# Building an Intelligent Transport Information Platform for Smart Cities

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Middlesex University

In partnership with

Department for Transport


Department of Computer Science
School of Science & Technology

**Middlesex University**


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# List of Abbreviations

**Acronyms / Abbreviations**

| | |
|---|---|
| BSM | Basic Safety Message |
| CAMs | Cooperative Awareness 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 |

# MIDDLESEX UNIVERSITY VANET TESTBED TRIAL

**By: MDX VANET Research Team**

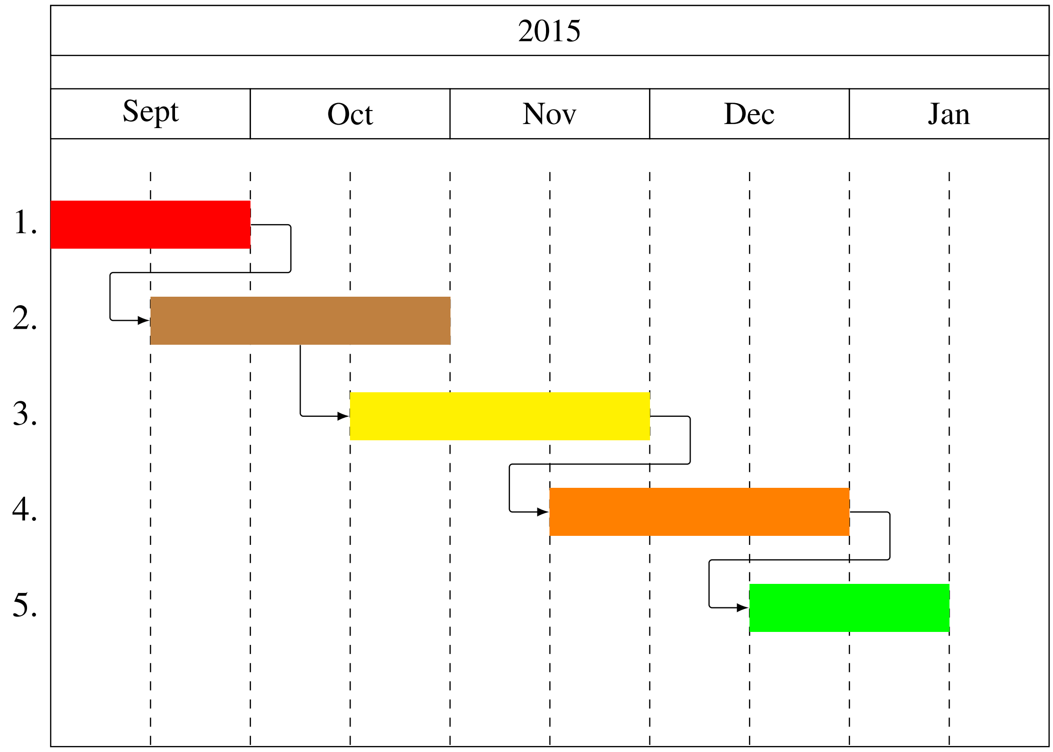
## 1.1 Project Summary

Intelligent Transportation management is a key requirement in the development of Smart Cities. This can be realised with a new technology known as Vehicular Ad hoc Networks or VANETs. VANETs allow us to integrate our transport and communication infrastructures through communication devices deployed along the roads called Roadside Units (RSUs). The RSUs talk to a device in your car called an Onboard Unit (OBU). OBUs can exchange information with RSUs as well as with each other, and because VANETs have been engineered to deliver information quickly and reliably, they can be used in a number of safety-critical areas such as collision avoidance, accident notification and disaster management.

This project was about building and evaluating a prototype VANET network on the Middlesex University Hendon Campus and surrounding roads. 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.

### 1.1.1 Modified Time-frame of the Project

As proposed, we expected to have the entire testbed up and running in one month after the start of the project, allowing six weeks of readings from the entire system but this was delayed due to several factors. Firstly, we had to seek authorisation to mount some of the RSUs outside the Hendon Campus along Watford Way (A41). This involved meetings with the Barnet Council and with the Highways Division at Transport for London (TfL). This resulted in a significant delay in ordering the equipment and hence the Project Time-frame had to be extended. Secondly, in order to effectively deploy the RSUs, 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 MDX VANET Trial being conducted at a much later date. We therefore, communicated with Department for Transport (DfT) and an extension of the project was granted until 15th January 2016. The modified final time-scale is shown Figure 1.1 below:




- Legends (as specified below):

1. Buy and Install the Equipment for Extended Testbed (4 weeks)
2. Trial using the MDX Testbed to cover the Burroughs road and the Greyhound Hill (8 weeks)
3. Trial on Extended Testbed (6 weeks)
4. Analysis of DATA from the Extended Testbed (4 weeks)
5. Final Report (15th Janv 2016)(2 weeks)

Fig. 1.1 Ganttchart for Project Time-line

### 1.1.2 Project Location

The proposed Testbed is shown in Figure 1.2 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.

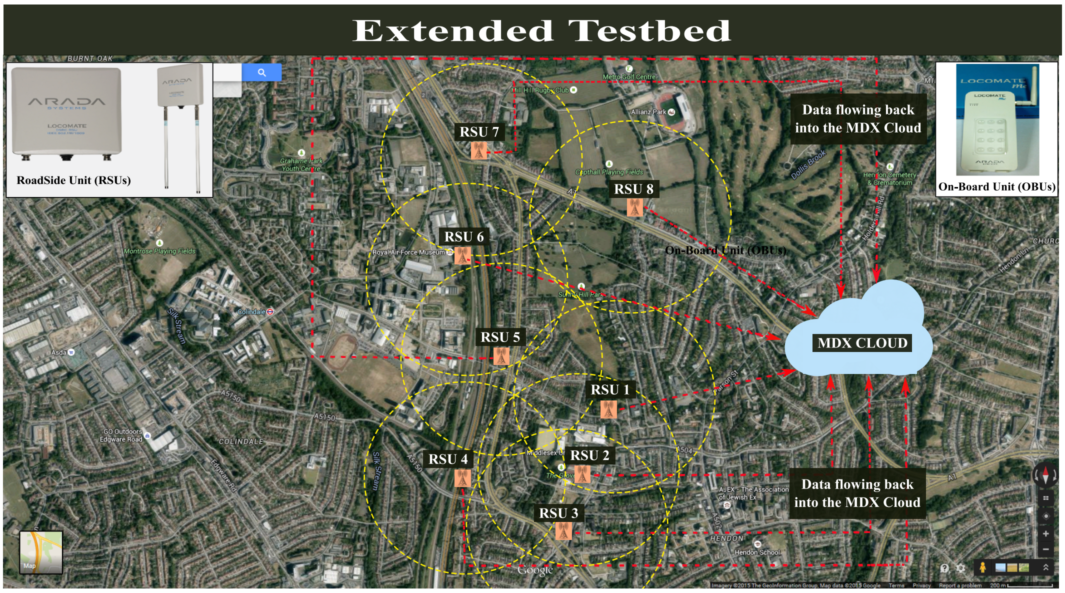



Fig. 1.2 Proposed Extended Scenario for MDX VANET testbed.

### 1.1.3 The Project Team

In order to guarantee a successful completion of the Project, we had to work closely with a number of companies and organisation. We were able to work closely with ARADA Systems, the company which supplied the RSUs and OBUs for this project. We had 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) team for expert advise on the matter of estate, facilities and infrastructural management wherever possible. 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 Executive Summary

### 1.2.1 Overview of the Project Objectives

Intelligent Transportation management is a key requirement in the development of Smart Cities. For example, it would allow the automatic re-routing of traffic in the face of accidents or congestion. In addition, it would enable greater ability to deal with life-critical situations such as major accidents, disaster management and man-made catastrophes.

Vehicular Ad-Hoc Networks (VANETs) are new networks that will enable support for life-critical and infotainment applications in vehicular environments. VANETs are realised by the deployment of Roadside Units (RSUs) located along the transport infrastructure and On-board Units (OBUs) in the vehicles or worn by pedestrians or cyclists. By using VANETs and collecting, analysing and displaying real-time data from the RSUs and OBUs, it should be possible to build a platform for Intelligent Transportation Management.

This Department for Transport (DfT) commissioned Middlesex University to build and test an extended VANET network to explore the potential of VANET Technology. The proposed network was intended to encompass the Hendon Campus of the University and surrounding roads including the Watford Way (A41). The Network was then used to do a VANET Trial in which OBUs were placed in vehicles and the drivers asked to drive around the area. 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.

### 1.2.2 Project Objectives and Intended Audience

The main purpose of the proposal was to explore the potential or feasibility of using VANET technology in building an Intelligent Information Management Platform for Smart Cities. The project was therefore intended to give those in the DfT responsible for developing the next generation Transportation and Traffic Management System a clear idea how the new VANET Technology can be used to accomplish this challenging goal. Hence the main objectives included:

1. To build an extensive VANET network around the Hendon Campus
2. To run a VANET Testbed Trial using the new VANET network
3. To analyse and display results using Visual and Data Analytic Techniques

4. To explore how data generated by a VANET network can be used a part of a platform for Intelligent Transport
5. To discover key strengths and weakness of VANET technology in the light of other technologies such as LTE.
6. To highlight key problems and issues in implementing deployment of a large-scale VANET system.
7. To investigate the issues in scaling this technology to explore different traffic environments such as urban and motorway traffic
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.

### 1.2.3 Project Methodology

In order to achieve these objectives, 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. There were four RSUs and these were mounted on top of four buildings on the Hendon Campus namely: the Hatchcroft, Grove and Williams Buildings as well as the Sheppard Library as depicted in Figure 1.3

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.

### 1.2.4 Challenges and Pitfalls

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.

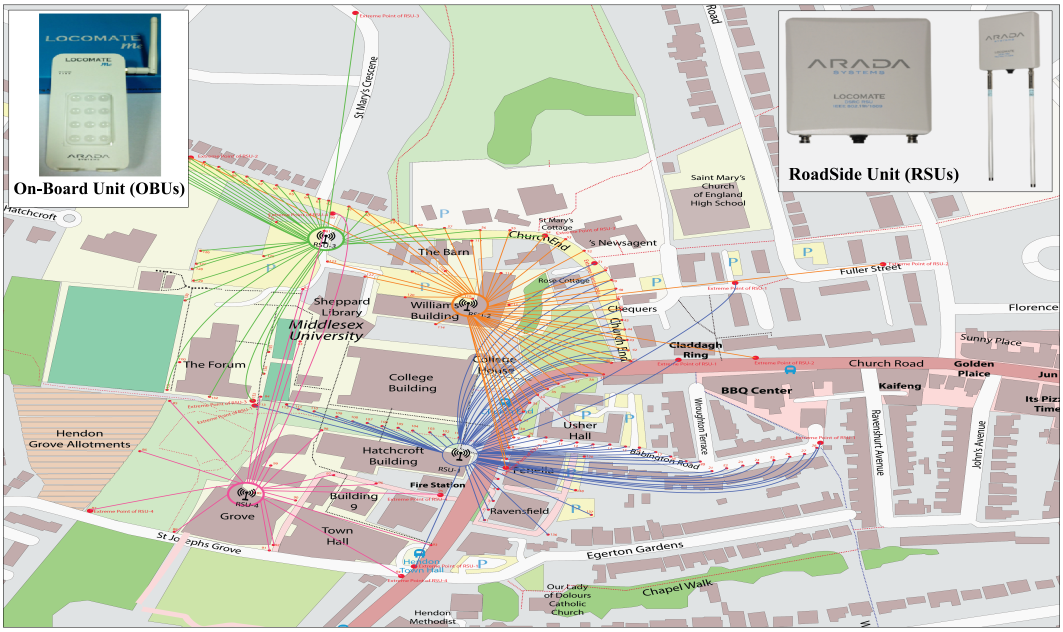



Fig. 1.3 Hendon Campus Coverage Map.

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.

### 1.2.5 Findings and Conclusions

Our main finding is that VANET does have the potential to provide a platform to Intelligent Traffic Management Platform. 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 VANETs. However, the report also clearly showed that actual deployment of this relatively small VANET network was a non-trivial exercise and so mechanisms need to be developed to make deployment of VANETs easier. Hence, the new technology requires much more planning, but this could change as larger VANET networks are developed.

Though the issue of backhauling using commercial networks such as LTE was not directly explored. This will become a key performance issue if there is wide-sale deployment of VANET systems.

Finally, research is needed to model VANET networks where the RSU is mounted at street-level. This is key to the wide-scale adoption of VANETs.

### 1.2.6 Recommendations and Next Steps

Firstly a much wider trial of VANET Technology should be attempted. Secondly, in terms of cost, it would be good to build a cheap OBU. Since RSUs will always be fewer in number compared to OBUs, a cheap OBU will play a significant part in the deployment and acceptance of VANETs. Academically, we need research into developing better communications models for VANETs that will help us understand the deployment of VANETs in different environments.

## 1.3 A Quick Tutorial on VANET Technology

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 1.4.

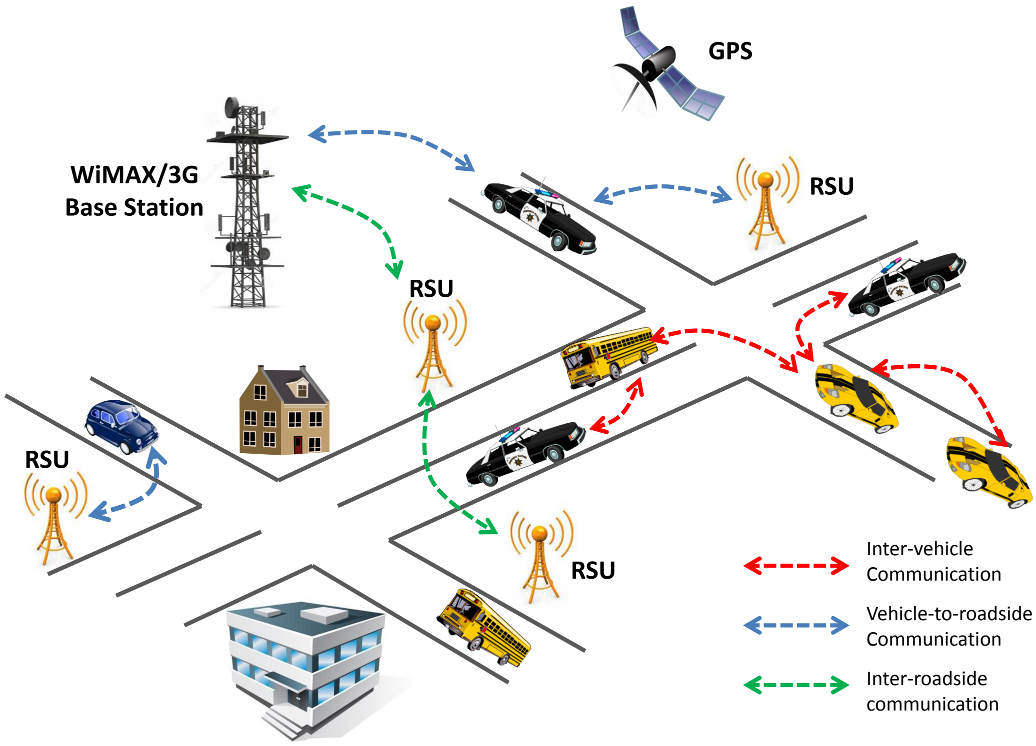



Fig. 1.4 VANET Scenario.

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 [**?** ]. 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) [**?** ].

- 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 [3]. This shown in the figure below:

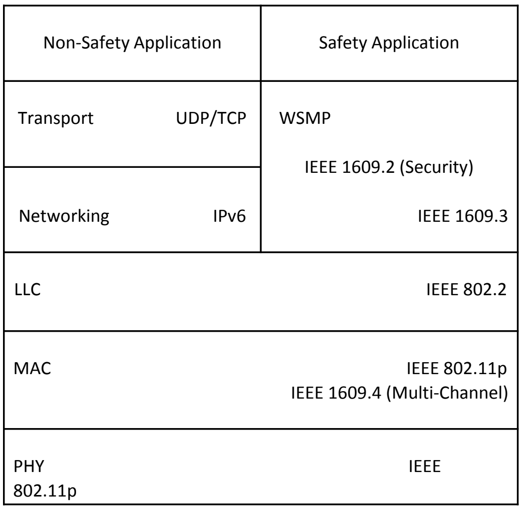



Fig. 1.5 WAVE Protocol Architecture.

### 1.3.1 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) [4], Decentralized Environmental Notification Message (DEN) [5], Basic Safety Message (BSM), 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. 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 as shown in the Figure 1.6.

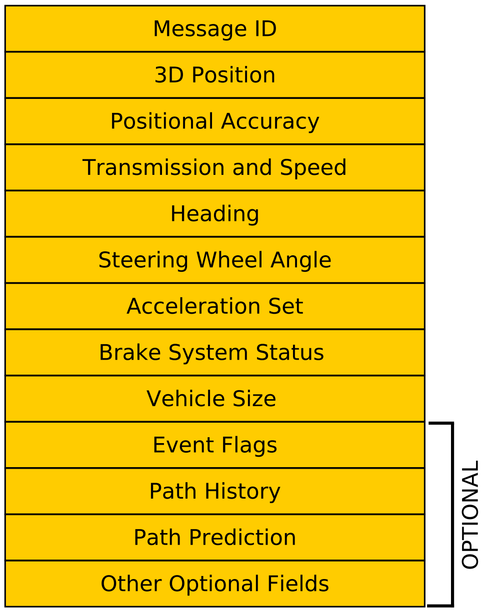



Fig. 1.6 Basic Safety Message Format.

In our project we were able to only use the Message ID and 3D Position i.e., Latitude, Longitude and Elevation parameters of the BSM message. 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 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.

## 1.4 Design and Implementation of the MDX VANET Research Testbed

The objective of this project was to design of the MDX VANET Research 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. 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. This involved making a detailed coverage map based on proposed locations of the RSUs. This was done manually and with the assistance of the undergraduate students. In order to determine the best location for the RSU, it was important to minimise the distance between the RSU and the router elements in the university network. 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 the university network.

Fig. 1.7 Mapping the Coverage to find the suitable places for RSU deployment.

Figure 1.8 shows the network diagram of the MDX VANET Testbed for the Hendon campus. Four RSUs have been deployed on top of the Hatchcroft building, Williams building, Sheppard's library building and Grove building. Figure 1.8 also shows the applications running at the respective devices. Wave Short Message

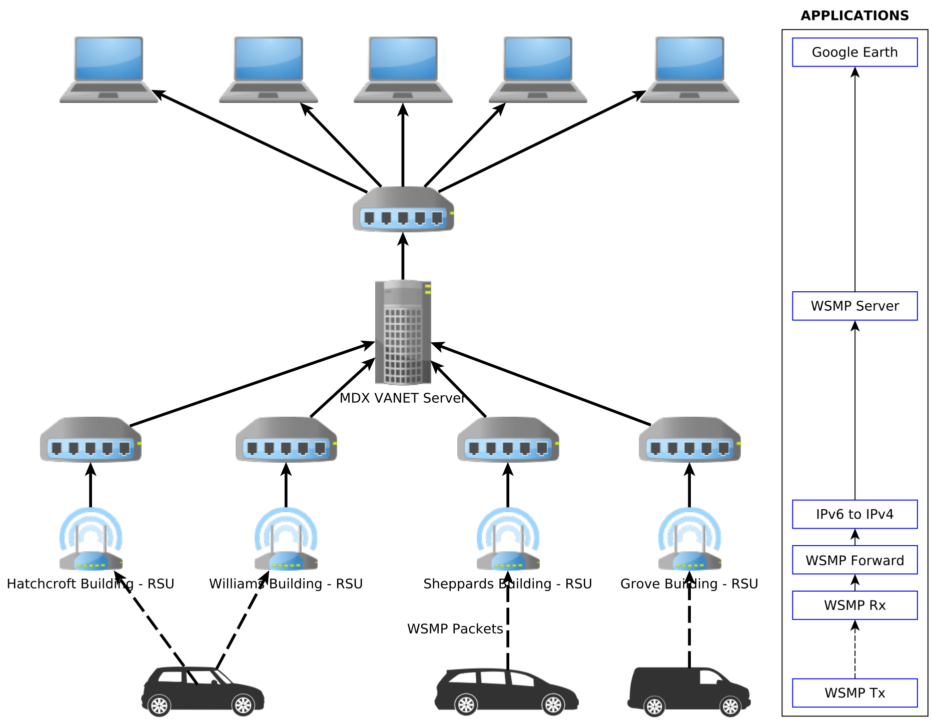



Fig. 1.8 NETWORK DIAGRAM.

Protocol (WSMP) Tx is an application used by the OBU to broadcast 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 timestamp 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

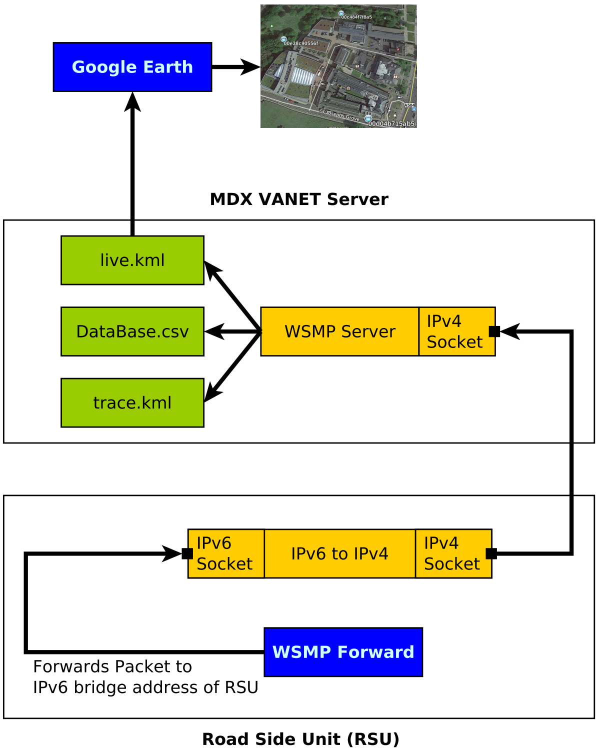



Fig. 1.9 Data forwarding from RSU to Server.

of the received packet, GPS coordinates along with the time stamp of the packet 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 occured 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.

## 1.5 MDX VANET Trial

With the successful deployment of the Testbed it was now possible to move to the second objective of the project which was to conduct an extenssive trial of the VANET Testbed. In order to do this, we first had to publicise the trial to obtain volunteered drivers who were willing to have OBUs placed in the cars for at least a day. This was achieved through the development of a VANET webpage (www.vanet.mdx.ac.uk), emails and the deployment of a blog via the University's website. The trial was originally intended to last for one week i.e., Jan 4th to Jan 11th 2016 but was extended to 15th Jan 2016.

Around ten people volunteered for the trial and OBUs were placed in their cars over several days. Each OBU contained very simple instructions about the trial showing how to operate such that successful readings could be obtained. In addition, an addtional OBU was placed in a small utility vehicle belonging to the Middlesex University. This utility vehicle enabled us to obtain continuous readings of the vehicles position within the Hendon campus. However the other participants drove around different roads in the surrounding area including Watford Way (A41) at different times so as to obtain to get a picture of the traffic patterns in the area. Photos of the trial are shown in Figure 1.10.

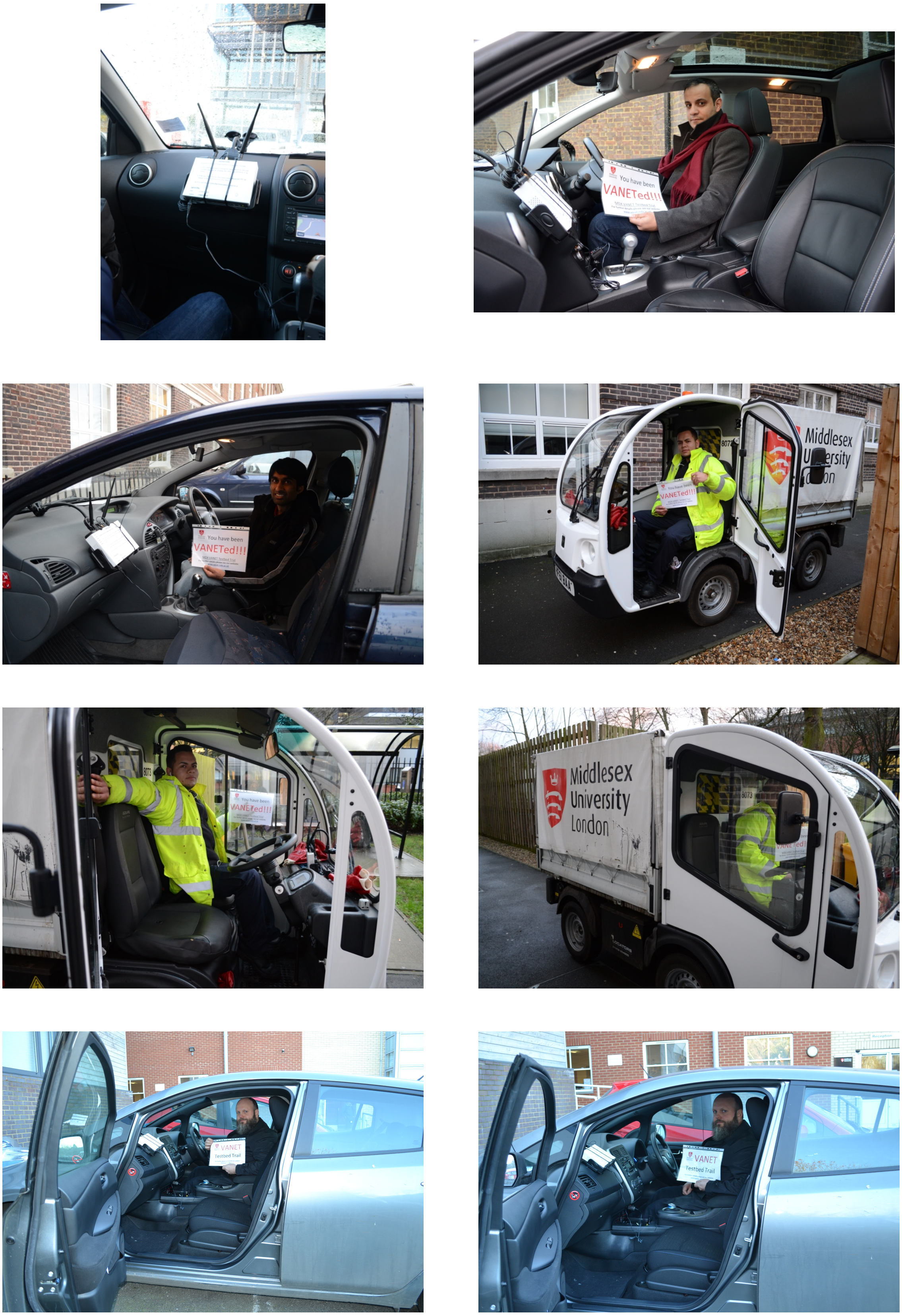



Fig. 1.10 MDX VANET Trial Photos.

## 1.6 Results

### 1.6.1 Coverage Graph

The image in Figure 1.11 shows the unique GPS coordinates from the packets received by the MDX VANET Server, sent by the OBUs which were placed in the cars of the volunteers. Figure 1.11 displays the trial data for a 24 hour period which was collected on 8th January 2016 and a total of 390653 packets (around 17.14 MB) was received in that period. The coverage was better than anticipated but this was only because of the height of the RSU deployment. There are some blind spots that can be observed; these were purely due to effects of surrounding buildings. By these observations it is clear that we need more RSUs alongside the road to be deployed in an urban area, but if deployed on high raise buildings the advantages can be seen and might need less RSU. The dense line indicate very reliable communication and random spots indicate only few packets were received and not a continuous reliable communication is happening.

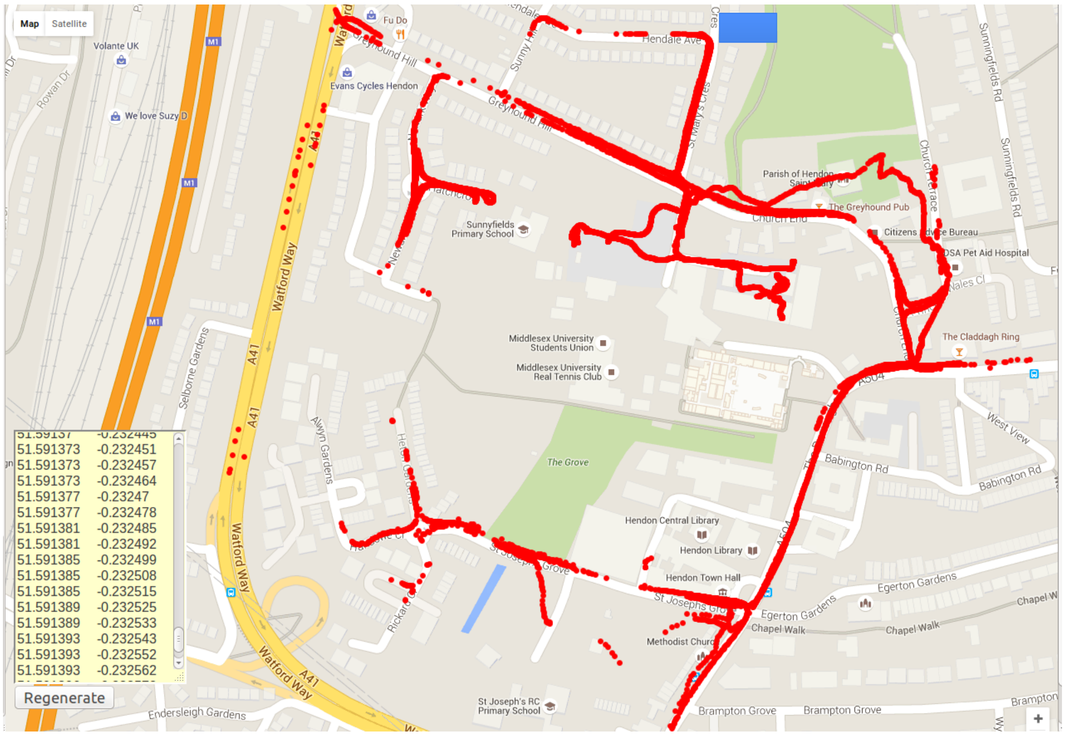
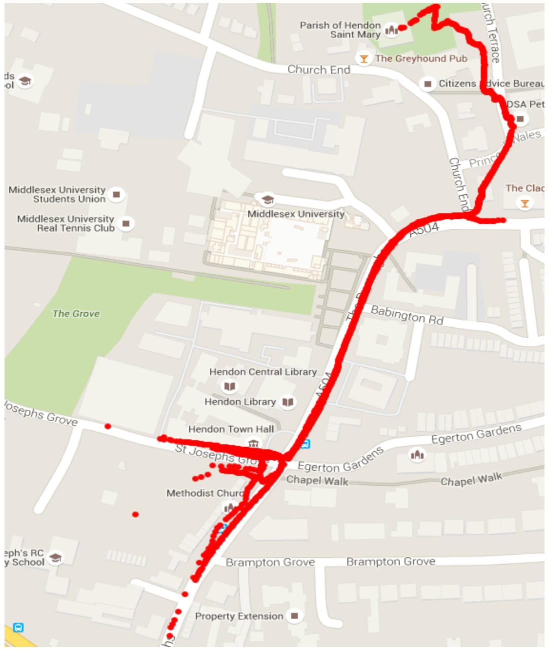
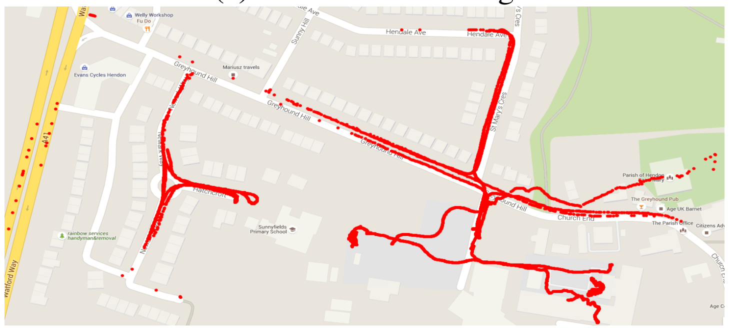



Fig. 1.11 Coverage Map.

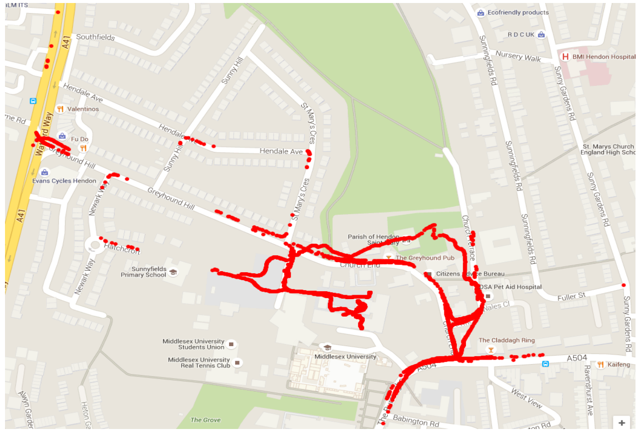
The farthest point from where the packets were sent by the vehicles and successfully received by the RSU was approximately 1.15 Km from the Williams Building RSU to a point on the East side of Watford way close to where the A41 and A1 divide! This was achieved purely due to the very high elevation of the RSU on the Williams Building hence allowing Line of Sight communication over a great distance.



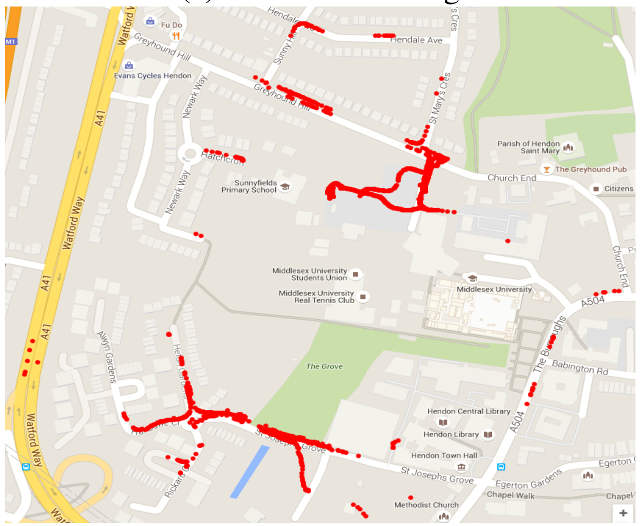

(a) Hatchcroft Building



(b) Sheppard’s Building



(c) Williams Building



(d) Grove Building

Fig. 1.12 Coverage of each RSU.

The Figure 1.12 shows the individual coverage achieved by the RSU located on each building. We can observe that the more coverage is achieved for the RSUs deployed at higher heights and also which have clear Line of Sight for the intended roads around. In Figure 1.12 we can observe some blind spots i.e., there are spots were the red dots are not continuous. For example the coverage map of RSU deployed at Grove building has almost no coverage on the A504 due to the blockade of signal propagation because of the buildings.

### 1.6.2 Live Vehicle Tracking

Figure 1.13 shows a screen shots with three cars moving around. Google Earth was used and the web address of the live.kml file was used for displaying and live tracking of multiple cars remotely. This test was performed by fixing an OBUs in one of our volunteer's car, one on the MDX Electric Cart which is used to collect rubbish inside university and one carried by a pedestrian. The movement of the vehicles was updated periodically every one second (least time interval that can be set in Google earth). Each vehicle was labelled and displayed with their respective MAC address of the OBU.

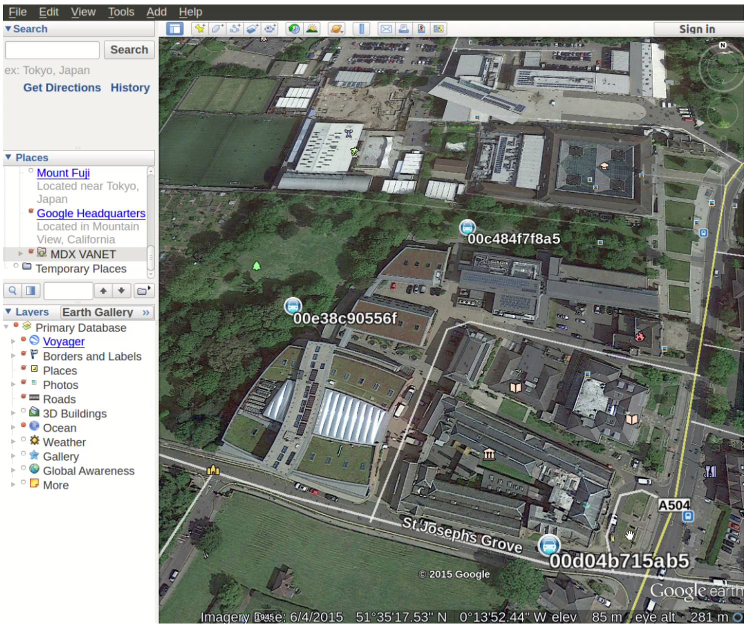



Fig. 1.13 Live Tracking Screen shot.

These were the primary results of the initial trial of the MDX VANET Testbed. Further observations are discussed in the next section.

## 1.7 General Observations from the MDX 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 suprised 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.

In terms of hardware, we found that the firmware of the devices was not stable and we had to do various updates and sometimes we had to revert to older versions due to bugs being introduced because of lack of testing. This was time consuming because we did not have enough information, from manuals etc., to quickly fix the problem. A lot of these problems reflect the fact that VANET is still a very new technology hence, it will take some time for the hardware platform to work seamlessly. In addition, a low level software platform should be defined to drive the hardware functionality. In essence, we were too dependent on the manufacturers, in this case ARADA Systems, and so we were unable to get some program code for key functions on the RSU.

Because the equipment was purchased from ARADA Systems, which is a US based company, it was necessary to adjust the operational frequency parameters in order to comply with EU standard requirements. 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 Next step/recommendations for testing and implementation

It is quite clear that the next step for this project should be a deployment along a significant motorway in this country. This will allow a detailed understanding of VANET systems in such environments to be obtained leading to wide scale deployment of VANETs regionally and nationally. As previously mentioned this would require a complete roll-out strategy between all the stakeholders. If we consider London in particular, local Boroughs should be working with the Transport for London (TfL) and the Department for Transport (DfT) to do more trials on VANET technology.

We are also building a Mobile RSU as shown in Figure 1.14 which will allow us to move the RSU setup anywhere required for future tests. The physical setup is shown in 1.15. In order to backhaul the data received by the RSU, an LTE Outdoor Router will be interfaced to the RSU. Hence, 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,

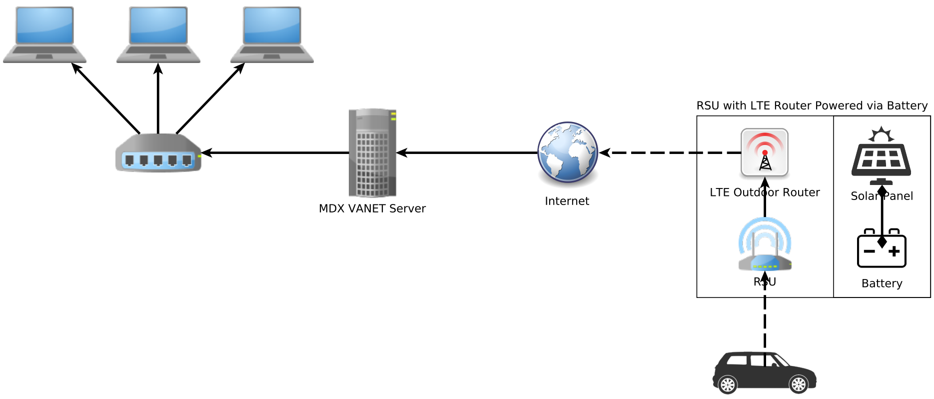



Fig. 1.14 Network Diagram of a LTE Backhauled Mobile RSU.

built and used. This further allows us to measure the power consumption and identify the challenges in building such green energy systems for ITS.

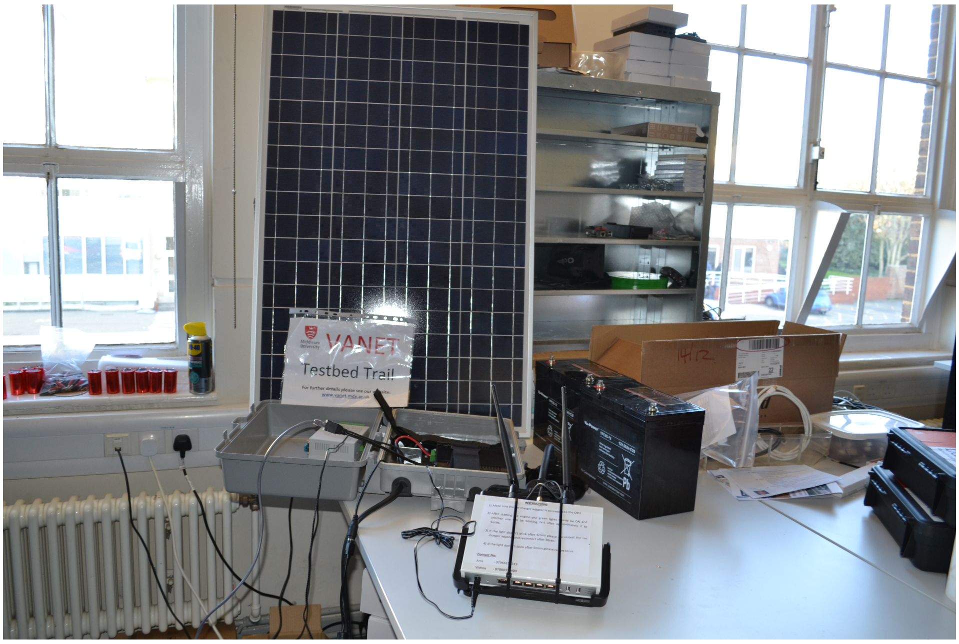



Fig. 1.15 Building LTE Backhauled Mobile RSU in Lab.

## 1.10 Conclusion

This project has clearly shown that VANET technology can be used to form an Intelligent Information Platform for Smart Cities. It has also highlighted the weaknesses and strengths of this new technology and the key issues to be addressed in its wide scale deployment. Hence, the evolution of this technology and its potential to transform Smart Cities need to be fully understood by the transport authorities.

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[1] IEEE-Std., "Ieee standard for information technology–local and metropolitan area networks–specific requirements–part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications - amendment 8: Medium access control (mac) quality of service enhancements," 2005. 8

[2] IEEE-Std., "Ieee standard for information technology– local and metropolitan area networks– specific requirements– part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications amendment 6: Wireless access in vehicular environments," *IEEE Std 802.11p-2010 (Amendment to IEEE Std 802.11-2007 as amended by IEEE Std 802.11k-2008, IEEE Std 802.11r-2008, IEEE Std 802.11y-2008, IEEE Std 802.11n-2009, and IEEE Std 802.11w-2009)*, pp. 1–51, July 2010. 8, 9

[3] IEEE-Std., "Ieee draft standard for wireless access in vehicular environments (wave) - multi-channel operation," 2010. 9

[4] ETSI-CAM-Std., "Etsi en 302 637-2 v1.3.2 (2014-11) intelligent transport systems (its); vehicular communications; basic set of applications; part 2: Specification of cooperative awareness basic service (cam)," 2014. 9

[5] ETSI-DEN-Std., "Etsi en 302 637-3 v1.2.2 (2014-11) intelligent transport systems (its); vehicular communications; basic set of applications; part 3: Specifications of decentralized environmental notification basic service (den)," 2014. 9

## A.1 Arada Systems Locomoate Road-Side Unit (RSU) - Specifications

ARADA SYSTEMS

Fueling Advanced Intelligent Transportation Systems



# LocoMate™ COMMANDO | Rugged V2I DSRC Road Side Equipment


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

## 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

## 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 |

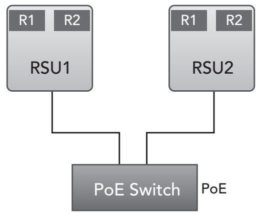
| Throughput Traffic Test Results Full-Rates on Channel 175 (Mbps) Without Channel Switch | | |
|---|---|---|
| 20 MHz Data Rates | TCP | UDP |
| 6M | 4.7 | 5.0 |
| 9M | 6.7 | 7.2 |
| 12M | 9.8 | 10.5 |
| 18M | 12.9 | 14.52 |
| 24M | 16.6 | 18.661 |
| 36M | 22.630 | 26.022 |
| 48M | 27.782 | 32.231 |

| 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 |

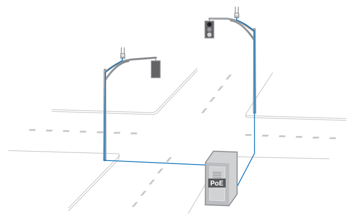
| Average per Packet Latency Values with Different Content Type Messages | | | |
|---|---|---|---|
| | Plain | Sign/Sign Verify | Encrypted/ Decrypted |
| Average packet interval with 100 mS transmit periodicity | 102 mS | 112 mS | 139 mS |
| Latency | 2 mS | 10 mS | 35-40 mS |

| 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

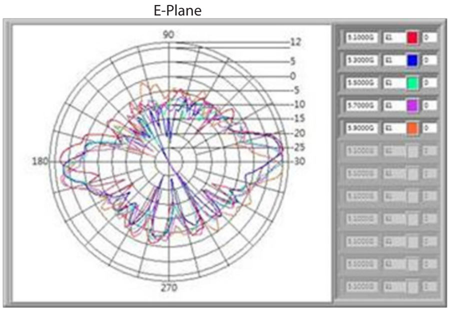
## Ordering Information

COMMANDO™ 201 RSE

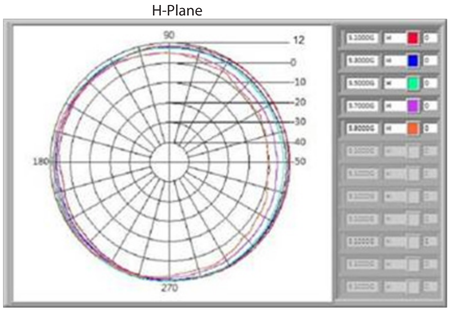
sales@aradasystems.com

## Antenna Patterns

E-Plane




H-Plane




ARADA SYSTEMS

www.aradasystems.com

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

## B.1 Arada Systems Locomoate On-Board Unit (OBU) - Specifications

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 | OmniAir | US DOT CERTIFIED | C2C | 1609 WAVE SUPPORT 2 3 4 | SAE J2735 | BLUETOOTH COMPATIBLE | DSRC 802.11p 5.9 | CAN bus SUPPORT |
|---|---|---|---|---|---|---|---|---|
| Intelligent Transportation Systems America Member | OmniAir Certified Member | Approved US Dept of Transportation Qualify Product List Vendor | The CAR-2-CAR Communication Consortium Member | WAVE standard support 1609.2, 1609.3, 1609.4 | SAE J2735 Support | Bluetooth Support for Mobile | Dedicated Short Range 5.9 Communication 802.11p | 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 | |
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| 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 |
| 54M | 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 | 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.

ARADA SYSTEMS

www.aradasystems.com



Part Number OBU001-812