Connected Vehicle Testbed: Development & Deployment of C-ITS in the UK

Central London Testbed Project - DfT Grant Funding
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Middlesex University London & King's College London

In Partnership with

Department for Transport

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**Cooperative-Intelligent Transport Systems (C-ITS)
Connected Vehicles Research Team**

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ACKNOWLEDGEMENTS

This project is a joint collaborative research effort between Middlesex University's (MDX) - Intelligent Transport Systems - Connected Vehicles (CVs) Research Team and King's College London (KCL) in particular Centre for Telecommunications Research (CTR). This was MDX's ITS - Connected Vehicles Research Team's second government funding following the Transport-Technology Research Innovation (T-TRIG) grant in 2015 from the Department for Transport (DfT). The Central London Testbed Project (CLTP) was about building a VANET/ITS-G5 Cloud testbed in Central London. This testbed is located at King's College, Strand Campus. This testbed is being joined with the Middlesex VANET Cloud testbed along with the Extended Testbed on the A41/M1 motorway to form a Federated Cloud System which enabled us to explore the new networking techniques such as Software Defined Networking (SDN) to provide 5G capabilities. This arrangement will then be used to build an Intelligent Information Platform (IIP), containing detailed information about vehicles, communication and urban infrastructure.

First of all, our team would like to acknowledge our debt of gratitude towards Department for Transport (DfT) - Mr Graham Hanson, ITS Policy Lead, Traffic and Technology Division, and Mr Suku Phull, Chief Technical Expert, Traffic and Technology Division. We would also like to express our sincere thanks to Mr David Parkyns, Chief Engineer - Technology, Asset Management Directorate - Surface Transport, Transport for London (TfL) and his entire team for especially helping us mount our equipment along the Watford Way (A41) for the Extended Testbed and in particular Mr Chris Ashby, Street Lighting Maintenance Manager, North West Region, Transport for London (TfL).

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Acronyms / Abbreviations

BSM	Basic Safety Message
CAMs	Cooperative Awareness Messages
DENMs	Decentralized Environmental Notification Messages
ETSI	European Telecommunications Standards Institute
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport System
OBUs	On-Board Units
P2I	Pedestrian to Infrastructure
RSUs	Road-Side Units
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VANET	Vehicular Ad hoc Network
WSMP	WAVE Short Message Protocol

C-ITS - Connected Vehicles Testbed Project

1.1 Project Summary

The age of the connected vehicle is rapidly dawning. This will allow us to revolutionise both our transport and communication infrastructures. In terms of transport, connected vehicles will enable an Intelligent Transport System (ITS) to be built which will lead to better traffic and road management, shorter journey times, less accidents, better collision avoidance mechanisms and increased efficiency in the management of transport disasters.

In terms of communication, this means that the mobile phone will no longer be the only major communication device for the user, as the connected vehicle will also be viewed as a first class communication object. Hence, applications will be able to migrate between the phone and the vehicle as people move around. In order to understand this coming age, it is necessary to build new technologies, testbeds and applications that will give us insight into this brave new world. Vehicular Ad-Hoc Networks (VANETs) or ITS-G5 provide low-latency and high bandwidth enabling life-critical safety and infotainment applications to be developed. There is also a need to integrate VANET/ITS-G5 technology with emerging standards such as 5G.

This Central London Testbed Project (CLTP) was about building a VANET/ITS-G5 Cloud testbed in Central London. This testbed is located at King's College, Strand Campus. This testbed is being joined with the Middlesex VANET Cloud testbed along with the extended testbed on the A41/M1 motorway to form a Federated Cloud System which enabled us to explore the new networking techniques such as Software Defined Networking (SDN) to provide 5G capabilities. This arrangement will then be used to build an Intelligent Information Platform (IIP), containing detailed information about vehicles, communication and urban infrastructure. This will allow VANET/ITS-G5 and 5G applications to be built and run on the Federated Cloud System. The IIP will also be used to build applications for Smart Cities. The applications being considered include remote monitoring and control of connected vehicles using haptic techniques, connected services, integrated transport, traffic analysis of different transport models, road safety and disaster management. The information from this VANET Testbed was stored and processed using a Cloud platform at Middlesex University, enabling visual and data analytics to be applied in order to provide an intelligent platform for transport management.

In 2015, the Department for Transport (DfT) commissioned Middlesex University to build and test a communication network to explore the potential of VANET/ITS-G5 Technology. The proposed network was intended to encompass the Hendon Campus of the University and its surrounding roads including the Watford Way (A41) for creating an extended testbed. This setup was then used to do a VANET/ITS-G5 Trial in which OBUs were placed in vehicles and the drivers were asked to drive around the area both the sites. The data was then analysed and displayed using Google Maps and Google Earth to give a comprehensive set of data points which shows that VANETs do have the potential to play a key role in the development of Intelligent Transportation for Smart Cities. A similar setup was used in order to replicate the VANET/ITS-G5 network around Central London Testbed at King's College premises. The only difference between MDX and Central London testbed setup was the way the backhauling was done in order to enable collection of data was achieved.

This new testbed, therefore looked at building new VANET applications and explored how the VANET/ITS-G5 systems could be integrated into the standards for 5G. It enabled us to examine the interactions between different transport modes in Central London, such as driving, cycling and walking. In addition, it was used to explore an integrated transport solutions in the urban environment.

Finally, the authors believe that this work is essential for the UK to meet these new challenges and to maintain its cutting-edge in the transport and telecommunications industries.

1.1.1 Project Objectives and Intended Audience

The main purpose of the CLTP project was to build a new VANET/ITS-G5 Cloud Testbed with 5G capabilities along the Strand around the area of Kings College London (KCL). The RSUs would be placed on top of the buildings belonging to KCL. Data from the RSUs would be back-hauled to an Software Defined Network (SDN) switch in the Centre for Telecommunications Research (CTR). The proposed new Central London Testbed is shown in Figure 1.1.

In addition this project was developed to explore the potential or feasibility of using VANET/ITS-G5 technology in building an Intelligent Information Platform

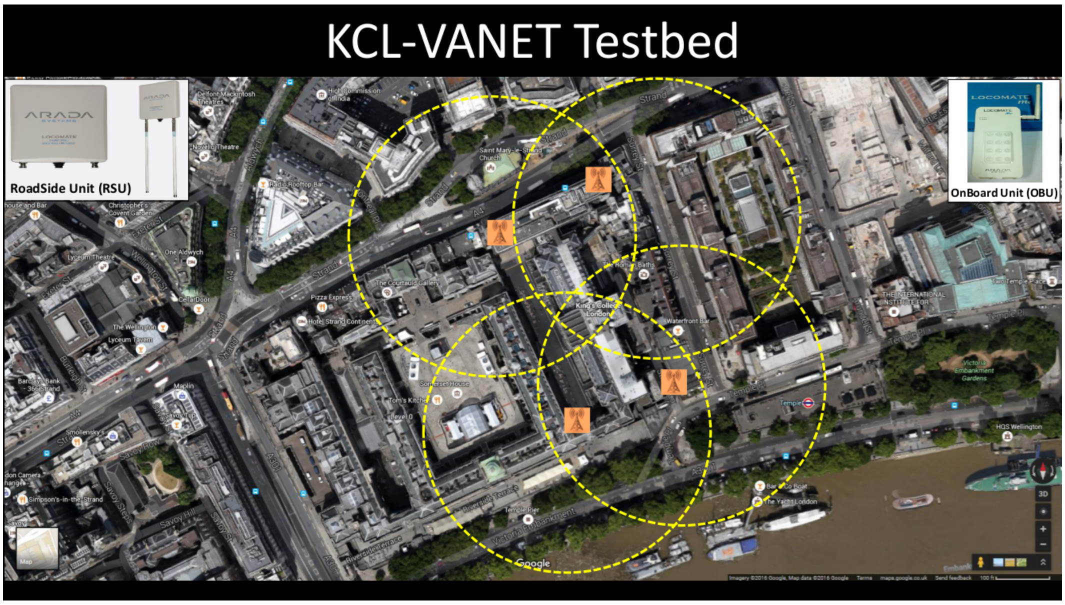

Fig. 1.1 The New ITS-G5/VANET Testbed in Central London (KCL, Strand Campus).

for Smart Cities. The project was therefore intended to give those in the DfT who are responsible for developing the next generation Transportation and Traffic Management Systems, a platform to test and validate the new VANET/ITS-G5 Technology which can be used to accomplish the 5G infrastructural goals for developing future Smart Cities.

For this project, the KCL VANET Cloud Server will also be connected to the SDN switch and will store the data from the RSUs. The SDN controller will run on the KCL VANET Cloud Server and applications will run on the Cloud Server using Network Function Virtualization (NFV). The Middlesex and KCL testbeds will be linked forming Federated Clouds. The Clouds will be connected using a high-speed link from JANET (the Joint Academic University Network). The overall configuration is shown in Figure 1.2.

A better representation of the above diagram of both the testbeds has been illustrated by combing and super imposing the two testbed sites using Google Earth in order to create a Real-Time - C-ITS - Connected Vehicles - Federated Cloud Infrastructure as shown in Figure

The Central London VANET/ITS-G5 Cloud Testbed with 5G capabilities will be built to support Connected Services in which a large number of diverse applications between mobile users and the Internet will be tested including high quality video steaming, large file downloads via the Web and a high-quality network music server. In addition, directly interactive applications, such as video-conferencing, which will

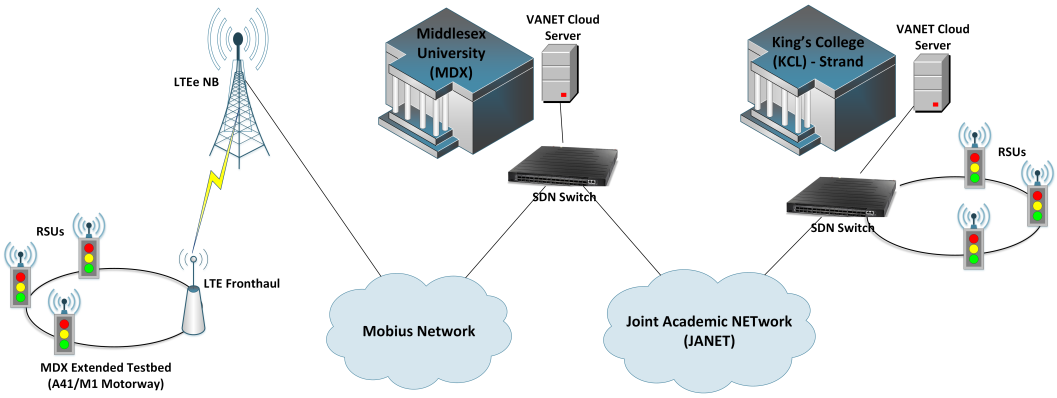

Fig. 1.2 Showing the Network Diagram for the Federated VANET Cloud.

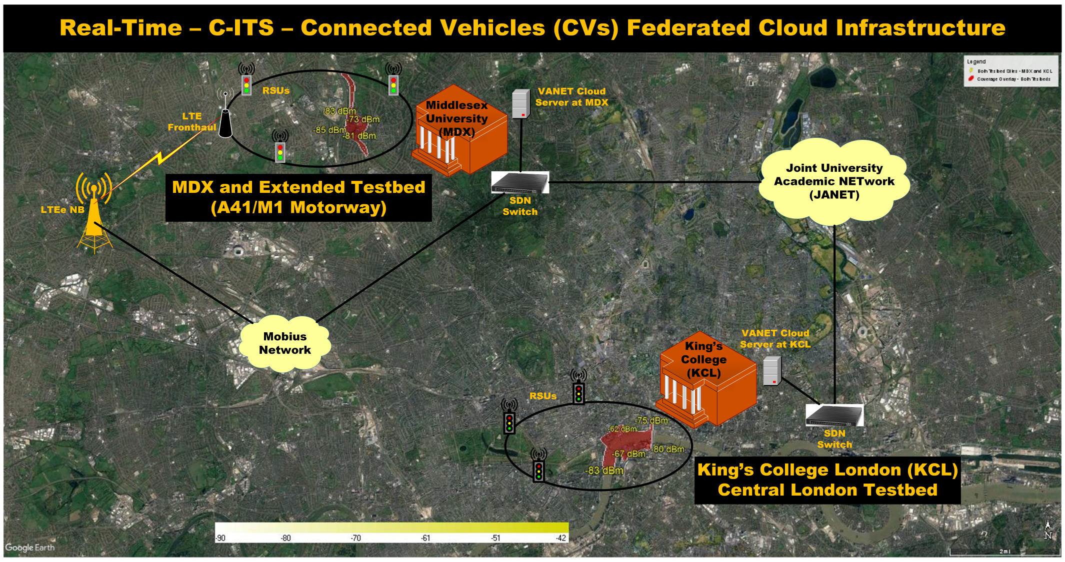

Fig. 1.3 Showing the Real-Time - C-ITS Connected Vehicles Federated Cloud Infrastructure.

allow mobile users in vehicles to talk to each other via the Federated Clouds will also be instrumented. The aim here is to come up numbers that can be used to quantify the performance of these applications in a connected vehicular environment and thus to give 5G developers real figures at which they should aim as they develop the new communication standards.

This Testbed therefore is being used to look at the interface between VANET/ITS-G5 and emerging technologies such as 5G with regard to Quality-of-Service provision for VANET applications through network slicing. Network slicing is a new way of enabling support for Quality-of-Service in communication networks using Software Defined Networking (SDN) and Network Function Virtualisation (NFV) techniques.

The overall system will allow network slicing to be explored in the context of VANETs.

The VANET/ITS-G5 Cloud testbed at KCL was will also explore different transportation modes including using the buses or underground, driving, cycling and walking. VANET/ITS-G5 will enable us to look closely at how the different modes interact in a very urban environment such as Central London. This will help us to better understand the safety issues with respect to urban transport leading to better road layout and management to reduce dangers to the users of the transport infrastructure.

Finally, it showed that the VANET/ITS-G5 Cloud testbed at KCL used to begin to look at the issue of integrated transport. As users employing different modes of transport are monitored by the system, which made it possible to see how different modes of transport affect the variability of arrival times to a given destination within central London (in this case Kings College).

Hence the main objectives included:

1. To build an extended network around the Hendon Campus and its surrounding areas along Watford Way (A41).

2. To build an extensive testbed in Central London around the King's College's Strand Campus.

3. To ensure that the Central London Testbed at KCL is deployed, configured and running live appropriately.

4. To run VANET/ITS-G5 Testbed Trial on both the sites using the new VANET/ITS-G5 network.

5. To connect both the testbed sites (MDX extended testbed on Watford Way (A41) and KCL site) over the Internet using Virtual Private Network (VPN) facilities and ensuring that data collection is happening appropriately at the MDX VANET server situated at Middlesex University.

6. To join these testbeds at remote locations in order to facilitate Connected Services by creating a Federated Cloud environment.

7. To analyse and display results using Data and Visual Analytic Techniques.

8. To explore how data generated by a VANET/ITS-G5 network can be used to create an Intelligent Transport Platform (IIP).

9. To discover key strengths and weakness of VANET/ITS-G5 technology in the light of other technologies such as LTE.

10. To highlight key problems and issues in implementing deployment of a large-scale VANET/ITS-G5 system.

11. To investigate the issues in scaling this technology to explore different traffic environments such as urban and motorway traffic.

12. To make recommendations to the DfT about how VANET/ITS-G5 could be used in other research efforts related to transport such as connected vehicles, etc.

1.1.2 The New VANET Research Framework - Intelligent Information Platform

In order to produce an environment to develop VANET applications using the ITS-G5/VANET testbeds with 5G capabilities, a new framework has been developed. This is shown in Figure 1.4. Using the Apache Hadoop Framework (AHF), and the

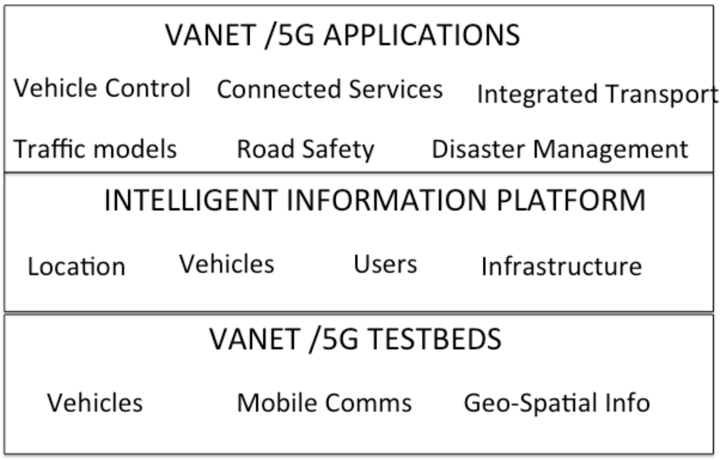

Fig. 1.4 The New ITS-G5/VANET Research Framework.

data stored on the VANET Cloud Servers, techniques will be developed to look at data in various ways including:

1. Location: There will be the ability to look at all the traffic at a given location or in a specific region over any period of time.

2. Vehicles: The system will also allow us to look at a particular vehicle or group of vehicles.

3. Users: The system will allow us to look at the movement of a user or a group of users.

4. Infrastructure: The system will allow us to examine readings from a given RSU or Mobile Access Point or Base Station. This will allow us to look at better deployment strategies for the transport and communication infrastructures.

   Because a lot of this data will be classed as sensitive or personal data, the Intelligent Information Platform must have the highest level of security to prevent unauthorised access to and tampering of the data held in the IIP. Middlesex University has recently proposed a new Security Framework for Cloud Storage. The framework will be deployed for this project

1.1.2.1 Future 5G technology integration into VANET Testbeds

These testbeds will gather huge amount of information from vehicles, including speed, location and direction of travel. In addition, information about the vehicle status from the Controller Area Network (CAN) including: braking pressure, wheel acceleration, fuel usage as well as readings from the Electronic Control Unit (ECU) that will indicate how the engine of the vehicle is performing will also be obtained.

The testbeds will also gather information from the Roadside Units as well as Mobile Access Points and Base Stations of mobile operators. Geo-spatial information, including the location of buildings, roads, etc., in a given area will also be looked at.

All this information from the Testbeds will be stored on the VANET Cloud Servers.

1.1.2.2 Some Key Applications: Integrated into 5G Next Generation Communication Systems

In the future, we intend to work on these key applications:

- Vehicle Control: Using information from the CAN and ECU, this will be possible by using Haptic techniques and Virtual Reality (VR) to experience all the stresses that the driver or passengers are experiencing in real-time.

- Connected Services: This is about developing applications around Internet access. This includes high-quality video-streaming, listening to network audio delivered to the mobile user and playing games such as immersive gaming as in the future the driver will also be a passenger. All these applications require support for very low latency. VANETs can deliver such low latencies.

- Integrated Transport: Integrated transport has been a popular goal for many researchers in the transport industry. However, it will not be possible without the development of the Intelligent Information Platform that we have proposed.

- Traffic models: It is useful to separate traffic into different traffic types, for example: motorway traffic and urban traffic. One of the key ideas is to look at how urban traffic and motorway traffic combine to cause traffic congestion in many parts of London. Middlesex University, Hendon Campus, is an ideal area to study such interactions which connect to London.

- Road Safety: This will look at different types of transport including walking, cycling, taking the bus or Tube, driving, etc. and the safety of using a given mode of transport in a certain area or region. This should lead to better road and transport layouts to protect commuters.

- Disaster Management: This application will look at better managing major accidents as well as man-made or natural disasters. The application seeks to provide information and direct traffic so that the security and emergency services could get to the scene of the incident quicker. Information about the disaster may be propagated by RSUs causing traffic to be automatically redirected away from the affected area.

1.1.3 Modified Time-frame of the Project

As proposed, we expected to have the entire testbed up and running in three to four months time after the start of the project, allowing eight weeks of readings from the entire system but this was delayed due to several factors. Firstly, we had to seek permission to mount some of the RSUs for the extended testbed outside the Hendon Campus along Watford Way (A41). This involved several meetings with the Barnet Council and the Highways Division at Transport for London (TfL).In the end, we managed to mount one RSU on King's College rooftop. The modified final time-scale is shown Figure 1.5 below:

- Legends (as specified below):

1. Buy and Install the equipment for Extended Testbed (8 weeks)

2. Trial using the MDX Connected Vehicles Testbed to cover the Burroughs road and the Greyhound Hill from the Ritterman building (6 weeks)

3. Trial on Extended Testbed on A41/M1 Motorway (8 weeks)

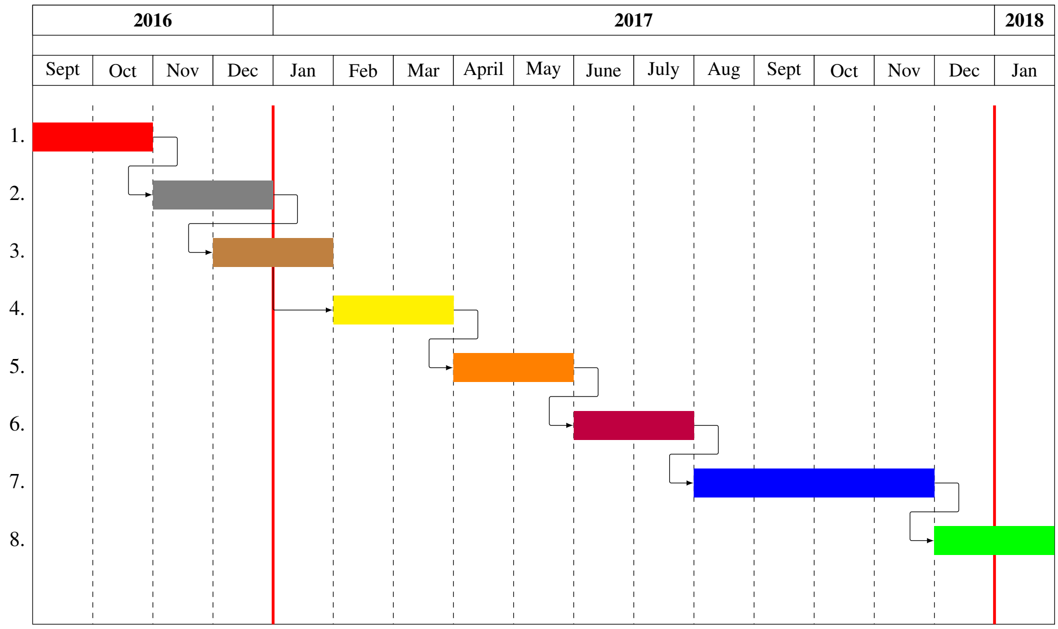

Fig. 1.5 Ganttchart for Project Time-line

4. Analysis of Data from the Extended Testbed (8 weeks)

5. Analysis of Data from the Central London Testbed at KCL Testbed (8 weeks)

6. Analysis of Data from the Extended Testbed (A41 Motorway) & CTLP Testbed at King's College London (12 weeks)

7. Final Report (Jan 2018)(8 weeks)

A similar situation was encountered at the King's College (KCL) site. We had to separately seek permission to mount some of the RSUs in the King's College along the Strand. These resulted in significant delays in ordering the equipment and hence the Project Time-frame had to be extended. Secondly, in order to effectively deploy the RSUs at both the sites (extended testbed along Watford Way (A41) and Central London Testbed at KCL campus), it was necessary to develop a detailed coverage map to identify the key positions for mounting the RSUs. The combination of these delays resulted in the Central London Testbed Trial being conducted at a much later date. We therefore, communicated this with Department for Transport (DfT) and an extension of the project was granted until end of January 2018.

1.1.4 Project Location

The proposed Testbed is shown in Figure 1.6 and encompasses the roads along the Burroughs (A504), Greyhound Hill, the Barnet By-Pass (where the A1 and A41 converge) and along Watford way (A41) to A504.

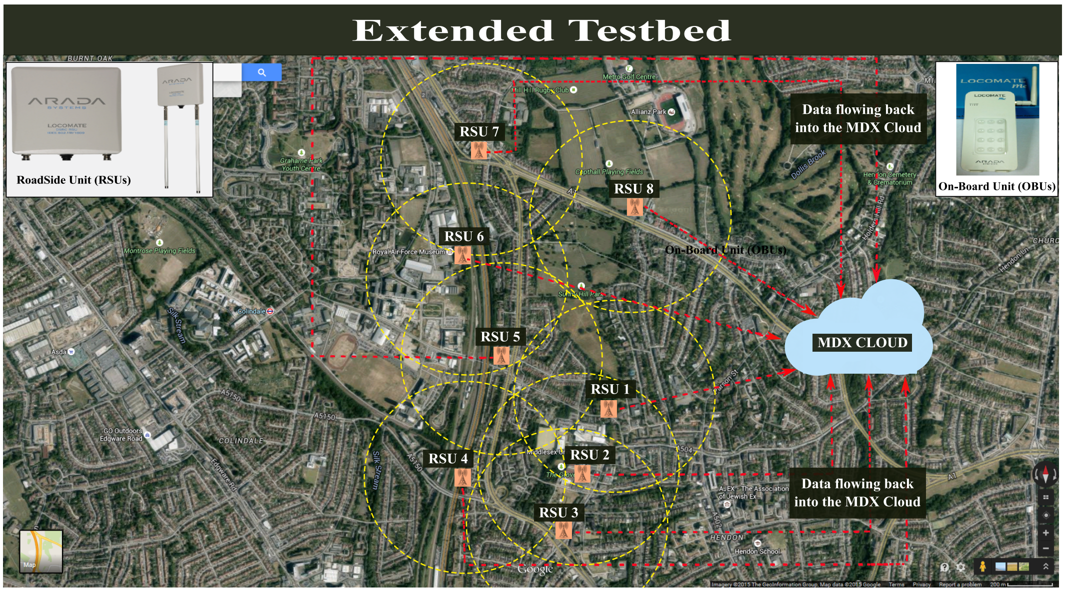

Fig. 1.6 The Extended Testbed including the MDX Testbed around Hendon Campus.

1.1.5 The Project Team

This Project was co-ordinated by Dr Glenford Mapp, Associate Professor, Head of Intelligent Transport Systems (ITS) - Connected Vehicles (ITS-G5/VANET) Research at Middlesex University and Professor Mischa Dohler, Head of the Centre for Telecommunications Research (CTR) at Kings College London. The Principal Investigators (PIs) who worked on the CLTP project were Dr Arindam Ghosh for Middlesex University (MDX) and Dr Fragkiskos Sardis for Kings College London (KCL). Mr Vishnu Vardhan Paranthaman, Mr Oneykachukwu Augustine Ezenwigbo were the PhD students and Mr Igor Topolski was the Undergrad student working on the CLTP project respectively. The funds for the project was administered by Middlesex University. The project began in September 2016 (formal start was from October 2016) and the final results were submitted by the end of 2017. Monthly progress reports were submitted to the Department for Transport (DfT) and the final report to the DfT was submitted by end of Jan 2018.

Central London Testbed Project Team Members:

Department for Transport (DfT) Team Members:

1. Department for Transport (DfT) - Mr Graham Hanson, ITS Policy Lead, Traffic and Technology Division.

2. Department for Transport (DfT) – Mr Suku Phull, Chief Technical Expert, Traffic and Technology Division.

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3. PhD Student working on the Project - Mr Vishnu Vardhan Paranthaman v.paranthaman@mdx.ac.uk.

4. PhD Student working on the Project - Mr Oneykachukwu Augustine Ezenwigbo.

5. Graduate Student working on the Project - Mr Igor Topolski.

1.1.6 Working with Others

In order to guarantee a successful completion of the Project, we had to work closely with a number of groups of experts, companies and organisations. We were working closely with ARADA Systems now part of Lear Corporation. This is the company which supplied all the RSUs and OBUs for the project. We had regular meetings and discussions with the Barnet Council and Transport for London (TfL) in order to demonstrate a collaborative effort on the project. We also had various discussions with the Middlesex University's Estate and Facilitate Management Services (EFMS) and Computing & Communication Systems Services (CCSS) teams for their expert advise on the matter of estate, facilities and infrastructural management along with servers, VPN and firewall issues wherever possible. We also got active technical support and expertise on networking, server management and backhauling from our technical support team of the Faculty of Science & Technology. We would like to extend our sincere thanks to Mobius Networks for their extended technical support outside of campus for LTE-backhauling issues. There were many technicians, teams and group of experts involved from the King's College side for the deployment of the testbed at Central London. Finally, we had good support from our project minders from the Department for Transport (DfT). Therefore, we would like to thank everyone who was involved in making this project a success.

1.2 Background

1.2.1 A Quick Tutorial on VANET Technology

Vehicular Ad-Hoc Networks (VANETs) are new networks that will enable support for life-critical safety and infotainment applications. VANETs are deployed using Roadside Units (RSUs) that are placed along the road and OnBoard Units (OBUs) that are placed in the vehicles or worn by cyclists or pedestrians. With its low latency and high bandwidth, VANET is a key technology in the development of ITS. VANETs allow communication between different entities: Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), Inter-roadside communication and Pedestrian to Infrastructure (P2I) as shown in Figure 1.7.

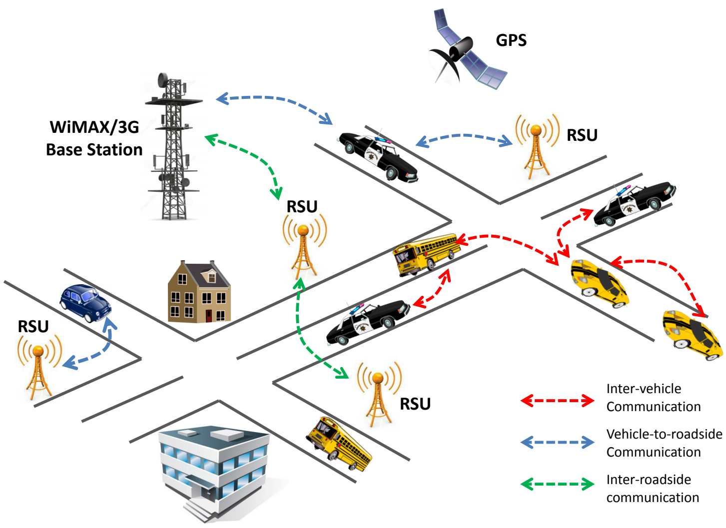


Fig. 1.7 Types of ITS-G5/VANET Communication.

VANETs are wireless networks that use technologies similar to current WiFi systems [1]. However, VANETs have a dedicated range of operation, channel frequency allocation and low level protocols that are different to WiFi and hence there is no interference between WiFi networks and VANET networks. In addition, because these two technologies are standardised there should be no interference with other technologies [2]. Typical RSUs/OBUs operate in the range of 20mW to 200mW with a maximum coverage range of 1000 meters [2]. The operation of VANETs is specified by the IEEE Standard for US operation and ETSI Standard for European operation [3]. There are minor operational differences between the two standards which are summarised as below:

- They operate on slightly different frequencies: North America (5.850-5.925GHz) [2] and European (5.875-5.925GHz) [4].
- In North America there are seven channels of 10MHz each, comprising one control channel and six service channels; while in Europe there are five channels comprising one control channel and two service channels dedicated to road safety and two additional service channels dedicated for traffic efficiency (i.e., non safety applications) [2].

In order to use VANET for safety critical applications, it is necessary to develop another protocol stack that can give low latency and reliability at the link level. Hence, there was a need to develop a new set of protocols to support these new features. Therefore, a VANET system has two protocol stacks; one for safety critical applications based around IEEE 1609.4 link level protocols and a normal IP stack for non safety critical applications [5]. This shown in the figure below:

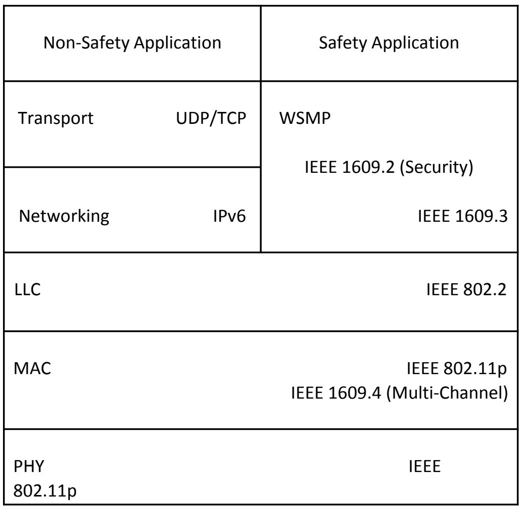


Fig. 1.8 WAVE Protocol Architecture.

1.2.2 Messages in VANET Systems

Beacons are small messages that are periodically broadcast by RSUs and OBUs and are used to discover and maintain neighbour relationships. Beacons therefore are used to communicate various items of information between RSUs and OBUs including Cooperative Awareness Message (CAM) [6], Decentralized Environmental Notification Messages (DEMN) [7]. Basic Safety Message (BSM) [8], Road Side Alert (RSA), Intersection Collision Alert (ICA) and Probe Vehicle Data (PVD). These messages contain key parameters such as GPS coordinates which allow us to know the location of the vehicle. In this project, only BSM messages are sent between the OBU and RSU. The Basic Safety Message (BSM) is used in multiple safety applications in each vehicle [8]. These applications are largely independent of each other, but all make use of the incoming stream of BSMs from surrounding (nearby) vehicles to detect potential events and dangers. One of these applications, referred to as intelligent braking, attempts to compare the motion vector and vehicle status found in the BSMs received from other vehicles with its own, in order to detect potential rear-end collisions and either warn the driver or take corrective action such as enhancing brake actions and pre-tensioning seat belts. BSM contains information regarding position, motion, time, and general status of the vehicle [8] as shown in the Figure 1.9.

US - Basic Safety Message Format. EU - Cooperative Awareness Message Format.

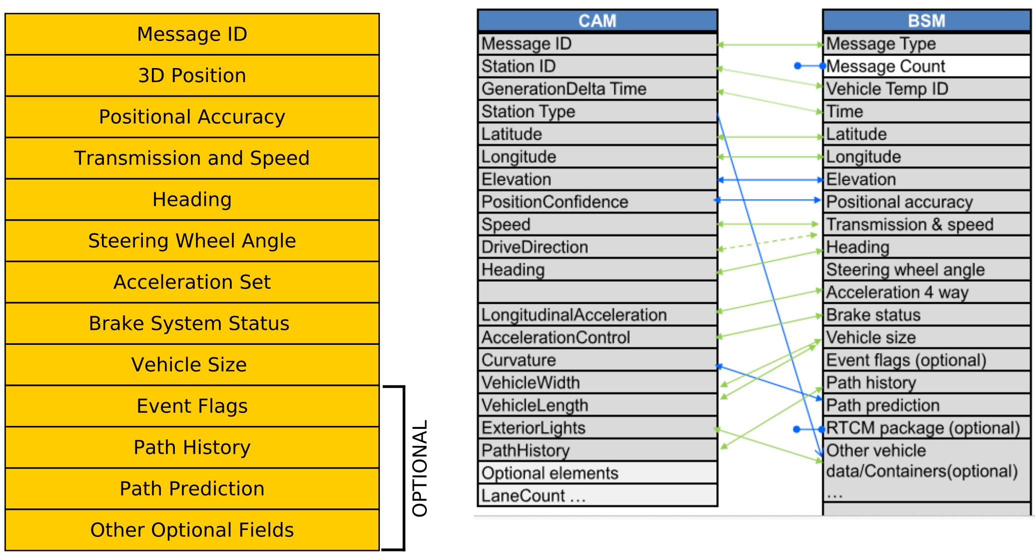


Fig. 1.9 Comparison of Basic Safety Message (BSM) .Vs Cooperative Awareness Message (CAM) Formats.

For this project we were able to only use the Message ID and 3D Position i.e., Latitude, Longitude and Elevation parameters of the BSM message [8]. This is because all other field information such as steering wheel angle, acceleration set, brake system etc., have to be gathered from the vehicle and then added to the BSM packet [8] and broadcast. This is part of our future work. VANETs are a new technology and hence there are very few VANET testbeds that allow researchers and engineers to experience this technology and explore its application to real world problems such as transportation management. In fact, the MDX VANET testbed is one of the first academic based testbeds in the United Kingdom.

1.2.3 The First MDX Research Testbed

In August 2014, Middlesex University decided to explore the building of a testbed to study seamless communication in highly mobile environments at its Hendon Campus. It was decided to use ITS-G5/VANET technology because of its coverage range and its ability to support a set of diverse applications. 4 RSUs and 10 OBUs were purchased. The 4 RSUs were mounted on four buildings on the Campus and they were able to provide access to vehicles within the Campus and the surroundings roads. Readings from the RSUs were sent to a central server and were then displayed on Google Earth. In June 2015, Middlesex University won a Transport Technology Research Innovation Grant (T-TRIG) award to extend the current system to the A41 (Watford Way) behind the Hendon Campus. This allowed us to run a Middlesex VANET Trial in January 2016. During this trial, OBUs were placed in the cars of students and staff as volunteers. The readings for a single day in January 2016 are shown in Figure 1.10.

1.2.3.1 Methodology - The MDX Research Testbed

There were four RSUs and these were mounted on top of four buildings on the Hendon Campus namely: the Hatchcroft, Williams and Grove Buildings as well as the Sheppard Library as depicted in Figure 1.10.

Once these RSUs were mounted, data from the OBUs was sent to the RSUs that, in turn, forwarded the data to the Central Middlesex Server, which was located in the basement of the Sheppard Library. Middlesex Trial data was initially stored in one file and Visual Analytic Techniques are used to analyse and display the data.

This work continued with Transport for London (TfL) to mount 4 RSUs on lampposts along Watford Way. This substantially improved the coverage of the Middlesex Testbed, which is being used to develop better propagation models in an attempt to understand the best way of deploying a citywide ITS-G5/VANET system. This testbed is also being used to investigate how safety could be improved

Fig. 1.10 Full Coverage Map of MDX Research Testbed.

by the development of vehicle monitoring and collision avoidance systems. Finally, investigations looked into how motorway traffic and urban traffic affect each other leading to traffic congestion.

However, there is also a need to explore how well traditional application/server environments work in the context of connected vehicles. This will allow a better understanding of how evolving network communication systems such as 5G can be integrated with ITS-G5/VANET systems. In addition, how ITS-G5/VANET could be used for integrated transport is also a key subject for future investigation. Commuters in Central London use several modes of transport e.g. buses or underground, driving, cycling and walking. Therefore, our testbed at King's College in Central London was an ideal location to explore this topic further.

1.3 Project Methodology

In order to achieve these objectives, there were two important aspects to explore: It was important to first understand the technology and the key physical parameters, such as transmission power and the protocols (in this case, IEEE 802.11p) that drive the technology. The second task was to explore how to build a real network using this technology. A major challenge was determining the best place to mount the RSUs. This necessitated the development of coverage maps based on proposed positions.

1.3.1 Methodology - The Extended Testbed along Watford Way (A41)

For the Extended Testbed the initial proposal was to mount 4 RSUs along the Watford Way (A41) as proposed and depicted in Figure 1.6. However, our initial coverage test obtained that there is a good signal strength with just 3 RSUs to cover the whole stretch of the motorway starting from the Burroughs (A504), Greyhound Hill intersection (between Greyhound Hill and Aerodrome Road on the A41) and the Barnet By-Pass (where the A1 and A41 converge) along Watford way (A41) to A504. Therefore, there were three RSUs and these were mounted at streetlight/lampposts height along the Watford Way on A41 namely: the first RSU was mounted on top of the 2nd lamppost on the A41 going northwards from the Burroughs junction, then the 2nd RSU was mounted on top of the lamppost around the Greyhound Hill intersection (between Greyhound Hill and Aerodrome Road on the A41) and the 3rd RSU was mounted on the lamppost just before the over-bridge on the Barnet By-Pass (where the A1 and A41 converge), going south bound. This Extended Testbed stretch covered an area of 3.2 kms/2 miles. Once these RSUs were mounted, data from the OBUs (which were placed in the volunteer's vehicles) was sent to the RSUs that, in turn, the RSUs mounted on top of the lampposts forwarded the data to the Central Middlesex VANET Server, which was located in the basement of the Sheppard Library. The Extended Testbed Trial data was initially stored in one file and Visual Analytic techniques have been used to analyse and display the data. The graphs generated from this trial has been discussed later in this report under the results section. Further, additional information on the RSUs, OBUs and LTE Units used for this project can be found in the AppendixA, AppendixB, AppendixC and AppendixD

1.3.2 Methodology - Central London Testbed at King's College London (KCL)

The initial proposal was to mount 4 RSUs around the King's College London along the Strand Campus. However, due to the location around the Strand and the initial coverage test readings obtained from the KCL's Strand Campus suggested that only one RSU is enough to cover an area of 3.80 kms/2.36 miles. The RSU mounted on top of KCL's main building on the Strand Campus namely: the Strand Building is depicted in Figure 1.11. The RSU is connected to the testbed via an LTE unit,

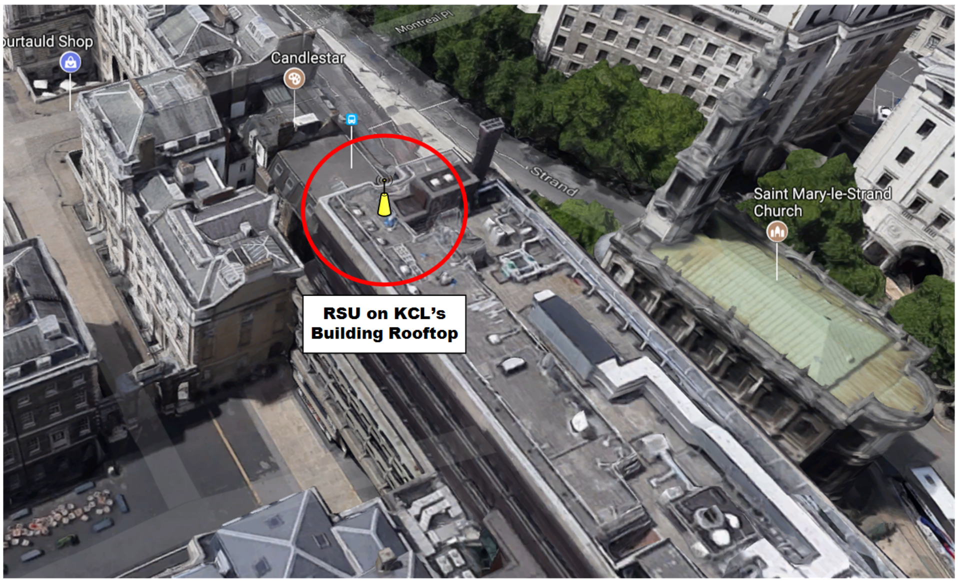


Fig. 1.11 Location of RSU at King's College, Strand Campus.

however, signal problems with the LTE network prevented reliable connectivity to the main logging server at Middlesex University. For our testing, we excluded the LTE connection by connecting to the LTE unit via Wi-Fi using a laptop running a local logging server.

1.4 Design and Implementation of the ITS-G5/VANET Federated Cloud Testbed

The objective of this project was to design of the ITS-G5/VANET Federated Cloud Testbed and this section details the challenges that were faced. The first objective was to test the equipment in the laboratory conditions to ensure there was no interference with other communication systems and to understand the basic elements of the technology such as beaconing.

Fig. 1.12 Members of MDX - ITS with TfL's Team - mounting RSUs along the A41

The next challenge was to identify the best locations to mount the RSUs in order to cover most of the Hendon Campus and the surrounding roads along the Watford way on A41 and around King's College in Central London. This involved making a detailed coverage map based on proposed locations of the RSUs. This was done manually and with the assistance of the MDX ITS - Connected Vehicles Research team, KCL's team and the Transport for London (TfL) highways division team. The entire team who were instrumental in deploying the RSUs along the Watford way (A41) is depicted in Figure 1.12. In order to determine the best location for the RSUs, it was important to minimize the distance between the RSU and the routing element of the data. Therefore, it was important to understand, evaluate and use the best option available for routing the data using the LTE backhauling technique. This enabled us to directly backhaul data from the RSU to the central MDX VANET Server located in the basement of Sheppard's library using LTE communication system unlike the university network used in the MDX VANET Testbed. Figure 1.13 shows the general network diagram of the ITS-G5/VANET Federated Cloud Testbeds for the Extended and the KCL testbeds. Four RSUs have been deployed on top of the Hatchcroft building, Williams building, Sheppard's library and Grove building.

Figure 1.13 also shows the applications running at the respective devices. Wave Short Message Protocol (WSMP) Tx is an application used by the OBU to broadcast

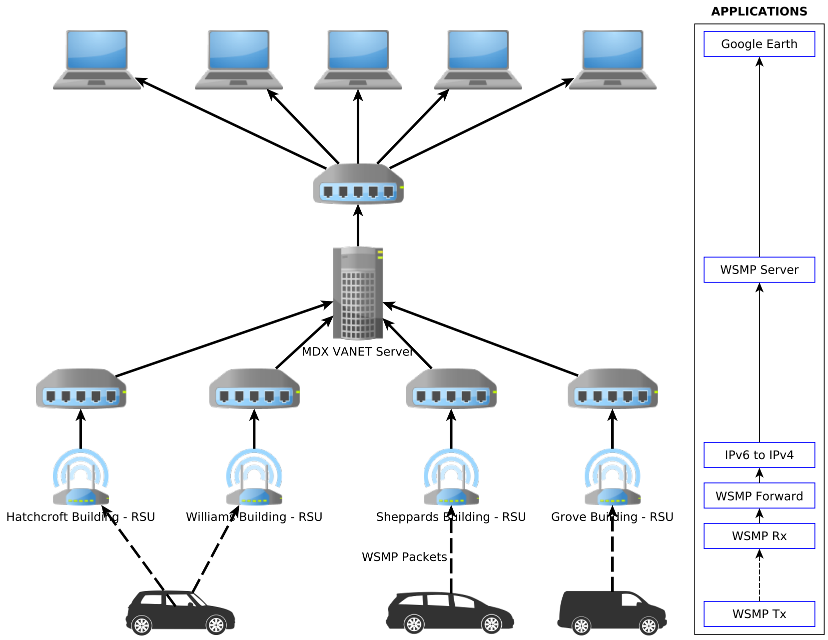


Fig. 1.13 NETWORK DIAGRAM.

the packets containing Basic Safety Messages (BSM) and the RSU receives these packets using WSMP Rx application. The received packets are forwarded to the server using the WSMP Forward application via an IPv6 address of the server. Since, the MDX Network is not IPv6 enabled; an IPv6 to IPv4 conversion application was developed.

This application was made to run on the RSU and it receives the IPv6 addressed packets on the bridge address of the RSU and redirects the packets to the IPv4 address of MDX VANET Server's. The MDX VANET Server uses WSMP Server application to receive the packets and will save the data. At this stage additional information such as a time-stamp and RSU's IP address are stored along with the message received. The received data was saved in three different files: trace.kml, live.kml and Database.csv. trace.kml contains the whole trace of the GPS coordinates contained in the received packet, live.kml contains the live or current positions of each OBU through the packets received from those OBU and this file is saved in the Apache Web Server space for remote access. Using Google earth, adding a network link to the live.kml file, the live tracking of the OBUs was achieved. The third file Database.csv contains the most of the available information in the packets such as the OBU's MAC address, the received signal strength indicator (RSSI) Value of the received packet, GPS coordinates along with the time stamp of the packet

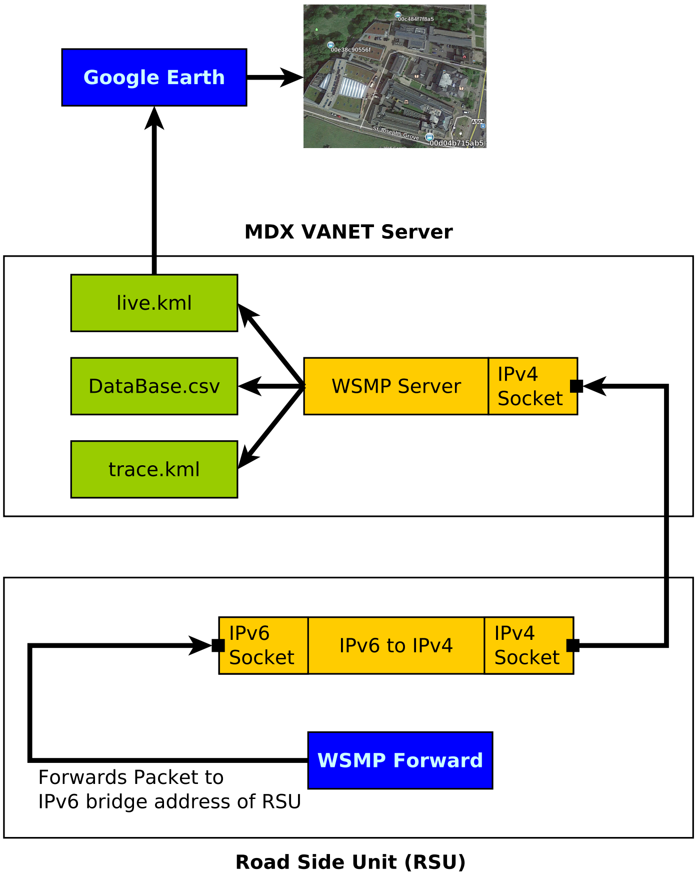


Fig. 1.14 Data forwarding from RSU to Server.

and IP address of the RSU by which the packet has been forwarded. Every day the Database.csv file was backed up for analysis through MySQL.

One of the major problem that had to be solved occurred when the RSU on the Williams Building was deployed and it was found not to be able to achieve the expected coverage area. We, therefore had to raise the height of the RSU by approximately five meters. Another major problem occurred, when deploying the RSUs on the Extended Testbed along the Watford way on A41. There were 3 RSUs mounted on the Barnet By-Pass on the A41 motorway. Therefore, the last RSU on the Barnet By-Pass (where the A1 and A41 converge) along Watford Way (A41) to A504, had to be moved a few lampposts ahead due to the over bridge which is intersecting at the A1 and A41 converge.

1.4.1 Deployment: The MDX Extended Testbed

The photos shown in Figure 1.15 are some of the deployment procedure followed by the Transport for London (TfL) highways division.

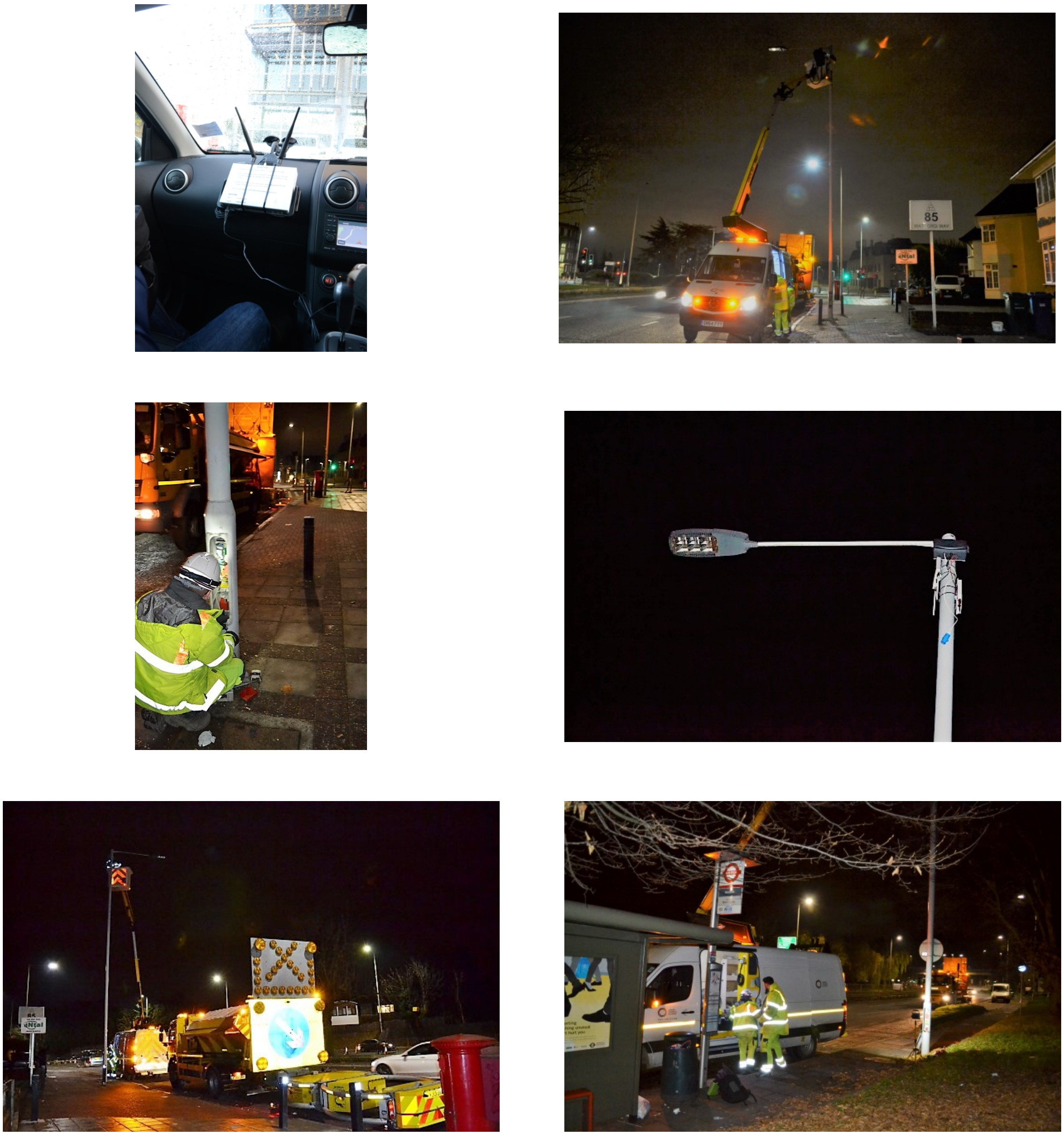


Fig. 1.15 Live Photos of Physical Deployment and the Trial of MDX & Extended ITS-G5/VANET Testbed.

1.4.2 Deployment: The King's College Testbed

The photos of the KCL deployment are shown in Figure 1.16.

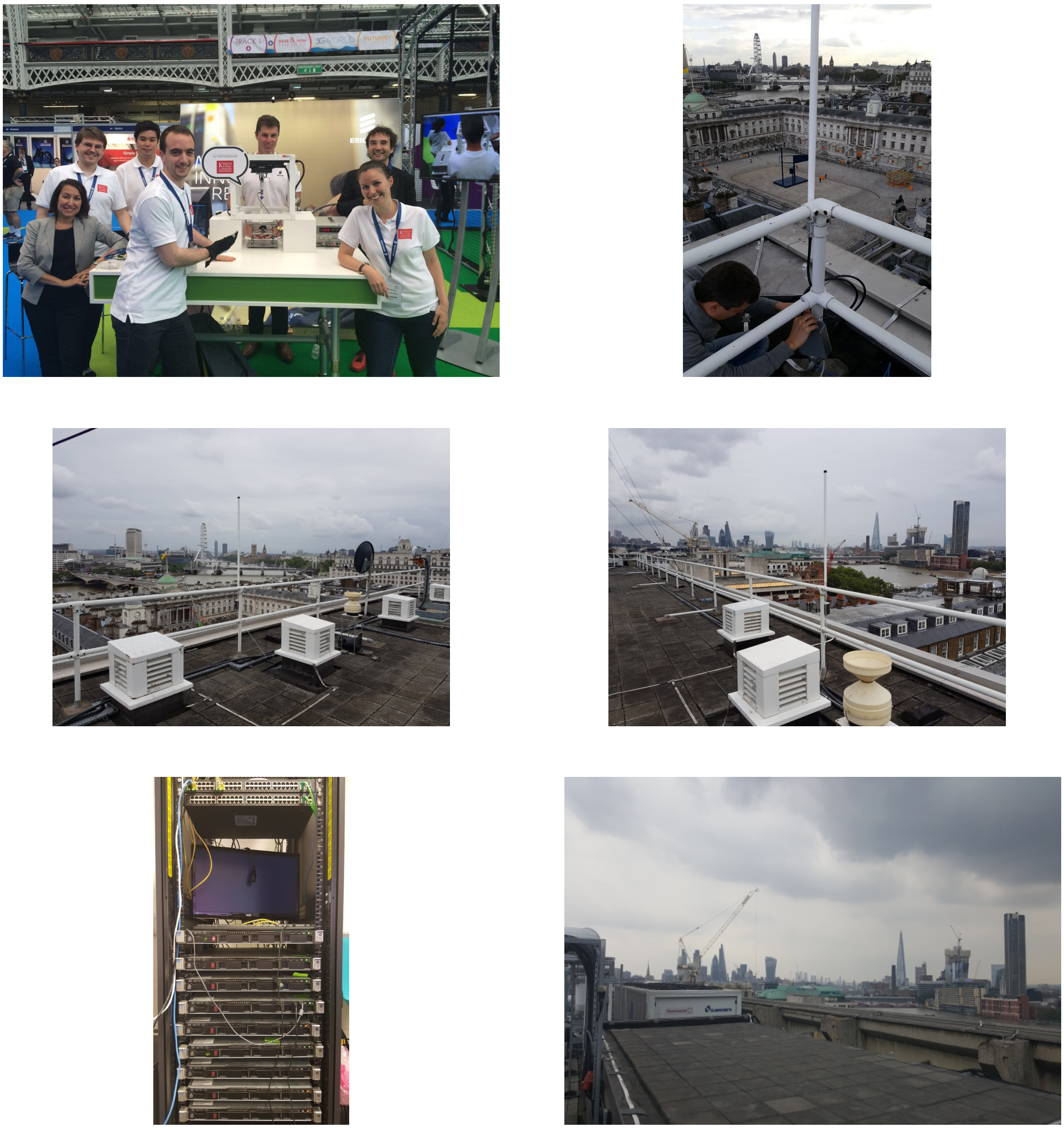


Fig. 1.16 Live Photos of Physical Deployment of the ITS-G5/VANET Testbed along with the 5G SDN Switch at KCL.

1.5 Results - C-ITS Federated Cloud Testbed Trials

1.5.1 Coverage Graph of the Extended Tesbted - (A41)

Figure 1.17 shows the coverage map of the full Extended Testbed stretch on the A41 Watford Way, starting all the way from the A41 - north bound road opposite Hendon Central and ending till the intersection of A41 and A1 i.e. the converge on A41 and A1 before the M1 over-bridge. The packets were logged by the MDX VANET Server, sent by the OBUs which were placed in the cars of the volunteers. There are two maps displayed in the Figure 1.17. The left hand-side map displays the trial data for a 24 hour period which was collected between 16th - 20th January 2017 with the colored dots representing different packets being received by all the 7 RSU including the four RSUs placed in the Middlesex Campus and three RSUs placed on the A41. In addition, the right hand-side map displays the exact location of the three RSUs placed along the A41 Watford way. The coverage map was extremely vital to

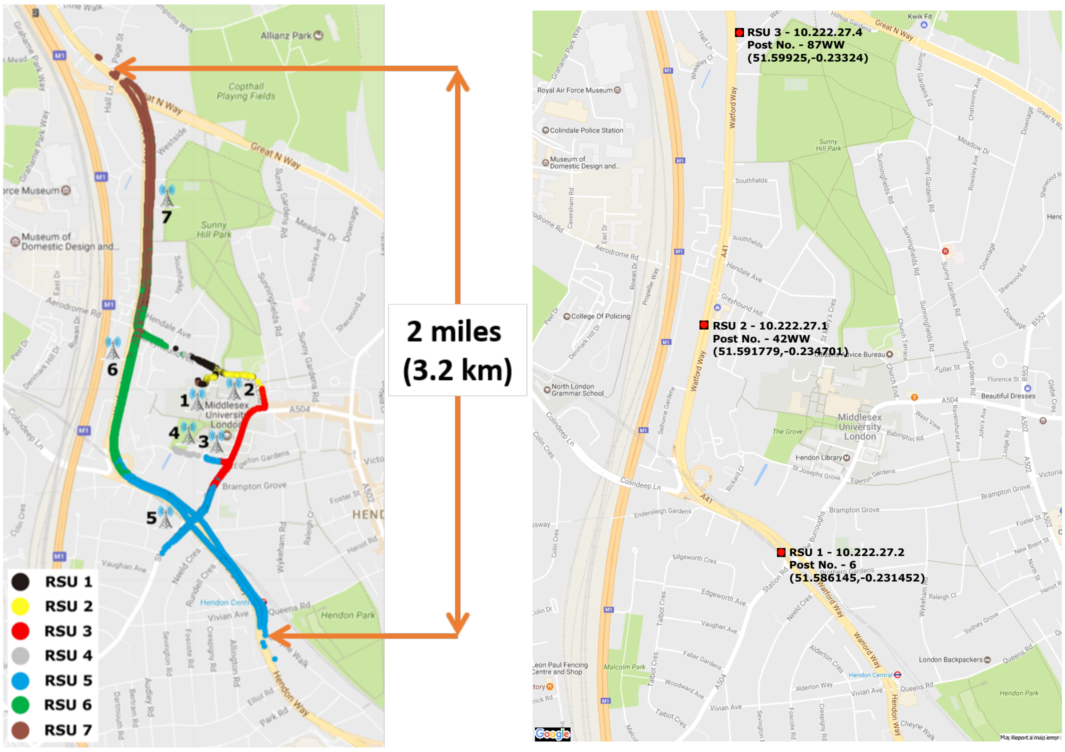


Fig. 1.17 Full Coverage Map of MDX Extended Testbed along Watford Way (A41).

us as there were some interesting observation were made. Hence the readings were way better than anticipated but this was only because of the height and the diligence placing of the RSU on A41. The interesting observation that we noticed from this Extended Testbed trial was the farthest point from where the packets were sent by the vehicles and successfully received by the RSU was approximately 3.2 km or 2 miles from the Williams Building RSU to a point on the east side of Watford way close to where the A41 and A1 converge. This was achieved purely due to the very high elevation of the RSU on the Williams Building hence allowing Line of Sight (LOS) communication over a great distance. There were also some blind spots that were be observed; these were purely due to effects of slight inclination of the road and also significant delays due the LTE backhauling setup. Further, the latency graphs have been discussed in detial in the latency graphs discussion section. A clear illustration of the Extended Testbed has been shown in Figure 1.18, where both Google Map and Google Earth of the depiction has been illustrated to give clear idea of the whole stretch.

Fig. 1.18 Extended Testbed along the Watford Way on A41.

1.5.2 Coverage Graph of the Central London Testbed at KCL

On 28/06/2017 we performed coverage testing for the RSU located on the roof of the Strand campus of King's College London. The mounting of the RSU was such that as shown in Figures 1.19 and 1.20 it has clear line of sight towards the south bank and part of The Strand. In more detail, the antenna has clear line of sight to the Blackfriars Bridge, Waterloo Bridge and Westminster Bridge and the junction between The Strand and Waterloo Bridge. The RSU is connected to the testbed via an LTE unit, however, signal problems with the LTE network prevented reliable connectivity to the main logging server at Middlesex University. For our testing, we excluded the LTE connection by connecting to the LTE unit via Wi-Fi using a laptop running a local logging server.

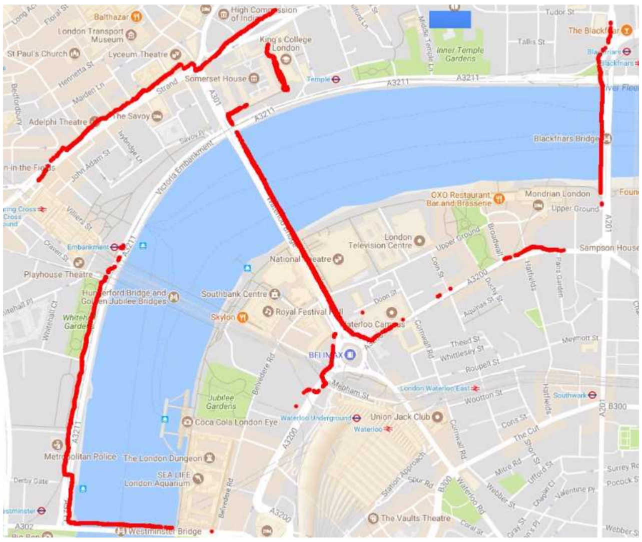


Fig. 1.19 Full Coverage Mapp of King's College London.

We started the testing by crossing the Waterloo bridge heading south from the Strand and then west towards Westminster Bridge. On Westminster bridge the signal was strong with no packet loss. After reaching the Waterloo station and heading west, the signal became intermittent due to blocked line of sight from the buildings along the south bank. Upon reaching Westminster Bridge, the signal was restored and we observed no packet loss. Based on the measured performance, we estimate that Lambeth Bridge should also have coverage, however, we did not test at the time. Instead, we headed north on Westminster Bridge and the walked east on Victoria Embankment were we also observed a good signal strength and no packet loss. Upon reaching Embankment station we headed north towards Charing Cross and then east towards KCL campus. On The Strand, we found intermittent connectivity, however at walking speed, there were several packets received between Charing Cross and up to the KCL campus. Going past the KCL campus and heading east towards Blackfriars, we lost connectivity. Heading south again on the Blackfriars Bridge, connectivity was restored with high signal strength on the bridge and no packet loss. Once again, upon reaching south bank and walking behind the buildings we lost connectivity except for a few locations on Stamford Street. We concluded our testing by heading north on the Waterloo Bridge and back into the KCL campus. Figure 1.19 presents coverage locations as observed during our testing. In Figrue 1.20 demonstrates the full coverage area of the KCL Tesbted which covers an area of 3.80 km.

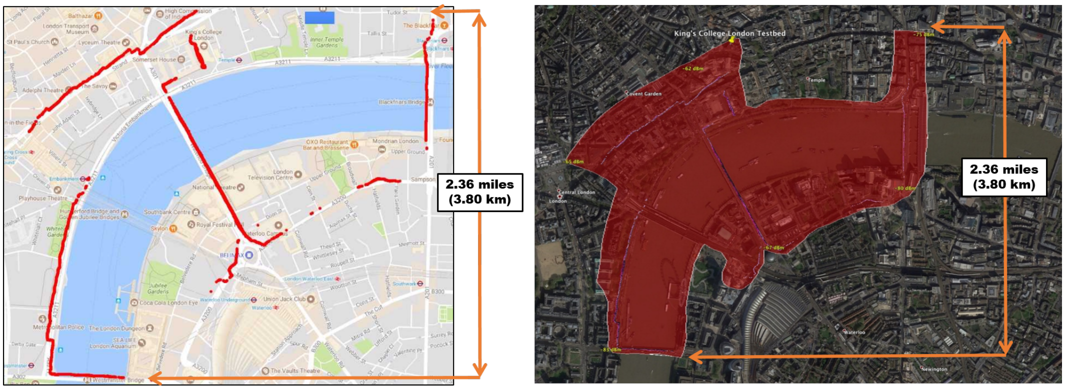


Fig. 1.20 Location of RSU at King's College, Strand Campus.

Based on our findings, we estimate that coverage might extend to the Millennium and Lambeth Bridges as well as some locations north of the KCL campus. Our observations also show that direct line of sight is an important factor to the packet loss although in some cases such as on The Strand, near Charing Cross, we have reception without having a line of sight to the antenna as shown in Figure 1.20. Due to the sensitivity of the communication to having a direct line of sight, and the location of the antenna at KCL, we do not believe that additional antennas at the KCL Strand Campus would improve the coverage. However, we do find that antennas on lamp posts in street junctions could greatly improve coverage for streets that go in a straight line. We have also identified that in central London, LTE can be unreliable due to network load, especially on peak times, which leads to problems with the VPN and collecting OBU data. Our plan was to eliminate LTE and deploy a wired topology within KCL with its own logging server and this has been achieved.

1.5.3 Propagation Model Graphs - MDX C-ITS Testbed

Propagation Graphs - Hatchcroft Building, Williams Building, Sheppards Building and the Grove Building RSUs

The graphs in Figures 1.21, 1.22, 1.23 and 1.24 show a comparison of four most prominently used propagation models in wireless communication namely: Free-Space Path Loss, Log-Distance Path Loss model, Free-Space Path Loss with Fast Fading and Two Ray Ground models against the real-time testbed values attained from the MDX ITS-G5/VANET trial.

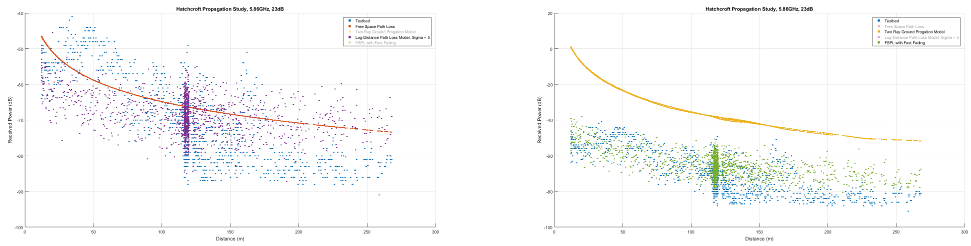


Fig. 1.21 Comparison of Propagation Models for Hatchcroft RSU - FSPL, LDPL, Two Ray Ground, FSPL - Fast Fading and Testbed Readings.

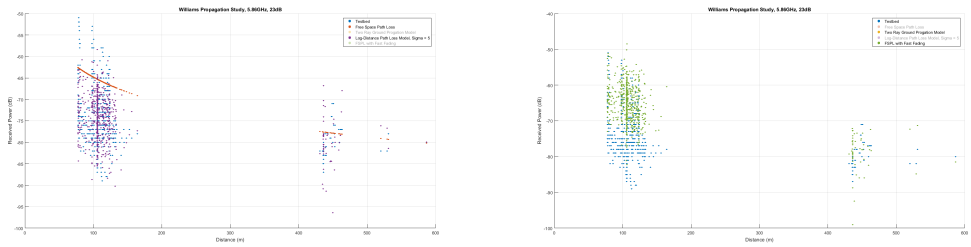


Fig. 1.22 Comparison of Propagation Models for Williams RSU - FSPL, LDPL, Two Ray Ground, FSPL - Fast Fading and Testbed Readings.

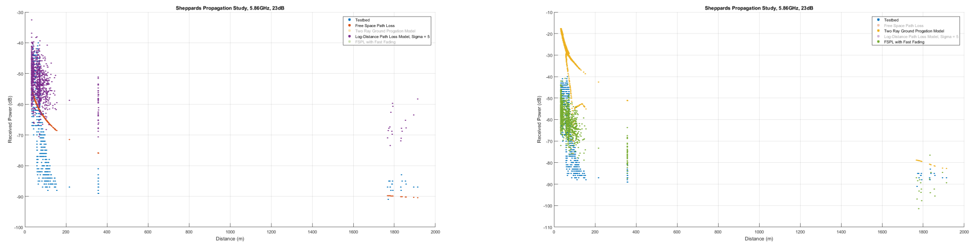


Fig. 1.23 Comparison of Propagation Models for Sheppards RSU - FSPL, LDPL, Two Ray Ground, FSPL - Fast Fading and Testbed Readings.

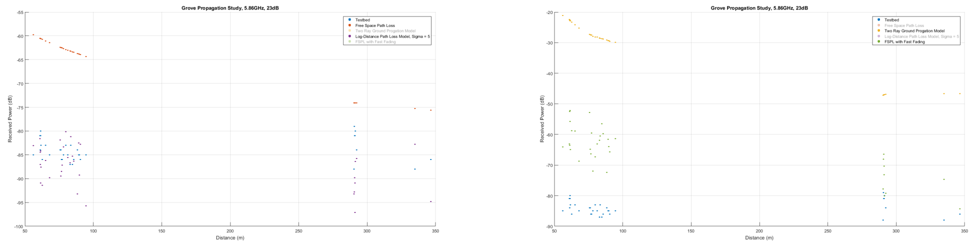


Fig. 1.24 Comparison of Propagation Models for Grove RSU - FSPL, LDPL, Two Ray Ground, FSPL - Fast Fading and Testbed Readings.

The readings depicted Figures 1.21, 1.22, 1.23 and 1.24 were observed over a period of time. The graphs comprises of received signal strength or in other words received power in Decibel (dB) represented over distance in meters. This was achieved by broadcasting of the beacons from the RSU placed on top of the MDX's Hatchcroft building to the OBU which was placed in the vehicle that was driven around Central London. The Y axis in the graph represents the Decibel (dB) of the received signal strength (RSSI) at the OBU and the X axis represents the distance in meters i.e. the distance traveled by the vehicle (having the OBU). In the left hand-side graph of Figures 1.21, 1.22, 1.23 and 1.24, the solid red line represents the calculated values of the Free-Space Path Loss model and the thick purple dots represents the calculated values of the Log-Distance Path Loss model. However, the blue scattered dots are the real-time RSSI values observed from the testbed. Similarly, the right hand-side graph of Figures 1.21, 1.22, 1.23 and 1.24, the solid yellow line represents the calculated values of the Two Ray Ground model and the thick green dots represents the calculated values of the Free-Space Path Loss with Fast Fading model. However, the blue scattered dots are the real-time RSSI values observed from the testbed. The calculations performed for all the four models were based on the following parameters, the RSU operated on 5.86 GHz Band with a transmission power of 23dB and a distance of 1300 meters or 1.3 km was observed. In addition, the calculations performed for the Two Ray Ground and the FSPL with Fast Fading models were based on the parameters as mentioned above. However, for the Two Ray Ground Reflection model there is an extra height parameter consider. It is due to this height parameter used for the Two Ray Ground model which shows better signal strength between the transmitter antenna and the receiver antenna. From the both the graphs, it was expected to have a gradual decline in the received signal strength for FSPL and LDPL, FSPL with Fast Fading and Two Ray Ground models over a distance. However, the real-time values from the testbed, evidently demonstrated a scattered effect on the graph this could be due to several reasons. Firstly, as the vehicle drove around Central London, therefore high chances of received signal strength dropping as the vehicles moved away from the RSU's coverage area. Secondly, the scattering effect is due to many buildings located around the MDX's Hatchcroft building, hence high chances of the beacons reflecting, deflecting from the buildings along with sharp turns on the narrow roads in Central London.

1.5.4 Propagation Model Graphs of the Extended Testbed (A41) Watford Way

The graphs in Figures 1.25, 1.26 and 1.27, show a comparison of four most prominently used propagation models in wireless communication namely: Free-Space Path Loss, Log-Distance Path Loss model, Free-Space Path Loss with Fast Fading and Two Ray Ground models against the real-time testbed values attained from the trial conducted for the Extended Testbed along A41 Watford Way.

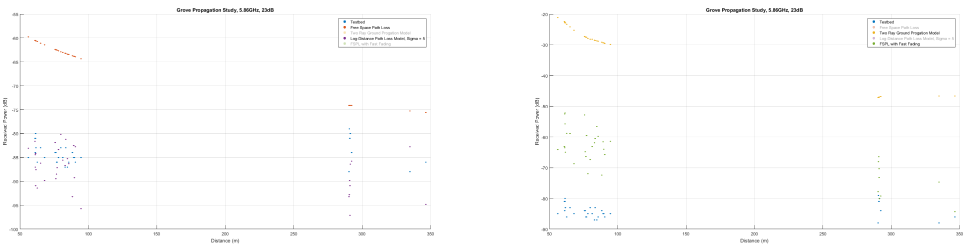


Fig. 1.25 Comparison of Propagation Models for Grove RSU - FSPL, LDPL, Two Ray Ground, FSPL - Fast Fading and Testbed Readings.

The readings depicted in Figures 1.25, 1.26 and 1.27 were observed over a period of time. These graph comprises of received signal strength or in other words received power in Decibel (dB) represented over distance in meters. This was achieved by broadcasting of the beacons from the RSU placed on top of the lampposts along A41

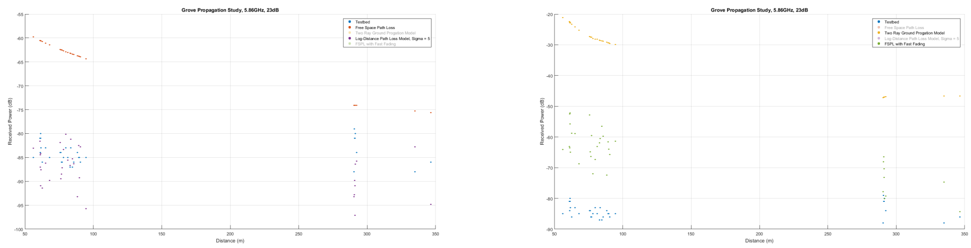


Fig. 1.26 Comparison of Propagation Models for Grove RSU - FSPL, LDPL, Two Ray Ground, FSPL - Fast Fading and Testbed Readings.

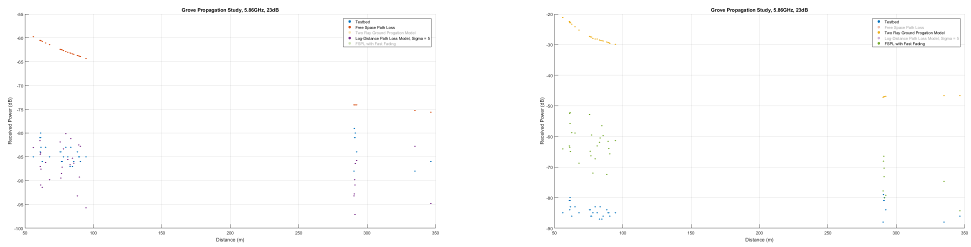
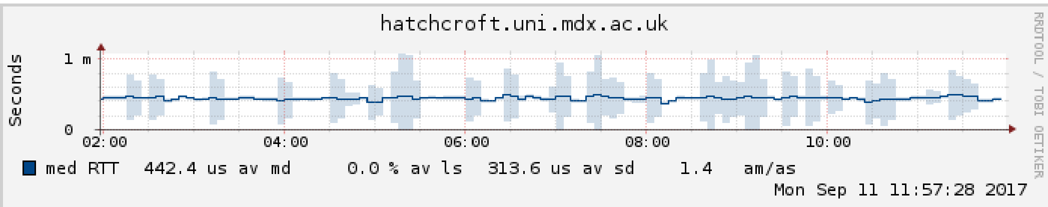


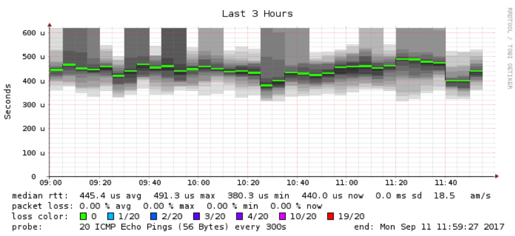
Fig. 1.27 Comparison of Propagation Models for Grove RSU - FSPL, LDPL, Two Ray Ground, FSPL - Fast Fading and Testbed Readings.

Watford way to the OBU which was placed in the vehicle that was driven around Middlesex University's Hendon Campus and A41 Watford way. The Y axis in the graph represents the Decibel (dB) of the received signal strength (RSSI) at the OBU and the X axis represents the distance in meters i.e. the distance traveled by the vehicle (having the OBU). In the left hand-side graph of Figures 1.25, 1.26 and 1.27, the solid red line represents the calculated values of the Free-Space Path Loss model and the thick purple dots represents the calculated values of the Log-Distance Path Loss model. However, the blue scattered dots are the real-time RSSI values observed from the testbed. Similarly, the right hand-side graph of Figures 1.25, 1.26 and 1.27, the solid yellow line represents the calculated values of the Two Ray Ground model and the thick green dots represents the calculated values of the Free-Space Path Loss with Fast Fading model. However, the blue scattered dots are the real-time RSSI values observed from the testbed. The calculations performed for all the four models were based on the following parameters, the RSU operated on 5.86 GHz Band with a transmission power of 23dB and a distance of 1300 meters or 1.3 km was observed. In addition, the calculations performed for the Two Ray Ground and the FSPL with Fast Fading models were based on the parameters as mentioned above. However, for the Two Ray Ground Reflection model there is an extra height parameter consider. It is due to this height parameter used for the Two Ray Ground model which shows better signal strength between the transmitter antenna and the receiver antenna. From the both the graphs, it was expected to have a gradual decline in the received signal strength for FSPL and LDPL, FSPL with Fast Fading and Two Ray Ground models over a distance. However, the real-time values from the testbed, evidently demonstrated a scattered effect on the graph this could be due to several reasons. Firstly, around Central London there is high chance of received signal strength dropping as the vehicles moved away from the RSU's coverage area. Secondly, the scattering effect is due to many buildings located around the MDX's Hatchcroft building, hence high chances of the beacons reflecting, deflecting from the buildings along with sharp turns on the narrow roads in Central London.

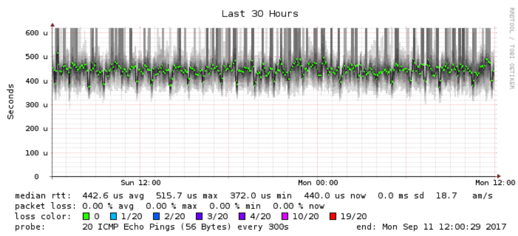
1.5.5 Backhauling Latency Graphs Discussed in Detail: MDX ITS-G5/VANET Testbed



(a) Latency Graph of the RSU on Hatchcroft Building.



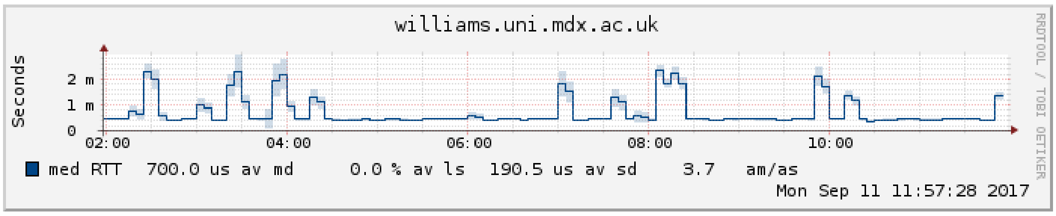
(b) Latency Graph of RTT of the RSU on Hatchcroft Building for 3Hrs.



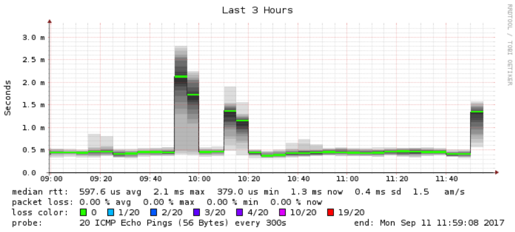
(c) Latency Graph of the RTT of the RSU on Hatchcroft Building for 30Hrs.

Fig. 1.28 Latency Graphs of the RSU on Hatchcroft Building.

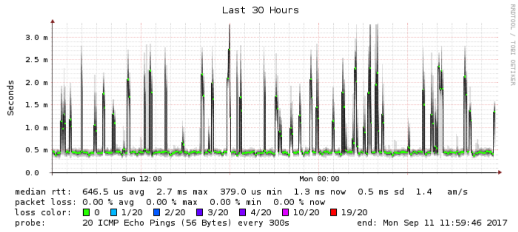
The graphs shown in Figures 1.28, 1.29, 1.30 and 1.31 have been generated by logging the data i.e. backhauling data from the RSUs located on rooftop of Hatchcroft, Williams, Sheppards and the Grove building in Hendon Campus of Middlesex University. The arrangement is such that the data packets travel from the OBUs placed in the cars to the RSUs and then forwarded from the RSUs to the central VANET server (which is the Main Server). This forwarding of the data packets from all the four RSUs to the VANET server has been achieved via connecting the RSUs to the Middlesex University's wired network. Middlesex University's wired network



(a) Latency Graph of the RSU on Williams Building.

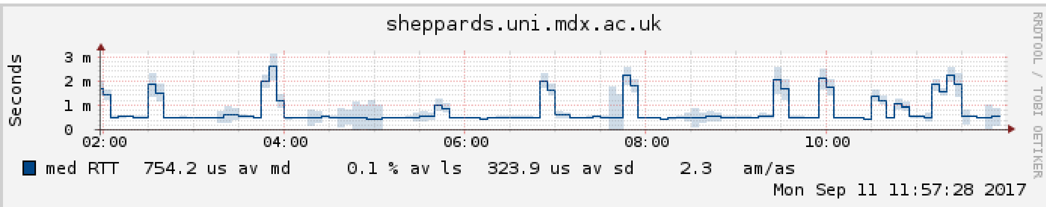


(b) Latency Graph of the RSU on Williams Building for RTT 3Hrs.

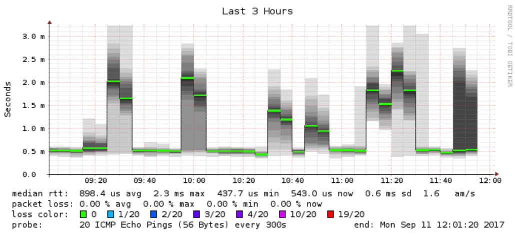


(c) Latency Graph of the RSU on Williams Building for RTT 30Hrs.

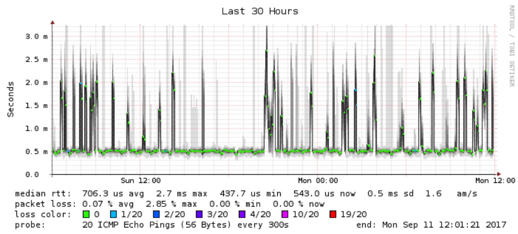
Fig. 1.29 Latency Graphs of the RSU on Williams Building.



(a) Latency Graph of the RSU on Sheppards Building.



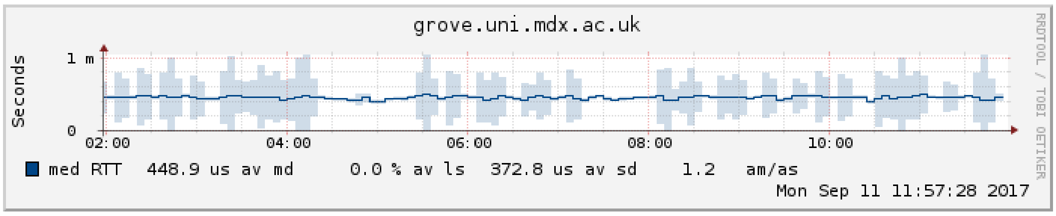
(b) Latency Graph of the RSU on Sheppards Building for RTT 3Hrs.



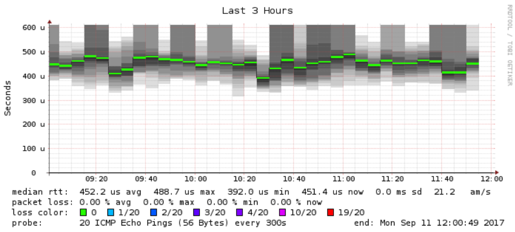
(c) Latency Graph of the RSU on Sheppards Building for RTT 30Hrs.

Fig. 1.30 Latency Graphs of the RSU on Sheppards Building.

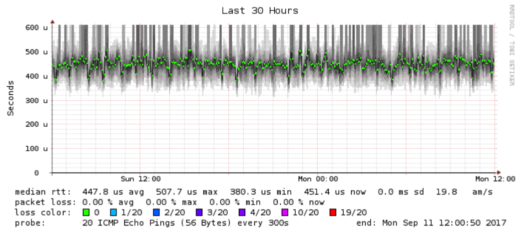
offers a Gigabyte Ethernet speed. Therefore, the graphs shown in Figures 1.28, 1.29, 1.30 and 1.31, adjacent next to each other demonstrate the Round-Trip Time (RTT) for 3 and 30 hours respectively. The graphs illustrate the RTT time taken for the data to route the data from the RSU to the central VANET server located at Middlesex University. The delay in the graphs logged for 3 hours is almost negligible, however the readings from the graphs logged for 30 hours show an average RTT time between 400 - 500 microseconds, 0.5 - 2.5 milliseconds, 0.5 - 2.7 milliseconds and 500 - 600



(a) Latency Graph of the RSU on Grove Building.



(b) Latency Graph of the RSU on Grove Building for RTT 3Hrs.



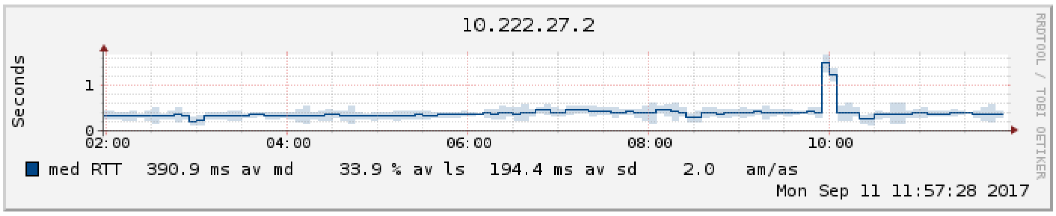
(c) Latency Graph of the RSU on Grove Building for RTT 30Hrs.

Fig. 1.31 Latency Graphs of the RSU on Grove Building.

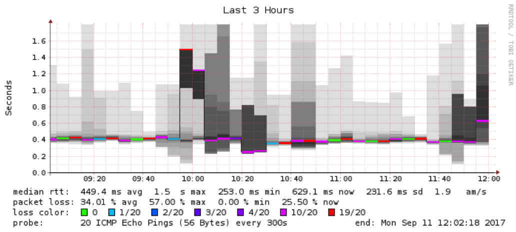
microseconds with no packet loss from the RSUs placed on Hatchcroft, Williams, Sheppards and the Grove Building respectively. This delay is almost next to nil. Therefore, this behaviour doesn't have any affect on backhauling the data back to the VANET server.

1.5.6 Backhauling Latency Graphs Discussed: Extended Testbed along the A41 Watford Way

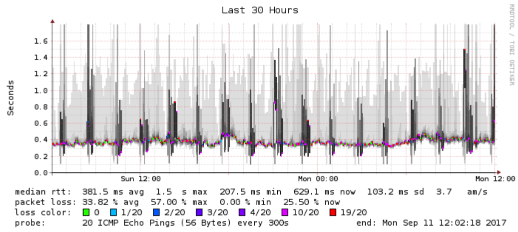
The graphs shown in Figures 1.32, 1.33 and 1.34 have been generated by logging the data i.e. backhauling data from the RSUs located on top of the three lampposts on A41 Watford Way. The arrangement is such that the data packets travel from the OBUs placed in the cars to the RSUs and then forwarded from all three RSUs to the central VANET server (which is the Main Server). This forwarding of the data packets from the RSUs to the VANET server is achieved using the LTE network, which uses a 4G mobile communication technology provided by Mobius Networks by placing LTE Units next to our RSUs on the lampposts on A41. Therefore, the graphs shown in Figures 1.32, 1.33 and 1.34, adjacent next to each other demonstrate the Round-Trip Time (RTT) for 3 and 30 hours respectively. The graphs illustrate the RTT time taken for the data to route the data from the RSUs to the central VANET server located at Middlesex University. The delay in the graphs logged for 3 hours is almost negligible, however the readings from the graph logged for 30 hours for RSUs 1, 2 and 3 on A41, show an average RTT time between 0.3 - 1.5 milliseconds, 250 -



(a) Latency Graph of RSU-1 on A41 Watford Way.

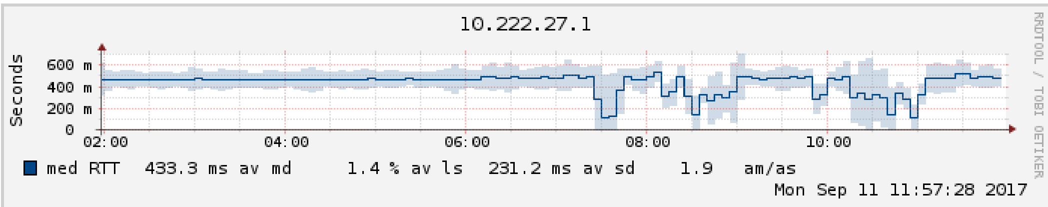


(b) Latency Graph of RSU-1 on A41 Watford Way for RTT 3Hrs.

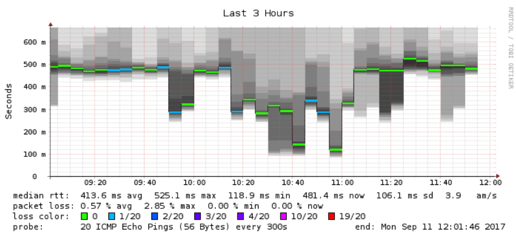


(c) Latency Graph of RSU-1 on A41 Watford Way for RTT 30Hrs.

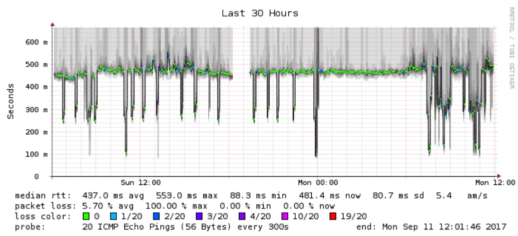
Fig. 1.32 Latency Graphs of RSU-1 on A41 Watford Way.



(a) Latency Graph of RSU-2 on A41 Watford Way.



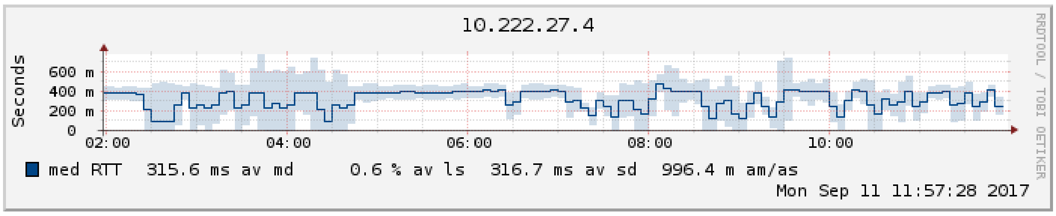
(b) Latency Graph of RSU-2 on A41 Watford Way for RTT 3Hrs.



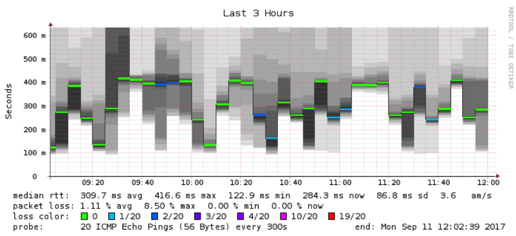
(c) Latency Graph of RSU-2 on A41 Watford Way for RTT 30Hrs.

Fig. 1.33 Latency Graphs of RSU-2 on A41 Watford Way.

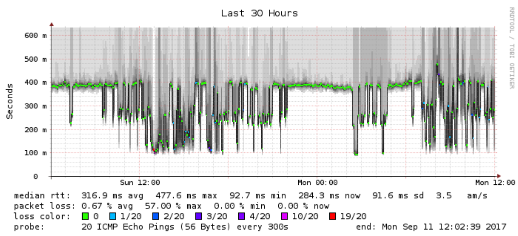
550 milliseconds and 100 - 450 milliseconds with packet losses of 33.83%, 5.70% and 0.67% respectively. This is slightly more than expected compared to the wired Ethernet Network backhauling used in our Middlesex University's Hendon Campus Testbed setup. Therefore, this behaviour does show significant delays affecting backhauling the data back to the VANET server, especially in order to grantee seamless connectivity which is key for achieving connected corridor environment.



(a) Latency Graph of RSU-3 on A41 Watford Way.



(b) Latency Graph of RSU-3 on A41 Watford Way for RTT 3Hrs.



(c) Latency Graph of RSU-3 on A41 Watford Way for RTT 30Hrs.

Fig. 1.34 Latency Graphs of RSU-3 on A41 Watford Way.

Table 1.1 Backhauling Latency of the RSUs on Middlesex University and Extended Testbed on A4

Table showing Latency of the RSUs on Middlesex University and Extended Testbed on A41							
	MDX ITS-G5 VANET Testbed				**Extended Testbed on A41 Watford Way**		
RSUs Location	**Hatchcroft Building**	**Williams Building**	**Sheppards Building**	**Grove Building**	**RSU-1 on A41**	**RSU-2 on A41**	**RSU-3 on A41**
Delay Time (secs)	400 – 550 microseconds	0.5 – 2.5 milliseconds	0.5 – 2.7 milliseconds	500 – 600 microseconds	0.3 – 1.5 milliseconds	250 – 550 milliseconds	100 – 450 milliseconds
Packet Loss (Percentage)	0%	0%	0%	0%	33.83%	5.70%	0.67%

1.5.7 Propagation Model Graphs of the Central London Testbed at KCL

As observed from the previous section that due the buildings surrounding the KCL's Strand Campus, it was expected to have this effect due to the dense urban setting. This effect in turn did influence our coverage map along with the way we deploy our RSUs. This was confirmed by our coverage readings and therefore, we further took the opportunity to observe and compare the traditional Path Loss Models used in wireless communication with our real-time testbed readings in order to have a comprehensive knowledge on how urban city will influence deployment strategy and further how to improve them for efficiency.

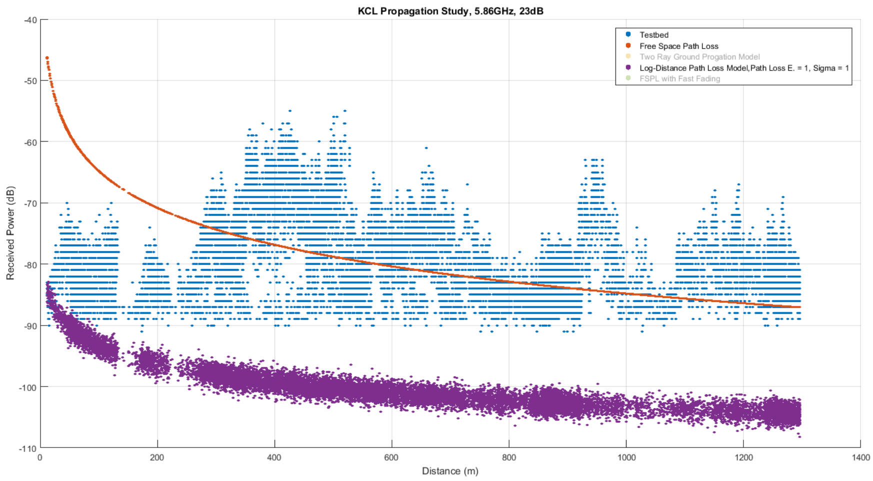


Fig. 1.35 Comparison of Propagation Models - FSPL, LDPL and Testbed Readings.

The graph in Figure 1.35 shows a comparison of two well-known traditional Path Loss models i.e. the Free-Space Path Loss (FSPL) and the Log-Distance Path Loss (LDPL) models against the real-time testbed. However, the real-time values from the testbed, evidently demonstrated a scattered effect on the graph this could be due to several reasons. The graph in Figure 1.36 shows a comparison of another two well-known traditional Path Loss models i.e. the Two Ray Ground Propagation Model and the Free-Space Path Loss with Fast Fading (FSPL with Fast Fading) models against the real-time testbed. The observations made above for the KCL Testbed, help us conclude that due to the sensitivity of the communication to having a direct line of sight, and the location of the antenna at KCL, we did believed that deployment of additional antennas at the KCL Strand Campus would not improve the coverage. However, we do find that antennas on lampposts in street junctions

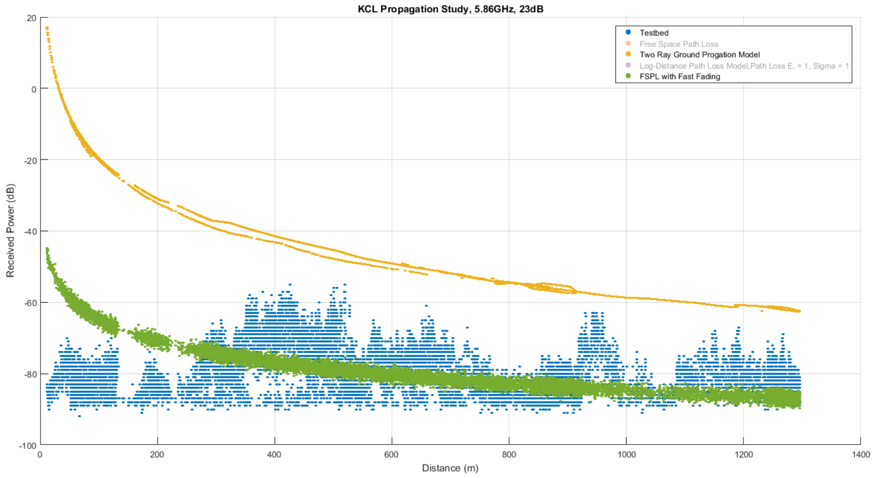


Fig. 1.36 Comparison of Propagation Models - Two Ray Ground, FSPL - Fast Fading and Testbed Readings.

could greatly improve coverage for streets that track on a straight line. We have also identified that in central London, LTE can be unreliable due to network load, especially on peak times, which leads to problems with the VPN and collecting OBU data. Our future plan is to eliminate LTE and deploy a wired topology within KCL with its own logging server.

1.6 Challenges and Pitfalls

1.6.0.1 The Extended Testbed along Watford Way (A41) Coverage Testing

Most of the task deliverables were achieved however there were few setbacks while deploying the RSUs along the extended testbed along the A41 motorway, as most of the roads covered belong the Transport for London (TfL).

The most significant setback was: though we were able to adequately cover the roads immediately around the Hendon Campus, we were unable to mount RSUs on top of the street lights along the A41 (Watford Way) as intended. Due to the short time, it was not possible to get authorization. It was therefore decided to build an RSU that could be used independently of location. Hence the RSU could backhaul as well as generate all or most of its power if necessary. We want to fully test this solution as part of the next steps of this project.

Another major drawback was the RSUs were mounted on the top of building so that it was possibly to get good communication because at those heights, the line-of-sight (LOS) dynamics apply. However, at street level, because of the obstacles (such as buildings), there will be much more interference leading to reduced communication. This needs to form part of on-going research into VANETs.

The third major drawback was because the OBUs and the RSUs talk to each other using IPv6 addresses; it was necessary to write a local program to convert take the data sent to the RSU and send it to the MDX Server using IPv4 addresses. This program must ported to each RSU which is time consuming task.

1.6.0.2 KCL Testbed Coverage Testing

The initial plan for the Testbed located in Central London at King's College's (KCL) was to mount four RSUs in order to cover the full area around King's College and it's surrounding areas. Due to the sensitivity of the communication to having a direct line of sight, and the location of the antenna at KCL, we do not believe that additional antennas at the KCL Strand Campus would improve the coverage. However, we do find that antennas on lamp posts in street junctions could greatly improve coverage for streets that track on a straight line. We have also identified that in central London, LTE can be unreliable due to network load, especially on peak times, which leads to problems with the VPN and collecting OBU data. Our future plan is to eliminate LTE and deploy a wired topology within KCL with its own logging server.

1.7 General Observations from MDX C-ITS VANET Trial

For the most part, the technology worked in the sense that we got substantial readings over a large coverage area. However, there were some issues including the need for better cooperation between the various stakeholders of the project including Middlesex University, Barnet Council, Transport for London and the Department for Transport. This means that in order to take this research further in terms of a larger deployment, a powerful strategic team from all parties will be needed to significantly increase the scale of deployment of VANET technology.

The actual results were interesting on several levels. Firstly, we were surprised at the coverage of the RSUs that were mounted on the buildings of the Hendon campus because we were able to get readings from quite a far distance on Watford way (A41). This leads to the need to investigate both roadside and non-roadside locations for the RSU deployment. For example, it would be good to compare RSUs along the roadside with RSUs mounted on a conventional cellular mast.

In both cases however, this project clearly shows the need to better understand the communication/propagation models in order to work out the best position for the RSUs to achieve good coverage in all types of environments, both urban and motorway. In this trial, determining the best place of deployment of the RSUs was done manually, better communication/propagation models would allow us to semi automate this process leading to more rapid deployment.

For this trial, this was a minor inconvenience, however, going forward the difference in Standards may have a significant impact on the applications since the EU Standard has dedicated service channels for both safety critical and non-safety critical applications but the US standard does not. Hence, there will be a need to have one standard in the future.

1.8 Findings relative to the aims and objectives of the project

In the section below we present our findings relative to the aims and objectives of the project as indicated in the Executive Summary.

Objective 5: To discover key strengths and weakness of VANET technology in the light of other technologies such as LTE.

The strengths were that VANET systems appear to be highly reliable if the VANET network is planned and effectively deployed. The system offers low latency and high reliability over an extensive coverage range. In addition, vehicles can also communicate directly with each other without the need of a base station. The main weaknesses were: the actual deployment was labour intensive and the equipment was relatively expensive. Both these observations reflect the fact that VANETs are relatively new technology. In addition, more work is needed to understand the communication dynamics of VANET systems in terms of penetration and coverage area in different environments.

Objective 6: To highlight key problems and issues in implementing deployment of a large-scale VANET system.

Since VANET is a new technology, it requires a well planned roll-out strategy which must involve all the stakeholders in the planned deployment. Hence, local councils, highway agencies, transport departments must be involved in developing a deployment strategy for VANETs. In addition, since a full city deployment could potentially involve millions of cars, the existing network at the roadside and the backhauling capacity of the central network need to be upgraded. Most of the research supports the idea of LTE based backhauling for VANET systems but this should probably be a key research area for new technologies such as 5G. Finally, as we have observed the cost of OBUs and RSUs are high since it is a new technology. More effort has to put in building an inexpensive OBUs. One way this could be achieved is to make this targeted research project involving many players including car companies.

Objective 7: To investigate the issues in scaling this technology to explore different traffic environments such as urban and motorway traffic.

From our coverage readings, the project highlighted the fact that urban and motorway environments may have different propagation/communication characteristics which will significantly affect how VANETs are deployed. This is because the urban environment is dominated by large and densely population areas leading to less effective coverage, while motorway environments should provide larger areas of coverage for individual RSUs. This may mean that different firmware may-be required for RSUs in urban and motorway environments. However, further research is needed to obtain the best stratery going forward.

Objective 8: To make recommendations to the DfT about how VANET could be used in other research efforts related to transport such as connected vehicles, etc such as connected cars, etc.

In order to fulfil the vision of connected cars it is necessary to have an Intelligent Transport Information System that was the purpose of this project. The results of this project showed that the VANET technology has the hardware and the networking capabilities to form the lower level platform for this vision. However, the real future challenges lie in the software/Cloud facilities that will be required to store, process and distribute in real time the information gathered by the VANET network. Hence, it is necessary to deploy a software platform that will allow developers to build applications for VANET systems. In addition, we also need to address V2V communications and related applications.

1.9 Impact of CLTP Project on the Stakeholders

This project offered the opportunity to establish a ITS-G5/VANET Cloud testbed with 5G capabilities in Central London. It allowed us to better understand how the connected vehicular environment is evolving and how this will affect the developing of future communication system such as 5G. It is a good moment to do this as new proposals for 5G standards will be discussed in detail in 2018-2019 before 5G is rolled out in 2020. This Extended Testbed will also being used to study different modes of transport in the urban area and algorithms for integrated transport in Central London.

This is the first research testbed of this kind in Central London where expertise from our previous experience in building the Middlesex VANET testbed was also demonstrated. In addition, the linking of this new testbed with the Middlesex testbed allowed an interesting set of mobile applications to be explored leading to a better understanding of the effects of connected vehicles on transport and communication systems. The testbed is therefore of significant interest to the transport authorities including the Department for Transport (DfT) in terms of examining the next generation of transport infrastructure, Transport for London (TfL) in terms of looking at the interaction between different modes of transport and integrated transport initiatives, the Office of Communication (Ofcom) and mobile operators in terms of how the provision of communication resources for the connected vehicle environment might evolve for the better future of the United Kingdom.

Finally, this project also realised the need to create a new research lab to look into Cooperative - Intelligent Transport Systems (C-ITS), VANET/ETSI-G5 applications and new emerging communication technologies etc.

1.10 Conclusion

Our main finding is that ITS-G5/VANET does have the potential to provide a platform to Intelligent Traffic Management Platform. This project has clearly shown that ITS-G5/VANET technology can be used to form an Intelligent Information Platform for Smart Cities. Hence, we quickly need to look at scalability issues by looking at doing a more extensive trial of this technology; but this initial trial, in terms of data obtained, clearly shows the potential of ITS-G5/VANETs. However, the report also clearly showed that actual deployment of this relatively small ITS-G5/VANET network was a non-trivial exercise and so mechanisms need to be developed to make deployment of ITS-G5/VANETs easier. Hence, the new technology requires much more planning, but this could change as larger ITS-G5/VANET networks are developed. Finally, further research is needed to model ITS-G5/VANET networks where the RSU is mounted at street-level. This is key to the wide-scale adoption of ITS-G5/VANETs. This document has also demonstrated the deployment strategies on how to build a full-blown VANET/-ITS-G5 testbed with 5G capabilities in Central London. Though the issue of backhauling using commercial networks such as LTE technology was explored (especially used for backhauling the data for the extended testbed on A41 and the KCL testbed in Central London). In addition, our results also demonstrated how this will become a key performance issue if there is wide-sale deployment of ITS-G5/VANET systems. This Central London Testbed is also connected to the Middlesex VANET Testbed to provide an environment to study the connected vehicle environment. After building the new network, it demonstrates results from a 4-month trial. This resulted in documenting a detailed report as well as a new dataset from Central London Testbed. We believe that this proposal will enable researchers in the UK to remain at the cutting edge of exciting developments in communication and transport systems.

1.11 Next Step & Future Recommendations

Further, we need research into developing better communications models for ITS-G5/VANETs that will help us understand and develop successful deployment strategies for connected corridors all over the UK in different environments. Lastly, these kinds of research testbeds have clearly shown that ITS-G5/VANET technology can be used to form an Intelligent Information Platform for Smart Cities. In addition, we are also in the process of building a Mobile RSU, which will allow us to move the RSU setup anywhere required for future tests. In order to backhaul the data received by the RSU, an LTE Outdoor Router will be interfaced to the RSU. Hence, the Internet will be used to forward the data to the MDX VANET Server. For powering both RSU and the LTE Outdoor Router, a battery along with a solar panel to recharge the battery will be customized, built and used. This further allows us to measure the power consumption and identify the challenges in building such green energy systems for ITS. Further, we intend to propose a C-ITS Connected Vehicles Corridor between the Middlesex University/Extended Testbed on A41, all the way to the testbed at King's College in Central London to the Department for Transport (DfT). This Connected Vehicle Corridor wil cover a stretch of 10.84 km or 6.73 miles. This is enable us to fully demonstrate a real C-ITS Connected Vehicles corridor giving a full sense of a urban and motorway traffic models. A diagrammatic representation of the proposal has been depicted in Figure 1.37.

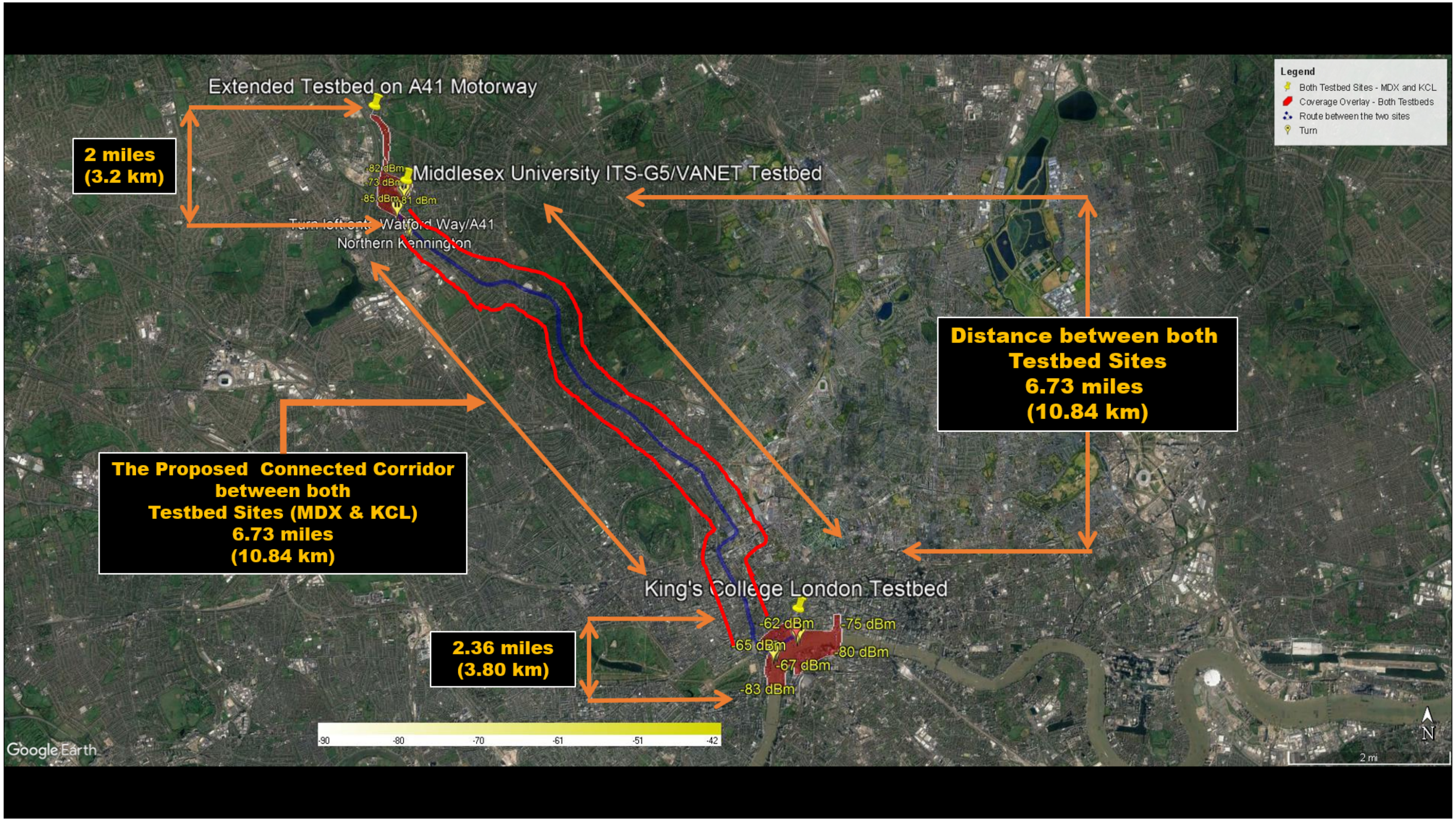


Fig. 1.37 Proposed Connected Vehicle Corridor between both the Testbed Sites.

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Appendix A: Arada Systems Locomoate Road-Side Unit (RSU) - Specifications

ARADA SYSTEMS

Fueling Advanced Intelligent Transportation Systems

LocoMate™ COMMANDO | Rugged V2I DSRC Road Side Equipment

Key Benefits

Rugged Features

- Full Environmental Protection
- Uses GORE Protective Vents to protect against water, dirt, dust and salts
- 100% Air Leak Testing

Designed for Harsh Outdoor Environments

- Weather proof NEMA 6 and IP67 rated
- Full Surge Protection
- Reliable Outdoor Connectors
- Designed to meet UL 60950-1 2nd Edition (EN 60950-22)

Software

- WAVE Standards Support
  - 802.11p
  - 1609.2
  - 1609.3
  - 1609.4
  - SAE J2735
- Fast channel switching capabilities
- Switching capability between control and service channels
- Multi-channel synchronization between service users
- Exclusive packet control
  - tx power control per packet
  - data rate control per packet
- Remote application support
- Software development kit (SDK) for application development

WAVE Mode

- Support for 5.9 GHz spectrum with 10 MHz channel width
- Support for WAVE data and management frames
- Support for multi channel (control channel and service channel) using single radio
- <= 3 mS channel switch time irrespective of traffic conditions
- Can preempt messages in transmit queue
- Support for multiple priority queues
- Support for GPS-based synchronization

ITSA MEMBER — Intelligent Transportation Systems America Member

OmniAir Certified Member

US DOT CERTIFIED — Approved US Department of Transportation Qualify Product List Vendor

C2C — The CAR-2-CAR Communication Consortium Member

1609 WAVE SUPPORT — WAVE standard support 1609.2, 1609.3, 1609.4

SAE J2735 — SAE J2735 Support

PoE — Power-over-Ethernet

DSRC 802.11p 5.9 — Dedicated Short Range 5.9 Communication 802.11p

Product Highlights

An integration of GPS, Bluetooth and Wi-Fi, LocoMate™ COMMANDO RSE (Roadside Equipment) is ideal for telematic applications by allowing vehicles on the road to talk to each other or to another road side equipment. The special Industrial Grade RUGGED enclosure option provides for special outdoor Road Side Unit deployment for Trucking, Busing, and Military DSRC implelmentations

It is fully compliant with Omni-Air's certification and is used in worldwide deployments including the US Department of Transportations' Safety Pilot in Ann Arbor, Michigan. Product applications include: Signal Coordination, Emergency Vehicle Management, Train Crossing,Tolling, Taxi Management, Geo-Fencing, MESH, and CLOUD.

LocoMate™ COMMANDO RSE comes in an industrial outdoor NEMA rated enclosure that allows for seamless outdoor deployments with a full DSRC WAVE software solution. The solution comes integrated with GPS, Bluetooth and high-power 802.11p radios.

WAVE Protocols
- 802.11p (WAVE)
- EEE 1609.2
- IEEE 1609.3
- IEEE 1609.4
- SAE J2735

Frequency
- 5.85 - 5.925 GHz
- 5.7 - 5.8 GHz (Europe)

DSRC Radio
- High power miniPCI optimized for 5.9 GHz
- 5.9 GHz: +23dBm at 64QAM from -40°C- +85°C

GPS Device
- GPS with internal RF antenna
- Accuracy <1m

Power Supply
- 802.3af PoE compliant
- IEC60950 compliant

Multi-channel operation
- Consistent 3 mS channel switch time

Supplementary 802.11 MAC features
- Control Channel (CCH) and Service Channels coordination
- 50 mS channel dwell time
- CCH for broadcast, high-priority and single-use safety messages and SCH for IP data

Channel Access
- Alternative, continuous

Channel Switching
- Consistent 3 mS switch time at every 50 mS

Software Queuing
- Transmit queues per channel
- Prioritized channel access queues, with configurable channel access parameters

Database Configuration
- CLI
- Database file backup, restore

Platform
- Linux/Unix compatible
- SDK with C libraries

Interactive Communication
- ssh/telnet

IP Protocols
- ipv4 / ipv6

Network Configuration
- Wired and DSRC
- ipv4 configuration
- ipv6 configuration
- SIT Tunnel Support

US DOT RSE spec
- QPL vendor

GPS Applications
- Approx. 1m accuracy
- Path history implementation
- Path prediction implementation

Local Time Synchronization
- GPS along with PPS

Security
- Signing and verification of messages, encryption and decryption of messages
- Signing and verification of WSAs

Message Logging
- DSRC Transmit packets, DSRC Receive Packets, Ethernet packets
- System events
- Heartbeat messages with configuration (ipv4 or ipv6)
- Log offload configuration (ipv4 or ipv6)
- Wave Service Announcement configuration

LEDs
- DSRC packet transmission
- Firmware upgrade

Software Development Kit
- Linux based tool chain
- Application library
- Sample applications
- Programmer guide
- User guide
- SAE J2735 ASN library
- Sample applications include the following J2735 message formats: BSM, SPAT, MAP, TIM
- Sample applications include GPS data extraction

Data and Management Planes
- UDP/TCP and WAVE Short Messaging Protocol (WSMP) support
- Manages WAVE Basic Service Set (WBSS)
- Application management

Channel Bandwidth
- WAVE mode (802.11p) at 5.9 GHz: reduced to 10 MHz, supports 20 MHz channels

DSRC Message Set - SAE J2735
- BSM Part I, BSM Part II
- SPAT, MAP, TIM

Flash/RAM
- 16 MB Flash
- 64 MB SDRAM (512 Mbits)

Shared Library
Applications Shared Library with Windows/Linux support for application development

Applications Support
- Menu-driven tool
- IP based applications
- WSM-based applications
- Periodic transmit of GPS data
- Remote and logging applications

Certificate Management
- 1609 certificate update
- Support for time limited 1609 certificate

DSRC Channel Support	
10 MHz Channels	Frequency (MHz)
172	5860
174	5870
176	5880
178	5890
180	5900
182	5910
184	5920
20 MHz Channels	Frequency (MHz)
173	5865
175	5875
177	5885
179	5895
181	5905
183	5915

Throughput Traffic Test Results Half-Rates on Channel 172 (Mbps) Without Channel Switch								
Rates	3M	4.5M	6M	9M	12M	18M	24M	27M
TCP	2.36	3.37	4.34	6.32	7.97	11.23	13.54	14.75
UDP	2.38	3.50	4.37	6.99	9.00	12.96	15.81	17.32

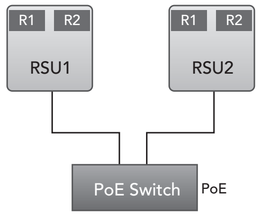
Throughput Traffic Test Results Full-Rates on Channel 175 (Mbps) Without Channel Switch		
20 MHz Data Rates	TCP	UDP
6M	4.7	5.0
9M	6.7	7.2
12M	9.8	10.5
18M	12.9	14.52
24M	16.6	18.661
36M	22.630	26.022
48M	27.782	32.231

TCP/UDP Throughput in Different Channels		
	TCP (Mbps)	UDP (Mbps)
WAVE operation in 20 MHz (max. phy rate=54 Mbps)	27.780	32.231
WAVE operation in 10 MHz (max. phy rate=27 Mbps)	14.75	17.32
WAVE operation in 10 MHz, with periodic channel switch	6.9	8.6

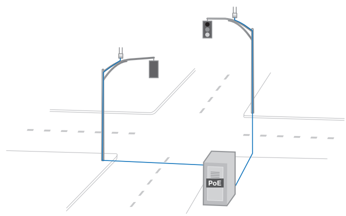
Average per Packet Latency Values with Different Content Type Messages			
	Plain	Sign/Sign Verify	Encrypted/ Decrypted
Average packet interval with 100 mS transmit periodicity	102 mS	112 mS	139 mS
Latency	2 mS	10 mS	35-40 mS

802.11p Radio Specifications			
Modulation	Data Rate	TX	RX
BPSK	3 Mbps	23±1dBm	-95±2dBm
16QAM	18 Mbps	23±1dBm	-83±2dBm
64QAM	27 Mbps	23±1dBm	-77±2dBm
Other Specifications			
Antenna Interface	N-Connector		
Operating Temperature	-40°C to +80°C (output power specified over full temperature profile)		
Channel Bandwidth	10 MHz, 20 MHz (FCC "Class C" Mask Compliant)		
Operating Voltage/Current	Input Voltage Range: 48-52V DC / 400mA Max.		

Antenna Information			
Antenna Configuration	V.S.W.R. (MAX) 1.5:1	Antenna Gain	12 dBi
Antenna Type	Collinear	Impedance	50 Ohms
Radiation	Omni Directional	Polarization	Vertical
Vertical Beam Width	8 Degrees	Horizontal Beam Width	360 Degrees
Maximum Power	100 watts	Max, nominal, Min. EIRP	34dBm, 30dBm, 10dBm



LocoMate™ 202 RSE Kit



Deployment Scenario

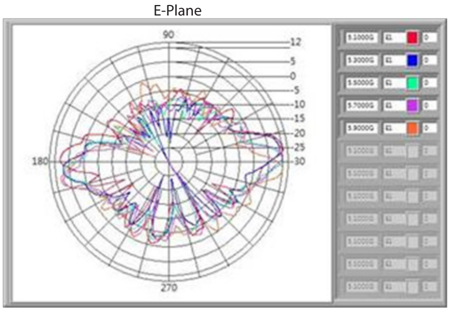
Ordering Information

COMMANDO™ 201 RSE

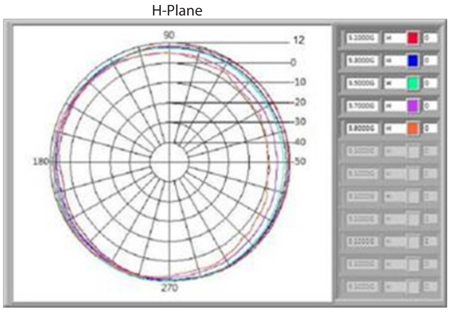
sales@aradasystems.com

Antenna Patterns

E-Plane



H-Plane



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Arada Systems is a leader in technologies meant for vehicle-based communication networks, particularly for applications such as toll collection, vehicle safety services, and commerce transactions via cars. LocoMate™ is being evaluated for real-time communication between vehicles and roadside access points or other vehicles creating a real-time public safety network.

Revision v2.10

APPENDIX B: ARADA SYSTEMS LOCOMOATE ON-BOARD UNIT (OBU) - SPECIFICATIONS

ARADA SYSTEMS

Fueling Advanced Intelligent Transportation Systems

LocoMate™ OBU | On-Board Unit

Key Benefits

Hardware

- Wireless access for vehicular environment
- 5.700 to 5.925 GHz frequencies
- 10 MHz and 20 MHz channel bandwidth
- Options for 2 DSRC radio
- Utilize radios designed by Arada Systems
- High throughput capability for varied applications
- Efficient handling of WSMP (WAVE Short Messaging Protocol) and IP traffic

Software

- WAVE Standards Support
  - 802.11p
  - 1609.2
  - 1609.3
  - 1609.4
  - SAE J2735
- Fast channel switching capabilities
- Switching capability between control and service channels
- Multi-channel synchronization between service users
- Exclusive packet control
  - TX power control per packet
  - Data rate control per packet
- Remote application support
- Software development kit (SDK) for application development

WAVE Mode

- Support for 5.9 GHz spectrum with 10 MHz channel width
- Support for WAVE data and management frames
- Support for multi channel (control channel and service channel) using single radio
- <= 3 mS channel switch time irrespective of traffic conditions
- Can preempt messages in transmit queue
- Support for multiple priority queues
- Support for GPS-based synchronization

ITSA MEMBER — Intelligent Transportation Systems America Member

OmniAir Certified Member

US DOT CERTIFIED — Approved US Dept of Transportation Qualify Product List Vendor

C2C — The CAR-2-CAR Communication Consortium Member

1609 WAVE SUPPORT — WAVE standard support 1609.2, 1609.3, 1609.4

SAE J2735 — SAE J2735 Support

BLUETOOTH COMPATIBLE — Bluetooth Support for Mobile

DSRC 802.11p 5.9 — Dedicated Short Range 5.9 Communication 802.11p

CAN bus SUPPORT — CAN BUS Support

Product Highlights

An integration of GPS and Wi-Fi, LocoMate™ OBU is ideal for telematic applications by allowing vehicles on the road to talk to each other or to another road side unit. It is fully compliant with Omni-Air's certification and is used in worldwide deployments including the US Department of Transportations' Safety Pilot in Ann Arbor, Michigan. Product applications include: Collision Avoidance, Emergency Vehicle Management,Train Crossing, Tolling, Commerce Applications ($), Truck Platooning, Taxi Management and Geo-Fencing.

LocoMate OBU comes in a small form factor for in-vehicle deployment and comes with a full DSRC WAVE software solution and applications for integration with Smart Phones to ease the human-user-interface. The solution comes integrated with GPS (with better than 1 meter accuracy), Bluetooth and high-power 802.11p radios.

Specifications

Protocols
- 802.11p (WAVE)
- EEE 1609.2
- IEEE 1609.3
- IEEE 1609.4
- SAE J2735

Frequency
- 5.85 - 5.925 GHz
- 5.7 - 5.8 GHz (Europe)

DSRC Radio
- High power miniPCI optimized for 5.9 GHz

GPS Device
- GPS with external RF antenna
- Accuracy <1m

Bluetooth
- OBU – Bluetooth radio allows sniffing Bluetooth radios around the OBU

Multi-channel operation
- Consistent 3 mS channel switch time

Supplementary 802.11 MAC features
- Control Channel (CCH) and Service Channels coordination
- 50 mS channel dwell time
- CCH for broadcast, high-priority and single-use safety messages and SCH for IP data

Output Power
- 5.9 GHz: +23dBm at 64QAM from -40°C to +85°C

Platform
- Linux/Unix compatible
- SDK with C libraries

Database Configuration
- CLI
- Database file backup, restore

Platform
- Linux/Unix compatible
- SDK with C libraries

Channel Access
- Alternative, continuous

Channel Switching
- Consistent 3 mS switch time at every 50 mS

Software Queuing
- Transmit queues per channel
- Prioritized channel access queues, with configurable channel access parameters

Interactive Communication
- ssh/telnet

Network Protocol
- ipv4 / ipv6

Network Configuration
- Wired and DSRC
- ipv4 configuration
- ipv6 configuration
- SIT Tunnel Support

US DOT VAD spec
- QPL vendor

GPS Applications
- Approx. 1m accuracy
- Path history implementation
- Path prediction implementation

Local Time Synchronization
- GPS along with PPS

Security
- Signing and verification of messages, encryption and decryption of messages
- Signing and verification of WSAs

Message Logging
- DSRC Transmit packets, DSRC Receive Packets, Ethernet packets
- System events
- Heartbeat messages with configuration (ipv4 or ipv6)
- Log offload configuration (ipv4 or ipv6)
- Wave Service Announcement configuration

LEDs
- DSRC packet transmission
- Firmware upgrade
- USB storage access

Software Development Kit
- Linux based tool chain
- Application library
- Sample applications
- Programmer guide
- User guide
- SAE J2735 ASN library
- Sample applications include the following J2735 message formats: BSM, SPAT, MAP, TIM
- Sample applications include GPS data extraction

Data and Management Planes
- UDP/TCP and WAVE Short Messaging Protocol (WSMP) support
- Manages WAVE Basic Service Set (WBSS)
- Application management

Channel Bandwidth
- WAVE mode (802.11p) at 5.9 GHz: reduced to 10 MHz, supports 20 MHz channels

DSRC Message Set - SAE J2735
- BSM Port I, BSM Port II, SAE J2735
- SPAT, MAP, TIM

Flash/RAM
- 16 MB Flash
- 64 MB SDRAM (512 Mbits)

Shared Library
Applications Shared Library with Windows/Linux support for application development

Applications Support
- Menu-driven tool
- IP based applications
- WSM-based applications
- Periodic transmit of GPS data
- Remote and logging applications

Certificate Management
- 1609 certificate update
- Support for time limited 1609 certificate

DSRC Channel Support	
10 MHz Channels	Frequency (MHz)
172	5860
174	5870
176	5880
178	5890
180	5900
182	5910
184	5920
20 MHz Channels	Frequency (MHz)
173	5865
175	5875
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Throughput Traffic Test Results Half-Rates on Channel 172 (Mbps) Without Channel Switch								
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WAVE operation in 10 MHz, with periodic channel switch	6.9	8.6

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802.11p Radio Specifications			
Modulation	Data Rate	TX	RX
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16QAM	18 Mbps	23±1dBm	-83±2dBm
64QAM	27 Mbps	23±1dBm	-77±2dBm
Other Specifications			
Antenna Interface	SMA Connector		
Operating Temperature	-40°C to +80°C (output power specified over full temperature profile)		
Channel Bandwidth	10 MHz, 5 MHz (FCC "Class C" Mask Compliant)		

Ordering Information

LocoMate Standard 200 OBU-On-Board Unit

200: Standard OBU

205 LocoMate ASD Kit (includes the standard OBU plus, quiet state board, Fakra connecter, Delphi connecter, 4 GB flash drive, surge protection compliant SAE J1113-11)

sales@aradasystems.com

About Arada Systems

Arada Systems is a leader in technologies meant for vehicle-based communication networks, particularly for applications such as toll collection, vehicle safety services, and commerce transactions via cars. LocoMate™ is being evaluated for real-time communication between vehicles and roadside access points or other vehicles creating a real-time public safety network.

www.aradasystems.com

Part Number OBU001-812

Appendix C: Teltonika - LTE Outdoor Router (LTE-RUT750) - Specifications

TELTONIKA

LTE Outdoor Router
RUT750

Teltonika RUT750 is outdoor LTE router with high speed wireless and Ethernet connections. Internal LTE modem can reach download rate of up to 100Mbps. Router supports the latest IEEE802.11n as well as IEEE802.11b/g standards and provides wireless receiving and transmitting rate of up to 150 Mbps. High gain directional LTE antenna allows the router to be used in low signal locations while external Wi-Fi connector makes it possible to attach desired antenna. IEEE 802.3af-2003 compliant POE uses single Ethernet cable to communicate with the device and to power it making for an easy installation.

Key Features

- LTE downlink of up to 100Mbps
- LTE uplink of up to 50Mbps
- DC-HSPA+ downlink of up to 42Mbps
- DC-HSPA+ uplink of up to 5.76Mbps
- Complies with IEEE 802.11n, IEEE 802.11g, IEEE 802.11b wireless standards
- Complies with IEEE 802.3 and IEEE 802.3u standards
- IEEE 802.3af-2003 compliant POE
- One 10/100 Base-T Ethernet port
- Adjustable pole mounting kit
- Waterproof RJ45 socket
- Secure SIM card socket
- Dual-polarization 6/8 dBi MIMO antenna
- Integrated OpenVPN, IPSec and SNMP
- SMS reboot, Status via SMS functions

RoHS Compliant

ISO 9001
DNV
CERTIFIED ORGANISATION

LTE/UMTS/GSM Specifications

LTE

- FDD 800/850/900/1800/1900/2100/2600 MHz
- (FDD B1/B2/B3/B5/B7/B8/B20)
- Up to 100 Mbps downlink speed
- Up to 50 Mbps uplink speed
- All bands with diversity

UMTS

- 850/900/1900/2100 MHz
- DC-HSPA+ mode: DL up to 43.2 Mbps, UL 5.76 Mbps
- HSPA+ mode: DL up to 21.6 Mbps, UL 5.76 Mbps
- UMTS mode: 384 kbps DL/384 kbps UL
- All bands with diversity

GSM/GPRS/EDGE

- 850/900/1800/1900 MHz
- Power Class 4 (2 W, 33 dBm) GSM/GPRS 850/900 MHz
- Power Class 1 (1 W, 30 dBm) GSM/GPRS 1800/1900 Mhz
- Power Class E2 (0.5 W, 27 dBm) for EDGE 850/900 MHz
- GPRS: 85.6 kbps DL/85.6 kbps UL (class 12)
- EDGE: 236.8 kbps DL/236.8 kbps UL (class 12)

Specifications

LAN and Wi-Fi

- High performance 320 MHz CPU with 256 Mbits SDRAM
- IEEE 802.11b/g/n, IEEE 802.3, IEEE 802.3u standards
- IEEE 802.3af-2003 compliant POE
- 64/128-bit WEP, WPA, WPA2, WPA&WPA2 encryption methods
- 1x LAN 10/100Mbps Ethernet port
- Supports Auto MDI/MDIX
- Remote/local Web management
- 1x RP-SMA Wi-Fi antenna connector
- SSID stealth mode and access control based over MAC address
- System log to record the status of the Router
- Auto negotiation/manual mode for IEEE 802.11b/g/n
- Dynamic DNS
- LAN access control over Internet connection
- Virtual server
- Auto wireless channel selection
- OpenVPN, IPSec, SNMP
- LTE – LAN bridge mode
- SMS and Ping reboot, Status via SMS
- 1 x LAN LED

Electrical, Mechanical & Environmental

Dimensions (H x W x D)	290mm x 240mm x 45mm
Weight	1.3kg
Power supply	36 – 57VDC POE adapter
Power consumption	< 7W
Antenna connectors	1 x RP-SMA for Wi-Fi
Indicators	1 x Power LED, 1 x LAN LED, 1 x Status LED
Operating temperature	-20º to 50º C
Storage temperature	-20º to 70º C
Operating humidity	10% to 90% Non-condensing
Storage humidity	5% to 95% Non-condensing

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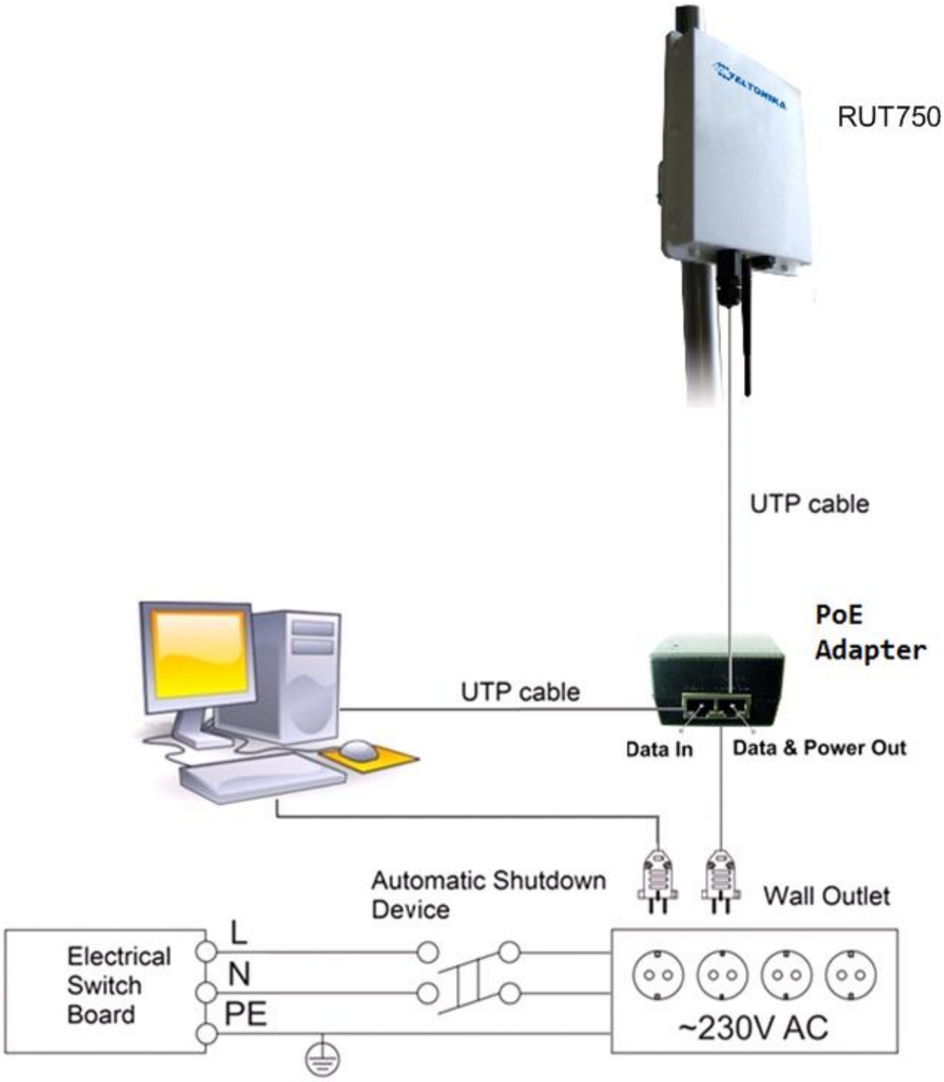
Device connection



Introduction

Thank you for purchasing a RUT750 LTE router!

Teltonika RUT750 is outdoor LTE router with high speed wireless and Ethernet connections. Internal LTE modem can reach download rate of up to 100Mbps. Router supports the latest IEEE802.11n as well as IEEE802.11b/g standards and provides wireless receiving and transmitting rate of up to 150 Mbps. High gain directional antenna LTE antenna allows the router to be used in low signal locations while external Wi-Fi connector makes it possible to attach desired antenna. IEEE 802.3af-2003 compliant POE uses single Ethernet cable to communicate with the device and to power it making for an easy installation.

Key features

- LTE downlink of up to 100Mbps
- LTE uplink of up to 50Mbps
- DC-HSPA+ downlink of up to 42Mbps
- DC-HSPA+ uplink of up to 5.76Mbps
- Complies with IEEE 802.11n, IEEE 802.11g, IEEE 802.11b wireless standards
- Complies with IEEE 802.3 and IEEE 802.3u standards
- IEEE 802.3af-2003 compliant POE
- One 10/100 Base-T Ethernet port
- Adjustable pole mounting kit
- Waterproof RJ45 socket
- Secure SIM card socket
- Dual-poliarization 6/8 dBi MIMO antenna
- Integrated OpenVPN, IPSec and Dynamic DNS
- SMS reboot function

Specifications

LTE

- FDD 800/850/900/1800/1900/2100/2600 MHz
- Up to 100 Mbps downlink speed
- Up to 50 Mbps uplink speed
- All bands with diversity

UMTS

- 850/900/1900/2100 MHz
- DC-HSPA+ mode: DL up to 43.2 Mbps, UL 5.76 Mbps
- HSPA+ mode: DL up to 21.6 Mbps, UL 5.76 Mbps
- UMTS mode: 384 kbps DL/384 kbps UL
- All bands with diversity

GSM/GPRS/EDGE

- 850/900/1800/1900 MHz
- Power Class 4 (2 W, 33 dBm) GSM/GPRS 850/900 MHz
- Power Class 1 (1 W, 30 dBm) GSM/GPRS 1800/1900 Mhz
- Power Class E2 (0.5 W, 27 dBm) for EDGE 850/900 MHz
- GPRS: 85.6 kbps DL/85.6 kbps UL (class 12)
- EDGE: 236.8 kbps DL/236.8 kbps UL (class 12)

LAN and Wi-Fi

- High performance 320 MHz CPU with 256 Mbits SDRAM
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- IEEE 802.3af-2003 compliant POE
- 64/128-bit WEP, WPA, WPA2, WPA&WPA2 encryption methods
- 1x LAN 10/100Mbps Ethernet port
- Supports Auto MDI/MDIX
- Remote/local Web management
- 1x RP-SMA Wi-Fi antenna connector
- SSID stealth mode and access control based over MAC address
- System log to record the status of the Router
- Auto negotiation/manual mode for IEEE 802.11b/g/n
- Dynamic DNS
- LAN access control over Internet connection
- Virtual server
- Auto wireless channel selection
- OpenVPN, IPSec, PPPoE
- SMS and Ping reboot, Status via SMS
- 1 x LAN LED

Electrical, Mechanical & Environmental

• Dimensions (H x W x D)	290mm x 240mm x 45mm
• Weight	1.3kg
• Power supply	36 – 57VDC POE adapter
• Power consumption	< 7W
• Antenna connectors	1 x RP-SMA for Wi-Fi
• Indicators	1 x Power LED, 1 x LAN LED, 1 x Status LED
• Operating temperature	-20º to 50º C
• Storage temperature	-20º to 70º C
• Operating humidity	10% to 90% Non-condensing
• Storage humidity	5% to 95% Non-condensing

Applications

Device can provide internet connection by either Wi-Fi or Ethernet cable. Ethernet switch can be used to provide more Ethernet ports and to be able to connect several devices.

APPENDIX D: ROAD-SIDE UNIT (RSU) AND LTE OUTDOOR ROUTER UNIT - PHYSICAL SPECIFICATIONS

The Physical Dimensions of the RSU and the LTE Outdoor Units mounted on the lampposts on A41 are as follows:
Weight of the RSUs and the LTE Units:

- RSU Unit with 2 antennas is 1.4 kg
- RSU Cabling, clamps and PSU is 950 grams
- LTE Unit is 1Kg
- LTE Cabling, clamps and PSU is 500 grams

Physical dimensions

- **RSU** - Height = (including the Antennas = 75 cm) (excluding Antennas is 24 cm)
- Width = 23 cm Depth = 7cm
- **LTE** - Height = (including Antenna = 50 cm) (excluding Antenna = 30 cm)
- Width = 24 cm Depth = 5 cm

Mounting arrangements

- Clamps are provided and mounting instructions attached:

1 RSE Installation

1.1 Mechanical Requirements

There are two ways to install the DSRC radio.

1.1.1 Device attachment (Option 1)

Figure 1 provides a way to install using clamps. With this type of installation, the DSRC radios can be adjusted to point at a different angle. This may be useful depending on the location of the roadside unit and the pole. We provide clamps required in installation as per this option.

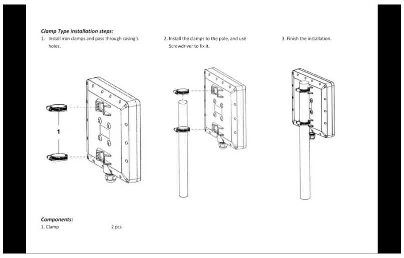

Figure 1 RSE Installation with clamps

1.1.2 Device attachment (Option 2)

Figure 2 describes the U-type screw installation type to be mounted on a traffic signal controller or a utility pole on the roadside.

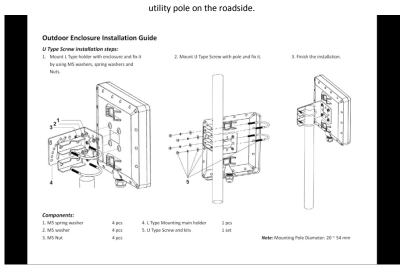

Figure 2 RSE Installation with U-type screw

1.2 Final typical mounting