what kind of circumstances.

3.3 Trial Network

3.3.1 Overview of Trial Network Architecture

In the technology trial, two V2X communication channels were used for the V2I and V2N communication respectively and the details are included in the table below:

V2X Communication Channel	Description	Frequency (MHz)	Band Description
V2I	LTE PC5	5905-5925	C-V2X 5.9GHz
V2N	LTE Uu	Uplink 1720-1740 Downlink 1815-1835	3GPP Band 3

Upon the arrival of all C-V2X equipment, the project team begins the installation of the trial network and necessary equipment.

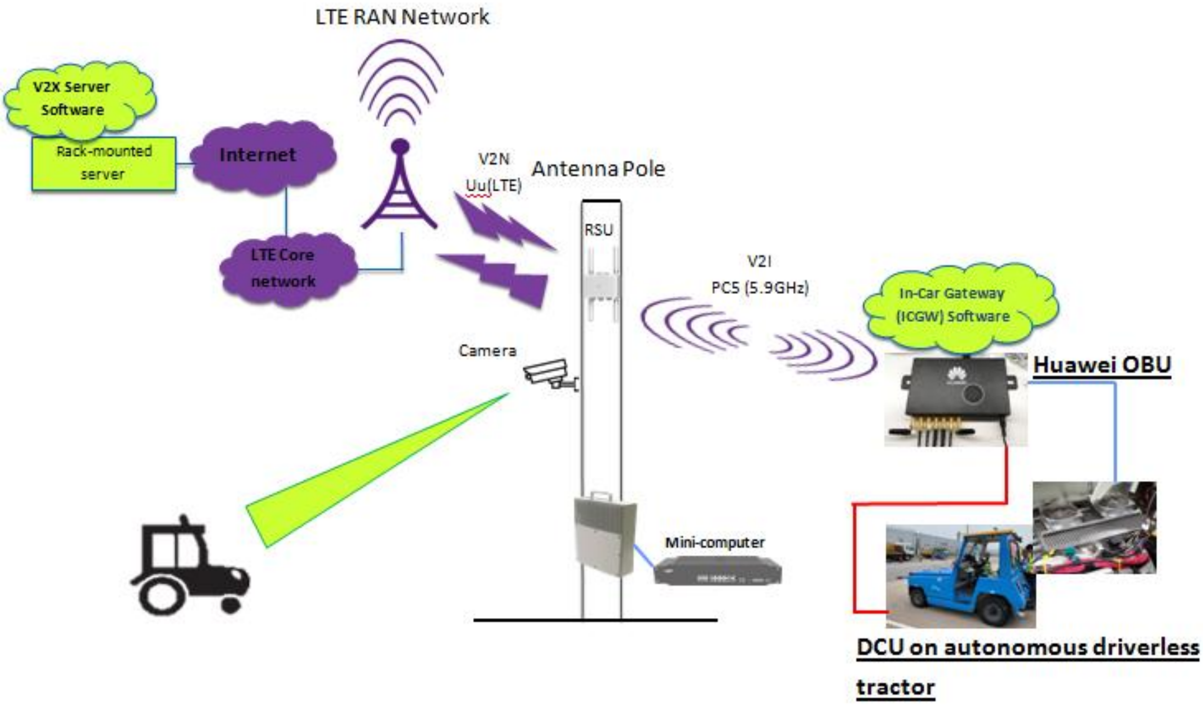


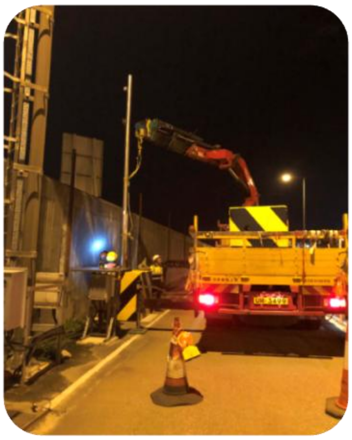
Figure 5. Overview of Trial Network Architecture

Figure 5 shows an end-to-end trial network architecture. The autonomous tractor equips an in-car V2X system with In-car Gateway (ICGW), OBU and DCU. The roadside equipment such as IP camera and localized mini-computer for video analytic purpose, RSU which has 2 sets of antenna supporting both LTE and V2X PC5 communication to convey results of video analytic to the server and OBU respectively. Lastly, the V2X server is used for V2X central management.

3.3.2 Test Setup – Roadside Equipment Setup

After doing the site survey and considering different kinds of factor, the roadside equipment cannot be mounted on the existing pole due to the limitation in weight and safety concern, therefore it is required to install new poles in order to hold the equipment for the C-V2X trial.

Site survey and pole installation:



For the roadside equipment, each antenna pole consists of a RSU with 2 pairs of antennas (PC5 and Uu interface), an IP camera, mini-computer and Power-over-Ethernet (PoE) switch.

Pole1

Pole2

Pole3

The video is captured by IP camera and the analyzed data by mini-computer will be transmitted to the V2X server by the RSU, in which it contains the camera ID, event value (i.e. the travelling direction of the vehicle) and a unique vehicle ID. In order to observe the performance of the C-V2X system in single-lane road, the cameras at P1 and P2 are turned on, and also the camera at P3 is deliberately turned off, since P3 is not included in the designated test area.

3.3.3 Test Setup – V2X Server Setup

For the V2X server, it is configured to have a fixed IP and able to communicate bi-directionally with all RSUs through LTE network. When a vehicle is successfully detected, the RSU will transmit the message packet mentioned in part 3.3.2 to the V2X server. After that, the V2X server translates and converts the message to an OBU-understandable language which consists of two counter-based parameters, namely number of eastbound and westbound vehicles.

3.3.4 Test Setup – In-Car System Setup

Inside the Autonomous Vehicle, the DCU is connected to the OBU via the ICGW. The OBU receives the downlink data from the nearest RSU via PC5 communication channel, and then the data is forwarded to the DCU. Therefore, the Autonomous Vehicle is able to understand the current road conditions such as the road occupancy by reading the number of westbound and eastbound vehicles on the road, so it may know the appropriate timing to execute the follow-up actions based on the designed logic, such as stop immediately, park at the nearest passing place to let vehicle pass, etc.

OBU installed with the DCU in the Autonomous Tractor:

4 C-V2X Technology Trial Results

In this section, results for the C-V2X technology trial will be discussed, including actual results and outcomes for different use cases with autonomous vehicles trials.

4.1 Autonomous Vehicles Use Cases & Trial Results

As in 3GPP Release 15 (TS 22.185 V15.0.0), there are different preconceived V2X use cases, which spans different kinds of V2X communication and use case scenario, 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 in the V2I with Autonomous Vehicle technology developed by Hong Kong Airport Authority. The OBU uses counter results from RSU to determine the road occupancy, for example the OBU may know there are other cars on the road when the counter is non-zero.

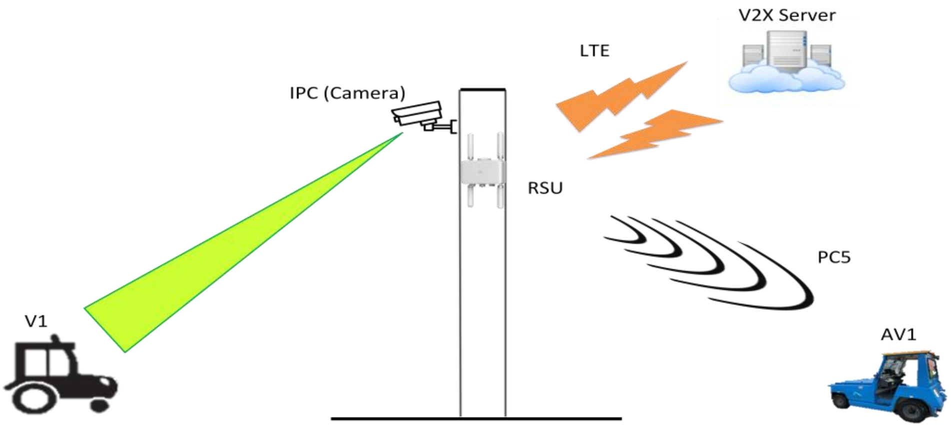


Figure 6. Target V2I Use Case with Autonomous Vehicle in HKIA

Pre-conditions/ Equipment Setup

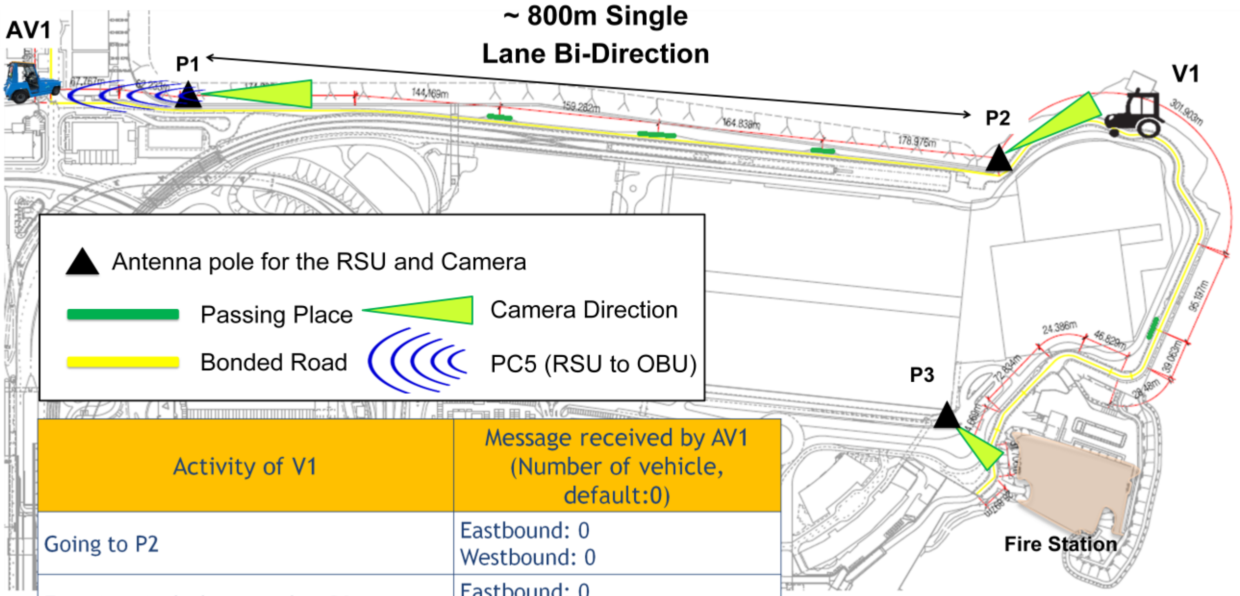
- All Antenna Poles (P1, P2, P3) are equipped with IP camera, mini-computer and RSU
- The Autonomous Vehicle 1 (AV1) is equipped with OBU and DCU
- In-Car Gateway software (ICGW) is installed inside the OBU
- RSU has two pairs of antenna, which is designed for server connectivity (via LTE Uu channel) and OBU connectivity (via V2X PC5 channel)
- OBU communicates with RSU via the V2X PC5 communication channel
- All RSUs connect to the V2X server through LTE
- All equipment inside each pole are interconnected under LAN connection
- All use cases are tested with one AV

4.1.1 Use Case 1: Early detection for Autonomous Vehicle before it enters single-lane road

Descriptions

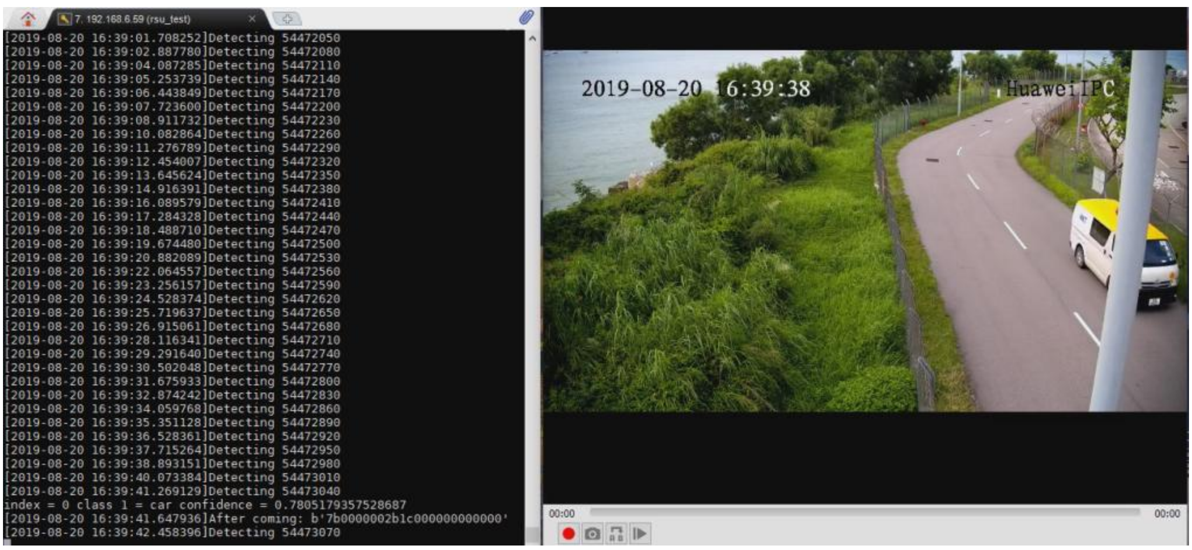
Autonomous Vehicle 1 (AV1) will receive a message and stop when Vehicle 1(V1) enters bonded road. This case facilitates the early detection of other vehicles for AV1 before entering P2

End-to-End Service Flow and Procedure



Activity of V1	Message received by AV1 (Number of vehicle, default:0)
Going to P2	Eastbound: 0 Westbound: 0
Entering single-lane road at P2	Eastbound: 0 Westbound: 1
Leaving single-lane road at P1	Eastbound: 0 Westbound: 0

1. AV1 is going to P1
2. V1 enters the single lane road from Antenna Pole 2 (P2) and its travelling direction is identified by the camera and mini-computer at P2



3. The RSU at P2 transmits results to V2X server via LTE network
4. The server increments counter of westbound vehicles to "1" to indicate the presence of V1

Message captured by V2X server:

```
send info :{"west":"1","east":"0","rsuId":"2102312ETX10K3000164","srcRsu":"2102312ETX10K3000164"}, to all rsu
semd sendRoadStatusToRsus to rsu2102312ETX10K3000164
send camera alarm to rsu2102312ETX10K3000164
start to send rsu config msg to rsu:2102312ETX10K3000164and msg is {"type":4,"rsuESN":"2102312ETX10K3000164",
semd sendRoadStatusToRsus to rsu2102312ETX10K3000171
send camera alarm to rsu2102312ETX10K3000171
start to send rsu config msg to rsu:2102312ETX10K3000171and msg is {"type":4,"rsuESN":"2102312ETX10K3000171",
Frame opCode=1 length=327
semd sendRoadStatusToRsus to rsu2102312ETX10K3000160
send camera alarm to rsu2102312ETX10K3000160
Frame opCode=1 length=327
start to send rsu config msg to rsu:2102312ETX10K3000160and msg is {"type":4,"rsuESN":"2102312ETX10K3000160",
Frame opCode=1 length=327
Frame opCode=1
Frame length=115
```

5. The server broadcasts message to all RSUs (P1 & P2) via LTE network, and they update the OBU at AV1 through CV2X PC5 interface
6. AV1 receives the updated counter "1" that implies one vehicle is coming on the opposite direction , therefore it performs subsequent action (Stop near P1)
7. After V1 is leaving P1, the counter will be drop to "0" that implies no vehicle is travelling in the bonded road. Therefore, AV1 performs subsequent action (Start entering P1)

Message captured by V2X server:

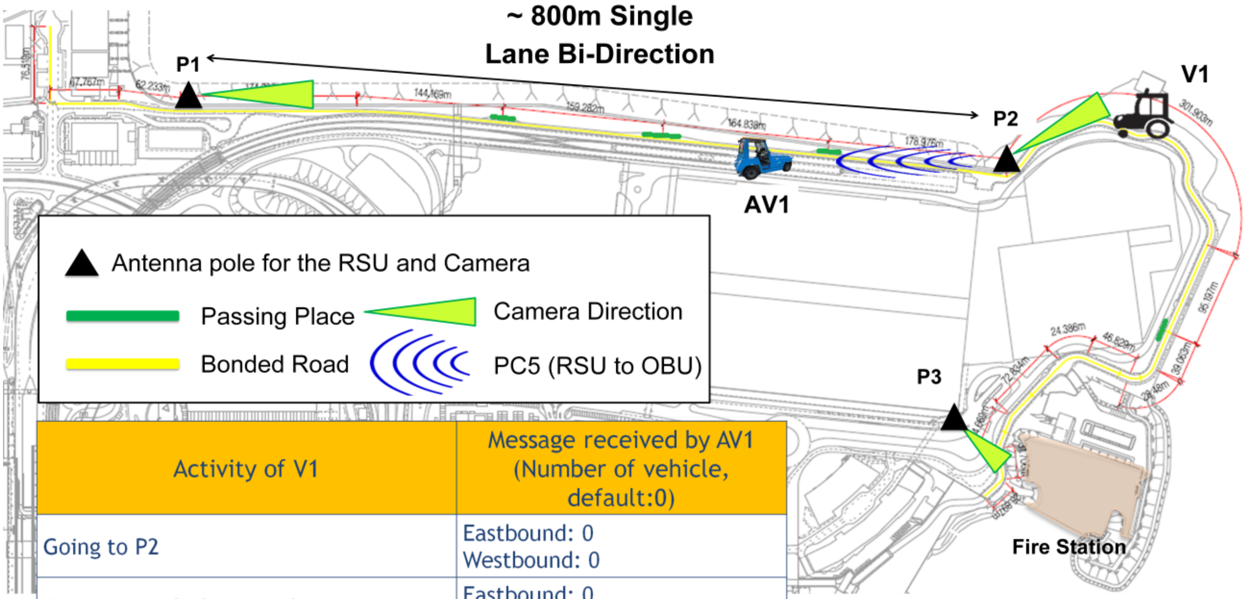
```
send info :{"west":"0","east":"0","rsuId":"2102312ETX10K3000164","srcRsu":"2102312ETX10K3000164"}, to all rsu
semd sendRoadStatusToRsus to rsu2102312ETX10K3000164
send camera alarm to rsu2102312ETX10K3000164
start to send rsu config msg to rsu:2102312ETX10K3000164and msg is {"type":4,"rsuESN":"2102312ETX10K3000164",
semd sendRoadStatusToRsus to rsu2102312ETX10K3000171
send camera alarm to rsu2102312ETX10K3000171
start to send rsu config msg to rsu:2102312ETX10K3000171and msg is {"type":4,"rsuESN":"2102312ETX10K3000171",
Frame opCode=1 length=327
semd sendRoadStatusToRsus to rsu2102312ETX10K3000160
send camera alarm to rsu2102312ETX10K3000160
Frame opCode=1 length=327
start to send rsu config msg to rsu:2102312ETX10K3000160and msg is {"type":4,"rsuESN":"2102312ETX10K3000160",
Frame opCode=1 length=327
Frame opCode=1
Frame length=115
```

4.1.2 Use Case 2: Early detection for Autonomous Vehicle after it enters single-lane road

Descriptions

Autonomous Vehicle 1 (AV1) will receive a message and park at the nearest passing place when Vehicle 1 (V1) is entering the bonded road. This case facilitates the early detection of other vehicles for the autonomous vehicle when the AV1 is inside bonded road.

End-to-End Service Flow and Procedure



Activity of V1	Message received by AV1 (Number of vehicle, default:0)
Going to P2	Eastbound: 0 Westbound: 0
Entering single-lane road at P2	Eastbound: 0 Westbound: 1
Leaving single-lane road at P1	Eastbound: 0 Westbound: 0

1. AV1 is travelling on the single lane road
2. V1 enters the single lane road from P2 and its travelling direction is identified by the camera and mini-computer at P2
3. The RSU at P2 transmits results to V2X server through LTE network
4. The server increments counter of westbound vehicles to “1” to indicate the presence of V1
5. The server broadcasts message to all RSUs (P1 & P2) via LTE network, and they update the OBU at AV1 through CV2X PC5 interface
6. AV1 receives the updated counter “1” that implies one vehicle is coming on the opposite direction , therefore it performs subsequent action (Park at the nearest passing place)
7. After V1 is leaving P1, the counter will be drop to “0” that implies no vehicle is travelling in the bonded road. Therefore, AV1 performs subsequent action (Re-enter the single lane road)

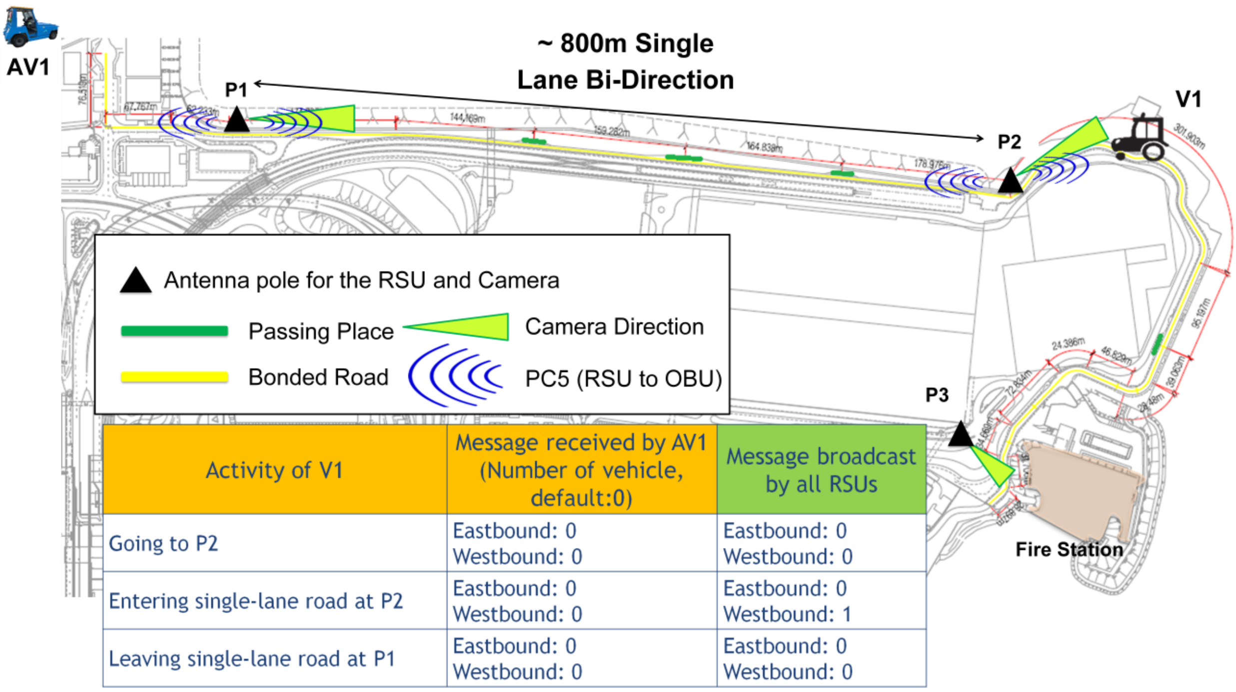
*Same results as User Case 1 captured by camera, RSU and AV1

4.1.3 Use Case 3: Autonomous Vehicle is out of the RSU coverage

Descriptions

Since Autonomous Vehicle 1 (AV1) is out of reach from RSU, AV1 do nothing when Vehicle 1 (V1) is entering the bonded road. This case shows how RSU works to ensure the AV1 could receive the updates about the bonded road after entered the RSU covered area.

End-to-End Service Flow and Procedure



Activity of V1	Message received by AV1 (Number of vehicle, default:0)	Message broadcast by all RSUs
Going to P2	Eastbound: 0 Westbound: 0	Eastbound: 0 Westbound: 0
Entering single-lane road at P2	Eastbound: 0 Westbound: 0	Eastbound: 0 Westbound: 1
Leaving single-lane road at P1	Eastbound: 0 Westbound: 0	Eastbound: 0 Westbound: 0

1. AV1 is not in proximity of single-lane road, so it cannot receive RSU’s message
2. V1 enters the single lane road from P2 and its travelling direction is identified by the camera and mini-computer at P2
3. The RSU at P2 transmits results to V2X server through LTE network
4. The server increments counter of westbound vehicles to “1” to indicate the presence of V1
5. The server broadcasts message to all RSUs (P1 & P2) via LTE network
6. All RSUs broadcast the message regularly by a dedicated period until V1 leaves the P1

5 Conclusion of the Technology Trial

Throughout the half-year trial period, the C-V2X technology was tested successfully in the bonded road at Hong Kong International Airport, including V2I and V2N communications. Furthermore, this C-V2X technology was integrate with Autonomous Tractors that provided by HKAA during the trial period. In future, if this project earns great success and proves its importance in enhancing the airfield operation efficiency and road safety, all conventional tractors may be replaced by Autonomous Driverless Tractors to cope with the airport's development plan.

Last but not least, one or more scenarios will be tested in the future, for example the early detection of fire truck and alert the Autonomous Vehicle that may be a blockage to the fire truck to stop at the nearest passing place in order to clear the path, so that the fire truck can arrive at destination even faster so as to execute any kinds of emergent mission more efficiently.

Appendix A – Equipment List & Testing Parameters

Equipment List

Equipment Name	Model No.	Supplier	Major Function(s)	Technical Standard (if applicable)
Server (As well as V2X software)	DELL PowerEdge R740	ASTRI	V2X server	N/A
RSU	LTE-V RSU5201	Huawei	Communications with V2X server and OBU	3GPP Rel14, HKCA 1057
Camera	X2391-EPL	Huawei	Capture videos for further video analytics use	N/A
Mini-Computer	JDBXA2019041701	控端	Perform video analytic on camera's video	N/A
8Port PoE switch	AR550C-2C6GE	Huawei	Connectivity between RSU, Camera and Mini-computer	N/A
OBU	LTE-V2X OBU	Huawei	Communication with RSU through 5.9GHz	3GPP Rel14
ICGW software in OBU	N/A	ASTRI	In Car Gateway (ICGW) for V2X application	N/A

Testing Parameters

Parameter Name	Parameter Descriptions	Parameter Values
Operating frequencies & BW- Uu	Operating frequency	Uplink: 1720-1740 MHz Downlink: 1815 – 1835 MHz
	Bandwidth	20 MHz
Operating frequencies & BW- PC5	Operating frequency	5905-5925MHz
	Bandwidth - PC5	20MHz