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Chair of Communication Engineering

Master Thesis

Enhancement of Communication Model for Driving Simulators by Relevant Physical Effects of Radio Propagation.

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Abstract

Vehicle-2-Vehicle (V2V) and Vehicle-2-Infrastructure (V2I) communication has been an emerging area of interest in the recent times. It offers applications ranging from road safety (e.g.: collision avoidance) to infotainment (e.g.: multimedia, navigation, traffic information etc.). Due to growing number of driver assistance systems, it is very important to evaluate the interaction with users and acceptance of these systems. Suitable tools for doing this are driving simulators. The goal of this master thesis is to enhance an already existing communication model for V2V communication scenarios that is used for the driving simulators of the DLR-Institute of Transportation Systems. The current communication simulation implements a simple propagation model based on free space communication and is already integrated in the simulator environment that provides all necessary information and parameters. This work focuses on the enhancement of existing communication model with two major physical effects: the multi-path propagation to provide “urban canyon” effects and the directional antenna (main lobe) to take the direction of the communication into account. Algorithms for assessing the environment are developed based on the open source graphics engine “Open Scene Graph” and the prototype implementation is later integrated in the DLR Institute’s own system architecture called “Dominion”.

Contents

List of Figures.....	6
List of Abbreviations.....	7
1. Introduction.....	8
1.1 Motivation.....	9
1.2 Problem statement.....	9
1.3 Thesis structure.....	10
2. Vehicle-to-Vehicle Communication.....	11
2.1 Car 2 Car Communication Consortium.....	11
2.2 Scenarios.....	12
2.3 Use Cases.....	13
2.3.1 Safety.....	13
2.3.2 Traffic Efficiency.....	14
2.3.3 Infotainment and others.....	15
2.4 System Architecture.....	17
3. Radio System.....	19
3.1 General.....	19
3.2 Application Categories.....	19
3.3 Physical Layer.....	20
3.4 MAC layer.....	21
4. Open Scene Graph.....	22
5. Dominion System Architecture.....	25
6. Communication Simulation and its Requirements.....	27
6.1 Approach.....	28
6.1.1 Propagation Models.....	29
6.1.1.1 Free Space Model.....	30
6.1.1.2 Two Ray Ground Model.....	31
6.1.1.3 Knife Edge Diffraction Model.....	32
6.1.2 Antenna.....	34
7. Implementation.....	38
7.1 Algorithm.....	39
7.1.1 Function main().....	40
7.1.2 Function LineIntersection().....	41

7.1.3 Function FindNamedNode()	42
7.1.4 Function reflection()	43
7.1.5 Function diffraction()	43
7.1.6 Function totalReceivedPower()	44
7.1.7 Function lookup(int).....	44
7.1.8 Traversing the Scene graph	44
7.1.9 Pickup Handler	46
8. Results	47
9. Summary and Conclusion	53
Bibliography	55

List of Figures

Figure 1: Use Cases	12
Figure 2: Reference Architecture	17
Figure 3: A Scene graph of a virtual world consisting of vegetation, building and vehicle	24
Figure 4: General Dominion system architecture with test vehicles on upper left corner and simulators in upper right corner	25
Figure 5: Concept of Data Flow	28
Figure 6: Multipath propagation effects	29
Figure 7: Two-Ray ground reflection	31
Figure 8: Knife edge Diffraction	33
Figure 9: Antenna positions in Vehicle	34
Figure 10: Beam steerable Antenna in mobile V2V context	35
Figure 11: Radiation Patterns.....	37
Figure 12: 3D model of urban environment	38
Figure 13: Flowchart for object classification.....	41
Figure 14: Flowchart for search Node	43
Figure 15: Hierarchy of 3D model	44
Figure 16: Console output of direct LOS	48
Figure 17: 3D Scenario of free space.....	48
Figure 18: Free space propagation.	49
Figure 19: Console output of NLOS links with intersection co-ordinates.....	49
Figure 20: Console output of NLOS links with propagation output parameters	50
Figure 21: Urban canyon effect with orientation angle 0° of antenna	50
Figure 22: Urban canyon effect with orientation angle 30° of antenna	51
Figure 23: Urban canyon effect with orientation angle 60° of antenna	51

List of Abbreviations

AU: Application Unit

C2C-CC: Car 2 Car Communication Consortium.

DLR: German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.)

ESP: Electronic Stability Program.

GW: Gateways

HS: Hot spots.

IEEE: Institute of Electrical and Electronics Engineers

LOS: Line of Sight

NLOS: Non Line of Sight

OFDM: Orthogonal Frequency Division Multiplexing.

OSG: Open Scene Graph.

OBUs: Onboard Units.

RSUs: Road Side Units.

V2I: Vehicle-2-Infrastructure.

V2V: Vehicle-2-Vehicle.

VANET: Vehicular Ad-hoc Network.

1. Introduction

Today, increasing number of vehicles on the road has resulted in drastic increase in traffic jams and road accidents. Therefore, for the purpose of safety on the road, research in Vehicular Ad-hoc Networks (VANET) has gained more importance in the recent past. The idea of VANET is to form an ad-hoc network with vehicles as the network nodes. VANET research has progressed mainly in two areas i.e. Vehicle-2-Infrastructure (V2I) and Vehicle-2-Vehicle (V2V) communication. In V2I communication, connectivity between vehicle and the roadside infrastructure is established, whereas in V2V communication, the network is maintained among the group of vehicles. In this work, focus is on V2V communication [1].

The German Aerospace Center (DLR) is the national research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and safety is integrated into national and international cooperative ventures. In 16 German locations (headquarter in Cologne), DLR employs approximately 7,400 employees and has offices in Brussels, Paris, Tokyo and Washington DC.

The Institute of Transportation Systems in Braunschweig, Germany focuses on the research activities on increasing safety and efficiency of traffic. This includes for example the development of assistance and automation systems within the automotive domain. Three different degrees of assistance are possible: information, warnings and recommendations are provided to the driver; corrections of lateral and longitudinal movement of the vehicle or the fully autonomous vehicle control. Therefore, the acceptance of these systems has to be evaluated. This is done at DLR by using different types of simulators, test vehicles and stationary test facilities.

For future assistance and automation systems, Vehicle-2-Vehicle and Vehicle-2-Infrastructure (both together called V2X) communication will be the underlying technology to develop and deploy a new class of assistance systems, which exchanges information like recommendations, warnings, and status information that vehicles could not gather on their own.

1.1 Motivation

Due to the dynamic nature of vehicular traffic and the road surroundings, the propagation characteristics of Vehicle-2-Vehicle communication vary greatly both on large-scale and small-scale. The large static objects like buildings will have a profound impact on Vehicle-2-Vehicle communication. The existing geometry-based models like ray-tracing yield results that are in very good agreement with the real world. However these models are computationally too expensive to be practically useful for modelling large-scale networks in VANET simulators.

The solution is to come up with simple, computationally inexpensive communication model considering the physical effects like reflection and diffraction in Vehicle-2-Vehicle communication.

1.2 Problem statement

The main goals of this Master Thesis are listed below:

- To become familiar with the environment model and current vehicle representation of the current communication simulation and adapting the implementation of the DLR simulation environment for driving simulations.
- Development of a multi-path propagation without modification of the damping rate of the air as done in the previous implementation.
- Development of a directional antenna simulation.
- Modular implementation of the algorithms in communication simulation for a later on intended integration into the existing simulator.
- Test and evaluation of the implemented communication simulation using appropriate model scenarios.
- Discussion of approaches for further development of the communication simulation with respect to other, more realistic simulation conditions.

1.3 Thesis structure

The structure of this Master Thesis is organised in the following chapters.

Chapter 2 describes the objectives of CAR 2 CAR Communication Consortium. It also describes the safety use cases and system architecture of CAR 2 CAR communication system.

Chapter 3 describes the communication channels, design principles for dedicated channel and the short description of channel access mechanism of MAC layer.

Chapter 4 describes the 3D computer graphics engine called “Open Scene Graph”. The core libraries and Node Kits of Open Scene Graph are also described.

Chapter 5 describes the system architecture “Dominion” developed by DLR-Institute of Transportation Systems.

Chapter 6 describes the communication simulation and its requirements. The suitable radio wave propagation models for prototype implementation and the merits of using directional antenna over Omni-directional antenna are also described.

Chapter 7 describes the implementation algorithm and the functionalities used in the implementation code.

Chapter 8 describes the results obtained. The critical analysis of the results is carried out.

Chapter 9 presents the conclusion to this work underlining the goal to be achieved in this Master Thesis. It also identifies some key enhancements to the existing set-up for future development.

2. Vehicle-to-Vehicle Communication

2.1 Car 2 Car Communication Consortium

The main aim of CAR 2 CAR Communication Consortium (C2C-CC) is to standardize the protocols and the interfaces of wireless communication between the vehicles and their environment. It makes different vehicle manufacturers and Tier 1 supplier compatible to each other and enables them to communicate with access points or the road side units (RSUs) [2].

The objectives of CAR 2 CAR Communication Consortium are:

- To create European industry standard worldwide for CAR 2 CAR communication system.
- To enable development of safety applications by specifying, prototyping and demonstrating the CAR 2 CAR system.
- To allow inter vehicle operability.
- Allocation and promotion of frequency band for CAR 2 CAR communication.
- To promote Harmonization of CAR 2 CAR communication standards worldwide.

The top level attributes of CAR 2 CAR communication are as follows:

- Fast and reliable data transmission between the vehicles and between the vehicles and the roadside units.
- Transmission of infotainment data like traffic information, entertainment information, as well as warnings.
- The CAR 2 CAR communication is based on ad-hoc network and do not require pre-installed network infrastructure.

CAR 2 CAR communications form a decentralized network that is well suited for active safety applications. Apart from safety applications, gathered information helps in traffic management to support traffic flow [2].

2.2 Scenarios

To improve driving safety or traffic efficiency and provide information or entertainment to the driver, V2X communication enables large number of use cases. This section introduces the use cases and shows how the use cases imply certain requirements to the system [2].

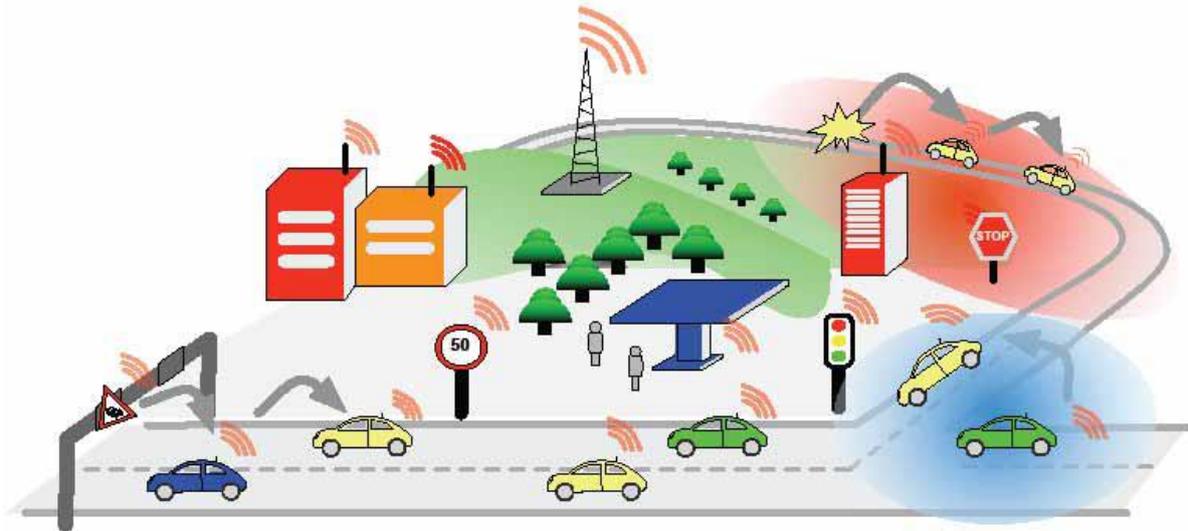


Figure 1: Use Cases [2].

The figure 1 involves many actors for V2X communication. They are as follows:

- **Driver:** the driver benefits from the system by receiving e.g. warning messages and recommendations about the route.
- **Road operators:** the road operators receive traffic data and control the traffic efficiently.
- **Hot spots and internet service providers:** it provides attachment of vehicle communication systems to the point of interests like restaurants, gas stations, banks etc.

2.3 Use Cases

In the following, some V2X use cases are described to demonstrate the advantages of V2X communication [2].

2.3.1 Safety

The safety use cases are as follows.

Cooperative Forward Collision Warning: Typical causes of rear-end collisions are driver distraction or sudden braking ahead of a following vehicle. In all regions of the world, rear-end collisions cause a significant percentage of all accidents. The Cooperative Forward Collision Warning use case provides assistance to the driver primarily to avoid rear-end collisions with other vehicles. During normal driving, the equipped vehicles anonymously share relevant information such as position, speed, and heading. In order to predict an imminent rear-end collision, each vehicle monitors the actions of its own driver and the position and behaviour of all other nearby vehicles. When the vehicle detects a critical proximity, the vehicle warns the driver via visual, auditory, and/or haptic displays. Thus, the driver will have enough time to intervene and avoid a crash.

Pre-crash sensing: Here, the assumption is that a crash is unavoidable and will take place. Similar to the Cooperative Forward Collision Warning use case, this use case requires that all vehicles periodically share information from neighbouring vehicles to predict a collision. Once a collision is no longer avoidable (i.e., no possible way to steer or brake to avoid the crash), the involved vehicles engage in fast and reliable communication to exchange information such as more detailed position data and vehicle size. This extra information provided to both vehicles enables an optimized usage of actuators such as air bags, motorized seat belt pretensioners, and extendable bumpers.

Hazardous Location V2V Notification: The Hazardous Location V2V Notification use case utilizes the network of vehicles to share information that relates to dangerous locations on the roadway, as for instance slippery roadways or potholes. Thereby, a major issue is the generation of information about the driving condition at a specific location. For instance, a vehicle that experiences an actuation of its ESP (Electronic Stability Program) system, the vehicle retains information about the location and shares its knowledge with other vehicles in the surrounding area. Vehicles that receive the information either provide it to the driver or use it to automatically optimize its chassis or safety systems. The relevant information can be shared with any number of vehicles over an area, limited only by the current density of equipped vehicles.

2.3.2 Traffic Efficiency

Traffic Efficiency improves the efficiency of transportation network by providing information to the drivers or to the owners of transportation network. The more efficient transportation system will result in lesser delay and lower maintenance cost for the owners of transportation network. The example use cases for improving the traffic efficiency are as follows:

Enhanced Route Guidance and Navigation: The Enhanced Route Guidance and Navigation use case uses the information constantly collected from the roadside infrastructure regarding the traffic congestion on the roads over the large area. When an equipped vehicle passes through the roadside unit, the RSU sends the information about the current traffic conditions throughout the area. The vehicle uses this information and conveys the driver about the expected delay and the better routes if available.

The Enhanced Route Guidance and Navigation use case requires:

- A roadside infrastructure to collect the information on the traffic conditions,
- Ability for the RSU or infrastructure to offer service to the passing vehicles,

Green Light Optimal Speed Advisory: The main aim of this use case is to make the driving smoother and avoid stopping. As the vehicle approaches the intersection, the vehicle receives the information about the location of intersection and the signal timing. The vehicle now calculates the optimal speed and notifies it to the driver. If the vehicle travels at the optimal speed and the signal is green, the driver need not have to slow or stop the vehicle.

The Green Light Optimal Speed Advisory use case requires:

- To transmit information of the intersection position and the timing information of the traffic signal for each lane and the direction of travel,
- Vehicles to trust the information provided by the traffic signal.

Vehicle to Vehicle Merging Assistance: The V2V Merging Assistance use case allows the merging vehicles to join the traffic flow without disrupting the flow of traffic. When a vehicle enters the limited access roadways, it signals to the traffic adjacent to it attempting to merge into the roadways.

The V2V Merging Assistance use case requires:

- The ability for all the vehicles to share information with each other over a distance adequate to perform merging manoeuvre,
- Vehicles to trust the information they receive from other vehicles,
- Vehicles have to agree on the actions to provide spacing for merging vehicles.

2.3.3 Infotainment and others

These use cases are not directed at safety or traffic efficiency, instead they provide entertainment information's. The example use cases are as follows.

Internet Access in Vehicle: The Internet Access in Vehicle use case provides connection to the internet and allows the use of all kind of IP based services in the vehicle. The multi-hop route is established and maintained to the roadside infrastructure, which acts as an internet gateway.

The Internet Access in Vehicle use case requires:

- The ability for a vehicle to connect to the road side unit who offers the internet connection,
- The ability to multi-hop the messages from vehicle to the roadside unit,
- Dynamic route maintenance.

Point of Interest Notification: The Point of Interest Notification use case allows the local businesses, tourist attractions and other point of interests to advertise their availability to the nearby vehicles. The roadside unit broadcasts the information like the location, time required etc.

The Point of Interest Notification use case requires:

- The ability for roadside unit to broadcast the information to the surrounding vehicles,
- Vehicles to trust the information generated by the roadside units.

Remote Diagnostics: The remote diagnostics use case allows the service station to assess the state of vehicle without making physical connection to the vehicle.

The remote Diagnostics use case requires:

- The ability for vehicle to identify itself and the authorized requester,
- Vehicles to establish the secured connection with the roadside unit.

2.4 System Architecture

The reference architecture for CAR 2 CAR communication systems is shown in Figure 2 below.

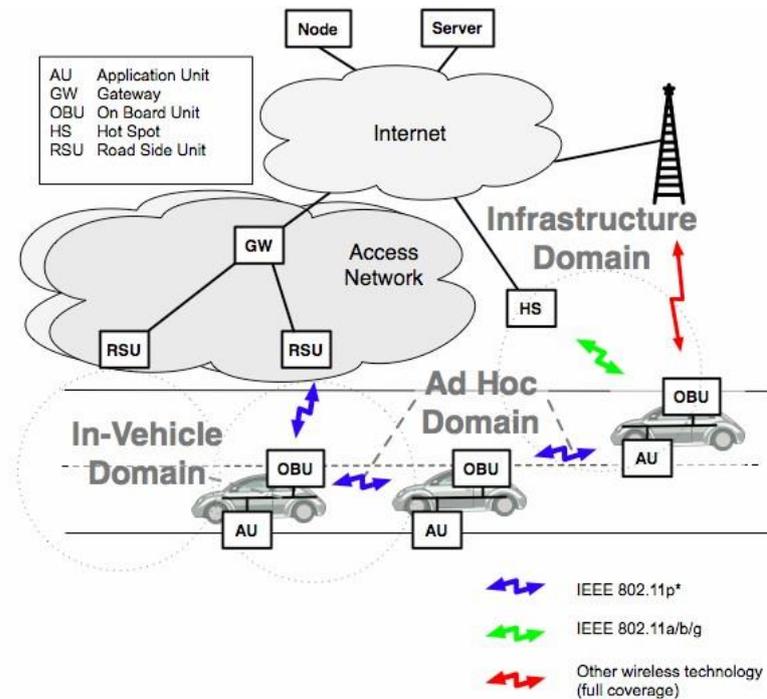


Figure 2: Reference Architecture [2].

In-Vehicle Domain: The in-Vehicle Domain is a network composed of onboard unit (OBUs) and the application units (AUs). The AU is in general an automotive PC but can be also a portable device like Laptop, PDAs etc. The AU is an integral part of vehicle and permanently connected to the OBUs. The connection can be wired or wireless. The AU executes the single or set of applications and utilizes the OBUs connection capabilities. The OBUs are responsible for V2V and V2I communications.

Ad-Hoc Domain: The Ad-Hoc Domain is composed of vehicles with OBUs and RSUs. OBUs form mobile ad-hoc network, which allows communication among the nodes in a fully distributed or decentralized manner. OBUs communicate directly if wireless communication exists. In case of non-wireless connectivity, dedicated routing protocols allow multi-hop communications where the data is forwarded from one OBU to other until the destination is reached.

The RSUs are responsible for executing special applications and by sending, receiving, or forwarding the data in the Ad-Hoc Domain. A RSU can be attached to an infrastructure network, which in turn can be connected to the Internet. As a result, RSUs may allow OBUs to access the infrastructure. In this way, it is possible for the OBUs to communicate with any hosts on the internet.

Infrastructure Domain: The communication stakeholders such as roadside administrators, public authorities or public or privately owned hotspots set up the RSUs for internet access. In case, neither RSUs nor hotspots provide internet access, OBUs can utilize the cellular radio networks like GSM; UMTS; LTE etc.

3. Radio System

3.1 General

In order to enable vehicles and the corresponding infrastructure to exchange data in adequate manner, the main requirements and the constraints are specified in the following sections.

For safety applications, the C2C-CC radio system should be able to transmit and receive the messages stably under expected European Traffic conditions. For example, the vehicle speed up to 250 km/h having relative speed of 500 km/h should be supported by C2C-CC radio system [2].

3.2 Application Categories

There are two types of communication channels used by C2C-CC radio system:

- Dedicated C2C channels for
 1. Network control and critical safety applications,
 2. Road safety and traffic efficiency applications,
 3. Non-safety related V2I and V2V applications.
- Public channels as specified in IEEE 802.11 a/b/g.

Among these two communication channels, only dedicated C2C channels are mandatory. In addition, C2C communication system may support other radio systems such as GSM, UMTS, GPRS, WIMAX, and 4G.

The following rules are set based on the above communication channel classification.

- The network control and service announcement for C2C-CC radio system shall use control channel,

-
- Critical applications need robust and reliable communication between V2V and V2I. Hence protected dedicated channels shall be used,
 - Infotainment and internet access applications are regarded as add-on services for C2C-CC radio system.

3.3 Physical Layer

The following subsections are the design principles relevant only for the dedicated channels [2].

Frequency Band:

- 10 MHz band from 5.885 to 5.895 GHz for network control and critical safety applications,
- 10 MHz band from 5.895 to 5.905 GHz for critical safety applications,
- three 10 MHz bands from 5.875 to 5.885 GHz and from 5.905 to 5.925 GHz for road safety and traffic efficiency applications,
- Two 10 MHz bands from 5.855 to 5.875 GHz for non-safety related car to roadside and car-to-car applications.

Maximum Transmit Power: Maximum Transmit Power allowed for the C2C-CC radio system is 33 dBm. The communication range to be achieved by the C2C-CC radio system is 500 to 1,000 m within one-hop in line-of-sight situations.

Transmit Power Control: The C2C-CC radio shall support dynamic transmits power control with minimum transmits power of 3 dBm.

Data Rates: Data rates of 3, 6, 9, 12, 18, 24, 27 Mb/s are supported. The default data rate shall be 6 Mb/s.

Antenna: Antennas influences significantly the communication range of C2C-CC radio system. The experimental results show that circular characteristics of antenna would be the best to achieve the expected performance under the traffic conditions. The design principles on antenna beams are not yet defined.

Communication Mode and Frequency Modulation: Half-duplex and broadcast communication modes are adequate to the applications used today. Orthogonal Frequency Division Multiplexing (OFDM) is the modulation technology used.

3.4 MAC layer

In general, the IEEE 802.11p and IEEE 1609.4 are the technical basis for C2C-CC radio system and the adopted MAC algorithm is the standard *carrier sense multiple access with collision avoidance* [2].

4. Open Scene Graph

The Open Scene Graph (OSG) is an open source, cross platform computer graphics toolkit for the development of high performance graphics applications such as flight simulators, driving simulators, games, virtual reality and scientific visualization. It provides an object-oriented framework on top of OpenGL. This frees the developer from implementing and optimizing low-level graphics calls and provides additional utilities for rapid development of graphics applications [3].

The OSG project is open sourced and released under a modified GNU Lesser General Public License (LGPL), named OSGPL. OSG provides significant benefits like superior performance, high scalability, software and Hardware portability and open source [3].

At DLR, the powerful OSG is used to simulate different environments for e.g. 3D urban environment in the driving simulator as well as desktop visualization.

The computing infrastructure of OSG is highly scalable to enable run time access to the extended functionalities. The standard core libraries and additional modular libraries called Node Kits have been delivered to meet specific development requirements.

The core OSG functionality consists of four libraries:

1. The *OpenThreads library*: This Third party open source library provides a minimal and complete object oriented thread interface for C++ programmers. It is used by OSG as main threading model implementation.
2. The *osg library*: This library provides basic elements used to build a scene graph with objects like nodes, geometries, rendering states and textures. It contains few math classes used to implement vector and matrix operations that are used in two-dimensional and three-dimensional spaces.
3. The *osgDB library*: This provides plugin mechanism for reading and writing of 2D and 3D files with derivable class containing access to data files and stream I/O operations.

-
4. The *osgUtil* library: This library is designed for building the OSG rendering backend, which traverses the scene tree, performs culling in each frame, and finally converts the OSG scene into series of OpenGL calls.

A Node Kit is an add-on library that extends the core Open Scene Graph nodes, draw able or state attributes to add specialist features such as particle system and text. Node Kits can be directly linked and used by user's applications, or used indirectly when loading a scene graph from disk, which references the Node Kit. The extra Node Kits and utilities available with current OSG distributions are [3]:

- *osgAnimation* library
- *osgFX* library
- *osgGA* library
- *osgManipulator* library
- *osgParticle* library
- *osgShadow* library
- *osgSim* library
- *osgTerrain* library
- *osgText* library
- *osgViewer* library
- *osgVolume* library
- *osgWidget* library
- *osgQt* library

All OSG core libraries and Node Kits have same prefix "osg".

The figure 3 below shows a simple scene graph of an exemplary traffic situation. The scene graph tree starts with a top-level root node *osg::Root*. Below that, a geometry-group node *osg::Geode* and *osg::Drawable* geometry organized by a general of Groups node *osg::Group*. The root node and the Group node can have multiple children. At the lower end of the scene graph to find the geometry node containing the objects in the scene.

The Group nodes are used to organize the geometry in a scene. The scene graph offers various types of nodes and group nodes that offer a wide range of functions. One example is a transformation node `osg::Transform` with that help you can rotate, move, or scale the underlying inserted objects [3].

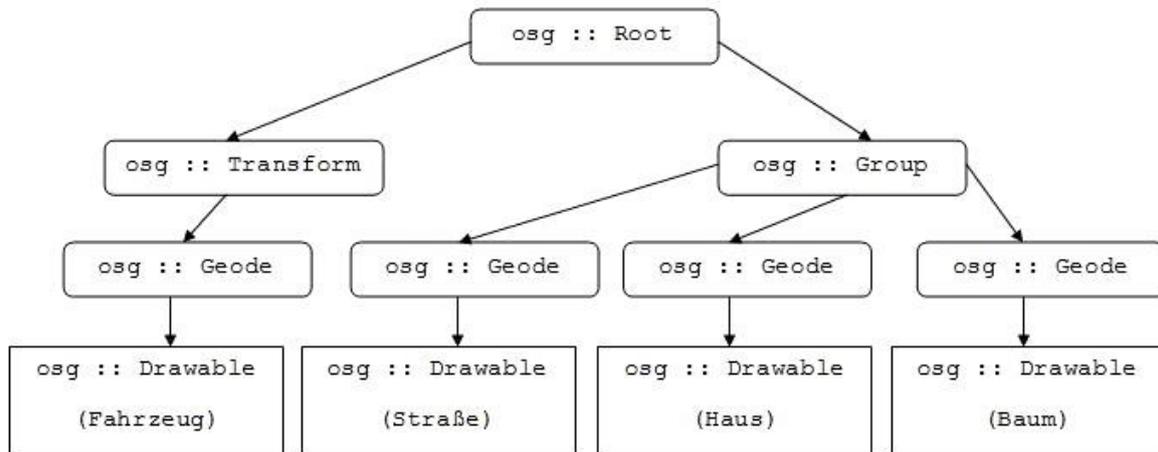


Figure 3: A Scene graph of a virtual world consisting of vegetation, building and vehicle

5. Dominion System Architecture

Dominion is a system architecture developed by DLR-Institute of Transportation Systems. It provides service oriented concept that supports the development of tightly embedded in-vehicle assistance and automation systems as well as loosely coupled comfort oriented applications.

It comes along with standardized user-interfaces for integrating third party applications, provides supporting tools for the operation of laboratories and for conducting test runs, which facilitate fast deployment of new applications and services.

For example, the supporting tool *Dominion Remote* manages the full-scale simulator setup including third party applications by parameterizing, monitoring and relocating the applications.

The *Dominion Data Store* (Dominion-DS) handles the data recording. It includes the runtime data as well as meta-data, which is modelled within the *Dominion Data Core*.

The structure of Dominion is shown in the following Figure 4.

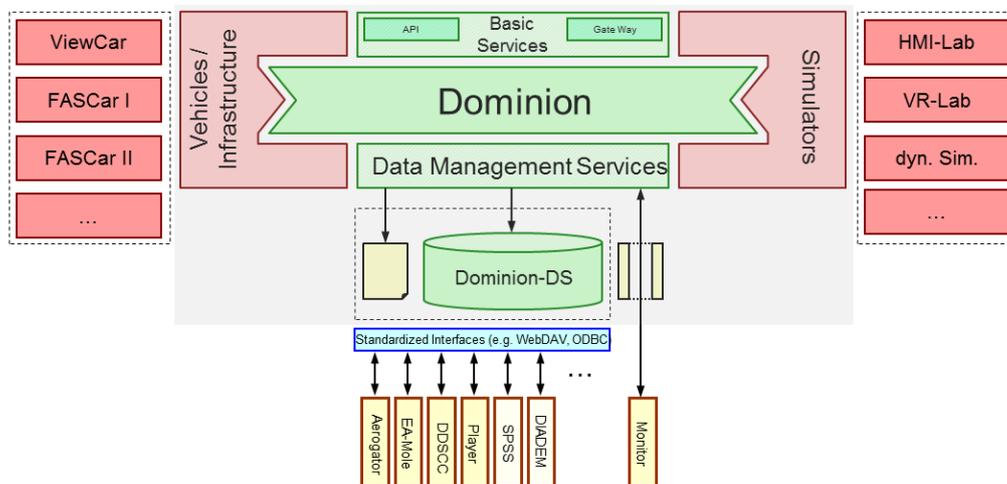


Figure 4: General Dominion system architecture with test vehicles on upper left corner and simulators in upper right corner [4].

Dominion is mainly used in two types of test facilities in particular in simulators and in test vehicles. Therefore, a transfer of software prototype and special hardware interfaces causes minimal migration effort. Additionally to that Dominion is running also in DLR's RSUs.

In Conclusion, the Dominion system architecture enables greater flexibility for set-up of simulator experiments [4].

6. Communication Simulation and its Requirements

Simulations play a pre-dominant role in the field of engineering research. Therefore, communication simulators are developed for the investigation of radio transmissions in all facets. The most widely used communication simulators are ns-2, ns-3, OMNETT++ and OPNET. These simulators are able to simulate large networks and for that, they use various stochastic communication models to compute faster than real time. These simulators can also be used with physical models for radio transmission simulation, if there is a small area of interest. However, the computational effort will have a major impact on simulation run time. In most scenarios, the information about the environment is missing because either it is not possible to integrate such type of data into communication simulator or it would influence the computational time [4].

Since environment has a major impact on V2V or V2X communication, it is therefore necessary to couple with driving simulators to achieve results in real time. To tackle the issues of simulating communication in real time considering the environment, a simplified communication model has to be developed. Additionally the simulation has to fulfil some requirements with respect to driving simulation. The most important requirements are as follows:

- **Run Time:** The simulator has to provide results in real time. The interest is to simulate the messages from different senders to mostly one receiver. It is not necessary to simulate the whole traffic.
- **Environment:** For driving simulator scenarios, it is necessary to consider the surrounding environment for instance trees, buildings and other vehicles.
- **Reproducibility:** The simulator has to provide same results for several test runs. The results should not be random.
- **Communication results:** The communication simulator should produce only three types of message outputs i.e. "Receiving a message" when transmission was successful, "No message" when transmission failed and the third message is "Noticed" state. The third message indicates that the signal power received is above the threshold power and is therefore unable to decrypt the message [4].

6.1 Approach

To meet these requirements, the idea was to come up with simple communication model considering the physical effects like reflection and diffraction in urban environment of V2V communication. This communication model is an enhancement to the existing communication model with free space propagation between the sender and receiver. Contrary to this, highly realistic models like ray-tracing models yield results that are in very good agreement with the real world.

However, these models are computationally very expensive as the network grows and most often bounded to specific location for which detailed geographic database is required. In our approach, obstacles like buildings are taken into account, as it has greater effect on communication. The objects like vehicles, trees are ignored in our case but can be integrated in the algorithm in the same way like buildings

The system architecture Dominion, which was introduced in section 5, provides a modular and service oriented approach. Hence, it is possible to integrate new modules with minimal efforts. The complete list of input and output data for communication simulation is shown in Fig 5 below.

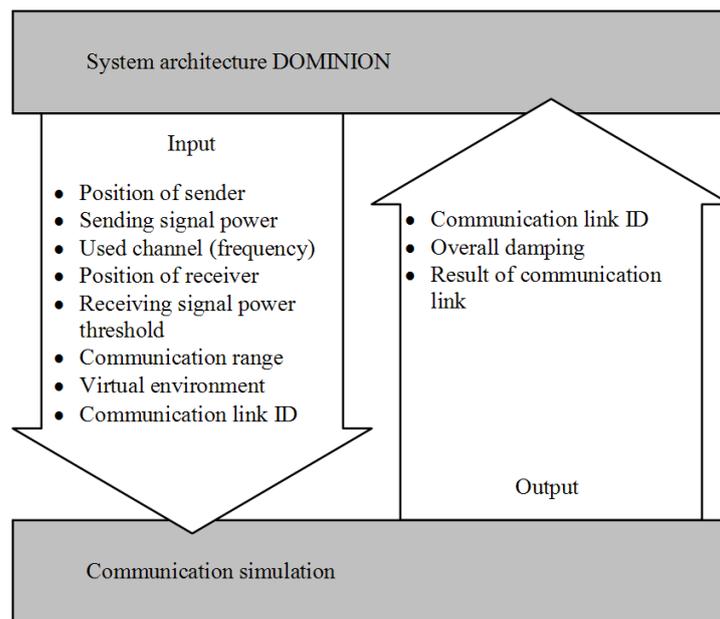


Figure 5: Concept of Data Flow [4]

For analysing the virtual world, the computer graphics library Open Scene Graph is used. The detailed description of Open Scene Graph is given in section 4. The detailed Implementation algorithm is explained in section 7.

6.1.1 Propagation Models

The implementation of communication model with physical effects like reflection, diffraction in V2V communication makes use of various radio wave propagation models like two-ray ground reflection model and single knife-edge diffraction model. This subsection describes these propagation models in details.

Radio waves encounter many obstacles in the urban environment while propagating from sender to receiver. This results in multipath propagation effects at the receiver. Multipath propagation is a phenomenon that results in radio signals reaching the receiver antenna by two or more paths.

The causes of multipath effects include reflections, diffraction and scattering from the obstacles like buildings, vegetation or vehicles in the environment. The figure 6 below shows the multipath propagation effects in the environment.

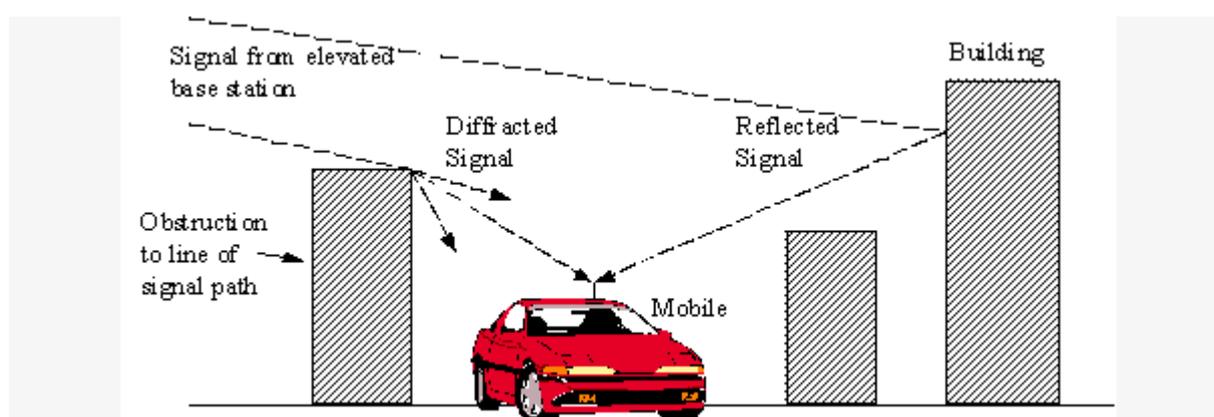


Figure 6: Multipath propagation effects [9].

The propagation of radio waves results in both large scale and small scale propagation effects. Large-scale propagation effects describe variations of received signal strength over relatively long distances in which path loss and shadowing are mainly considered. Small-scale propagation effects describe variations in received

signal strength over small distances, in which multipath delay and Doppler shift are mainly considered.

The Concept of path loss plays a vital role in describing the attenuation of signal power. In VANET simulation, to calculate received power path loss in several radio wave propagation models are considered [5].

6.1.1.1 Free Space Model

Free space model is used when there is no obstacle in between sender and receiver and the radio wave propagates along the straight line. The power received at distance d from the sender is given by:

$$P_r = P_t G_t G_r \frac{\lambda^2}{(4\pi)^2 l^2} \quad (1)$$

Where P_t is the transmitted power; P_r is the received power; $G_t G_r$ are the gain of transmitting and receiving antenna respectively; l is the distance between sender and receiver and λ is the wavelength.

The path loss in dB is calculated as:

$$PL[dB] = 10 \log_{10}\left(\frac{P_t}{P_r}\right) \quad (2)$$

In this work, this propagation model is used to calculate the path-loss in free space, when the environment around the sender and receiver is classified as rural environment [5].

6.1.1.2 Two Ray Ground Model

The received signal in two-ray ground model consists of two components: the signal propagating through free space and the signal reflected of the ground. The figure 7 below shows the two-ray ground model.

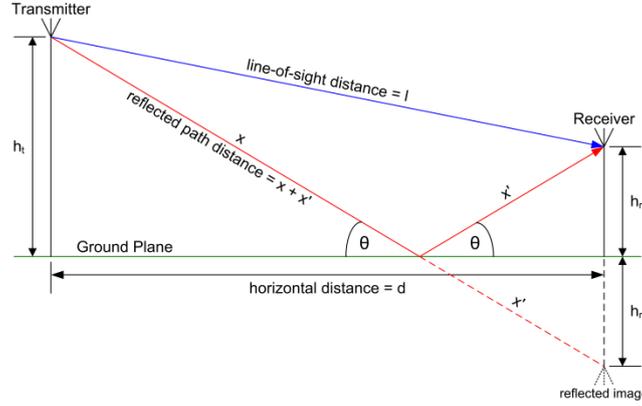


Figure 7: Two-Ray ground reflection [6].

The received power at a distance d from sender is given by:

$$P_r = P_t (\lambda / 4\pi)^2 \left| \frac{\sqrt{G_t}}{l} + \frac{R \sqrt{G_r} e^{-j\delta\psi}}{x + x'} \right|^2 \quad (3)$$

Where P_t, P_r are the power transmitted and power received by antenna; G_t, G_r are the gain of transmitting and receiving antenna respectively; l is the length of direct path; $x + x'$ is the length of reflection path; $\delta\psi$ is the phase difference between two received signal components and is given by:

$$\delta\psi = \frac{2\pi(x + x' - l)}{\lambda} \quad (4)$$

The Two-ray ground reflection model holds well when the reflecting surfaces are buildings as in the case of our communication model. Hence, the reflection coefficient R of buildings are used instead of ground surface in our implementation. The reflections can be calculated from surrounding vehicles as well. Since all buildings are significantly taller than any vehicle, any building can reflect the signal for any communicating pair.

For the vehicle to be a reflector it has to be taller than both communicating vehicle's antennas, otherwise the reflected ray does not exist. Furthermore, tall vehicles are more likely to block reflections coming off the buildings, whereas short vehicles are less likely to do so, since their height is often shorter than height of the line between communicating antennas discounted for the 60% of first Fresnel zone. In this work, only buildings as the reflecting surfaces are assumed [5].

6.1.1.3 Knife Edge Diffraction Model

When there is an obstacle between sender and receiver, the shape of an obstacle can be viewed as knife-edge for calculating the loss due to diffraction. The Fresnel-Kirchhoff diffraction parameter v is defined as

$$v = h \sqrt{\left(\frac{2}{\lambda}\right) \left(\frac{1}{d_1} + \frac{1}{d_2}\right)} \quad (5)$$

Where h is the height of the top of the obstacle above a straight line joining two ends of the path d_1 and d_2 are the distances of the two ends of the path from the top of obstacle. The approximation of loss caused by diffraction can be expressed as a function of v .

$$J(v) = 6.9 + 20 \log_{10} \sqrt{(v - 0.1)^2 + 1} + v - 0.1 \quad (6)$$

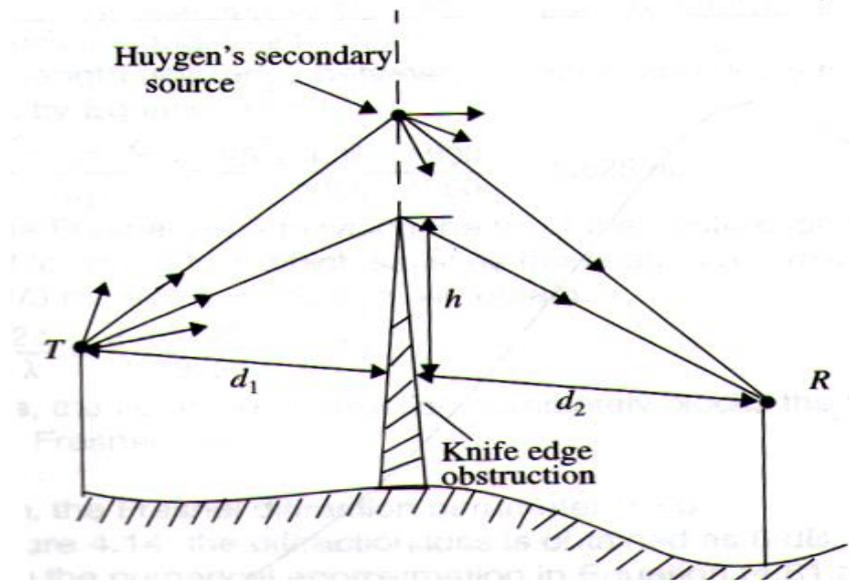


Figure 8: Knife edge Diffraction [7].

6.1.1.4 Multiple Knife Edge Diffraction Model

There may be several separate obstacles between the sender and receiver. If there are more than three obstacles multiple knife edge diffraction models is applied instead of single knife edge diffraction model. The procedure involved is as follows.

- Obtain the obstacle with highest value of v and is termed as principal edge p and the corresponding loss is $J(v_p)$.
- Obtain the largest v_t with loss $J(v_t)$ from sender to the principal edge.
- Obtain the largest v_r with loss $J(v_r)$ from principal edge to the receiver.
- Calculate total diffraction loss $J(v) = J(v_p) + J(v_t) + J(v_r)$.

In this work, this model is used is to calculate the path-loss due to diffraction of buildings when the environment around the communicating pair is classified as urban environment and the number of obstacles is greater than two between sender and receiver.

6.1.2 Antenna

The effectiveness of V2X applications require low latency and high reliability. In order to obtain high reliability it is necessary to have a stable radio link. In cellular communications the base station is at an elevated position and has a sectorized coverage around it. This is not the same case in V2V communication. Both the transmit (Tx) and receive (Rx) antennas are at the same height relatively close to the ground level.

In V2V communications, the position of antenna has a greater impact on the radio link performance. Therefore the experiences gained from the cellular communications cannot be directly applied to V2V communications.

The figure 9 shows the possibilities of antenna positions in a vehicle.

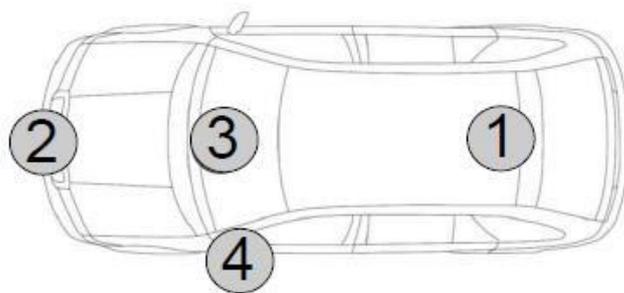


Figure 9: Antenna positions in Vehicle

Position 1 is roof top antenna at the rear end of the vehicle. Position 2 is the bumper antenna mounted near the registration plate. Position 3 is windscreen antenna and position 4 is left mirror antenna. In our scenario, position 1 (roof top antenna) is assumed.

In this thesis, directional antenna is assumed in contrast to the Omni-directional antenna. By focusing energy in one direction directional antenna can get a better transmit and receive gain in target direction compared to the Omni-directional counter parts.

Directional antenna also provides better immunity against co-channel interference and multi-path fading. This improves the signal-to-noise ratio (SNR) and better range as well as better physical layer data rates. However, when directional antenna is used in mobile V2V scenario, the direction must be steered appropriately to maintain best link quality. The Figure 10 below shows the Beam steerable antenna in case of mobile V2V communication [1].

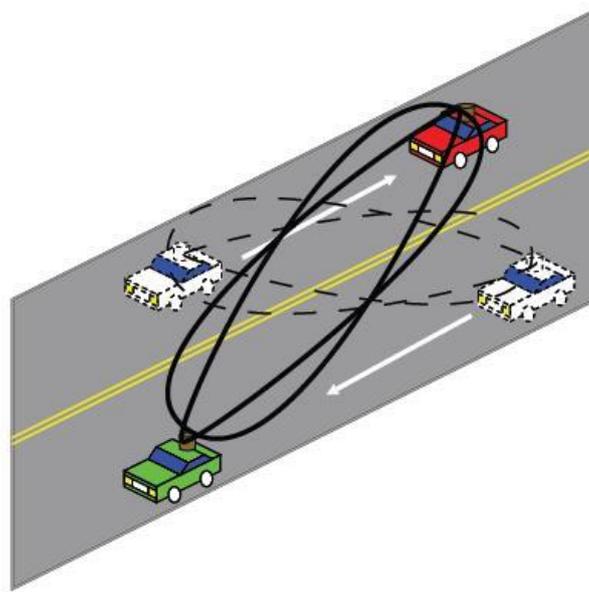


Figure 10: Beam steerable Antenna in mobile V2V context [1].

For this work, directional antenna with fixed sender and receiver position is considered. The look-up table is created with damping rates corresponding to different elevation angles of directional antenna. The look-up table can be created for any antenna. The model [PS14-5500-45¹](http://www.mobilemark.com/shop/category.asp?catid=687) of Mobile Mark antenna solutions is used as reference for creating the look-up table in this thesis. This antenna model can be

¹<http://www.mobilemark.com/shop/category.asp?catid=687>; Date accessed: 05/09/2014

used for intelligent transportation service (ITS) networks using DSRC at 5.9 GHz. The radiation pattern with elevation plot and azimuth plot is shown in figure 11 below.

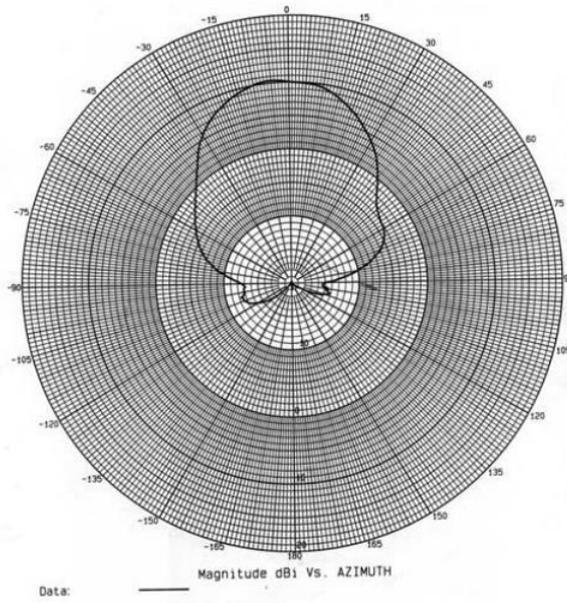
Angle	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°
Efficiency	0.80	0.78	0.70	0.60	0.50	0.45	0.20	0.15	0.12	0.10	0.0

Angle	165°	180°	195°	210°	225°	240°	255°	270°	285°	300°
Efficiency	0.0	0.0	0.0	0.0	0.10	0.12	0.15	0.20	0.45	0.50

Angle	315°	330°	345°	360°
Efficiency	0.60	0.70	0.78	0.80

Table 1: Look-up table for Reference antenna PS14-5500-45

PS14-5500-45 – Azimuth Plot



PS14-5500-45 – Elevation Plot

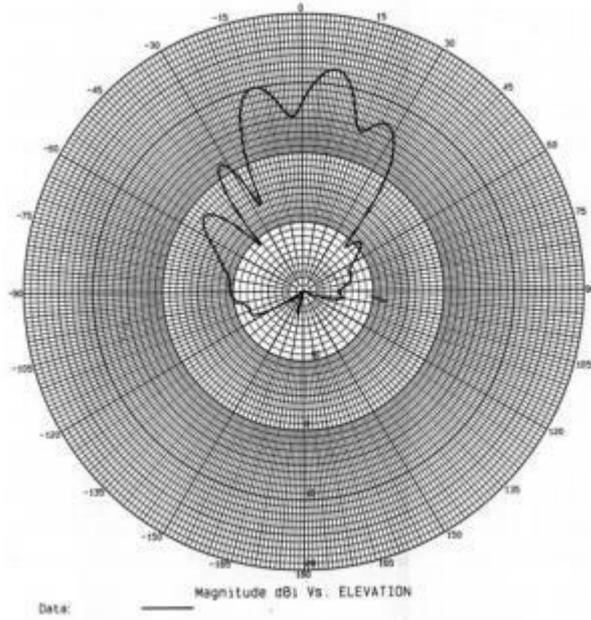


Figure 11: Radiation Patterns

7. Implementation

In this chapter, the implementation of communication model with physical effects of V2V communication in the urban environment is considered. Here the data structures and the functions used in the simulation are described.

The scenery of the urban environment or virtual world is loaded in the simulation. For analysing the virtual world, the computer graphics library Open Scene Graph is used. The use of 3D computer graphics provides an easy solution for investigating the virtual environment.

The 3D virtual world consists of objects like buildings, vehicles and vegetation. The figure 12 below shows the sample 3D urban environment used in the driving simulation. The 3D model is provided in OSG's own file format *.ive.



Figure 12: 3D model of urban environment

7.1 Algorithm

The new communication model considering the physical effects like reflection, diffraction in V2V communication has to be developed. The main idea behind this enhanced communication model is to show the effect of reflection, diffraction in urban environment and possibility to decrypt the sender's message over a large communication range as compared to the communication model in free space. The reason behind the larger communication range is because of the multipath propagation in the urban environment.

1. The sender and receiver are positioned in the virtual environment. In our simulation already existing 3D model, i.e. "*marker.3DS*" as placeholder is used as sender and receiver. Later on in the driving simulation Dominion will provide that information and 3D models of vehicles will be placed there.

2. The intersection node kit (line of sight as intersecting element) is used to determine all the objects between the sender and receiver coordinates. With the help of metadata like object names or identifier, it is possible to classify the objects between sender and receiver.

3. To classify the environment as urban or rural environment, helping points are used for each sender and receiver. In this work additional point's *sender 2*, *senders 3* are used as helping points for *sender 1*. Similarly *receiver 2* and *receiver 3* is used as helping points for *receiver 1*. The helping points are placed to the right and left of the *sender 1* and *receiver 1* respectively.

4. The helping points are moved one meter each time to check if there are any intersections between the sender and the corresponding receiver. If the intersections are found and the intersecting obstacles are buildings then the surrounding environment is classified as urban environment. The process is repeated for maximum of 20 meters to cover broad streets, too.

5. Based on the type of environment around the sender and receiver different radio wave propagation models as described in section 6 are considered. The propagation models are different for both the urban and rural environments.

6. Directional Antenna is assumed on the rooftop of the sender and receiver. The look up table for the antenna is created with different damping factor values for various angles.

7. The power received at the receiver is calculated. The received power threshold is set to -95 dBm. Later on this value will be provided by Dominion.

8. Decision is made based on the received power and threshold power set. If the received power is above the maximum power level, the message transmitted can be decrypted and is considered as transmission success.

The following paragraph gives a more detailed description about the implementation of the algorithm steps.

7.1.1 Function main()

In the main function *int main()*, the *osgDB::readNodeFile()* is used to load geometric models and add them to a scene. There are 45 plugin in the core Open Scene Graph distribution and these provides the support for reading and writing both native and third-party file formats. The Open Scene Graph plugin library *osgDB* automatically loads plugin on demand, using the extension of the file being loaded/saved to determine which plugin to load. In this work two different files are read i.e. “*demo-tile.ive*” and “*marker.3DS*”.The “*demo-tile.ive*” loads 3D virtual environment and “*marker.3DS*” are used to indicate communicating pairs and the helping points in the visualisation.

The position attitude transform *osg::PositionAttitudeTransform()* is a public member function of OSG class and is used to set the position and attitude of sender and receiver. The position of sender and receiver is a 3D vector coordinates declared as *OSG::Vec3 sender*, where the variable *sender* is a three-dimensional coordinate represented as (x, y, z). Quaternion class *OSG::Quat()* is used to represent an orientation in 3D space.

7.1.2 Function LineIntersection()

This function is used to determine the objects in the line of sight between the sender and receiver. The objects in virtual environment include buildings, vegetation, infrastructure and vehicles. For our communication model with urban canyon effect, buildings are taken into account as they have major impact on the communication. Other obstacles like vegetation and vehicles are neglected but could be considered the same way if necessary.

In the given virtual environment, buildings are further classified as small buildings, large buildings, buildings with shops, buildings with residences etc. This function also returns the intersection coordinates of obstacles. The objects classified are named as *BldShopSingle02*, *BldResSingle10*, *Bld*, *db*, *BldResSingle12*, *Fence*, *external object exlo*, etc.

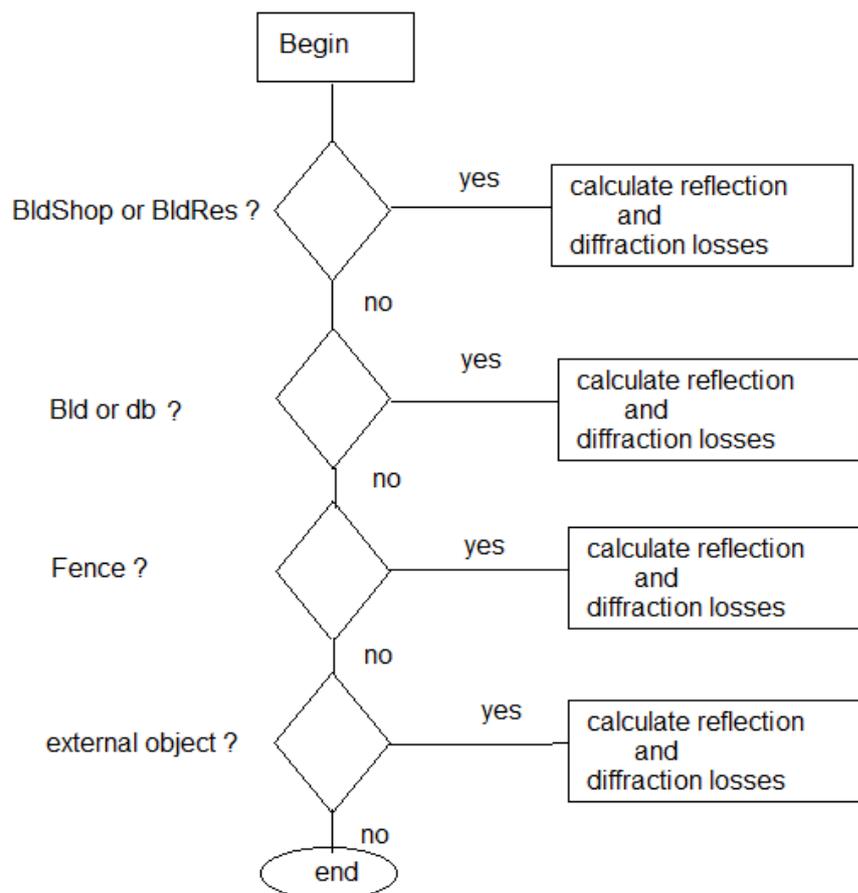


Figure 13: Flowchart for object classification

Based on the type of intersection between the sender and receiver, the surrounding environment is classified as urban or rural area. If the intersecting objects between sender and receiver are buildings, then the environment is considered as urban environment, otherwise the environment is rural. The reflection and diffraction losses are calculated for the urban environment in order to calculate the power received due to urban-canyon effect at the receiver.

7.1.3 Function FindNamedNode()

Model files can contain number of different nodes that allows users to update or articulate parts of the model. The function *FindNamedNode()* is a recursive function that accepts two arguments: a string to search for and a current node from which to start a search. The function checks if there is a valid (non-NULL) node, if there is a null node the function returns *NULL*. If there is a valid node, the function checks whether the node is same as search name passed as a function argument, if yes the function returns the current node. If the node is valid node but not the one looking for then traverse through the hierarchy from bottom to top i.e. from leaf node to parent node. If there is a match return the current node otherwise the function returns *NULL*.

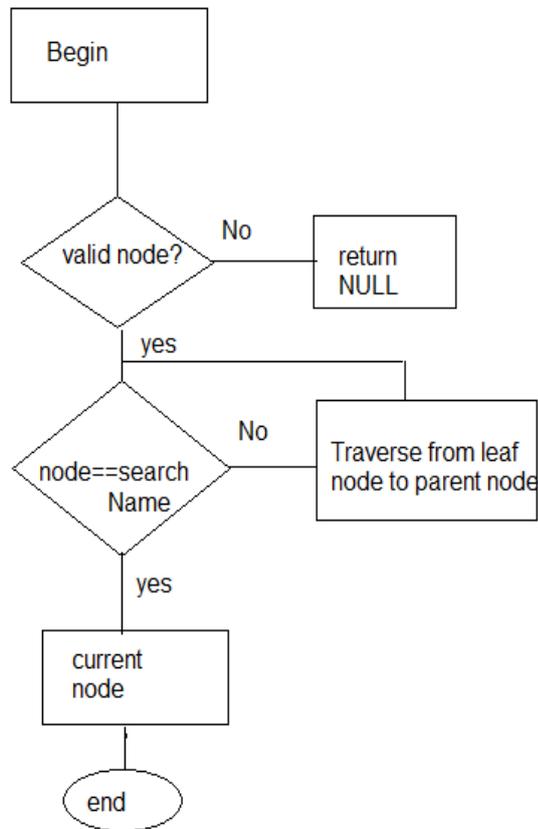


Figure 14: Flowchart for search Node

7.1.4 Function reflection()

This function defines the “two-ray ground reflection model” as described in section 6. When the intersecting objects between the sender and receiver are buildings and the surrounding environment is classified as urban environment, the function *reflection()* calculates the path-loss due to reflection from buildings. In the thesis, single intersection reflections from buildings are assumed as it has more dominating power compared to multiple intersection reflections.

7.1.5 Function diffraction()

This function defines the “knife-edge diffraction model” as described in section 6. When the link between the sender and receiver are classified as non-line-of-sight

(NLOS) and the surrounding environment is urban environment, the function *diffraction()* calculates the path-loss due to diffraction from buildings.

7.1.6 Function totalReceivedPower()

This function calculates the power received due to reflection and diffraction from the surrounding urban environment. The received power is measured in dBm.

7.1.7 Function lookup(int)

This function introduces the directional antenna on the roof top of sender and receiver. The look up table is created for different orientation angles as described in table 1 of section 6. The function *lookup(int)* makes a function call for look up table with orientation angle as its integer argument. The look up table returns the maximum power efficiency based on the orientation angle.

7.1.8 Traversing the Scene graph

The function *LineIntersection()* gives information about the intersection co-ordinates of the obstacle, but doesn't give information about the type of obstacle. In this work it is very necessary to understand the type of obstacle between sender and receiver.

Since scene graph is a hierarchical graph of nodes with root nodes and leaf nodes and to retrieve the nodes of interest (obstacles like buildings as nodes), it is therefore necessary to traverse the hierarchy of scene graph. The figure 15 below shows the sample hierarchy of nodes in 3D model.

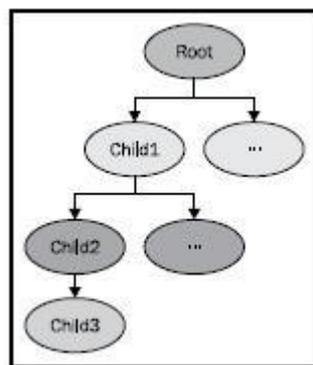


Figure 15: Hierarchy of 3D model [3].

The *osg::Group* type represents the group nodes or root nodes of an OSG Scene graph. It can have any number of child nodes including *osg::Geode* leaf nodes and other *osg::Group* nodes.

In the 3D model used in this work, the obstacles of interest like buildings are the group nodes and the intersecting co-ordinates returned by function *LineIntersection()* points towards the geometrical nodes or leaf node of the group. To understand the type of obstacle, it was necessary to traverse the hierarchy from leaf node to group node. Therefore the function *FindNamedNode()* is used.

In function *FindNamedNode()*, the method *getNumParents()* is used. This method is a built-in function which returns the total number of parents. If the node has single parent, it returns 1. A node without parent node will return 0. The method *getName()* is then used to return the name of a parent node, which is the type of obstacle in this case.

The above method is one way of traversing the scene graph. The visitor pattern method is alternative way that can be used to implement the traversals.

7.1.9 Pickup Handler

The Pickup handler functionality allows users to the mouse over portion of rendered scene and clicks a button. There are three main steps required to perform these kinds of actions.

Firstly, event handlers are used to receive mouse events. For example, a mouse push event comes along with X and Y positions of the cursor, which are the most important factors of picking operation.

Secondly, it is necessary to determine which part of scene graph is under the mouse cursor. This can be done by using intersection tools provided by *osg::Util* library. The result is set of intersections that include the picked Drawable, the intersection point and so on.

Finally, Intersection results are used to achieve goals of picking up objects [3].

In this work reference position co-ordinates are necessary to set the position of sender, receiver and also its helping points. The pickup handler provides the position co-ordinates. Similarly position of other objects can be obtained using pickup handler.

8. Results

In this section the results of the prototype communication model are analysed based on the power received at the receiver due to urban canyon effects. The comparison of urban canyon effects with free space propagation is also performed.

In order to verify the proper operation of prototype, a common scenario was designed to simulate variety of applications. Through the diverse landscape the need for suitable simulation environment for free space and urban canyon effects should be employed.

The figure 16 below shows the console output under the condition of free space propagation or direct line of sight. Here the distance between the sender and receiver is maintained at 200 m. The notification “Intersection not found” indicates that there are no obstacles between sender and receiver as a result of which the notification “No urban canyon effect “is displayed. The console output illustrates the positions of *sender 1* and *receiver 1* and the helping point’s *sender 2*, *receiver 2* and *sender 3*, *receiver 3*.The 3D scene for the above scenario is shown in Figure 17.

The graph in figure 18 illustrates the free space propagation wherein the received power decreases with increase in distance between sender and receiver. For a free space propagation or direct line-of-sight (LOS) situation, the reflection from ground surface is neglected.

The antenna parameters considered for the simulation are as follows.

- Gain of transmitting antenna: 2
- Gain of receiving antenna: 2
- Power of transmitting antenna : 20 dBm
- Height of transmitting antenna: 1.5 m
- Height of receiving antenna : 1.7 m

```
C:\Users\hpb world\Documents\Visual Studio 2010\Projects\osgtest5\Release\osgtest5.exe
Unknown Chunk: ***UNKNOWN*** (0xA08A)
distance between sender and receiver :200
Intersections not found
No Urban Canyon Effect
Sender:360.567 215.029 1
Receiver:160.567 215.029 1

Intersections not found
No Urban Canyon Effect
Sender:360.567 216.029 1
Receiver:160.567 216.029 1

Intersections not found
No Urban Canyon Effect
Sender:360.567 214.029 1
Receiver:160.567 214.029 1

Press any key to continue . . .
```

Figure 16: Console output of direct LOS



Figure 17: 3D Scenario of free space

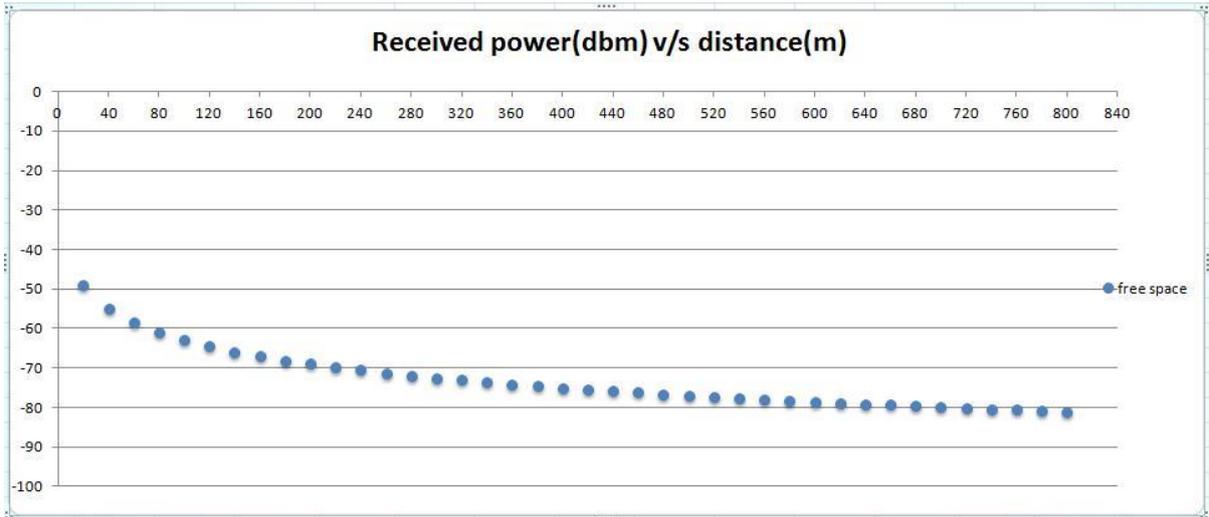


Figure 18: Free space propagation.

When a NLOS links or an intersection exists between the sender and receiver, the console output of the simulation is divided into three parts. First, all the intersections are calculated in Cartesian co-ordinates which were detected between the sender and receiver. Second, the type of intersections is determined and lastly all the output parameters of the propagation models described in section 6. The figure 19 below shows the console output of the NLOS links.

```

Intersections Found
Object:db
    world coords vertex<350.646 199.029 1> normal<-1 0 0>
power received due to reflection :7.06277e-011
diffraction parameter: 34.3688

Object:db
    world coords vertex<348.429 199.029 1> normal<1 0 -0>
power received due to reflection :7.12738e-011
diffraction parameter: 31.3834

Object:db
    world coords vertex<338.429 199.029 1> normal<-1 0 0>
power received due to reflection :7.31766e-011
diffraction parameter: 24.2205

Object:db
    world coords vertex<334.898 199.029 1> normal<1 0 0>
power received due to reflection :7.35935e-011
diffraction parameter: 22.8074

```

Figure 19: Console output of NLOS links with intersection co-ordinates

```

Number of intersections: 5
principle edge diffraction parameter:20.1064
Transmitter to principle edge diffraction parameter:22.8074
principle edge to receiver diffraction parameter:0
power maximum7.43955e-011
path loss due to reflection in dB: 91.2845
path loss due to diffraction in dB:86.2915
total received power due to reflection in dbm :-72.2536
total received power due to diffraction in dbm :-67.2606
Information::The message can be decrypted
Urban canyon effect exists
Sender:360.567 199.029 1
Receiver:160.567 199.029 1
Press any key to continue . . .

```

Figure 20: Console output of NLOS links with propagation output parameters

The amount of power transmitted and received is largely dependent on the directional antenna mounted on the roof top. In this thesis, the power received due to reflection and diffraction is evaluated at three different orientation angles i.e. 0°, 30°, 60° of directional antenna. The look-up table described in table 1 of section 6 is considered. The console output in figure 19 and 20 corresponds to the orientation angle 0° of antenna. The simulation graph in the figure 20, 21, 22 below shows the power received due to reflection and diffraction at different distances between sender and receiver with orientation angle 0°, 30°, 60°.

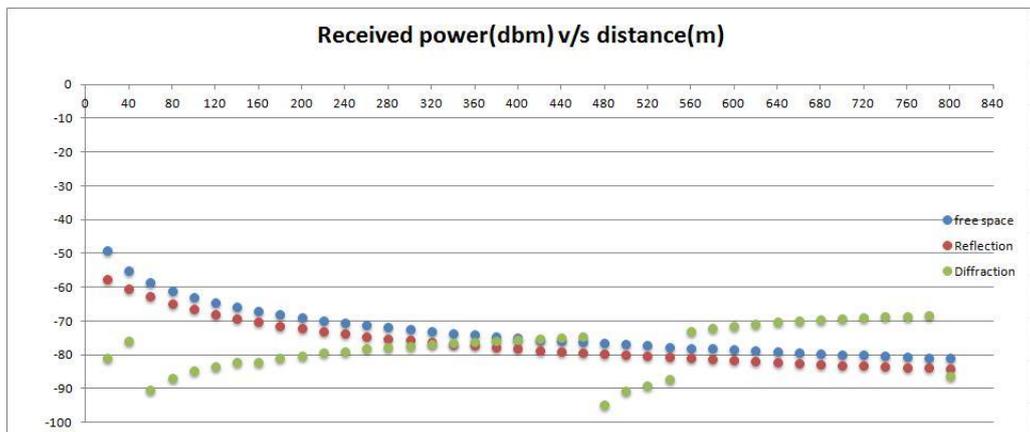


Figure 21: Urban canyon effect with orientation angle 0° of antenna

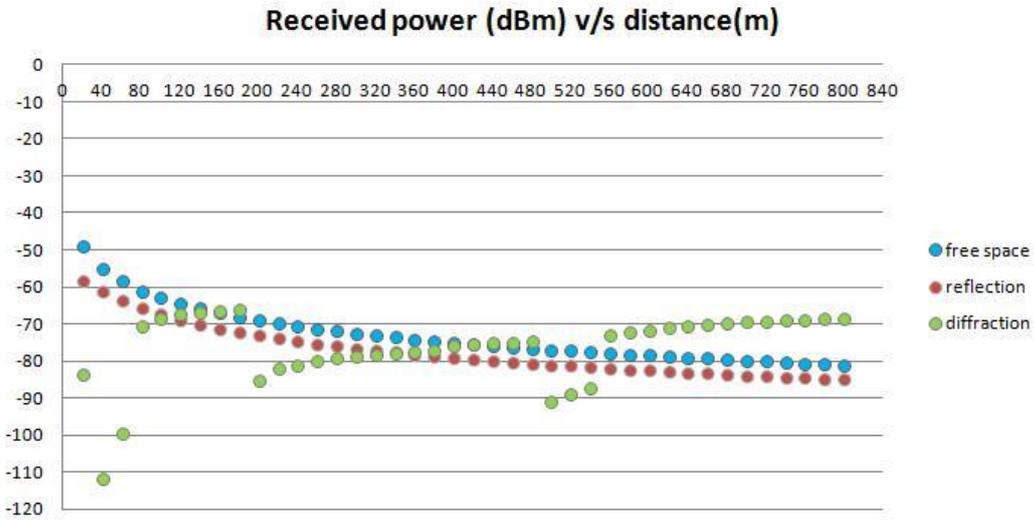


Figure 22: Urban canyon effect with orientation angle 30° of antenna

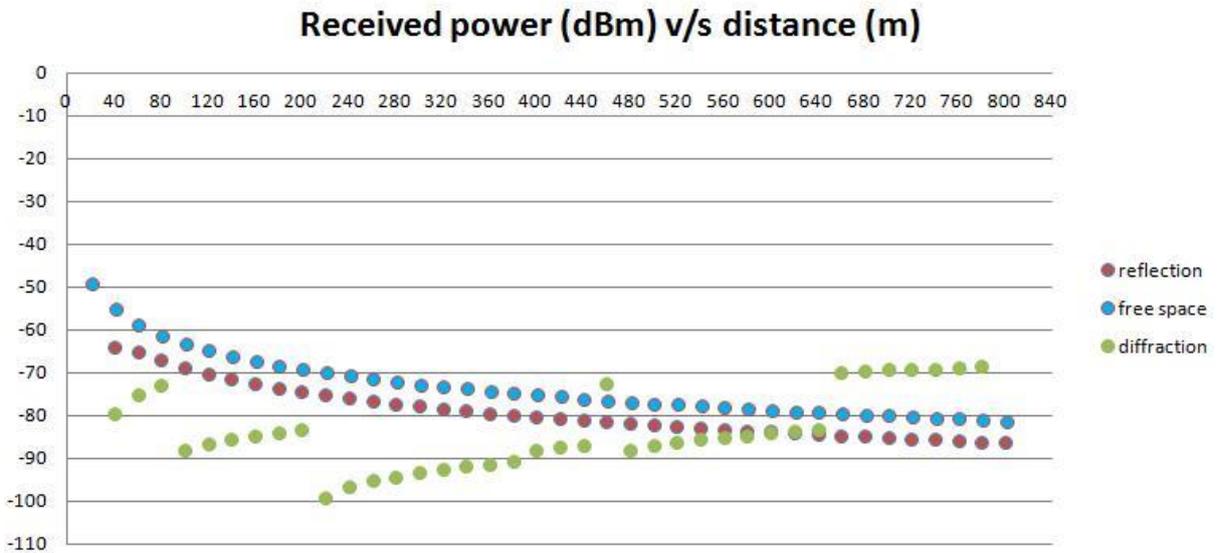


Figure 23: Urban canyon effect with orientation angle 60° of antenna

Once the direct LOS is obstructed by buildings, reflections and diffractions become predominant propagation mechanisms. Figure 21, 22, 23 shows the distinct transitions in the received power as the communicating pairs move from direct LOS to NLOS situation. The amount of power received due to reflection and diffraction reduces with increase in the orientation angle of directional antenna.

The average difference between power received due to free space and power received by reflection is around -3 to -6 dBm. The same is not true for diffraction effects, as the power received depends on the height of obstacle and its distance between the sender and receiver.

For 5.9 GHz carrier frequency of IEEE 802.11p, wavelength of 0.051 m, the receiver power threshold is set to -95 dBm. From the above graphs, it is evident that maximum possible messages can be decrypted with receiver threshold power of -95 dBm. Therefore, a notification “message can be decrypted” is displayed on the console output.

9. Summary and Conclusion

The vision of V2V communication in general fascinated most of the researchers in the automotive industry. Current standardization activities are based on yet to be developed IEEE 802.11p technology. Future vehicles will have an opportunity to exchange information among themselves, road sensors and traffic signs by vehicular ad-hoc network.

Car 2 Car is now a consortium of 60 members. The vehicle manufacturers including Volkswagen, BMW, Renault, Audi, Volvo, Daimler have been joined by 17 technology suppliers such as Swarco, NEC, Continental, Bosch and Denso corporations plus 30 academic institutions and research organisations including DLR. Further still Car 2 Car is by no means a sole industry group in European V2X developments [8].

In this thesis a computationally inexpensive prototype communication model for the physical effects in urban environment is presented. This model allows to estimate the signal attenuation and power received as a result of propagation effects like reflection, diffraction in the urban environment due to obstacles like buildings.

Compared to more complex geometry-based models like ray-tracing, the proposed prototype model is beneficial in terms of:

- Computational complexity, since it performs only a subset of complex calculations required for full ray-tracing model.
- Reduced requirements for geographical information as the required information is limited to the outlines of buildings and trees.

To determine the power received at the receiver, various propagation models are used as described in section 6. The directional antenna at the roof-top is also considered to take the direction of communication into account.

The implementation of this prototype communication model is done using C++ Visual Studio IDE and open source graphics engine Open Scene Graph. The results and the analysis are carried out in section 8.

As an enhancement to the current work, it is possible to evaluate the urban canyon effects with sender and receiver in motion wherein the environment around the sender and receiver changes with every timestamp. The effect of vehicles as an obstacle between the sender and receiver can also be modelled as the vehicles are the major source of diffraction. Since the application prototypes are developed in modular form, it is possible to integrate easily the future applications and expansion of existing simulation.

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