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INTEGRATION OF RAIN FADE INTO OPNET

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Abstract

OPNET is one of the widely used modelling and simulation software packages in the telecommunications industry for planning, design, and research and development. In the wireless modeller module, it uses common propagation models to model radio propagation. It is also possible for users to include their own custom made propagation models to run as part of simulations.

This dissertation covers the study done to integrate rain fade into OPNET by including in one of the propagation models, the ability to access channel information from an external file and using the data to calculate attenuation along the simulated radio path.

First the operation of OPNET is summarised, and a simulation model is developed to demonstrate some functions and results available when performing studies with the software.

Synthesised fine scale rain fields data, for use as the channel model data, was created. The measurement data was obtained from the Chilbolton Radar Interference Experiment, CRIE, which was made over a period of two years (1987 – 1989) at Chilbolton Advanced Meteorological Radar (CAMRa) station.

Then, the free space propagation model available in OPNET was modified to read rain fade time series data from an external file, and to use the data to scale radio signal levels between transmitter and receiver models in simulations. Shared libraries to enable the running between OPNET and the customised propagation model were to be created, but due to limited time, these were not completed. Hence the customised model was not tested in OPNET.

It is presented, as recommendations for future work to further explore the capabilities of OPNET, and to complete the creation of the shared libraries not achieved in this project, and finally to test the propagation model with rain fade by investigating the availability of route diverse radio link implemented as a Fade Mitigation Technique.

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Contents

Abstract.....	i
Acknowledgements.....	ii
List of figures.....	v
List of abbreviations.....	vi
Chapter One – Project Introduction.....	1
1.1Project objectives.....	1
1.2Limitation of the project.....	2
1.3Report structure.....	3
Chapter Two - Modelling & Simulation, and OPNET.....	5
2.1Introduction	5
2.2Modelling and Simulation.....	5
2.2.1Advantages and Limitations of M & S.....	6
2.2.2Commercially available simulator packages.....	6
2.3Overview of OPNET modeller.....	7
2.3.1Structure of OPNET network element models.....	7
2.3.2The wireless component of OPNET modeller.....	9
2.3.3Simulation.....	9
Chapter Three - Radio propagation, attenuation and rain fade models.....	11
3.1Introduction.....	11
3.2Radio wave propagation and attenuation.....	11
3.3Rain fade in radiocommunication systems.....	12
3.3.1Rain drop size characterisation.....	13
3.3.2Rain rate characterisation.....	13
3.3.3Rain drop shape characterisation.....	14
3.3.4Rain fade dynamics.....	14
3.4Rain attenuation and rain fade models.....	15
3.4.1The Rec. ITU-R P.530-12.....	17
3.5Rain fade time series data from meteorological radars.....	18
3.5.1Meteorological radars.....	19
3.5.2The Chilbolton Advanced Meteorological Radar (CAMRa).....	20

3.5.3	Fade mitigation techniques.....	20
Chapter Four –	Project execution	21
5.1	Radio link model creation.....	21
5.1.1	Antenna module.....	22
5.1.2	Pointing processor	22
5.1.3	The transmitter and receiver node models.....	23
5.1.4	The network model.....	23
5.1.5	Packet generation and receive error model.....	26
5.1.6	Results collection set up and running simulations.....	26
5.1.7	Specifying results to be collected running the simulations.....	26
5.2	Generation of rain fade time series.....	26
5.2.1	Removal of advection.....	27
5.2.2	Rain field downscaling.....	27
5.2.3	Calculation of rain attenuation time series.....	28
5.3	Radio propagation models.....	28
5.3.1	Using channel data in the propagation model	29
Chapter Five -	Study results and discussions.....	32
5.1	Working with OPNET, modelling and simulation	32
5.2	Rain fade time series data.....	34
5.3	Integration of customised model into OPNET.....	35
5.3.1	Customisation of the propagation model.....	35
5.3.2	Shared libraries creation and rain fade simulation.....	35
5.4	Rain fade in route diverse links.....	36
Chapter Six –	Conclusions and future work.....	37
5.5	Summary of study conclusions.....	37
5.6	Future work on the project.....	37
Appendix A –	Creation of OPNET module models.....	39
Appendix B –	Code included in free space propagation model.....	50
References.....		52

List of figures

Figure 1: Antenna radiation pattern model.....	22
Figure 2: Transmitter and jam node model.....	23
Figure 3: Receiver node model.....	23
Figure 4: Schematic of a route diverse link.....	24
Figure 5: A dual route radio link model.....	25
Figure 6: Links on a rain data map.....	28
Figure 7: Propagation model program flow.....	30
Figure 8: BER and packet throughput for tx_1 in model in Figure 5.....	32
Figure 9: BER and packet throughput for tx_2 in of model in Figure 5.....	33
Figure 10: An example packet history for the simulation on model in Figure 5.....	33
Figure 11: attenuation graphs.....	34

List of abbreviations

1. ATPC: Adaptive Transmit Power Control
2. BER: Bit Error Rate
3. CAMRa: Chilbolton Advanced Meteorological Radar
4. CPU: Central Processing Unit
5. CRIE: Chilbolton Radar Interference Experiment
6. DSD: Drop Size Distribution
7. e.i.r.p.: Effective Isotropic Radiated Power
8. ECC: Error Correction Code
9. ECMWF: European Centre for Medium Range Weather Forecast
10. FMT: Fade Mitigation Technique
11. ITU – R: ITU Radiocommunication Bureau
12. ITU: International Telecommunications Union
13. LOS: Line of Sight
14. LPD: Log Poisson Distribution
15. M&S: Modelling and Simulation
16. OPNET: Optimised Network Engineering Tools
17. PER: Packet Error Rate
18. R&D: Research and Development
19. RMD: Random Midpoint Displacement
20. SES: Severely Errored Second

Chapter One – Project Introduction

Communication systems and network developers nowadays use simulators to gain insight into the behaviour of their products and networks before committing time, and other resources to the physical objects they are designing.

A number of simulation software packages exist in the market, each with its strong and weak points, mainly because they were designed with specific goals in mind, to solve certain problems. One of these packages, which is widely used in the telecommunications industry, and Research and Development (R & D), is OPNET.

The software consists of a comprehensive variety of tools that can be used to study behaviour and performance of telecommunications network nodes, modules and processes. In the radio module, it is capable of modelling all the aspect of radio communications. This project aims to explore some the functions available in OPNET.

1.1 Project objectives

The aim of the project is to study the operation of OPNET wireless modeller and apply rain fade in one of its radio propagation models. The modelling of processes, modules, nodes, links and networks is studied. As a demonstration of how simulation can be utilised, the performance of a route diverse link in a rain fading channel is investigated.

The process of the project execution entails:

- learning how to work with OPNET modeller,
- generating fine scale rain fade time series data from Chilbolton Radar Interference Experiment, CRIE measurements done at Chilbolton Advanced Meteorological Radar, CAMRa to model radio channel rain fade
- understanding C programming language code and modifying the free space propagation model to include rain fade as modelled with the time series data from an external file

- run simulations of a route diverse link to study the impact of rain fade on the link availability

To simulate the impact of the rain fade on the radio channel, the propagation model available in OPNET is modified and used to import rain fade time series data from an external file and the data used to model the link radio channel.

The ITU-R P.530-12 is a rain fade model, recommended by International Telecommunications Union (ITU) that provides a method to predict the signal fading experienced by Line of Sight (LOS) microwave links as a result of precipitation. However, the prediction is limited to only one hop in a link and does not provide any indication for the availability of either multi-hop or route diverse links, which are deployed as Fade Mitigation Techniques (FMT). It is desirable to have an idea of the availability of links with a number of hops, and those that are route diverse at the receive end.

The project attempts to characterise the availability of a route diverse microwave link, by simulating two paths of the link when exposed to rain and, from the information data quality at both receive points, calculate the overall availability of the link.

1.2 Limitation of the project

The OPNET simulation package is extensive in the number of functions and details of the systems it covers for simulation. It therefore requires a lot of time to appreciate the operation of the modules.

The project period is little more than 10 weeks, which is a short time. As a consequence, the project focuses only on the learning and creation of a radio network (fixed link) within the wireless modeller, its parameters' setup, simulation and collection of results.

The programming language used to create the model, C, is new to the researcher, and therefore imposes further limitation on the time as some appreciation of the language has to be developed before it can be put to use.

Finally, the online help available from OPNET Technologies was not accessible as the subscription fees for the service was in excess of the project budget. This implies

a slower pace in learning the software and limits the width of coverage of functions within the project period.

1.3 Report structure

In chapter two, modelling and simulation are summarised, emphasising the benefits of their application in R & D, planning and designing of telecommunications network modules and complete networks. The final part of the chapter deals with the specific modelling and simulation package, OPNET, that is discussed to some detail, and its properties are summarised.

Chapter three deals with radio wave propagation and attenuation which leads to the investigation of rain fade in telecommunication radio links. The discussion forms a prelude to the subject of rain fade models, and finally the ITU-R rec. P.837.12 that models the rain fade for microwave LOS links. Further, development of rain fade time series data from meteorological radars for use in modelling radio channels in rainy environments is looked at. The rain fade time series data finds lot of application in developing FMT.

Chapter four describes procedures followed to execute the project. The creation of the various sub-components of modules and processes in OPNET is summarised, and the details of customising the free space propagation model to include rain fade is addressed. The last portion of the chapter relates the procedures followed in the execution of the simulations undertaken in the study project.

Chapter five presents the results and achievements of the project and discusses the implications of the findings. The learning acquired and practical insights on the concepts dealt with in the investigation are put into perspective. The outcome of the demonstration study of obtaining results is also outlined.

In chapter six, conclusions and suggestions for future work on the development of the subjects studied in the project are advanced.

Chapter Two - Modelling & Simulation, and OPNET

2.1 Introduction

Usually, software simulation packages are utilised during the planning and design stages of communication systems to learn the response of the system performance to changes made on particular parameters. This chapter explores the field of Modelling and Simulation, and then discusses the specific package of interest in this project, OPNET.

2.2 Modelling and Simulation

Modelling and Simulation (M & S) is a tool designed to evaluate the performance of a system, either existing or proposed, and can be used to study the effects on performance of different configurations of a system. The process is useful to gain insight into the behaviour of complex systems. A model of sets of inputs, algorithms and routines which define the behaviour of a system is first created. Simulation represents the execution of the model. The user defines the inputs and, through simulation outputs such as bit error rate (BER), packet error rate (PER), and throughput are obtained to get insight into the system performance.

M & S is a critical element in the design and development, and test and evaluation (T & E) of a network product or solution. It is preferable to have insight into the behaviour of an algorithm or device to see how it will perform in the real world before deployment or production.

In network design, it is important to ascertain that the introduction of an element into a system will not have unintended consequences. Due to the growing complexity of communication networks, the role of M & S is expected to grow rapidly in the future as Burbank notes. The reason for this is the nature of present systems that have distributed functional subsystems which operate as a whole, and which cannot usually be tested in isolation since the system level performance is often of primary interest.

2.2.1 Advantages and Limitations of M & S

M & S avails the ability to exercise scenarios not easily achievable through empirical methods. Through M & S, it is also possible to test system sensitivity and tune performance. These have the advantage of allowing engineers to study the design without incurring too much cost and time building a physical test network and . The reduced cost and time also offers an opportunity to systems learners to have a better experience, by working with the visualised structures of systems and protocols as implemented in simulation packages.

The results of M & S should, however, be treated with caution. The reason for this is that the model is fundamentally not real. The simulation results are only a function of the aspects of the model and the degree of detail to which the model delves into defining the aspects. The effects of other elements not addressed in the model have to be catered for somehow in the analysis and use of the M & S results .

The other very realistic obstacle is the availability of the software. The cost of purchasing and maintaining licences can easily run into tens or even hundreds of thousands of pounds depending on the number of users (licenses), and the elements included in the package. This cost factor limits access for learners who would otherwise gain from practising communication protocols, systems and design aspect that the simulation packages present a little nearer to reality, as opposed to the theoretical treatment that is dispensed in the classroom.

Further, after M & S, empirical testing is still necessary. Analytical models, prototyping, laboratory and field tests must be carried out to ensure a successful design .

2.2.2 Commercially available simulator packages

Simulation modelling is becoming popular for network performance analysis. Many simulation software packages exist in the market, e.g. REAL, NS-2, etc, each with its specific strong performance point. An effective simulator is built in a modular and hierarchical format, as well as having graphical capabilities .

OPNET has become one of the most widely used software simulation packages in industry and learning institutions (with reduced capability and maintenance costs). It

is object-oriented and meets all the requirements of an effective simulator. It provides comprehensive development environment for the specification, simulation and performance analysis of communications networks .

Comparison studies have been made by [Garrido](#) between the performance of NS-2 and OPNET, which showed generally similar results. However, OPNET has been so taken up in the Research and Development (R & D) as it has a detailed approach that allows the building of complete networks for investigation.

2.3 Overview of OPNET modeller

OPNET, short for Optimised Network Engineering Tools, is a vast software package, covering almost all aspects of communications networks and systems. The focus of this discussion shall be very limited, attempting to touch only on the subjects that will be applicable in the study ahead.

With OPNET, models of physical layer link transceivers, antennas, CPU that runs processes to manage queues or running protocols can be constructed. Using OPNET programming, any protocol packet format, state transition machines for processes running protocols, process modules and transceiver modules for each device node can be defined. The network can then be assembled by connecting the device nodes together using user defined link models .

The environment provides a logical structure built on hierarchical models to achieve a system that can allow the simulation of complex and large networks.

The installation of OPNET involves a straight forward procedure. The small hurdles experienced mainly had to do with the operating system security, which blocked some of the software functionality. However, having appropriately set the security procedures, the software has a guiding installation process.

Further, the system environment settings should be appropriately configured to link the external compiler for execution of some processes during simulations. The settings are available in OPNET tutorials literature.

2.3.1 Structure of OPNET network element models

Two fundamental methods comprise the description of structures in OPNET models.

These are the *objects* – physical representation of network elements, and *procedures* – behaviour description of the network elements.

Objects in OPNET represent structures of communications networks. This concept also applies to substructures that represent the internal decomposition of the objects which can be referred to as sub-objects. Sub-objects operate together to achieve some functionality that forms a characteristic of the main object. Some objects are non-physical, and include elements like processes, packets, timers, etc. They usually do not have a visual representation in OPNET schematics.

Models are used to define object characteristics. Any change to aspects of a model effects change to all object aspects inherited from the model. However, other variables in objects are parameterized and exposed for modification by users. Therefore, objects of the same model can be different.

Objects have private and exposed characteristics. The private characteristics are hidden away from the user and cannot be modified. The exposed characteristics are known as *attributes*, and can be associated with the whole model, a class of objects, or one particular object. With the use of attributes, users can provide information, specify general characteristics, select behaviours, or modify internal structures for models and objects. Attributes can assume different data types, i.e. logical, numerical, text, etc.

The specifications of objects in the Node are defined by the Process which is the hierarchical component below the Node .

The modelling process in OPNET consists of first creating a project. The project has a scenario in which the topology, traffic, and results and reports to be collected are specified. The simulation is run and results are viewed within the scenario .

Within the project, it is possible to change settings, re-run the simulations and compare the results to learn the impact of the changes.

In general, in building a test model in OPNET, one can specify the functionality of the units he/she wishes to emulate in a network situation. From network nodes, the modules that constitute the nodes, and down to software controlled processes.

Moreover, one can use models of many commercially available network components, from major hardware manufactures which OPNET has in its libraries.

2.3.2 The wireless component of OPNET modeller

For simulation of radio networks, OPNET uses the Wireless Modeller. The module has all the aspects necessary to simulate the various radio network systems, i.e. fixed, mobile and satellite stations.

2.3.3 Simulation

OPNET simulations are event-driven. Events are activities that occur at certain times and when an event occurs, OPNET simulation time advances. This has a number of advantages over real time simulation. The accuracy of the results is not compromised as a result of limited sampling resolution. Also, simulation is time efficient as there are no moments when there is nothing happening.

The radio link

Packets are broadcast and replicated for each of the selected destinations. The packets are then analysed and modified independently in accordance with the transmitter – receiver link path conditions.

In OPNET, the radio links are not visible in the network model. The links are dynamically created during simulation. To establish a link between transmitter and receiver channel pair, many physical characteristics of the components involved and time-varying parameters have to be taken into account .

Connectivity

Since radio links depend on dynamically changing parameters, the transceiver pipeline must evaluate the possibility of connectivity between transmit and receive channel for each transmission. This evaluation considers elements like location of nodes (receivers and transmitters), separation distance between the nodes, and direction of travel of signal (as determined from antenna directivity). For mobile and satellite nodes, the location and related parameter normally change continuously as per the defined trajectory.

The relative positions of the transmitter and receiver nodes to each other also play

an important part in deciding the connectivity possibility. If there is an obstructing object or earth's surface between them, the source and destination nodes are occluded, no connection can be created and, depending on the propagation model in use, the simulation terminates. With no obstructing objects, the link closure exists and the link simulation goes ahead.

The simulation also calculates the propagation delay and path loss of the signal. The delay is determined from the distance separating the source and destination, and the speed of the signal, taken to be equal to that of light. The path loss assumes the free space model and which the loss is taken to be directly proportional to the inverse of the distance squared. The model can be changed by taking one of the many included or importing one defined by the user.

The power of the signal also depends on the antenna directivities. OPNET simulations take into account transmit and receive antenna directivities in determining transmitted (e.i.r.p.) and received power .

Simulation efficiency

Due to the huge number of calculations that wireless simulation involves, it can be quite time consuming. Therefore, the OPNET wireless module provides methods to mitigate the time required to run the simulations. One can choose to execute pipeline stages in parallel, reduced the number of pipeline calculated, reduce the number of site positions and/or duplicate packets for receivers that can actually receive them .

Chapter Three - Radio propagation, attenuation and rain fade models

3.1 Introduction

Radio waves used for information transmission in electronic communications systems experience attenuation and distortion as they travel through space between the sending and receive points. One of the major tasks confronting communications systems design engineers is the design of fade and distortion mitigation techniques to maximise the capacity of information carrying systems.

During the planning of a radio transmission system, proper allowance has to be made for attenuation processes so that they do not completely suppress the information transmission. The radio link power budget is calculated to establish the required transmit power given the receiver sensitivity and the envisaged extent of the signal attenuation along the propagation path.

The discussion that follows looks at the general causes of radio signal fade and distortion. It then focuses on the rain attenuation mechanisms as experienced by radio waves, then touching on the general rain fade modelling approaches. The final portion addresses the model recommended by the International Telecommunications Union (ITU), Rec. ITU-R P.530-12, which provides mechanisms for prediction of rain fade in the planning of line of sight microwave links.

3.2 Radio wave propagation and attenuation

Before delving into the dynamics of rain fade, it is important to briefly discuss the way radio waves in the microwave frequencies propagate and the likely causes of degradation they may suffer as they travel.

In the microwave region, radio frequencies of 1 GHz to 300 GHz, the propagation of waves is predominantly LOS. Unlike at lower frequencies, ground reflections are less pronounced because the ground roughness is greater compared to the wavelengths at these frequencies . However, as Collin further notes, over smooth

surfaces, and particularly over appropriately large water bodies, reflection interference can become more significant due to stronger specular reflection components.

The important factors at wavelengths of a few centimetres and under are attenuation and scattering by rain and snow, and by fog, water vapour and other atmospheric gases at even lower wavelengths. Radio waves generally interact with media of similar dimensions as their wavelength. Rain drops diameters range from one millimetre to about 10 mm and these are comparable to the wavelengths of 10 mm for radio waves at frequencies around 30 GHz. Hence, at these frequencies, radio waves suffer extreme attenuation due to scattering by rain.

For microwave terrestrial communications purposes, these are the important factors. However, for space communications systems, such as satellites, elements outside the atmosphere, like the ionosphere, come into play.

3.3 Rain fade in radiocommunication systems

Rain fade refers to the attenuation of RF signals due to precipitation along the path of propagation of the signal. It is one of the dominant causes of radio link outages, especially at high frequencies, around 5 GHz and above where its contribution becomes even more significant.

According to the ITU recommendations, outage can be defined from the duration of sustained sending of wrong bits. Digital data are sent in blocks of bits on bursts of radio emissions. If a bit in a block is incorrectly transmitted, the block is said to be "errored". A time duration of one second is termed Severely Errored if more than 30% of the blocks transmitted within the second are errored. The second is then called the "Severely Errored Second", abbreviated SES. Outage is defined by the period between the first of ten successive SES and first of ten successive non-SES.

Radio links are specified to have outage period caused by rain fade not exceeding a small percentage of an average year, normally 0.01% or 0.1% of the time, and rain fade margin is built into the link budget by estimating the attenuation exceeded for this time. The models are based on available statistics of rain rate measured over a one-minute integration time. They are good for long link, but may underestimate outage for links shorter than 1 km.

3.3.1 Rain drop size characterisation

The attenuation of radio waves due to precipitation depends on the radio system parameters and the precipitation parameters. System parameter include the radio parameters like frequency, polarisation, network parameters like geometry of links, link length elevation, network topology, etc, and precipitation parameters e.g. rain rate and drop size distribution .

Zhang discusses a number of methods to characterise rain drop size distribution. More detailed analysis is done by Laws and Parsons which tabulates the size distributions. Marshall and Palmer proposed an empirical exponential method to characterise drop size distribution. The Marshall and Palmer method is widely used for meteorological and radar applications .

Other rain drop size distribution models include the exponential linked to event type proposed by Josh and Waldvogel , where they split rainfall rate into three categories, i.e. drizzle, widespread and thunderstorm for purposes of characterising their drop sizes; and the gamma distribution proposed by Ulbrich and Atlas .

3.3.2 Rain rate characterisation

The rate at which rain falls is one of the major factors to consider when analysing the impact the rain has on the radio propagation through the rain.

Rain attenuation distribution data are derived from point rain rate statistics. The 0.01 percent exceeded level is generally estimated from at least five years of link rain fade data. For those attenuations that occur with lower probabilities, even more monitoring is required. Locally derived statistics of rainfall rate with a one minute integration time are preferred for calculation of radio signal rain fade .

The key parameter used for rain rate distribution is the rate exceeded for a given percentage in an average year. $R_{p,1}$ denotes an averaged rain rate over a period of one minute and exceeded 0.01 percent of an average year in the geographical region of the radio link . The ITU recommendation Rec. ITU-R P.837-5 provides the annual statistics for the whole world as a function of latitude and longitude derived from numerical weather models.

Two methods are available to calculate rainfall rate distribution for a region. In the

empirical method, the field measurements and recordings over long periods of time are used. Another method employs the use numerically derived weather prediction simulations such as the Rec. ITU-837 and the Global Crane model. The two methods generally yield much different results as shown by Myers .

3.3.3 Rain drop shape characterisation

Due to surface tension, small rain drops remain spherical in shape. But the drag from the air as the drop falls through it, distorts the shape away from spherical. The distortion leads to an oblate spheroid with a flat base. For drops with a diameter of above 4 mm, the base tends to become concave .

The analysis of rain drop shape has been studied for some time and Zhang discusses in some detail the different approaches. One of these is the Pruppacher-and-Pitter model, which is the most favoured in research on calculating microwave rain attenuation. The model predicts the rain drop to change shape from spherical, to spheroidal and to a terminal Pruppacher-and-Pitter shape .

A rain drop is said to be *canting* when its axis is not symmetrical. With strong vertical wind shear, many rain drops will usually have similar canting angles. This results in some exchange of energy between horizontally and vertically polarised waves. It has been suggested that, from cross-polar calculations, the drop falls such that its symmetry axis is parallel to the velocity of the air flow relative to the drop. Links of up to 40 m above ground will have a canting angle of about 5 degrees .

Due the rain drop shape deformation as discussed above, the radio wave propagation is changed. At low frequencies, horizontally polarised waves experience more attenuation and phase shift due to the rather big width of the drop compared to the height .

3.3.4 Rain fade dynamics

To quantify the level of rain fade, it is also important to learn the dynamics associated with rain fade.

The *rain fade slope* refers to the rate of change of rain attenuation and is essential for determining the required tracking speed of fade mitigation techniques. This property

is dependent upon the attenuation level, sample time and climatic parameters .

The *fade duration* indicates the time length during which the attenuation will be above a certain threshold value. It is useful in communications systems where the length of an outage is critical and in the design of fade mitigation techniques which make use of shared system resources .

Frequency scaling of attenuation provides the possibility of predicting attenuation at one frequency using the knowledge of the other measured at another frequency. The scaling can be instantaneous or long-term (statistical). Instantaneous scaling is applicable in mitigation techniques that predict attenuation on a link in real time while the long-term statistical scaling is used for attenuation at one frequency when the statistics at another frequency are known and .

The preceding rain properties and dynamics are used in creating models that help to predict the attenuation that rain impacts on radio signals as they travels through rain and space. Another application is in the implementation of fade mitigation mechanisms meant to minimise signal degradation.

3.4 Rain attenuation and rain fade models

Rain attenuation is dependent upon a number of random time-variant parameters, some of which have been discussed above. In addition to the parameters mentioned above, others include raindrop temperature, spatial variation of rain parameters, wind velocity, etc and . Some insight is available of the impact on rain attenuation as related to frequency and drop size as studied by Tat-soon Yee et al. .

The total attenuation A along a radio path of length L with rain falling, can be evaluated from the equation

$$A = \int_0^L \alpha(r, f) dz \quad (1)$$

(1)

$\alpha(r, f)$ is the total extinction cross section of the particle given by

$$k_{\text{eff}} = k \left(\frac{1 + \cos^2 \theta}{2} + \frac{1 - \cos^2 \theta}{2} \frac{C_{\text{eff}}}{C} \right) \quad (2)$$

C_{eff} is a dimensionless function of scattering angle θ and C is the forward scatter cross-section, .

Specific attenuation is defined as the attenuation in dB per unit length of the propagation path L and is calculated from

$$A_{\text{sp}} = \int_0^L k_{\text{eff}} \rho \, dl \quad (3)$$

The total attenuation can be evaluated from the integral of the specific attenuation as

$$A_{\text{tot}} = \int_0^L A_{\text{sp}} \, dl \quad (4)$$

It is not common that the specific attenuation for a specific path is known, but it can be estimated by transforming the historical point rain rate distribution for the region. The transformation is, however very involving. Many models usually include a factor to reduce the effective path length to allow for the spatial rain intensity. The path-reducing factor, r , depends on path length and rain rate . In the Rec. ITU-R P.530-12, the path-reducing factor is calculated as follows;

The aim of rain fade models is to produce rain fades over an average year. The average can then be refined to estimate the worst month performance. The models are designed to yield results for link rain fade margin and spectrum regulations purposes .

There are two categories of rain fade models. One category is derived from measured or modelled rain field. The other category is derived empirically from measurements on many links situated at different locations.

There are two rain fade models extensively used for in microwave systems design. One is the Rec. ITU-R P.530-12 which is based on the Rec. ITU-R P.837-5 climate maps, or local measurements where these are available, and the

Rec. ITU-R P.838-2 parameters for the specific attenuation calculation.

The other model is the Crane model which is primarily based on the Crane climatic model. It is of particular interest for applications in North America .

3.4.1 The Rec. ITU-R P.530-12

Rain attenuation is a result of a variety of elements, many of which were discussed in an earlier section on Rain fade in radiocommunication systems. The attenuation is also related to other variables with complex relationship. These include.

The total radio propagation loss is a sum of contributions from a number of factors that include attenuation due atmospheric gases, diffraction and multipath fading, arrival and launch angles, sand and duct, and, particularly at frequencies above 5 GHz, precipitation. These factors generally have dependence on frequency, path length and geographical location of the link .

Rec. ITU–R P.530-12 is the ITU recommendation for calculating estimates of rain fade in the design of LOS microwave links. The recommendation makes use of Rec. ITU-R P.837-2 and Rec. ITU-R P.838-1.

Rec. ITU-R P.837-2 provides methods to estimate the intensity of precipitation, R , and information needed for worldwide locations with a range of probabilities, P , for use in the prediction of attenuation and scattering. The model utilises data derived from the European Centre of Medium Range Weather Forecast (ECMWF), collected over 15 years. Using the data (available from the ITU), the various variables can be determined. Having determined the variables, the rain probability, P is calculated, and ultimately, the rainfall rate, R can be evaluated .

Rec. ITU-R P.838-1 provides a method to calculate rain attenuation, from which the specific attenuation can be determined .

The ITU-R P.530-12 model makes use of local sources of long-term measurements. If local statistics are not available, Rec. ITU-R P.837, as summarised above, which evaluates rain rate R exceeded 0.01% of the time, can be used to estimate the statistics. The Rec. ITU-R P.838-1 is then applied to determine the specific attenuation, A_{rain} for the frequency, polarisation and rain rate R .

$$A_{eff} = \int_0^L R(x) dx \quad (5)$$

In view of the fact that the rain does not usually exist throughout the propagation path, the effective path

$$A_{eff} = \int_0^L R(x) dx \quad (6)$$

is evaluated. A_{eff} is derived as follows

$$A_{eff} = \int_0^L R(x) dx \quad (7)$$

where $R(x)$ is the rainfall rate with an integrating time of 1 minute that occurs for 0.01% of the time and L is the path length .

The distance factor can be estimated for different rain rates $R(x)$ exceeded $\alpha\%$ of the time, as specified in .

The path attenuation exceeded for 0.01% of the time is the estimated from

$$A_{eff} = \int_0^L R(x) dx \quad (8)$$

For different latitudes, the estimate for the ratio $R(x)$ can be deduced with the use the criteria provided for a set of percentages, α . Hence the path attenuation exceeded for the $\alpha\%$ of the time, A_{eff} can be calculated.

3.5 Rain fade time series data from meteorological radars

Meteorological radars provide rain rate data for some areas. The data is collected for use in weather and other services and has some crude time resolution. For radio systems optimisation, more accuracy is required on the data, but the measurements of the acceptable accuracy are not available, hence attention has turned to synthesising more accurate rain fields for use in telecommunication systems for their

feasibility and efficiency studies .

3.5.1 Meteorological radars

Meteorological radars collect data used in weather forecasting and warnings for severe weather. These radars measure rainfall using the fact that the amount of power reflected from the space containing rain, and the rain rate are related to the DSD .

In measuring rain, meteorological radar measures an ensemble of targets in the form of rain drops. The power received consists of vector contributions from individual reflected powers from falling hydrometeors. The power varies randomly from radar pulse to pulse as a result of movement of the precipitation within the volume. This becomes independent over periods of 10 ms .

Therefore, meteorological radars have to average several independent samples to achieve a reliable echo estimate from each volume. Within a sample volume, rain drops will yield the same reflectivity whether stationary or falling, and a range of DSD, each with an associated rain rate, will yield the same radar reflectivity.

Many types of meteorological radars operate by estimating rain rate. To verify the estimated values, the rate is compared with local sources such as rain gauges which can also help reveal possible calibration errors in the radar measurements.

Radars calculate rain rate from the reflectivity factor. The reflectivity factor is then converted to rain rate using the power law Z - R relationship:

$$Z = k R^b \quad (9)$$

Z is the radar reflectivity factor, R the rain rate, and a and b constants , .

Various versions of the Z – R relationship exist for different rain types and radars .

3.5.2 The Chilbolton Advanced Meteorological Radar (CAMRa)

CAMRa is a dual-polarisation, Doppler radar operated by the Chilbolton Observatory to collect weather data and, sited in southern England. The dual polarisation nature allows it to alternate between vertical and horizontal polarisation from pulse to pulse.

The data used in this project were acquired from the Chilbolton Radar Interference Experiment, CRIE. The data were collected from 1987 to 1989 and provide detailed samples of rain events experienced in Southern England during the period.

The data were captured in an 18 days on; nine days off cycle, with CAMRa scanning both horizontally and vertically every 10 minutes over a 50 degree horizontal sector and a range of up to 160 km .

3.5.3 Fade mitigation techniques

Most radio link system mostly operated at low frequencies whose performance was not adversely affected by rain. But the requirement for more bandwidth in modern wireless technologies has dictated either more spectrum efficient technologies or higher frequencies, which happen to be more prone to rain fade, be used .

Fade mitigation techniques seek to compensate for rain attenuation. There are a number of approaches to achieve the mitigation, and these include the Adaptive Transmit Power Control (ATPC), and diversity methods. In ATPC, the transmit power is increased dynamically in response to the level of attenuation being experienced. Diversity techniques utilise different sites or routes, placed far apart for better de-correlation, so that the link traffic can be switched through the node experiencing the least fading.

Synthesised spatial and temporal varying rain fields can be produced from meteorological radar measurements, which may also be customised for different climatic regions. The fields can be converted to simulated attenuation time series and applied to radio network simulations . The work by Zhang produced a method which synthesised scan times of 10 s from the 10 minutes of the original CRIE data.

Chapter Four – Project execution

Following the learning of how OPNET operates, much of which was achieved through the use of the documentation available within the package, and through practice, a network model was created and some simulations executed as described hereafter. This chapter describes:

- The creation of a radio link model in OPNET
- The creation of fine scale rain fade time series data from the CRIE data
- The accessing and modification of the propagation model to include rain fade
- The creation of shared libraries linking the propagation model programme and OPNET environment

5.1 Radio link model creation¹

The first step in setting up a network model in OPNET is to define the characteristics of the modules that make up the network nodes. For this case of a radio link model, the modules were:

- the antenna
- the pointing processor for the receive antenna
- the radio transmitter
- the radio receiver modules

The attributes of the modules were modified to achieve the specific functioning desired for the simulation carried out. Two types of transmitter models were used; the model for a normal packet transmitter and the jamming transmitter to simulate background radio noise. The step by step method of creating the module models is in appendix A.

¹ The procedure is adopted from the OPNET tutorial, "Creating a wireless network"

5.1.1 Antenna module

An antenna module that models a physical antenna was created and its characteristics defined. Using the default omni directional module in OPNET, the directivity, gain, and radiation pattern were defined using the antenna pattern editor. Figure 4.1 shows the finished antenna pattern model; it is a high gain directional antenna model.

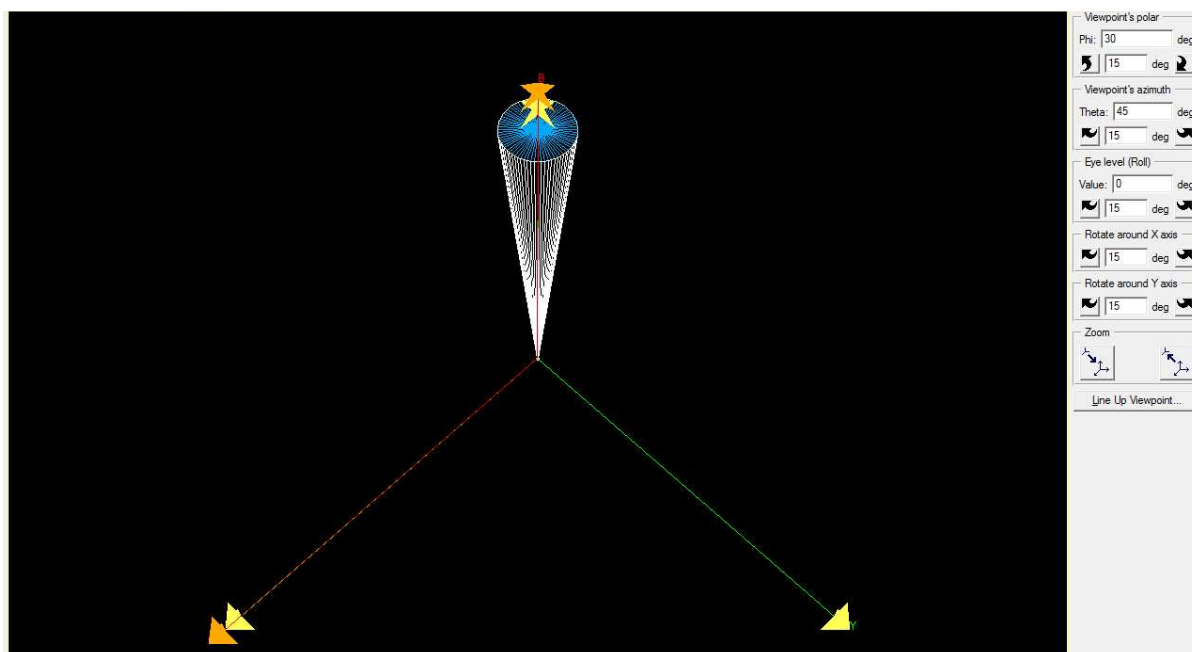


Figure 1: Antenna radiation pattern model

The directional antenna module was used in the receiver nodes. In the jammer and transmitter nodes the default omni directional module was used.

5.1.2 Pointing processor

The antenna pointing processor is a software module whose function is to steer a receive antenna towards a target transmitter. The processor contains a function that references the target transmitter, and achieves the tracking of the transmitter by calculating the coordinates of the transmitter from its model attributes.

For this project, an example C++ code from one OPNET tutorial was used with a few modifications to some parameters to produce the desired processor function for the task at hand.

The pointing processor was included only in the receiver node models.

5.1.3 The transmitter and receiver node models

The transmitter and receiver models resemble each other with three major differences:

- the receiver node includes a pointing processor while the transmitter node has none,
- the transmitter node has packet generator whereas the receiver node has packet sink, and
- the packet stream directions point in opposite directions in the two nodes.

The transmitter, jam, and receiver nodes were created as depicted in figures below.

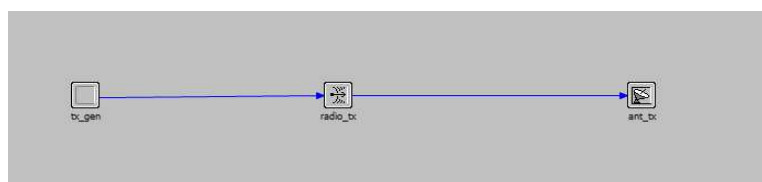


Figure 2: Transmitter and jam node model

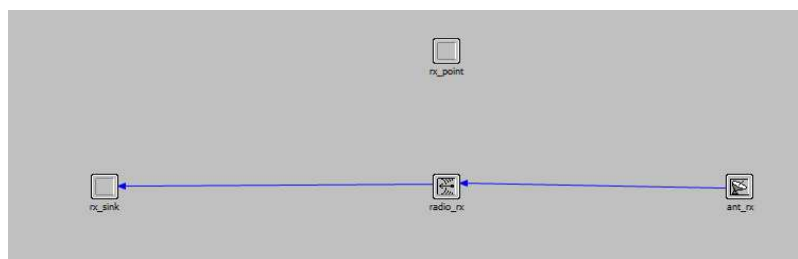


Figure 3: Receiver node model

The jam transmitter is similar to the transmitter, but internal attributes, such as modulation and link (it was mobile in this case) are set different to that of the transmitter.

5.1.4 The network model

A simple route diverse link model, as illustrated, was created in OPNET. The transmitter has an omni directional antenna and sends data, picked up by two directional antennas at the two receive points, receiver 1 and receiver 2, that are spatially separated. The information signal, therefore, spreads in different paths and

experiences different channel characteristics, en-route to the receivers.

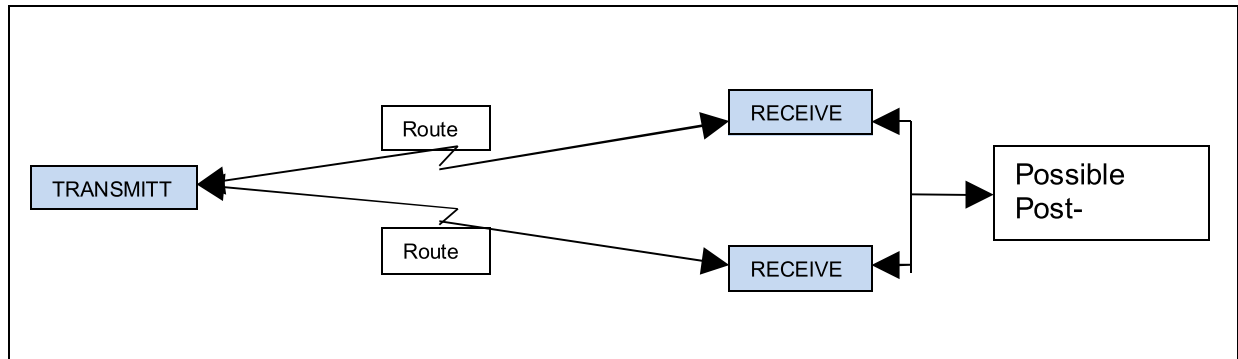


Figure 4: Schematic of a route diverse link

Having defined the appropriate process and node models in sections 4.1.1 to 4.1.3 above, the network model was created.

First, a *project* in OPNET was created. The *scenario* under the project was then established, specifying the scale of the network as *campus* (a small network), and the dimensions of the area it covers. Many scenarios can be created under a project to address different investigation aspects.

The *object palette* is a module that contains the network node models, including the ones created in this project. There is an overwhelmingly large number of models in the object palette. Therefore, to avoid confusion, a palette specific for this project was created and given a name. This was done by deleting all other models, and leaving only the ones defined above, using the configure palette function.

Within the scenario workspace, using the *object palette*, the network model was then created. The process involved dragging the node models from the object palette onto the workspace, placing them to build the layout of the network being modelled. After this stage, the node model attributes were then modified to define their function within the network model. The model attributes were accessed by right-clicking on the node model and choosing *edit attributes*.

The node interface attributes were used to configure the node models position and

declaring if node is mobile, fixed or satellite.

Figure 5 below shows the completed network model. Note the different appearances between the jammer and transmitter models; the jam has a number of arrows on the symbol, indicating it is a mobile node.

Since the jammer was configured to be mobile, a trajectory was defined as seen on the figure by the arrowed line. The trajectory was defined using the *define trajectory* function under the *topology* menu in the project workspace. The jammer node follows that route during the simulation.

The jammer was included to mimic the possible background radio environment that could cause errors in information transmission along the two routes. The interferer's, or jammer's, trajectory cuts through the link routes in turn. As a result, it degrades the performance on the two routes, at different points in simulation time.

Beyond the receivers, there is some post-processing to combine the availability of the signals from the two sources, receiver 1 and 2. The aim was to study the performance statistics of the link at the receive points, as the route channels between the transmit and receive ends are modified to simulate varying rain attenuation.

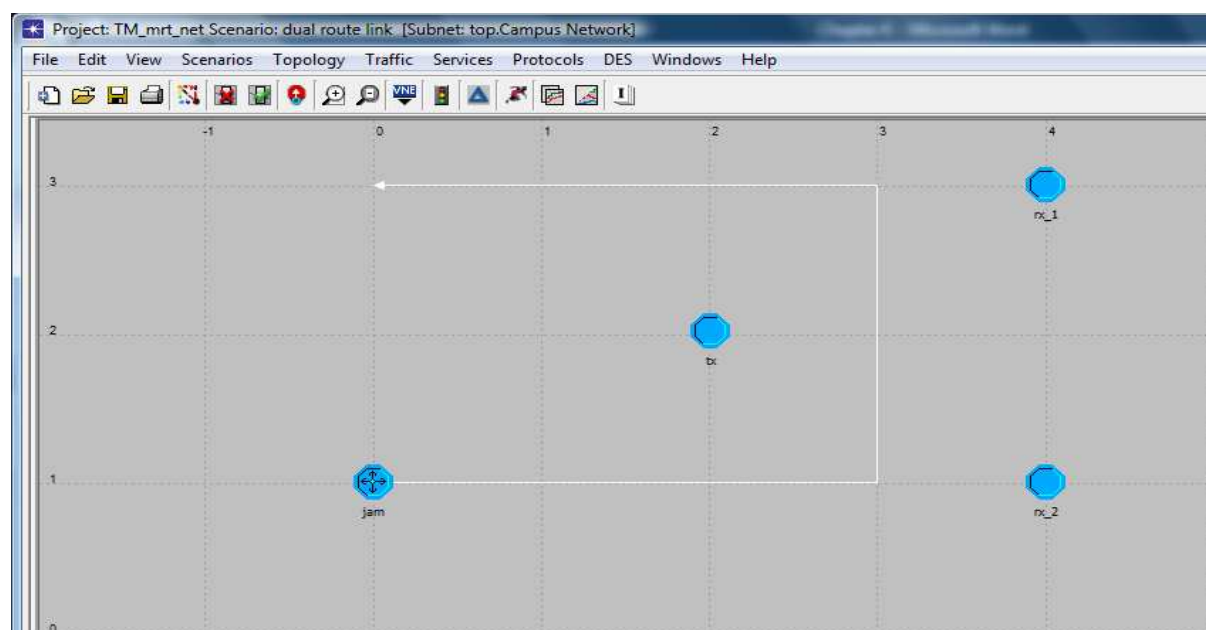


Figure 5: A dual route radio link model

5.1.5 Packet generation and receive error model

In the transmitter node, the packet generator module was configured to the default settings of 1024 bits per packet, produced at the rate of 1.0 packets/second. The packets then pass into the transmitter via the packet stream 1024 bits/second.

In the receiver module, an error allocation model was used to define when a received packet is in error. The chosen scheme has an Error Correction Code (ECC) threshold of 0.0 errors/bit, meaning any packet with a least one bit in error was discarded.

From the received packet, the sink processor determines the Bit Error Rate (BER), packet throughput (packets/second), and received power are monitored and recorded and the results analysed for various conditions.

5.1.6 Results collection set up and running simulations

Having constructed the network model, the required statistics were specified. Because there is a vast number of statistics available, a lot of disc space would be required to store them if they were all to be collected. OPNET allows users pick the statistics that are required in a simulation, using the probe function.

5.1.7 Specifying results to be collected running the simulations

Three types of probes exist in OPNET, namely a statistics probe, an animation probe and an attributes probe. They have their specialised purposes for displaying output from various network aspects in special ways. The statistics probe was configured to collect node statistics, which include packet throughput and error rates.

Running the simulations at this stage was meant to test the model and demonstrate the way to collect the statistics. The simulations were run and the statistics extracted for each receive node, and correlated in time to observe the difference in the results.

5.2 Generation of rain fade time series

The channel information data used for simulating links was generated from the CRIE data measured by the CAMRa. The CRIE data were scanned every 10 minutes, with a spatial resolution of 300 m by 300 m. However, for simulation of radio networks, a finer sampling period is preferable. Therefore the algorithm developed by Zhang

(2008) was used to synthesise the fine scale rain fade time series at 10 seconds sampling periods, reduced to 30 m spatial resolution using Matlab.

In brief, the Matlab program, developed by the research group in Department of Engineering, at University of Hull, processes the data through the following stages:

5.2.1 Removal of advection

Advection refers to the displacement of rain events across a scanned area. This factor has to be removed from the rain fields before other processes are carried out. The advection is removed so that after interpolation, to be implemented later, the rain events can evolve smoothly between the synthesised scans, and more importantly, to avoid errors in calculating rain fade time series values for radio links.

5.2.2 Rain field downscaling

This stage comprises two steps;

Disaggregation

In disaggregation, the data spatial resolution is separated into smaller parts. The original CRIE data was captured with a resolution of 300 m by 300 m. Since for simulation of radio networks, a finer resolution is preferable, disaggregation is necessary. The programme achieves the disaggregation through the use of a statistical algorithm called the Log Poisson Distribution, and scales down the resolution to around 30 m by 30 m. The ultimate effect is that the synthesised data matrix possesses more pixels with estimated values between the original radar readings. In practice, the smaller averaging volumes enable greater variation in rain rate measurement, meaning very high rain rates can be measured accurately.

Interpolation

Interpolation estimates the rain events values between the 10 minute scan periods using the Random Midpoint Displacement algorithm (RDM). This algorithm continuously cuts the scan interval into two, until the 10 minutes interval is broken into numerous 10 second intervals. The rain events are estimated using the Hurst exponent to fill in the rain rate values.

When the down scaling has been done, advection is then re-introduced into the rain

events data. Now the rain events data carry the drifting tendency of the rain between radar scans and the rain can spread appropriately on the map.

5.2.3 Calculation of rain attenuation time series

At this stage, on the rain map of values established above, an arbitrary radio link, with two radio paths link 1 and link 2, is created in the rain area, as shown in Figure 6. The rain intensity is represented by the colour scale, where the red parts show places of heaviest rain, and blue shows no rain at all.

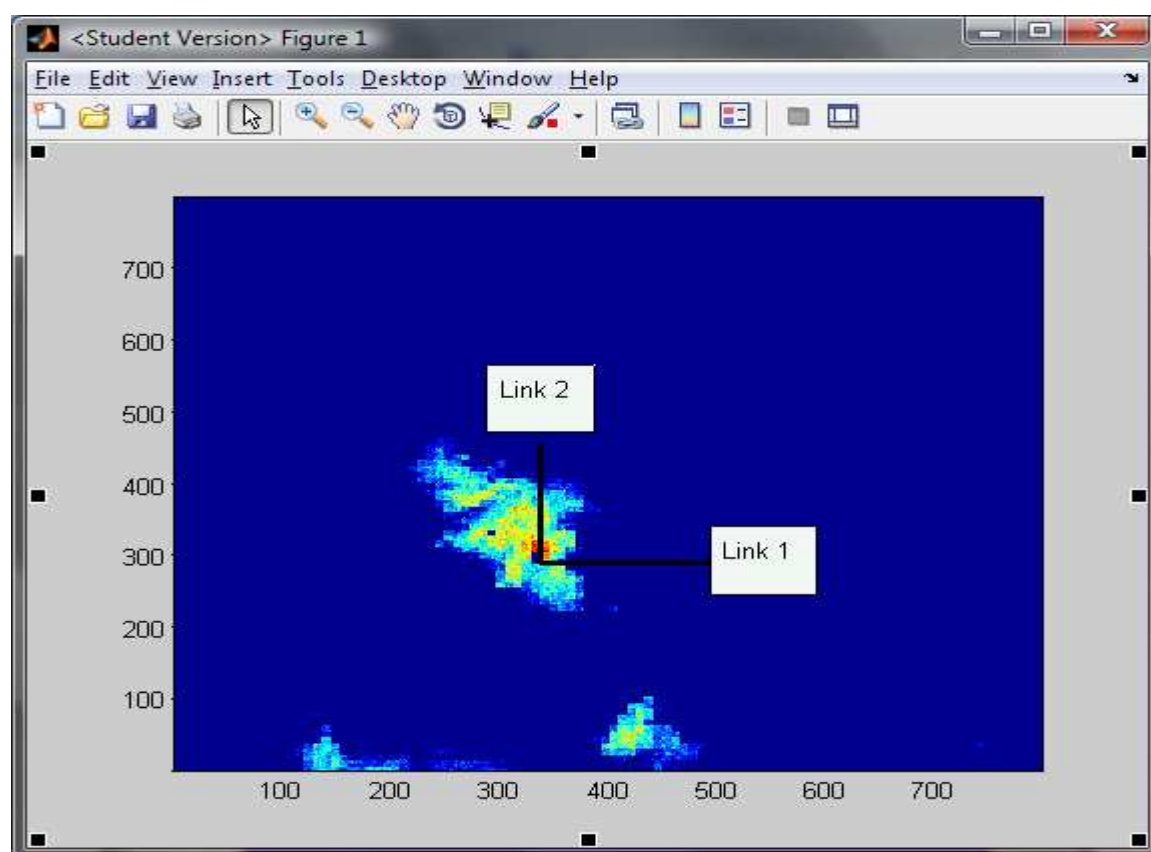


Figure 6: Links on a rain data map

The rain rate estimates evaluated in section 5.2.2 are then used to calculate the specific attenuations α , along the radio links using equation (5). Every 10 seconds the summations of the specific attenuations along each link provide the total attenuation. These form elements of the channel model.

5.3 Radio propagation models

OPNET has a number of common radio propagation models which can be used

within the package to simulate the attenuation for various environmental conditions; for instance, the Hata model which is designed to model propagation in various areas to calculate radio propagation for mobile radio reception.

The propagation model codes are available as open source C or C++ language codes within the OPNET application. They can be modified and developed by users to suit the particular needs the user desires to address with the application.

The free space model was chosen for customisation to include rain fade. The model was chosen because it is the least complex. It assumes there are no atmospheric, environmental, and terrain (optional, as later described) effects on the radio waves as they travel from the transmitter to the receiver. The only attenuation factor catered for in the model is the free-space attenuation; that is, the diminishing of signal strength as the energy spreads into an ever increasing area of a sphere (ideally for isotropic antenna) in travelling away from its source.

Another option the model offers is the LOS *on* or *off* choice. With LOS on, the programme determines if there are obstructions due to terrain, or other obstacles between the receiver and transmitter, and can decide to terminate the simulation if the obstruction exists. However, for the envisaged study, no terrain or actual geographical map would be invoked, and therefore all situations would be LOS. Hence the model was used in only the non-LOS mode.

5.3.1 Using channel data in the propagation model

An external file that has rain fade time series data, and whose creation is described in section 5.2, provides the behaviour of the radio channel as a consequence of rain existence in the radio path. The propagation C/C++ language programme (open source code available as part of OPNET) model was modified to:

1. Access the external data file with the rain fade time series data
2. Read and import the contents of the data into OPNET,
3. Apply the amplitude scaling according to the values imported from the rain fade data to determine the receive level at the receivers.

The schematic in Figure 7 depicts the general idea of the way the time series data

was used to simulate rain fade.

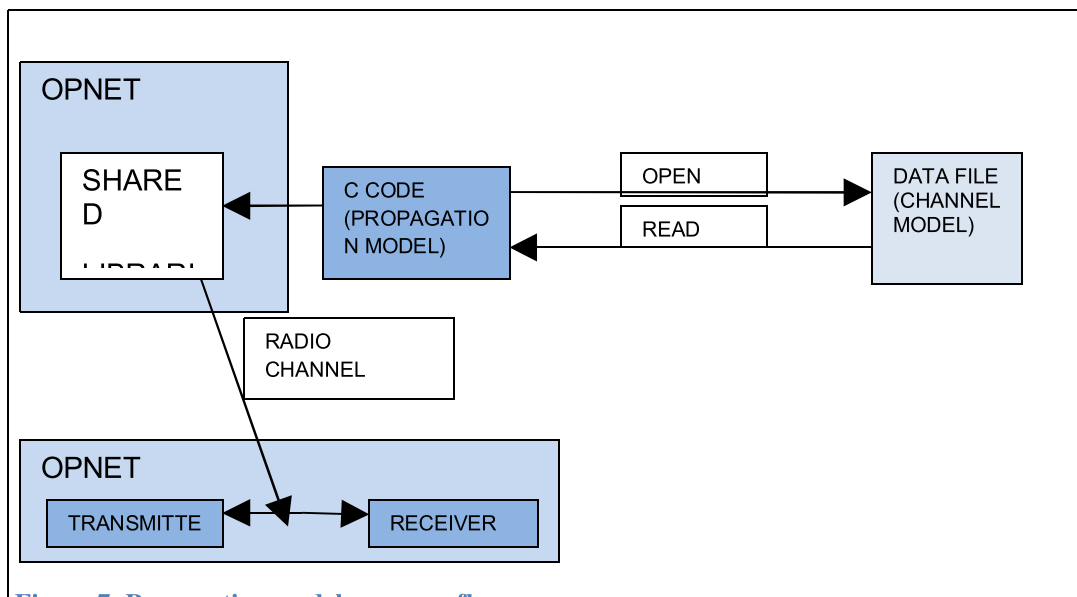


Figure 7: Propagation model program flow

Having acquired the data, the programme was further modified to use the data to scale the signal strength as it travels from the transmitter to the receivers according to the attenuation the channel imposed on the signal. This calculation was done in addition to the free space attenuation inherent in the model. Therefore the received signal at link end is:

$$P_r = P_t - \alpha_{fs} - \alpha_{rain} - \alpha_{other}$$

The propagation model programme resides in the local OPNET working directory and can be modified independently outside OPNET. However, the code calls many sub programmes, and depends on libraries within OPNET. Therefore, to compile and run the model program, the model programme was imported into OPNET where it could access all the ancillary resources needed for its execution. The customised programme was successfully compiled.

Further, having created a compiled program, the next step was to create the running environment for it. This involved building repository libraries linking the files within OPNET and where the various processes can access the necessary executable codes to complete their tasks.

The libraries for the original free space model, available in OPNET working directory,

were studied for modification to run with the customised model. However, the time available was not enough for the task. The creation of shared libraries happens to be a very complex undertaking which would need more time to appreciate. As a result of the above, this part of the project was not completed.

Chapter Five - Study results and discussions

5.1 Working with OPNET, modelling and simulation

The first achievement of the study has been gaining working knowledge of the OPNET package. The basic building blocks to model modules, nodes and a network were learned.

The various functions of the models can be modified through the use of the many attributes available which help one to model a situation and, through the available statistics extracting methods, can learn the impact of the simulated scenarios in a network.

Figure 8 and Figure 9 show the simulation results the network model of Figure 5. They show the impact of the jammer on the selected statistics, BER and packet throughput, from different locations along the defined trajectory.

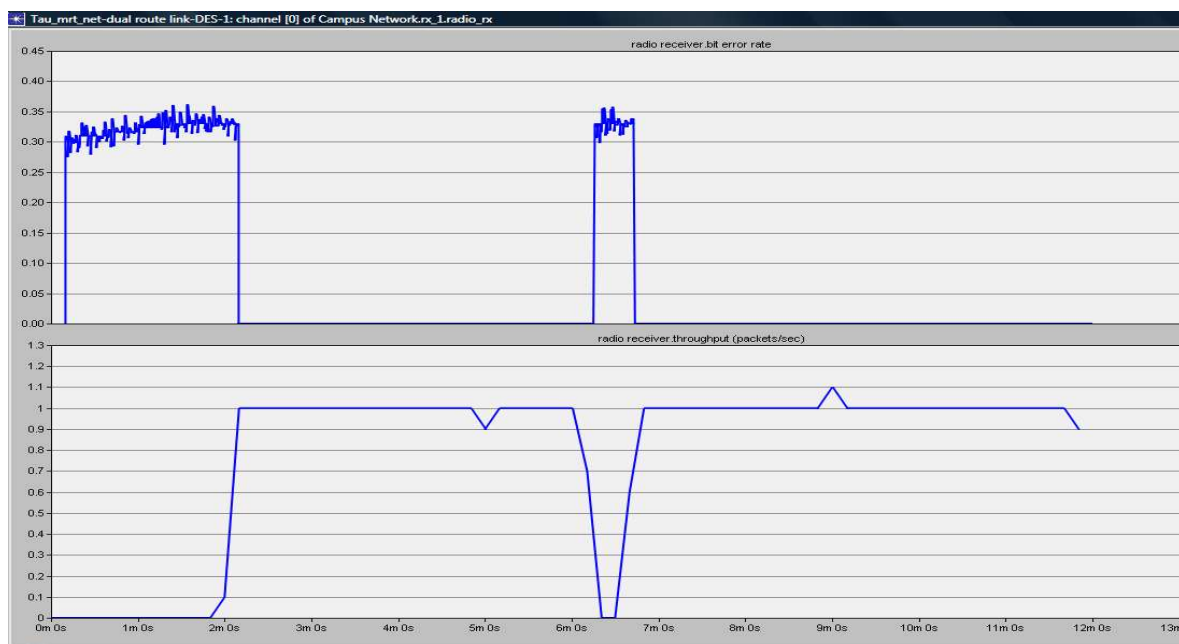


Figure 8: BER and packet throughput for tx_1 in model in Figure 5

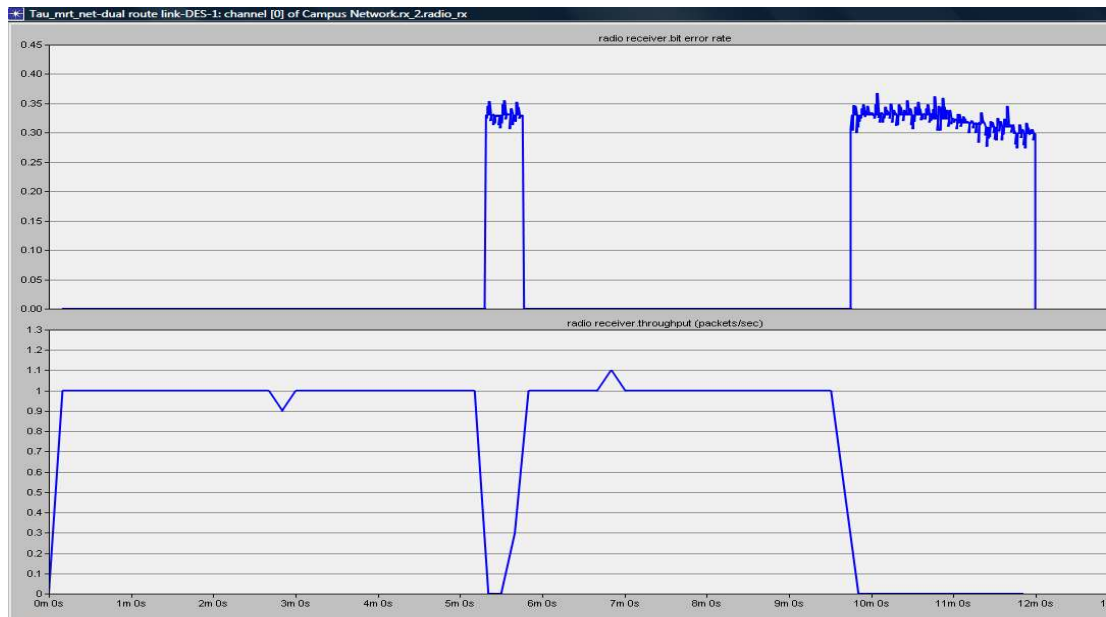


Figure 9: BER and packet throughput for tx_2 in of model in Figure 5

And with reference to the topology of the network model in Figure 5, the BER rises tremendously when the interferer passes through the major lobe of the receiver model antennas. This of course is accompanied by a fall in packets throughput as expected. The duration of the BER blast lasts longer further away from the receiver because the beam is wider there.

The simulation results can alternatively be displayed in tabular form as demonstrated by Figure 10. Here statistics of packets destroyed within the individual network modules are shown. Various statistics from the either from the nodes or from modules within nodes can be selected for analysis.

Packet Statistics:Node-centric,Number of Packets Destroyed			
File Edit View Help			
Node Name	[Total]	[Unformatted]	
1 Campus Network.jam	0		
2 Campus Network.rx_1	1418	1418	
3 Campus Network.rx_2	1418	1418	
4 Campus Network.tx	0		
5 [Total]	2836	2836	

Figure 10: An example packet history for the simulation on model in Figure 5

From the limited use of OPNET that has been applied in the project, a lot could be demonstrated as to how various network parameters can be varied and their effects on the network be predicted with the use of the simulation package.

Further, as one works through the package environment, many possibilities emerged

of the many telecommunications protocols, technologies, networks and systems that can be investigated and analysed, for purposes of planning, design and development, and learning using OPNET.

The advantage offered by this approach is the visual nature of demonstrating network objects, which helps impart in the user, the understanding of the subcomponents and processes that in real hardware appear as black boxes that one manipulates through inputs.

5.2 Rain fade time series data

In Figure 11 below, the rain rates have been converted into specific attenuations (dB/km) and subsequently to total attenuations in dB by summing the specific attenuations along the link path for both links in Figure 6.

The dB attenuations as depicted in Figure 6 represent the amount of rain fade the link experiences, and are stored in a text file which OPNET accesses through the customised radio propagation model. During simulations OPNET would read these in for the appropriate link and apply them on the radio signals to calculate receive signal levels.

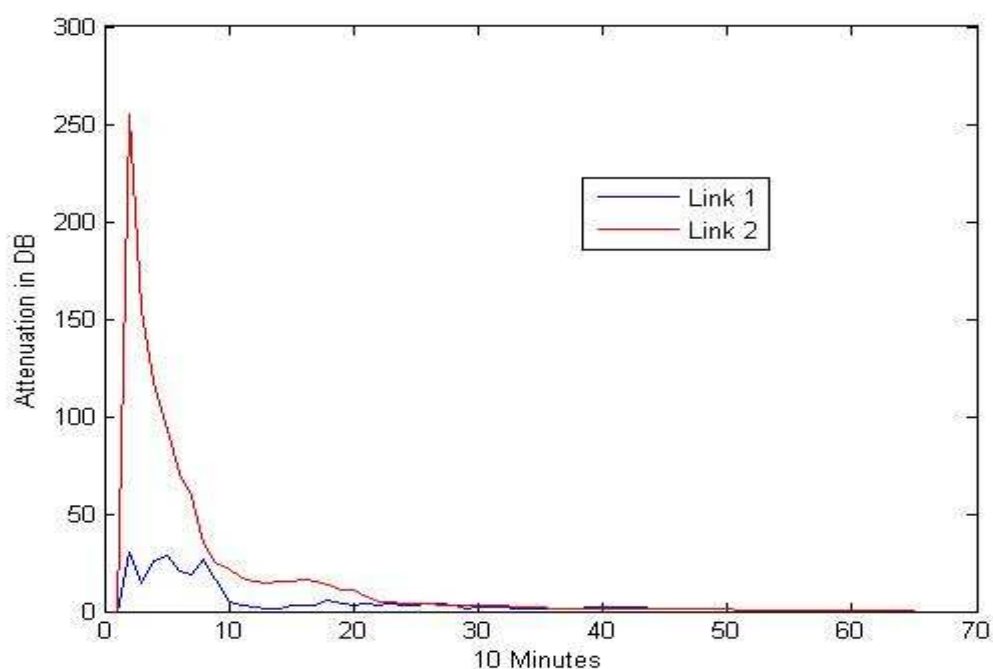


Figure 11: attenuation graphs

Now, the two link attenuation profiles can be analysed and it is evident that link 2 experiences significantly more attenuation than link 1, especially in the first 1.5 minutes, and to a less extent in the next 1.5 minutes. This corresponds well with the link locations on the rain map on Figure 6 which shows that link 2 path cuts through more, and heavier rain than link 1.

The situation represents a scenario when link 1 would be relied upon to maintain the connection availability despite the likely failure expected on link 2 in approximately the first 1.5 minutes of the simulation.

Although these data were collected for a specific area, and can be applicable only for that climatic type, the principle can be applied for other data collected from different climatic regions.

5.3 Integration of customised model into OPNET

This included the customisation of propagation model to include rain fade, creation of shared libraries for proper running of the model within OPNET, and running simulations to study the impact of rain fade on a route diverse link experiencing rain fade.

5.3.1 Customisation of the propagation model

The customised propagation model was successfully compiled. The new model can access the generated external data file with rain fade time series data. The time series provides a dynamic series of rain fade levels, derived from the CRIE data. These data provide updates every 10 seconds.

The propagation model then calculates the receive signal level at the receiver modules. The continuously updated signal receive level is used by the simulator to evaluate the link BER and throughput more accurately, and the simulation results can give a more reliable idea of the radio link performance in the presence of rain.

5.3.2 Shared libraries creation and rain fade simulation

In order for the customised propagation model to properly run within OPNET, shared libraries and repositories had to be created. It was not possible to complete the task because of limited time as the process is complicated.

5.4 Rain fade in route diverse links

The main aim of this project was to ultimately have rain fade simulated in OPNET using radar measurement data. Rain fade presents one of the major challenges for radio engineers in ensuring and maintaining availability of radio links, and one of the common FMTs mode used is route diverse links.

Although the ITU recommendation ITU-R 837-12 provides a detailed treatment of rain fade for LOS links in the microwave frequency region, it does not give any guidance on multi-hop and route diverse links. The idea of using statistical methods to determine availability is useful for practical applications as these radio link configurations are widely used as FMTs.

Simulations run for long enough time would provide BER and packet throughput performance statistics from which the percentage of time of unavailability, as per ITU criteria explained in section 3.3, could be deduced and compared with tolerable down times for designing links.

The perfect operation scenario for route diverse links is in the presence of de-correlated rain (localised in the region of one of the link paths), which would affect one of the links separately, leaving the other completely unaffected. In cases like that, the link is maintained by switching the traffic to the unaffected path. This would give 100% link availability.

However, almost all rain events affect both paths simultaneously, but mostly with unequal fade levels. The least affected carries the traffic with some finite BER, and the average of the BER over a year provides guidance for availability of the links planners.

As noted in the previous chapter, the simulation was not completed as the final stages of building software links did not work. It was envisaged the statistics obtained would be used to evaluate the overall availability of the link.

Chapter Six – Conclusions and future work

The main objectives of this project were to develop a working knowledge of OPNET, generate fine scale rain time series for rain fade channel modelling from the CAMRa data, customise the propagation model to include rain fade which is modelled by the fine scale rain time series from radar measurements, and run the new propagation model to establish availability statistics of a route diverse link.

5.5 Summary of study conclusions

The acclimatisation and learning of OPNET were achieved and demonstrated with modelling and simulation of a radio link model. Some statistics were collected to measure the BER and throughput given different locations of an interfering source.

Using methods developed in earlier studies, the fine scale rain time series data were generated to model two arbitrarily placed links in a rain map. The coarse scale radar acquired rain events data was synthesised into fine scale time series for better application telecommunication radio network simulations.

The customisation of the free space model to include rain fade was achieved and the programme successfully compiled. The running of simulations to study the availability statistics of the route diverse link, using the customised propagation, was not performed. This was because the development of shared libraries for the model and OPNET was not completed.

5.6 Future work on the project

OPNET is vast engineering tool which encompasses far more facilities than covered in the current study. The successful inclusion of a rain fading procedure to run as part of the available radio propagation models would allow more benefits to be gained from the modelling and simulation capabilities the software offers, particularly in the wireless modeller module. As a way forward:

- many of the capabilities and functionalities can be explored for implementing studies of different communications technologies.
- OPNET can be used, as a laboratory tool, in learning to enhance understanding

of the various communications protocols and networks.

- the creation of shared libraries for the current project can be completed, and the customised propagation model properly tested by running it from OPNET. This would probably reveal other bugs which require improvement of the propagation model. Such run time errors may not be detected without the full run of the programme within the OPNET environment.

Appendix A – Creation of OPNET module models

To prepare for the simulation of the radio link with rain fade included, an appropriate project is built in OPNET environment. The procedure followed here is adopted from the tutorial “Creating a wireless network” in the OPNET documentation, and introduces the necessary changes to suit the investigation at hand.

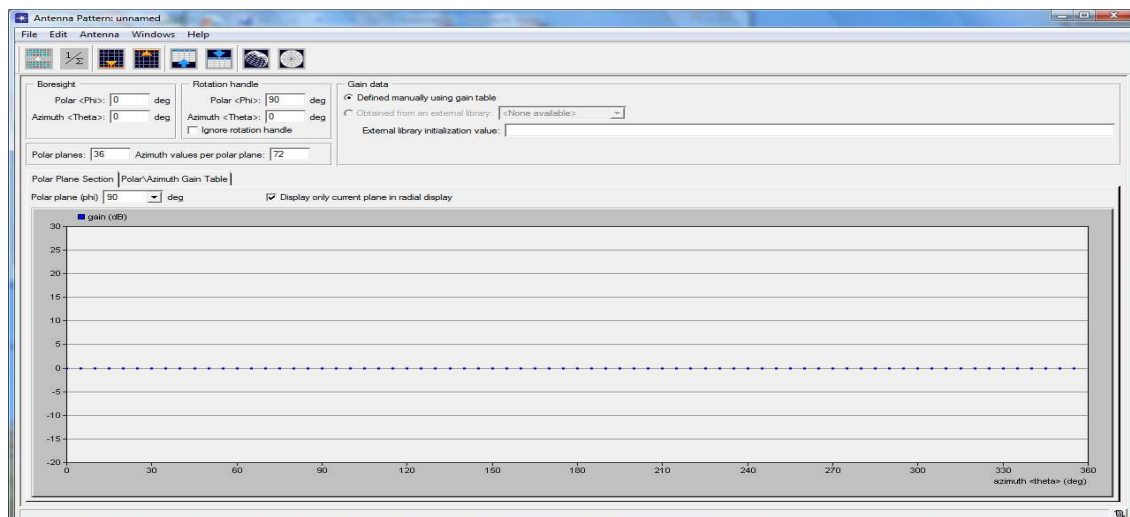
Antenna pattern model

The schematic begins with the creation of the antenna module. First the antenna pattern was produced. In the OPNET main window, follow the path:

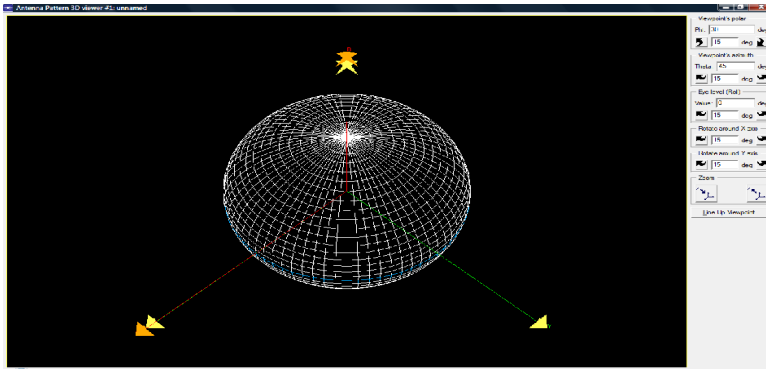
File > Open..., and choose **Antenna Pattern** from the pull-down menu. The antenna pattern editor and 3D antenna pattern viewer windows appear.

The default setting for the number of polar planes and the number of azimuth values per polar plane are left unchanged (36 and 72 respectively).

Antenna pattern editor



Antenna pattern 3D viewer



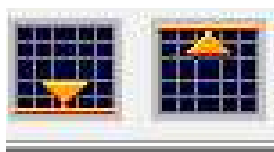
In the antenna pattern editor, the polar plane was adjusted to 5 degrees by selecting 5 in the pull-down menu near polar plane (phi).

Polar plane option values



The bounds on the ordinate were set using the upper and lower bound buttons (to 24.5 and 25.5, respectively) shown below, from the tool bar. The values were directly entered into the dialogue box that appears when the buttons are pressed. The range chosen resolves the scale to small intervals allowing easy setting of a gain of 25 dB to great accuracy.

Lower and upper bound buttons

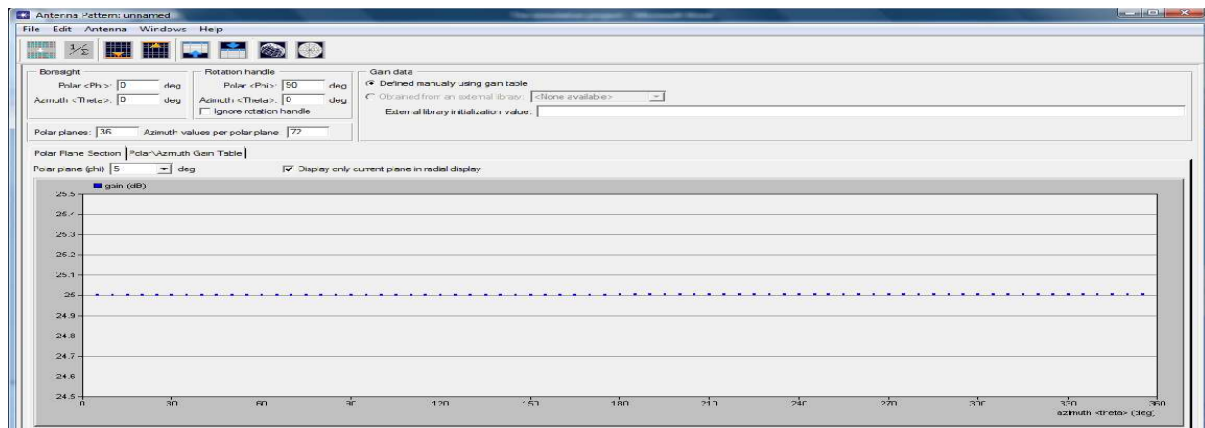


Now the sample points for the polar = 5 degrees were set as follows:

- The cursor was moved as close to the 25 dB mark as possible followed by clicking on the first sample point on the horizontal, 0 (zero) degrees
- Next, the cursor was moved to the far right of the 25 dB line, and clicked on a second point (close to 360 degrees).

All the points between the specified points are automatically set to linearly interpolated gain.

The sample points



After the polar = 5 degrees gain values, proceed to the polar = 0. This specifies a gain of 25 dB for the planes 0 to 5 degrees and the azimuth of 0 to 360 degrees.

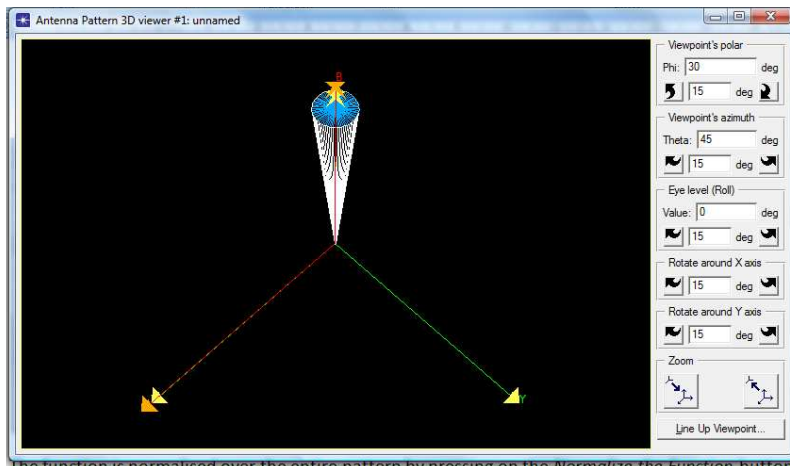
The procedure goes as follows.

- In the antenna pattern editor, either
 - Press Ctrl + [up arrow], or
 - Choose *Antenna > Decrease Polar Plane*

The plane changes from 5 to 0 degrees

- Verify the ordinate lower and upper bounds are 24.5 and 25.5 respectively
- On the 25 dB line, click at 0 degrees and again at the far right, close to 360 degrees.

The final 3D antenna pattern view




The function was normalised over the entire pattern by pressing on the *Normalize the Function* button, and the lines shifted up out of display.

The antenna pattern was saved as *PROJ_mrt_cone*, and the antenna pattern editor was closed.

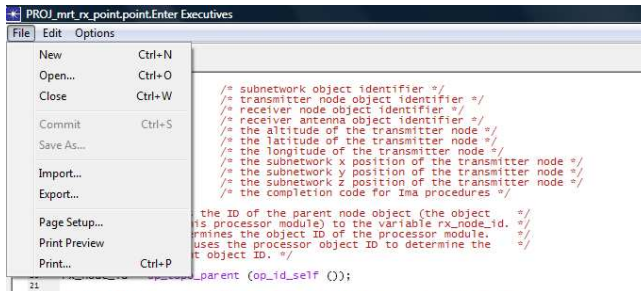
The antenna pointing processor

The antenna pointing processor calculates the position of the transmitter module and sets antenna module targeting attributes. The processor was created as follows:

- Open *File > New...* and pick *Process Model*, then click *OK*.
 - The process editor window opens
- With the *Create State* tool button,  place a state in the workspace
- Right click on the state and access the *Set Name* attribute field in the pop-up menu
- The state was named *point*.

The already designed software code for the process model, used in the “Creating a wireless network” tutorial was found adequate for the function here and therefore used. The code for the process model was imported into the model from the working drive:

- Double-click on the top half of the point state and the *Enter Executives* block opens

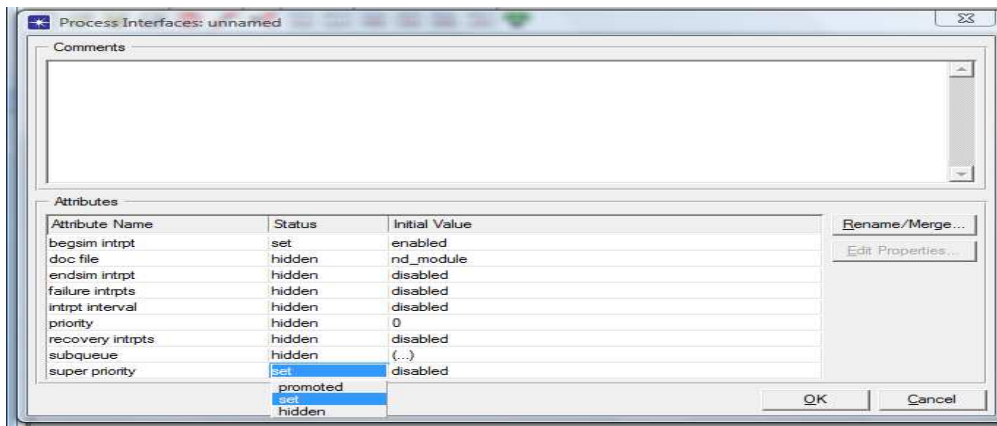


- Choose **File > Import...**, and then select the file
 <working drive>\15.0.A\models\std\tutorial_req\modeller\mrt_ex,
 and click *Import*. The file is imported. This is the code created for the tutorial and completely suffices for the simulation envisaged.
- The *Enter Executives* is then saved

The Enter Executives code defines the conditions that determine when a process model enters a state. This contrasts the function of the Exit Executives which decide when a state is exited.

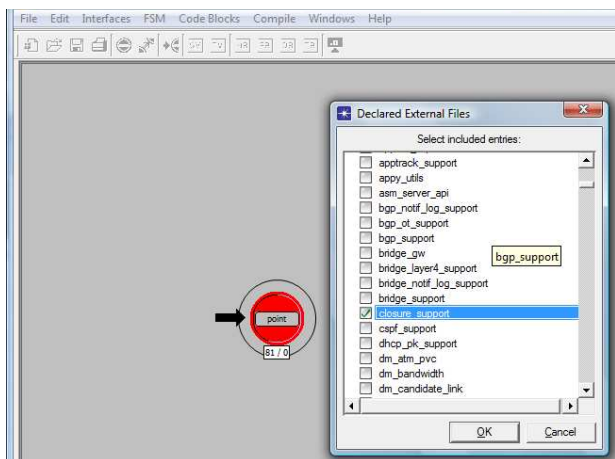
The next task was to modify the process attributes, from the process model window:

- Choose *Interfaces > Process Interfaces*
- Set the value of the *begsim intrpt* attribute to *enabled*
- Set the status of all other attributes to *hidden*
- Save the changes by clicking *OK*



Packet transmission is modelled with radio transceiver pipeline in wireless networks. In this investigation, only closure stage of the pipeline (line of sight) was of interest. Therefore, the C library that defines the function used for closure was included such that it could be loaded when the simulation executes:

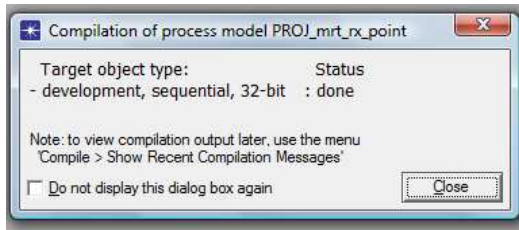
- Choose **File > Declare External Files...**



- Tick **closure_support** and then click **OK**
- The model was compiled by pressing the **Compile Process Model** tool button,



- It was then saved as **PROJ_mrt_rx_point**



In case the model does not compile, it can be edited as appropriate.

Creating the network node models

The radio network model for the simulation consists of two types of nodes, namely, transmitters and receivers. The transmitter node model has a packet generator, radio transmitter and antenna modules, feeding packets in that order. The receiver is built from an antenna, radio receiver, packet sink, and the pointing processor modules.

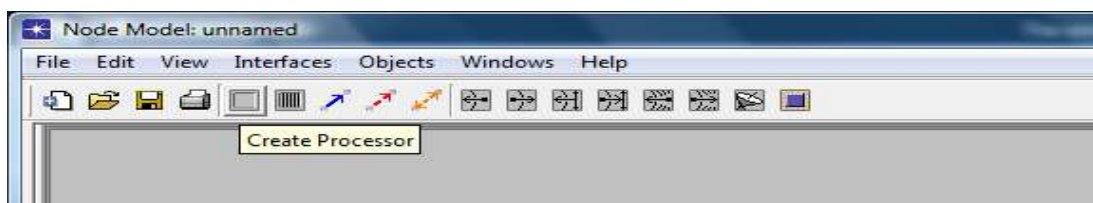
The transmitter node

The packet generator module used in this project takes default values of 1024 bits arriving at 1.0 packets per second with a constant inter-arrival time. The packets are then fed to the transmitter module through a packet stream, whence they are transmitted at a rate of 1024 bits/second, using the full 100% bandwidth of the channel, to the antenna module. A directional antenna with 25 dB gain is used.

The transmitter node model was created as follows:

1. *File > New...*, from pull-down menu pick *Node Model* and click *OK*

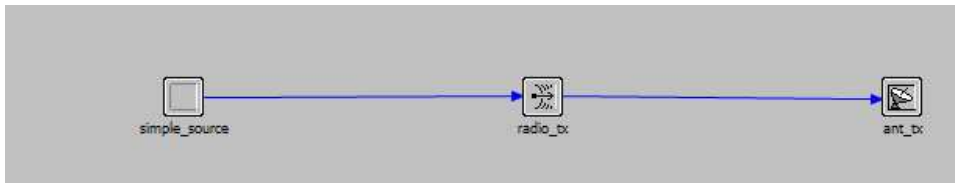
The node editor appears. The node editor tool bar is shown below and the functions of all the buttons pop-up as the cursor is passed over the button, e.g. *Create Processor* as displayed.



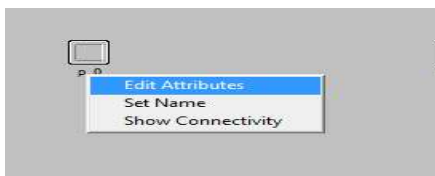
2. The *Create Processor*, *Create Radio Transmitter*, *Create Antenna* and *Create Packet Stream* tool buttons were used to build the node. After clicking the

specific module button, the module can be dropped in the workspace by the left mouse click. This can be repeated as many times as required depending on the number of the modules required, and the right mouse used to deactivate the *create* capability.

3. Following the steps in 2., the models was constructed as shown below



4. The module names were modified by right clicking on them and accessing the *Edit Attributes* or *Set Name* menu



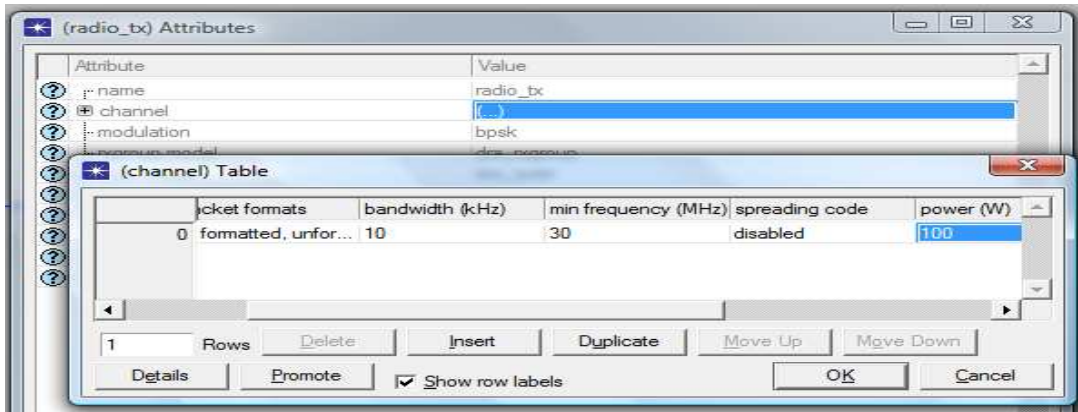
To collect statistics from the network model, two ways can be used. One way is to collect the statistics in the *Project Editor*, which is limited in some ways, and another way is to use the more versatile *Probe Editor*.

In order to run the parameterised simulations, the power attribute is promoted. This means the power attribute can be changed easily during simulation run time.

To promote the power attribute, follow the steps;

1. Right click on radio_tx node and select *Edit Attributes*
2. From the transmitter *Attributes* dialogue box, click on the *Value* field for *Channel* attribute. The dialogue box for channel attributes table displays.

Transmitter attribute dialogue box with the channel attribute table on top



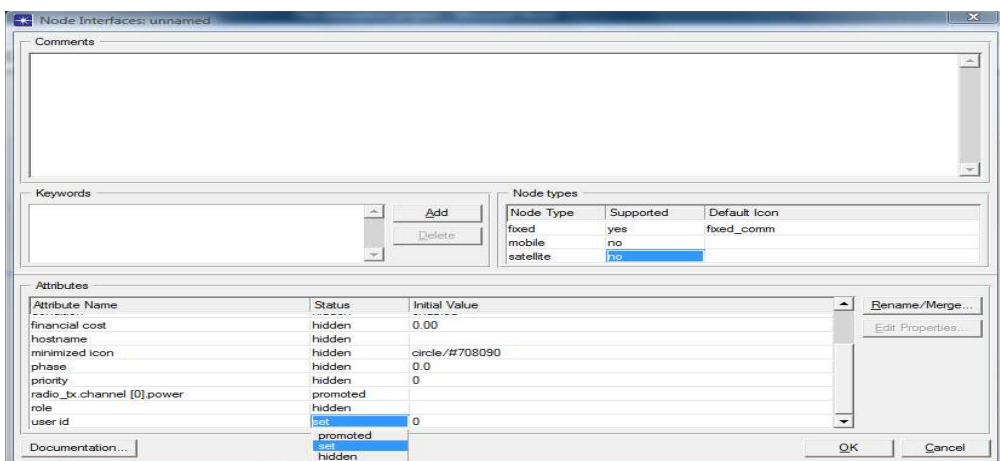
- Promote power by selecting its value and clicking the *Promote* button.

The value for power then changes to *promoted*.

- Clicking *OK* on the *channel table* and the *transmitter attributes* closes both the dialogue boxes.

The node model interface attributes were next defined:

- Click *Interfaces > Node Interfaces*
- On the *Nodes Interfaces* dialogue box, in the *Node Types* table, the *Supported* value was changed to *no* for *mobile* and *satellite* types. The effectively defines the node as fixed.
- In the *Attributes* table, the *Status* was changed to *hidden* for all attributes except the promoted power attribute.



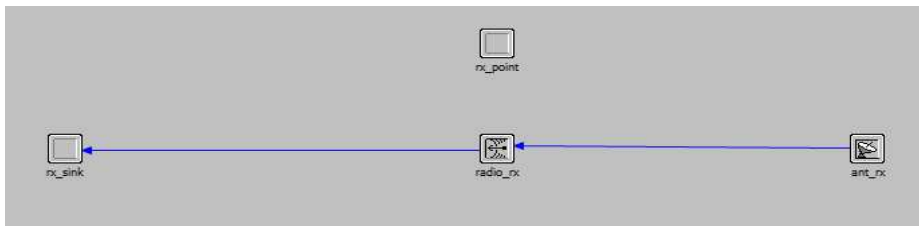
4. Click **OK** to save the changes
5. The node model was saved as follows:

- a. Click **File > Save**,
- b. Type **PROJ_mrx_tx** for the model name, then save.

The receiver node

The receiver node constructed as the transmitter node, the only difference being the data stream direction:

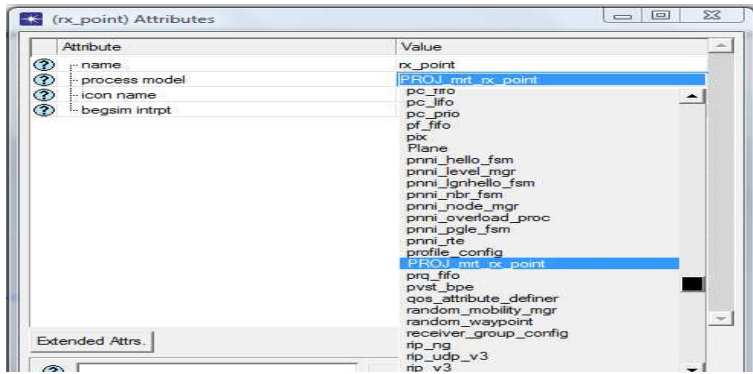
1. Choose **Edit > Clear Model**, in the Node model editor window
2. The modules and data streams were created and named as shown below



The name of the antenna module is particularly important as it is referenced by the antenna pointing processor, **PROJ_mrt_rx_point** as **ant_rx**.

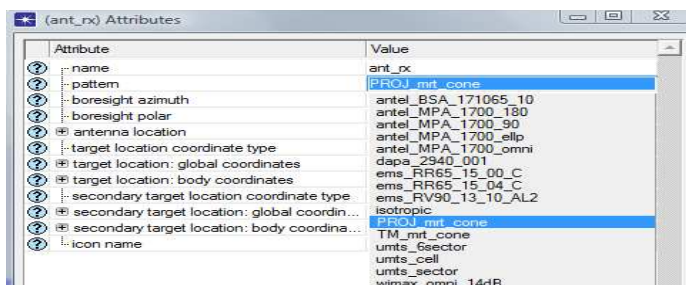
The attributes were modified as follows:

1. Right click on **rx_point** and open the **Set Attributes** box.
2. Set the **process model** attribute to **PROJ_mrt_rx_point**, and click **OK**.



3. In the *radio_rx* attributes dialogue box, set the value of *error model* to *dra_error_all_stats*, and click *OK*.

4. The *ant_rx pattern* value was set to *PROJ_mrt_cone* (the pattern created in the earlier section)



5. Click *OK*.

Finally, the node model interface attributes were defined:

1. Follow *Interface > Node Interfaces*
2. Change the *value* for *Supported* to *no* for *mobile* and *satellite* in the Node types table
3. Set all attributes' status to *hidden* in the attributes table
4. Save changes by clicking *OK*
5. Choose *File > Save as...*, and save model as *PROJ_mrt_rx* and close Node Editor.

Appendix B – Code included in free space propagation model

The following was the code added to the free space model to include the rain fade:

```
FILE* fp;

float scaleVar;2

fp = fopen("data/test.txt", "r");

    if(fp == 0)

    {

        printf("Error opening file");

        return -1;

    }

while(fscanf(fp, "%f", &scaleVar) != EOF)

{

    path_loss_db = 20.0 * log10 (C_OVER_4PI / (center_frequency *

propagation_dist_m)) - scaleVar;

}

    path_loss_db = 20.0 * log10 (C_OVER_4PI / (center_frequency *
```

² These first two line cause an error if they appear under an FIN micro in the model programme (around line 150). The cause of the problem could not be established.

propagation_dist_m));

References