BECE 307P – WIRELESS AND MOBILE COMMUNICATION LAB

Laboratory Manual

DEPARTMENT OF COMMUNICATION ENGINEERING

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ECE-4009 - Wireless and Mobile Communication Lab

List of Experiments

Serial Number	Title of the experiment	Marks allotted	Remarks
1	A brief introduction to network simulation through the NetSim simulation package		
2	Study how call blocking probability varies as the load on a GSM network is continuously increased		
3.	Analysis of LTE Handover using NetSim simulator		
4.	Study how the throughput of LTE network varies as the Channel bandwidth changes in the ENB (Evolved node B)		
5	Study how the throughput of LTE network varies as the distance between the ENB and UE (User Equipment) is increased		
6	Testing and validating principles of Pathloss in Mobile Radio Propagation through Smartphone and CRFO		
7.	MATLAB based comparative analysis between Outdoor Propagation Models – Okumura and Hata Model		
8.	BER plot for BPSK in Rayleigh channel with Selection Diversity		
9.	OFDM based PAPR analysis using MATLAB		

Evaluation Procedure:

ASSIGNMENT/ LAB CONFIGURATION		
Category	**Marks**	**Weightage**
Task -1	**10**	**10**
Task -2	**10**	**10**
Task - 3	**10**	**10**
Task - 4	**10**	**10**
Task-5	**10**	**10**
Lab Midcat	**10**	**10**
Final Assessment Test	**40**	
Total Marks	**100**	

Continuous Assessment Mark split-up:

Type	**Mark**
Performance of the basics Experiment leading towards Task	**2**
Design of the uniqueness in Task	**3**
Implementation of Tasks	**3**
Report and presentation	**2**
Total	**10**

EXPERIMENT – 1

Aim : A brief introduction to network simulation through the NetSim simulation package

Theory:

What is NetSim?

NetSim is a network simulation tool that allows you to create network scenarios, model traffic, and study performance metrics.

What is a network?

A network is a set of hardware devices connected together, either physically or logically. This allows them to exchange information.

A network is a system that provides its users with unique capabilities, above and beyond what the individual machines and their software applications can provide.

What is simulation?

A simulation is the imitation of the operation of a real-world process or system over time. Network simulation is a technique where a program models the behavior of a network either by calculating the interaction between the different network entities (hosts/routers, data links, packets, etc) using mathematical formulae, or actually capturing and playing back observations from a production network. The behavior of the network and the various applications and services it supports can then be observed in a test lab; various attributes of the environment can also be modified in a controlled manner to assess how the network would behave under different conditions.

What does NetSim provide?

Simulation: NetSim provides simulation of various protocols working in various networks as follows: Internetworks, Legacy Networks, BGP Networks, Advanced Wireless Networks, Cellular Networks, Wireless Sensor Networks, Personal Area Networks, LTE/LTE-A Networks, Cognitive Radio Networks, and Internet of Things. Users can open the experiments and save the experiments as desired. The different experiments can also be analyzed using the analytics option in the simulation menu.

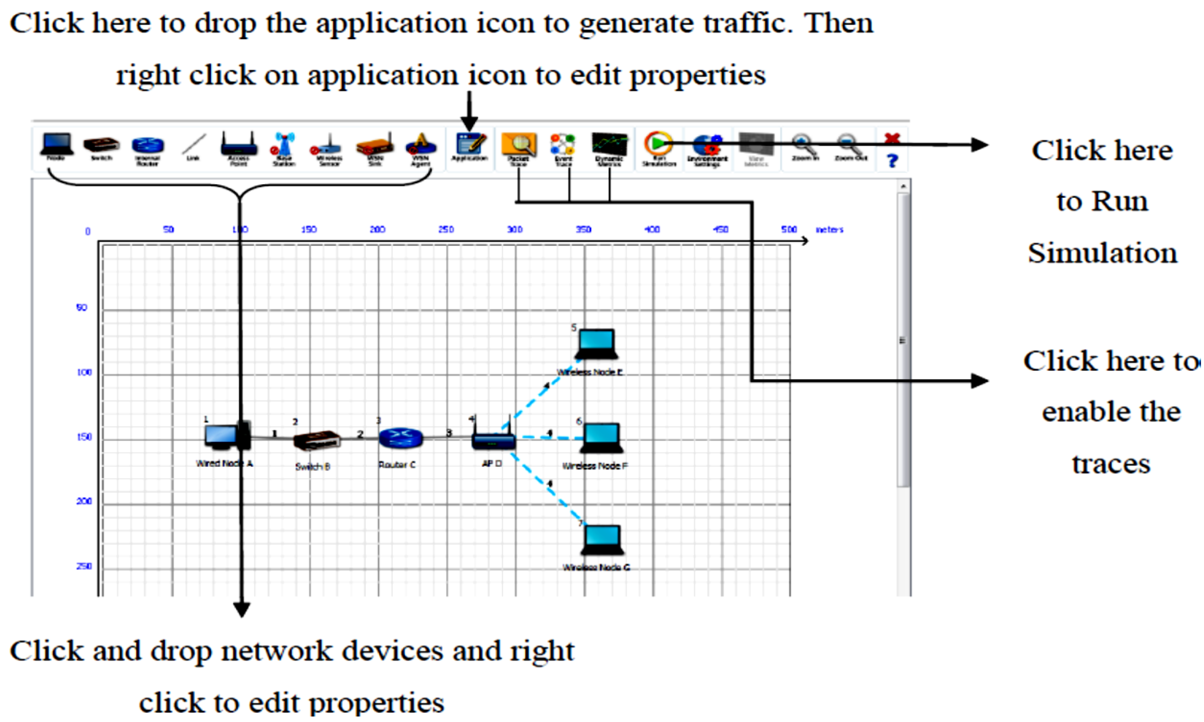
Programming: NetSim covers various programming exercises along with concepts, algorithms, pseudo code and flowcharts. Users can also write their own source codes in C/C++ and can link them to NetSim.

Some of the programming concepts are Address resolution protocol (ARP), Classless inter domain routing (CIDR), Cryptography, Distance vector routing, shortest path, Subnetting etc.

Task :

Design and configure a simple network model, collect statistics and analyze network performance.

Network model: A Network model is a flexible way of representing devices and their relationships. Networking devices like hubs, switches, routers, nodes, connecting wires etc. are used to create a network model.

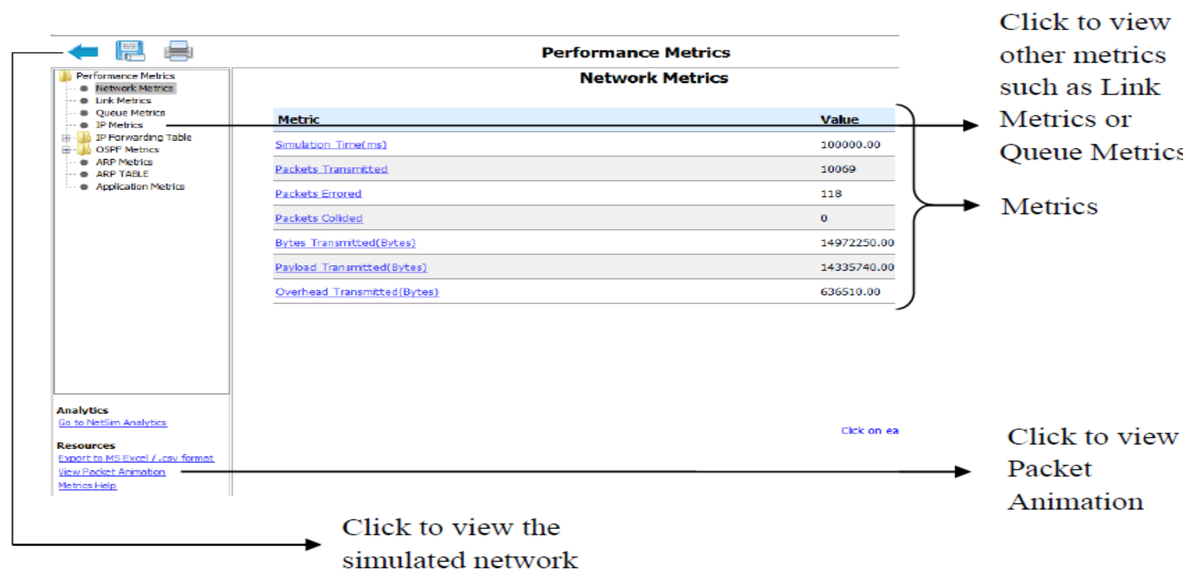


Scenario: A Scenario is a narrative describing foreseeable interactions of types of input data and its respective output data in the system.

Network performance: To measure the performance of a network, performance metrics constitutes of Network Statistics.

What are network statistics?

Network statistics are network performance related metrics displayed after simulating a network. The report at the end of the completion of a simulation experiment include metrics like throughput, simulation time, frames generated, frames dropped, frames errored, collision counts etc, and their respective values.

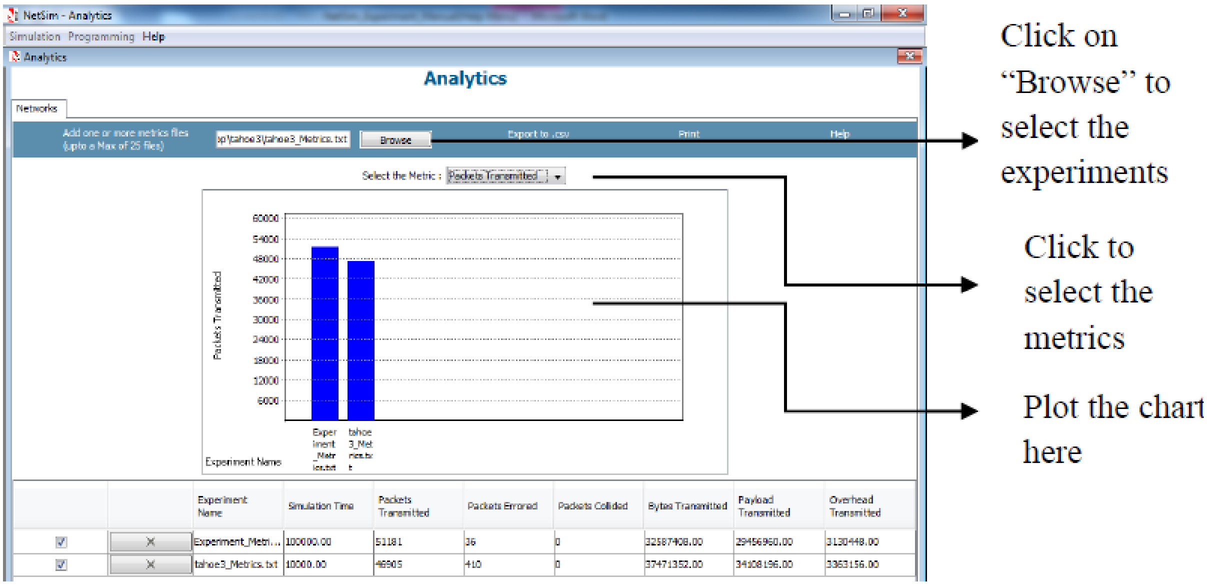


What is Packet Animation?

When running simulation, options are available to play and record animations which allow users to watch traffic flow through the network for in-depth visualization and analysis.

What is NetSim analytics used for?

It is used to compare and analyze various protocols scenarios under Internetworks, Legacy Networks, BGP Networks, Advanced Wireless Networks – MANET and Wi-Max, Cellular Networks, Wireless Sensor Networks, Zigbee Networks, Internet of Things, LTE/LTE-A Networks and Cognitive Radio Networks. Parameters like utilization, loss, queuing delay, transmission time etc of different sample experiments are compared with help of graphs.



Experiment No: 2

Aim:

Study how call blocking probability varies as the load on a GSM network is continuously increased

Theory

The erlang (symbol E[1]) is a dimensionless unit that is used in telephony as a measure of offered load or carried load on service-providing elements such as telephone circuits or telephone switching equipment. A single cord circuit has the capacity to be used for 60 minutes in one hour. Full utilization of that capacity, 60 minutes of traffic, constitutes 1 erlang.

When used to represent **carried traffic**, a value (which can be a non-integer such as 43.5) followed by "erlangs" represents the average number of concurrent calls carried by the circuits (or other service-providing elements), where that average is calculated over some reasonable period of time.

$$\boxed{Pr[blocking] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} = GOS}$$

Where, C is the number of trunked channels offered by a trunked system and A is the total offered traffic.

Procedure

In NetSim, Select —Simulation -> New -> Cellular Networks -> GSM

Follow the steps given in the different samples to arrive at the objective.

In this Experiment,

- One BTS (BTS A) and one MSC (MSC B) is used
- Total no of MS used: Vary from 4 to 20 in steps of 2.

The devices are inter connected as given below,

- All the MS are placed in the range of BTS A

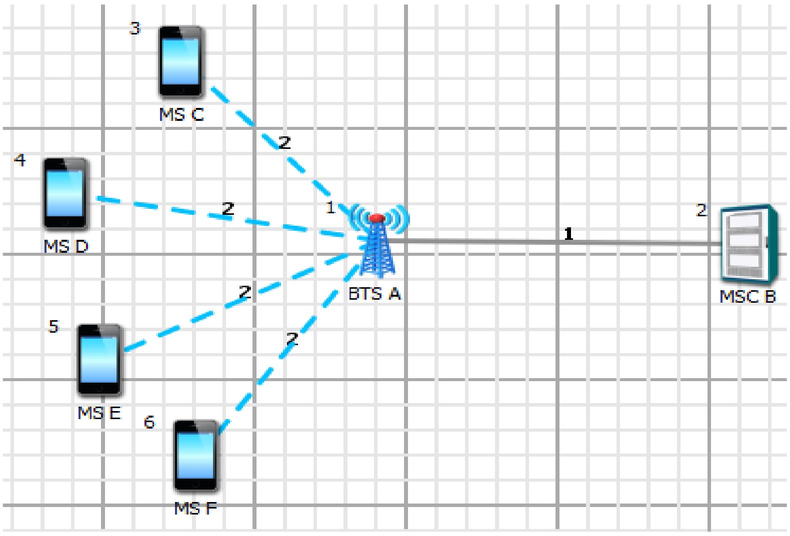
Set the properties by following the tables for each sample,

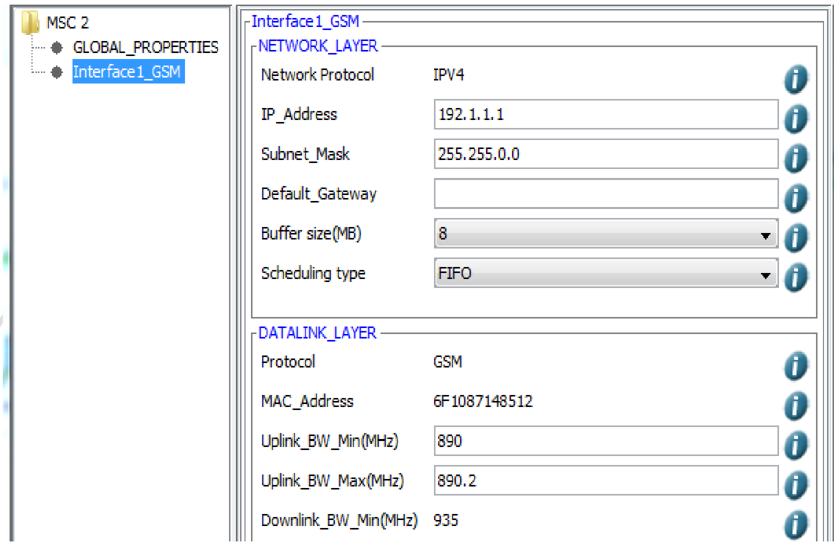
Inputs for Sample 1

Number of MS = 4

Accept default properties for BTS.

Edit Uplink Bandwidth Min to 890 MHz and Uplink Bandwidth Max to 890.2 MHz in MSC properties.





In the Sample 1, two Applications are run. After dropping Application on the Environment menu, add application 2 from the left pane and change the following properties. Set Simulation Time – 100 sec

Application Properties	Application 1	Application2
Application type	Erlang_call	Erlang_call
Source_Id	3	5
Destination_Id	4	6
Call		
Duration_ Distribution	Exponential	Exponential
Duration(s)	60	60
Inter Arrival Time (sec)	10	10
IAT_ Distribution	Exponential	Exponential
Codec		
Codec	Custom	Custom
Service Type	CBR	CBR
Packet Size	33	33
Inter Arrival Time (µs)	20000	20000

Inputs for Sample 2

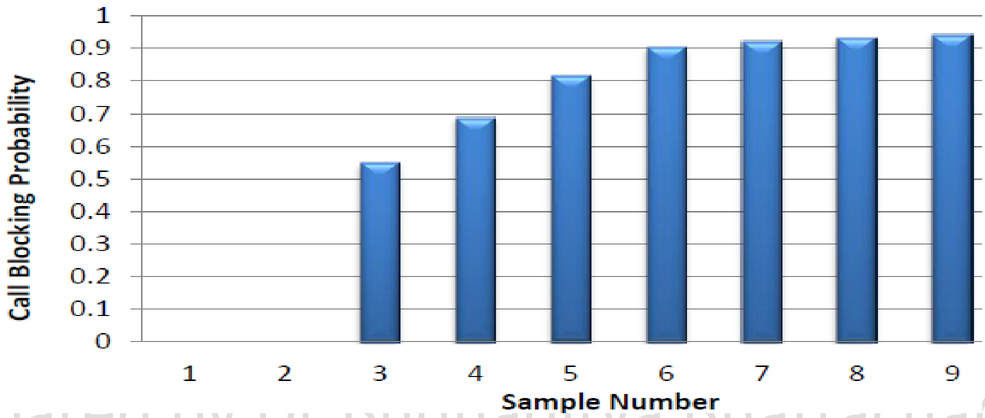
Number of MS = 6

Add one more Application and set the properties as above with Source_Id as 7 and Destination_Id as 8. Likewise, increase the number of MS by 2 upto 20 and set properties for different Samples by adding an application every time and changing Source_Id and Destination_Id.

Simulation Time – 100 sec

Result

To view the output, go to the Cellular Metrics. In MS metrics, add the call blocked and call generated column. Call blocking probability is calculated as ratio of Total call blocked to Total call generated.



Inferences:

Experiment No: 3

Aim

Analysis of LTE Handover using NetSim simulator

Theory

Handover is an important function that maintains seamless connectivity when transitioning from one base station to another.

- **LTE Handover Call Flow Description**

1. A data call is established between the UE, S-eNB (Source-eNB) and the network elements. Data packets are transferred to/from the UE to/from the network in both directions (Downlink as well as Uplink)

2. The network sends the MEASUREMENT CONTROL REQ message to the UE to set the parameters to measure and set thresholds for those parameters. Its purpose is to instruct the UE to send a measurement report to the network as soon as it detects the thresholds.

3. The UE sends the MEASUREMENT REPORT to the S-eNB after it meets the measurement report criteria communicated previously. The S-eNB makes the decision to hand off the UE to a T-eNB (Target-eNB) using the handover algorithm; each network operator could have its own handover algorithm.

4. The S-eNB issues the RESOURCE STATUS REQUEST message to determine the load on T-eNB (this is optional). Based on the received RESOURCE STATUS RESPONSE, the S-eNB can make the decision to proceed further in continuing the handover procedure using the X2 interface.

5. The S-eNB issues a HANDOVER REQUEST message to the T-eNB passing necessary information to prepare the handover at the target side

6. The T-eNB checks for resource availability and, if available, reserves the resources and sends back the HANDOVER REQUEST ACKNOWLEDGE message including a transparent container to be sent to the UE as an RRC message to perform the handover.

7. The S-eNB generates the RRC (Radio resource control->used for signalling transfer) message to perform the handover, i.e., RRC CONNECTION RECONFIGURATION message including the mobility Control Information. The S-eNB performs the necessary integrity protection and ciphering of the message and sends it to the UE.

135

8. The S-eNB starts forwarding the downlink data packets to the T-eNB for all the data bearers (which are being established in the T-eNB during the HANDOVER REQ message processing).

9. In the meantime, the UE tries to access the T-eNB cell using the non-contention-based Random Access Procedure. If it succeeds in accessing the target cell, it sends the RRC CONNECTION RECONFIGURATION COMPLETE to the T-eNB.

10. The T-eNB now requests the S-eNB to release the resources. With this, the handover procedure is complete.

Due to mobility UEs can move from one place to another

- As shown in the above image, User Equipment is moving from Source-eNB to the Target-eNB
- Then UE sends the MEASUREMENT REPORT to the S-eNB
- The S-eNB issues a HANDOVER REQUEST message to the T-eNB
- The T-eNB checks for resource availability and, if available, reserves the resources and sends back the HANDOVER REQUEST ACKNOWLEDGE message

Procedure

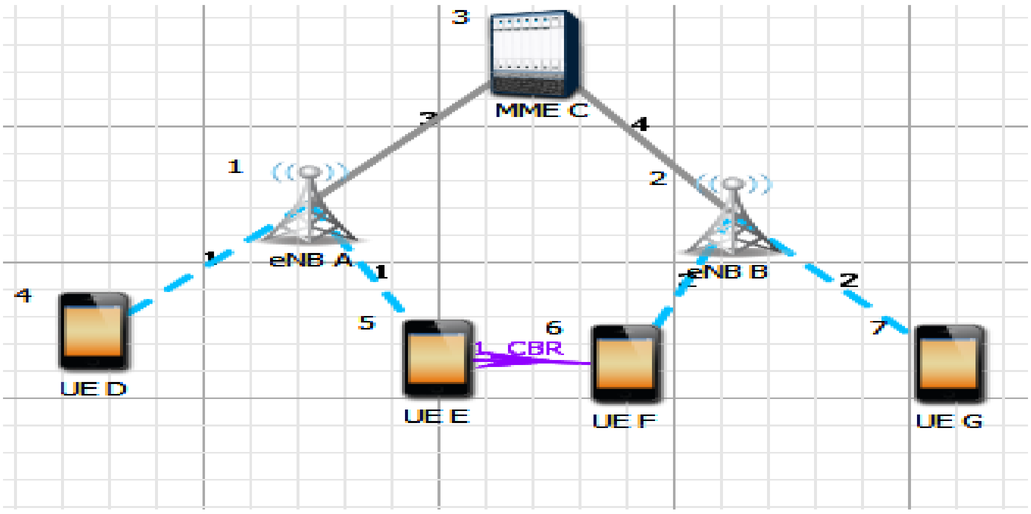
How to Create Scenario & Generate Traffic in NetSim:

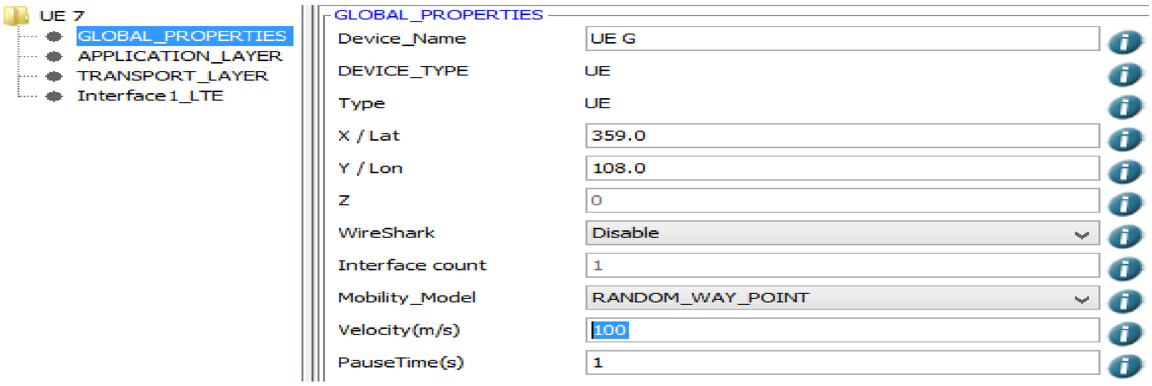
Step 1: Go to Simulation -> New -> LTE/LTE-A

Step 2: Click & drop 2 eNB's, 1 MME and 4 UE's onto the Simulation Environment. Connect the 2 eNB's with MME using Wired Link.

Step 3: Right click on UE and select Properties. Change the Velocity to 100m/s in Global Properties for all UE's.

Step 4 : Accept default properties for eNB and MME





Step 5: Application Properties

To add application, drop the Application icon. Edit the Application properties as given in table. All other properties are default.

Step 6:

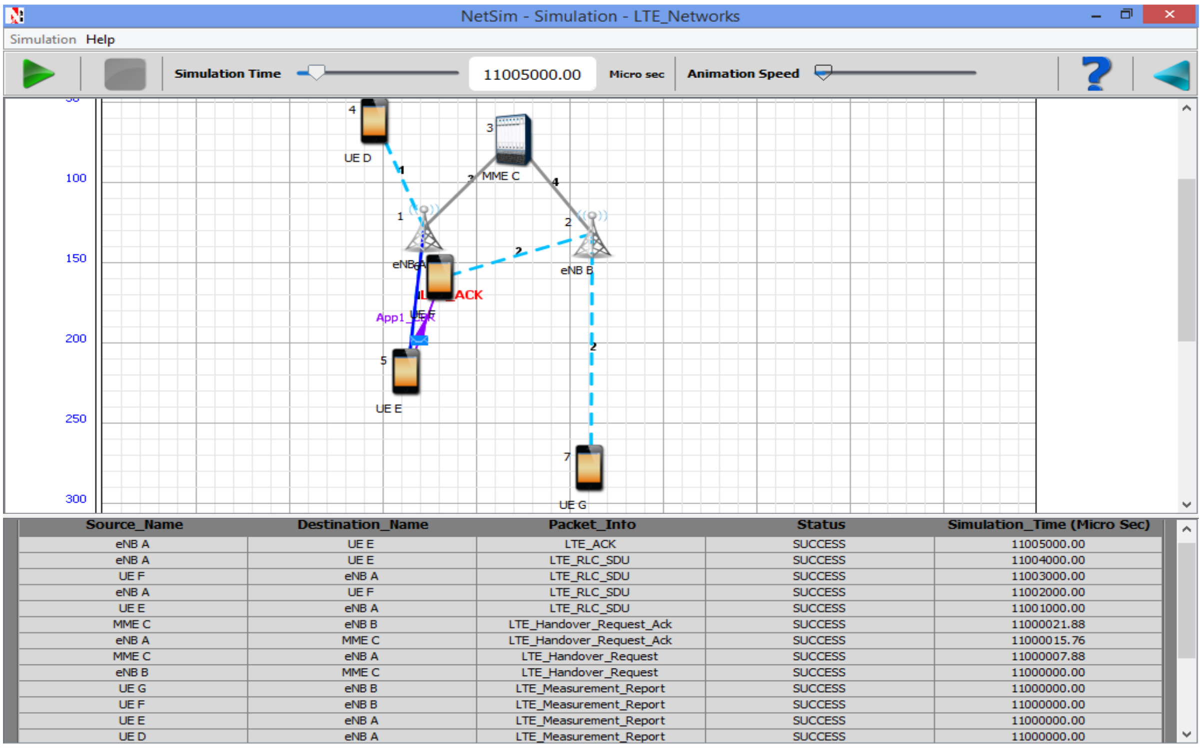
Click on Run Simulation icon and set simulation time = 100s.

Application Type	**CUSTOM**
Source ID	5
Destination ID	6

Results

Open Packet Animation:

Due to Mobility UEs can move from one cell to another. In the below figure, users can see the handover packet flow in packet animation table.



Users can see the Handover messages in red box present in the above image

- As shown in the above packet animation table, UE E, UE D connected to eNB A and UE F, UE G connected to eNB B.
- UE F is moving from eNB B to eNB A due to mobility.
- Then UEs send the LTE_Measurement_Report to eNB A, eNB B.
- The eNB B sends a LTE_Handover_Request message to the eNB A.
- The eNB A checks for resource availability and sends a LTE_Handover_Request_Ack message to the eNB B

Inference

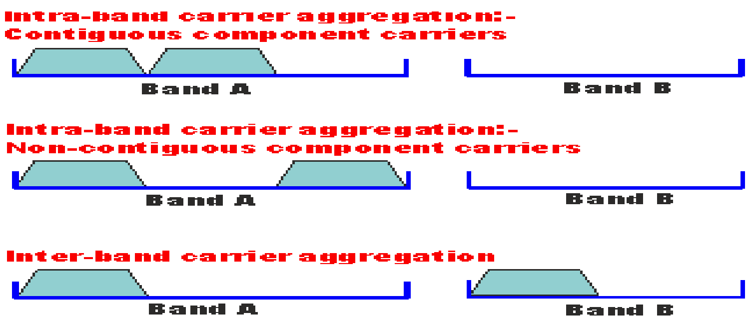
Experiment No: 4

Aim

Study how the throughput of LTE network varies as the Channel bandwidth changes in the ENB (Evolved node B)

Theory:

LTE or Long Term Evolution, commonly known as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface. LTE supports flexible carrier bandwidths, from 1.4 MHz up to 20 MHz as well as both FDD and TDD. LTE designed with a scalable carrier bandwidth from 1.4 MHz up to 20 MHz which bandwidth is used depends on the frequency band and the amount of spectrum available with a network operator. LTE Advanced offers considerably higher data rates than even the initial releases of LTE. Carrier aggregation or channel aggregation enables multiple LTE carriers to be used together to provide the high data rates required for 4G LTE Advanced. To achieve these very high data rates it is necessary to increase the transmission bandwidths over those that can be supported by a single carrier or channel. The method being proposed is termed Carrier Aggregation (CA), or sometimes channel aggregation. Using LTE Advanced carrier aggregation, it is possible to utilise more than one carrier and in this way increase the overall transmission bandwidth. These channels or carriers may be in contiguous elements of the spectrum, or they may be in different bands. Spectrum availability is a key issue for 4G LTE. In many areas only small bands are available, often as small as 10 MHz. As a result carrier aggregation over more than one band is contained within the specification



Types of LTE carrier aggregation

Intra-band: This form of carrier aggregation uses a single band. There are two main formats for this type of carrier aggregation:

1. ***Contiguous:*** The Intra-band contiguous carrier aggregation is the easiest form of LTE carrier aggregation to implement. Here the carriers are adjacent to each other.
2. ***Non –Contiguous:*** Non-contiguous intra-band carrier aggregation is somewhat more complicated than the instance where adjacent carriers are used.

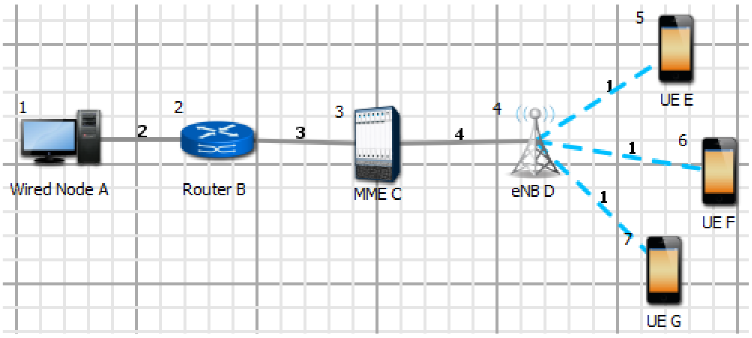
Inter-band non-contiguous: This form of carrier aggregation uses different bands. It will be of particular use because of the fragmentation of bands - some of which are only 10 MHz wide.

For the UE it requires the use of multiple transceivers within the single item, with the usual impact on cost, performance and power. In addition to this there are also additional complexities resulting from the requirements to reduce intermodulation and cross modulation from the two transceivers

The current standards allow for up to five 20 MHz carriers to be aggregated, although in practice two or three is likely to be the practical limit. These aggregated carriers can be transmitted in parallel to or from the same terminal, thereby enabling a much higher throughput to be obtained.

Procedure

Create Scenario: Go to Simulation -> New -> LTE/LTE-A networks.



Sample Inputs:

In this experiment, 1 Wired Node ,1 Router, 1 MME , 1 ENB and 3 UE are clicked and dropped onto the Simulation environment from tool bar as shown.

Sample 1:

Note: These properties can be set only after devices are linked to each other as shown above. 129

Wired Node Properties:

Node Properties	Wired Node A
Transport Layer Properties	
TCP	Disable

Router Properties: Default properties.

MME Properties: Default properties.

ENB Properties:

ENB Properties	ENB D
Interface_LTE (Physical Layer)	
Carrier aggregation	Inter_Band_Noncontingious_CA
1st CA	
Channel Bandwidth (MHz)	10
2nd CA	
Channel Bandwidth (MHz)	10

To run the simulation, drop the Application icon and change the following properties:

Application Properties	Application 1	Application 2	Application 3
Application Type	Custom	Custom	Custom
Source ID	1 (Wired Node A)	1 (Wired Node A)	1 (Wired Node A)
Destination ID	5(UE E)	6(UE F)	7(UE G)
Packet Size			
Distribution	Constant	Constant	Constant
Value(Bytes)	1460	1460	1460
Inter Arrival Time			
Distribution	Constant	Constant	Constant
Value(µs)	146	146	146

UE Properties:

UE Properties	UE E	UE F	UE G
Global Properties			
Velocity(m/s)	0	0	0

Wired Link Properties:

Link Properties	Wired Link 2	Wired Link 3	Wired Link 4
Uplink Speed (Mbps)	1000	1000	1000
Downlink Speed (Mbps)	1000	1000	1000
Uplink BER	0	0	0
Downlink BER	0	0	0

Wireless Link Properties:

Link Properties	Wireless Link 1
Channel characteristics	No Path Loss

Simulation Time – 10 Sec

Note: *The Simulation Time can be selected only after the following two tasks,*

- *Set the properties for the Wired Node, Router, MME, UE, Wired, Wireless Links and Application.*
- *Click on Run Simulation*.

Upon completion of the experiment —Save|| the experiment and note down the Application throughputs of all applications which is available in Application metrics for each sample case.

Sample 2:

Change the following properties in ENB and run the simulation for 10 seconds as above. All other properties are default.

ENB Properties	ENB D
Interface_LTE (Physical Layer)	
Carrier aggregation	Inter_Band_Noncontingious_CA
1st CA	
Channel Bandwidth (MHz)	10
2nd CA	
Channel Bandwidth (MHz)	5

From Sample 3:

Change the ENB property, Channel Bandwidth to 10, 5, 3, 1.4 MHz (Refer below table). And note down the throughput values from the Application metrics in each sample case.

ENB Properties	ENB D
Interface_LTE (Physical Layer)	
Carrier aggregation	Inter_Band_Noncontingious_CA
1st CA	
Channel Bandwidth (MHz)	5
2nd CA	
Channel Bandwidth (MHz)	5

Results

Step 1: Add the sum of all throughput values in each sample case:

Example:

Sample 1:	Application ID	Throughput (mbps)
	1	23.177
	2	23.177
	3	23.177
	Sum =	69.531 mbps

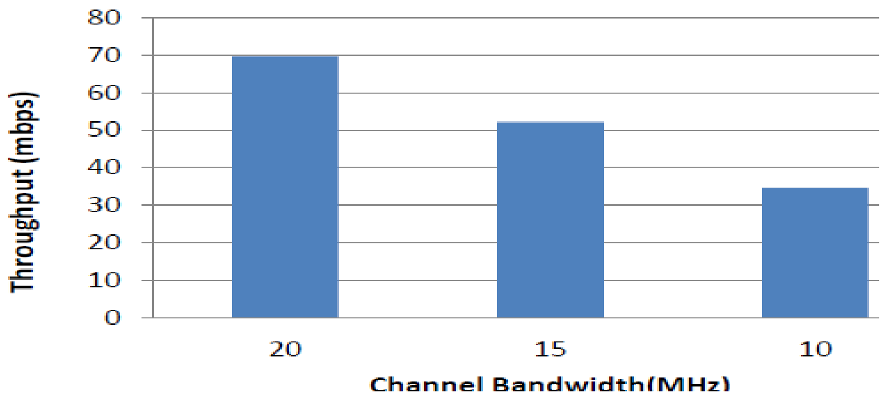
Sum = 69.531 mbps

Same procedure for all other sample cases also.

Step 2: Open the Excel file and note down the sum of applications throughput values as shown in below table.

Sample nos.	Channel Bandwidth(MHz)	Throughput (Mbps)
1	20	69.533
2	15	52.117
3	10	34.703

To draw these graphs by using Excel —Insert -> Chart option and then select chart type as —Line chart.



Inference

Experiment No : 5

Throughput analysis of LTE network with respect to varying distance between the ENB and UE (User Equipment)

Objective

Study how the throughput of LTE network varies as the distance between the ENB and UE (User Equipment) is increased

Theory:

LTE or Long Term Evolution, commonly known as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface.

The path loss in LTE is the decay of the signal power dissipated due to radiation on the wireless channels. Path loss may be due to many effects, such as free space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption.

Received power (**Pr**) can be calculated as:

Case 1: When no **path loss** Received power is same as Transmitted power, i.e., Pr = Pt

Case 2: When **Line of Sight** is there, Received power Pr is

$$\boxed{P_r = P_t + G_t + G_r + 20 \log_{10}\left(\frac{\lambda}{4\pi d}\right) + 10\, n \log_{10}\frac{d0}{d}}$$

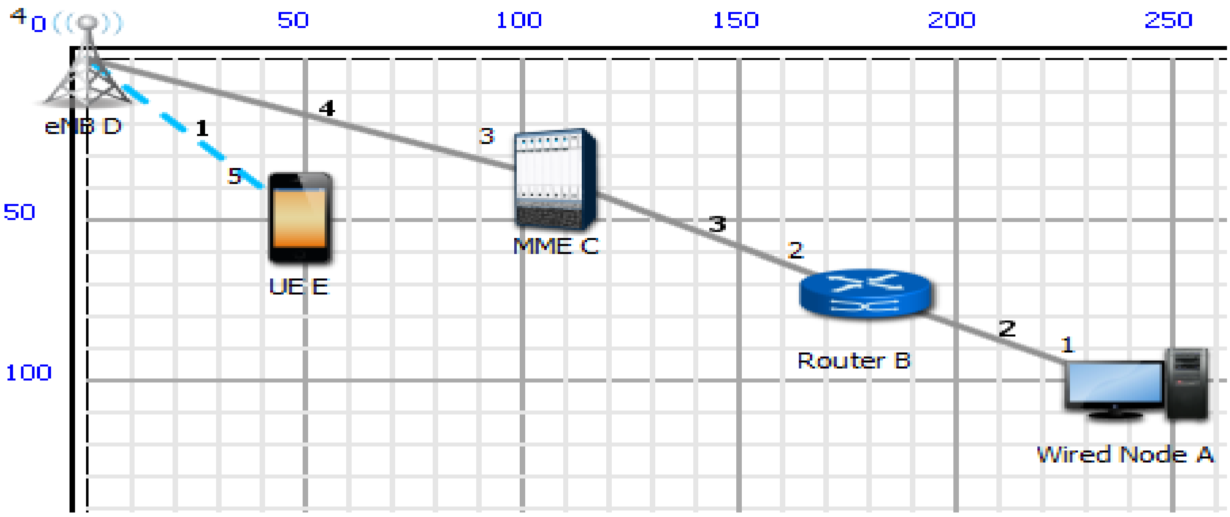
Where **Gt** and **Gr** are gains of transmitting and receiving antenna respectively. Here **d** is the distance between transmitter and receiver, **λ** is the wavelength of the transmitted signal and is reference distance at which channel gain becomes 1. **n** is path loss exponent and **Pt** is transmitted power.

Procedure:

To create a LTE Scenario, go to —Simulation -> New -> LTE Networks

Sample Inputs:

In this experiment, 1 Wired Node, 1 Router, 1 MME , 1 ENB and 1 UE is clicked and dropped onto the Simulation environment from tool bar as shown below.



Sample 1:
These properties can be set only after devices are linked to each other as shown above.

Wired Node Properties:

Node Properties	Wired Node A
Transport Layer Properties	
TCP	Disable

Router Properties: Default properties.

MME Properties: Default properties.

ENB Properties:

ENB Properties	ENB 4
Global Properties	
X_Coordinate	0
Y_Coordinate	0

UE Properties:

UE Properties	UE D
Global Properties	
X_Coordinate	50
Y_Coordinate	50
Velocity(m/s)	0

To run the simulation, drop the Application icon and change the following properties:

Application Properties	
Application Type	Custom
Source ID	1 (Wired Node A)
Destination ID	5 (UE D)
Packet Size	
Distribution	Constant
Value(Bytes)	1460
Inter Arrival Time	
Distribution	Constant
Value(µs)	165

Wired Link Properties:

Link Properties	Wired Link 2	Wired Link 3	Wired Link 4
Uplink Speed (Mbps)	100	100	100
Downlink Speed (Mbps)	100	100	100
Uplink BER	0	0	0
Downlink BER	0	0	0

Wireless Link Properties:

Link Properties	Wireless Link 1
Channel characteristics	Line of Sight
Path loss Exponent(n)	4

Simulation Time – 10 Sec

(Note: The Simulation Time can be selected only after the following two tasks,
→ Set the properties for the Wired Node, Router, MME, UE, Wired, Wireless Links and Application. → Click on Run Simulation).

Set Packet Animation to **Don't play/record animation (Simulation will run fast)** and click OK. If record animation option is selected, the simulation may take a long time to complete.

Sample 2:

Change the following properties in UE and run the simulation for 10 seconds as above. All other properties are default.

UE Properties:

UE Properties	UE D
	Global Properties
X_Coordinate	100
Y_Coordinate	100
Velocity(m/s)	0

From Sample 3 to Sample 9:
Change the UE property every time (for all samples) by varying the (x, y) coordinates values as follows:

Change in UE Properties: (x, y)	
Sample 3	(150,150)
Sample 4	(200,200)
Sample 5	(250,250)
Sample 6	(300,300)
Sample 7	(350,350)
Sample 8	(400,400)
Sample 9	(450,450)

and note down the throughput values from the Application metrics in each sample case.

Output:

Step 1: Distance calculation:

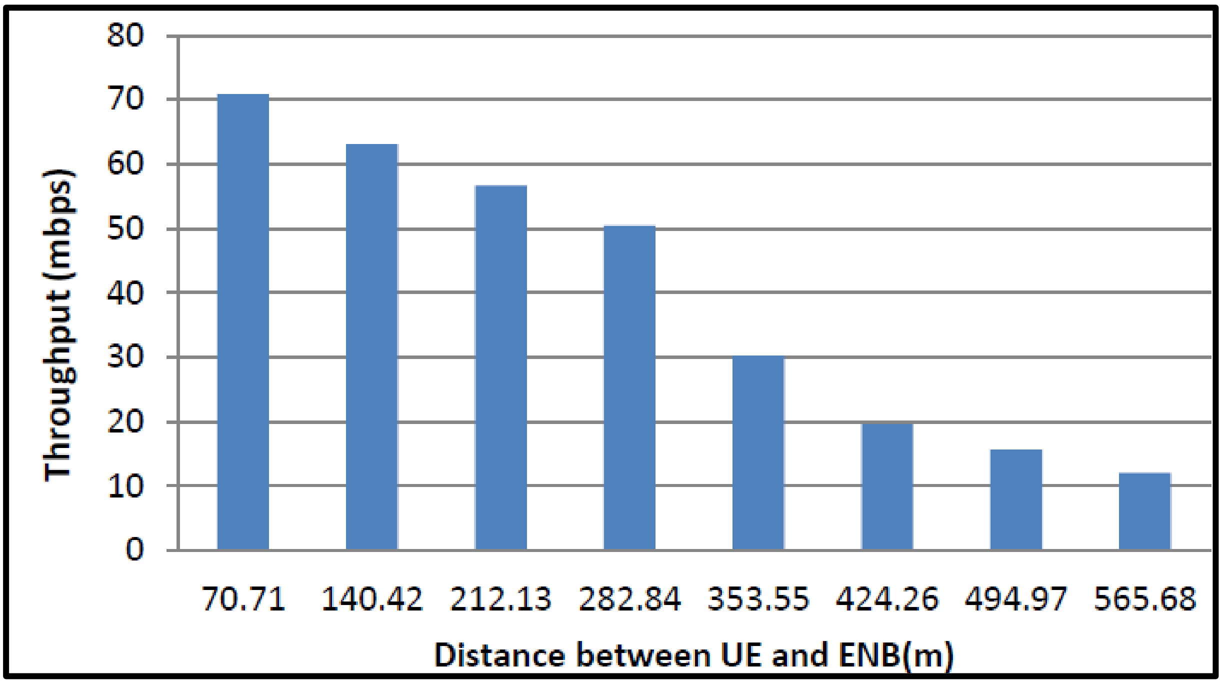
Calculate the Distance between ENB (x1, y1) and UE(x2, y2) as follows:

$$\sqrt{(x2-x1)^2+(y2-y1)^2}$$

For example for Sample 1:
ENB (x1, y1) = (0, 0); UE(x2, y2) = (50, 50);
Distance = $\sqrt{(50-0)2+(50-0)2}$ **=** $\sqrt{2} \times 50$ = **$50\sqrt{2}$** meters.
Step 2: Open the Excel file and note down the distance between UE and ENB and throughput values as shown in below table.

Sample nos.	Distance between UE and ENB (meters)			Throughput (Mbps)
1	50√2	=	70.71	70.786
2	100√2	=	140.42	63.07
3	150√2	=	212.13	56.7
4	200√2	=	282.84	50.448
5	250√2	=	353.55	30.223
6	300√2	=	424.26	19.603
7	350√2	=	494.97	15.645
8	400√2	=	565.68	12.065

Results:



<u>Inference</u>

As the distance increases between ENB and UE, throughput value is getting decreased. The reason is if distance increases between the devices, the received signal power will decrease due to high path loss.

Experiment Number 6:

Aim: Testing and validating principles of Pathloss in Mobile Radio Propagation through Smartphone and CRFO

Channel modeling plays an important role in designing and analyzing mobile cellular communication systems. In wireless communications, the electromagnetic wave propagation is severely affected by the physical phenomena such as reflection, diffraction, and scattering. Propagation models are used to characterize these propagation mechanisms and are categorized into large scale and small scale fading models. Propagation models that characterize the signal strength over large transmitter receiver separation are called large scale propagation models. Typically, the large scale propagation models are used to predict the coverage area of a transmitter. Propagation models that used to characterize the signal strength over short distances (a few wavelengths) or short time duration (a few milliseconds) are called small scale fading models. For an example, the distribution of envelope of small scale fading is modeled as Rayleigh and Rician distributions and the large-scale fading is modeled as Log- Normal distribution. We are supposed to test and check the following:

- Pathloss
- Shadow fading
- Small scale fading

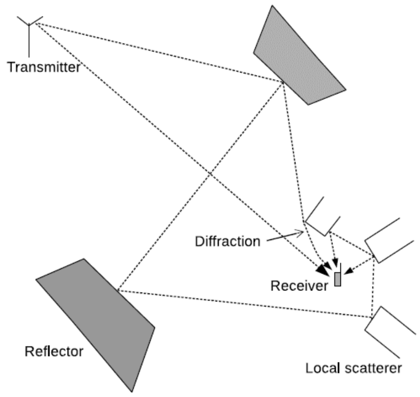


Fig. 1 Typical Multipath scenario

Tools to be used :

1) Collaborative Radio Frequency Observatory (CRFO)
2) TRAI MySpeed App

A. Collaborative Radio Frequency Observatory (CRFO)

CRFO is an online observatory containing radio frequency measurements from various locations in India. The primary purpose of CRFO is to enable collaborative research and development in the field of wireless communication in a cost- effective manner. The CRFO can be used for the following purposes:

- National spectrum monitoring in India
- Dynamic Spectrum Access (DSA)
- Cognitive Radio (CR)
- Development of Machine Learning (ML) tools for wire- less applications
- Teaching advanced signal processing and wireless communications.

B. TRAI MySpeed App

Telecom Regulatory Authority of India (TRAI) MySpeed App is a convenient tool to measure received signal strength, uplink data speed, downlink data speed and other network related information from the nearby 4G mobile towers.

C. Shadow Lab App

The Shadow Lab app [5] is developed by *Chandhar Re- search Labs* with the help of an open source android app 'LTE Coverage Tool' developed by the National Institute of Standards and Technology (NIST), Public Safety Communi- cations Research Division (PSCR), USA [7].

The Shadow Lab app collects Reference Signal Received Power (RSRP) samples at regular time intervals (currently for every second) and plots three different graphs: histogram, PDF, and line chart. In the PDF graph, we can also see the mean and standard deviation of the collected RSRP samples.

Pathloss represents the signal attenuation between a transmit and receive antenna as a function of propagation distance and other parameters. The average pathloss for a receiver located d distance away from the transmitter is expressed by

$$\overline{PL}(d) = \left(\frac{d}{d_0}\right)^{\alpha} \quad (1)$$

$$\overline{PL}(d) = \overline{PL}(d_0) + 10\alpha \log_{10}\left(\frac{d}{d_0}\right) \quad \text{dB}, \quad (2)$$

where α is pathloss exponent, d_0 is the close-in reference distance. d_0 is usually greater than the Faunhofer distance d_f which is given by

$$d_f = \frac{2D^2}{\lambda}, \quad (3)$$

where *D* is the largest physical linear dimension of the antenna and λ is the wavelength.. The received power in dBm at distance *d* is

$$\overline{P_r}(d) = P_t - \overline{PL}(d). \quad (4)$$

where P_t is transmit power in dBm.

A. *<u>Collecting RSRP samples using TRAI MySpeed app</u>*

In cellular communications, through the downlink transmissions from the base stations (BSs), the user equipment (UEs) or mobile phone periodically measures Reference Signal received Power (RSRP) and other metrics such as Reference Signal received Power (RSRQ) and Received Signal Strength Indicator (RSSI) for performing cell selection/re- selection and handover. For example, in LTE (4G) networks, there are 98 RSRP values defined, ranging from -140 dBm to -44 dBm with a 1 dB resolution as shown in Table I.

TABLE I
RSRP MEASUREMENT REPORT MAPPING IN LTE

Reported value	Measured value (dBm)
RSRP_00	RSRP $<$ -140
RSRP_01	-140 $\leq$ RSRP $<$ -139
RSRP_02	-139 $\leq$ RSRP $<$ -138
...	...
RSRP_96	-45 $\leq$ RSRP$<$ -44
RSRP_97	-44 $\leq$ RSRP

The RSRP values can be collected using TRAI MySpeed app by following the below steps:

1) Enable Mobile Internet
2) Open TRAI MySpeed app.
3) Press on 'BEGIN TEST'. Wait for a few seconds to complete.
4) Move to another location. Make sure that the distance between the current and next locations is greater than 20 m.
5) Repeat Step 3.

Figure 2 shows the screenshots of TRAI MySpeed app as prescribed in above steps.

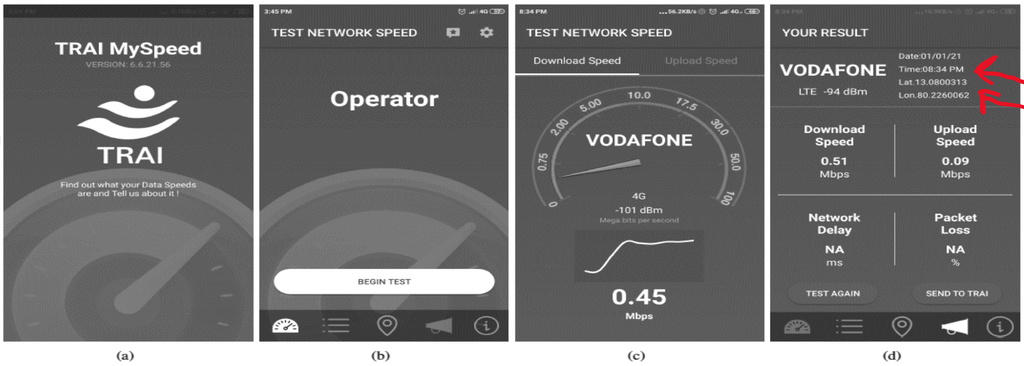


Fig. 2. Screenshots of 'TRAI MySpeed' app

B. *Generating CSV file*

Create a .CSV file with the following three columns: 'lon', 'lat', and 'val'. Fill the longitude and latitude values (with all decimal places) obtained from TRAI MySpeed app in the first two columns of the .CSV file. The purpose for considering all decimal places of latitude and longitude value is to clearly distinguish the measurement positions in the generated heatmap. The corresponding entries under 'val' column can be either RSRP or Downlink or Uplink Speed. Figure 4 shows the result of single measurement containing RSRP, latitude, longitude, download and upload speed. After conducting sufficient number of measurements, create a .CSV file in an appropriate format as explained in the next section. The login screen is shown in Fig.3

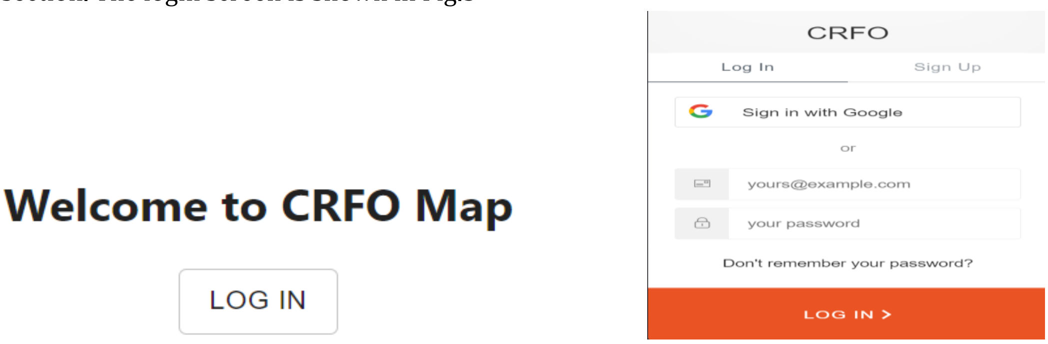


Fig. 3 Login screen for CRFO

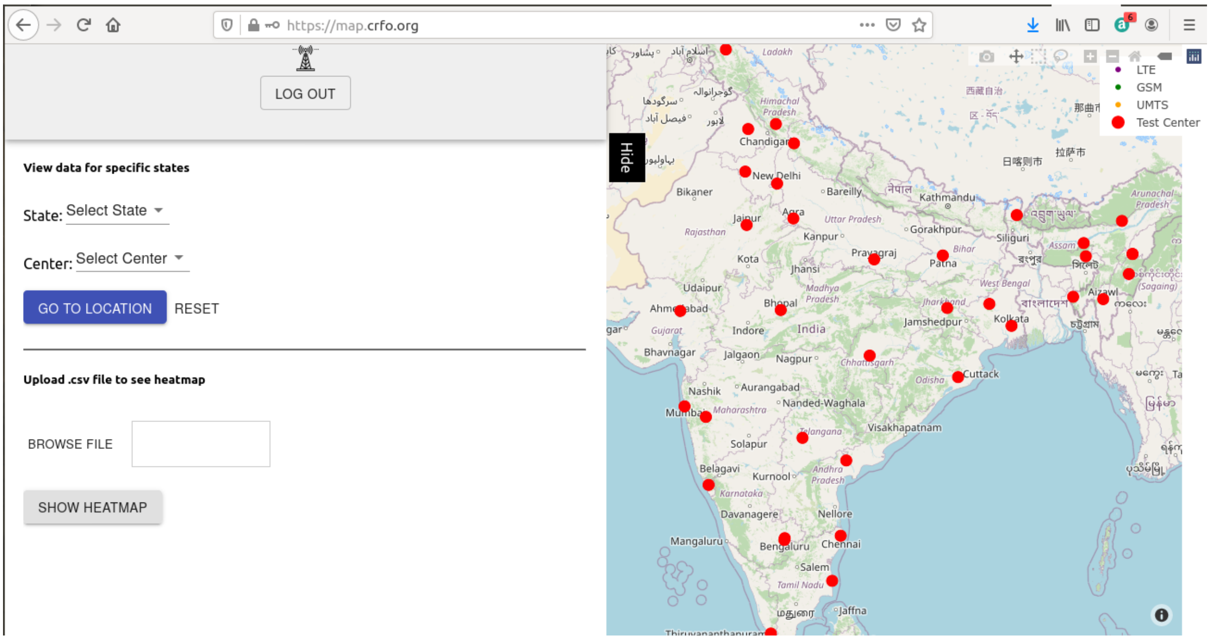
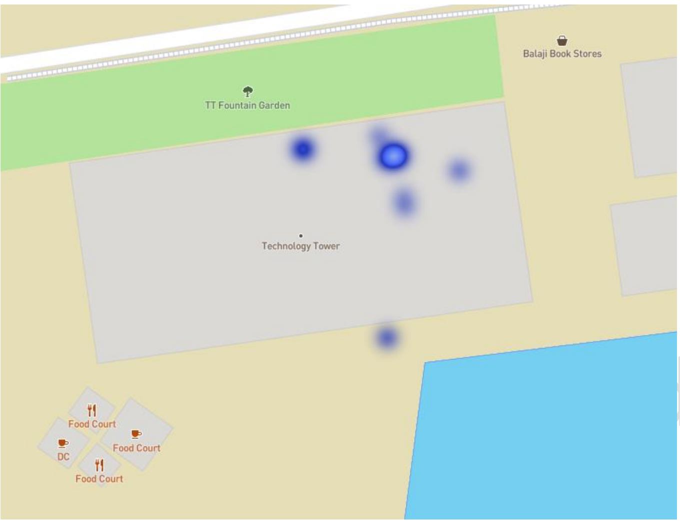


Figure 4. CRFO web interface

C. ***Procedure to view RSRP heatmap***

1) Open the website https://map.crfo.org in a web browser.
2) Click on “CRFO map” button (next to “Home” button) in the CRFO webpage.
3) Click on the link “Welcome to CRFO map”.
4) Create a new account by registering with your email id.
5) After successful registration, login to CRFO map with your email id and password.
6) Now, login into “Welcome to CRFO map” link.
7) The opened window is divided into two regions such as selection page on left side and Indian map on right side as shown in Figure 4.
8) Now, choose the tabs “Select State” and “Select Center” as per your choice and click on “GO TO LOCATION” to view data for specific states and location.
9) Now, click on “BROWSE FILE” to upload your .csv file (See Section III-C) and click on “SHOW HEATMAP” to visualise your locations on the map page. You can zoom in/out the map and select/unselect LTE/GSM/UMTS/Test for better visualization and understanding of generated map plot as shown in Figures 5 and 6. (Note: All the icons are present on top right side Indian map page).
10) Now click on “SHOW TOWERS” on selection page to visualize the towers present around your location/ test center/ generated map as shown in Figure 5.
11) Click on “LOG OUT” to return home page.

Figure 5. CRFO screenshot-1



Lon	Lat	RSRP	Distance (mt)
12.9703144	79.1597544	-69	300
12.9706472	79.1598028	-77	320
12.9707716	79.1597526	-67	335
12.9707801	79.1597784	-63	350
12.970779	79.1597783	-65	400
12.9707414	79.1599437	-73	325
12.9706782	79.1597989	-79	410
12.9077369	79.1597523	-69	375
12.9707959	79.1595338	-59	415
12.9077983	79.1595187	-77	440
12.9708283	79.159734	-75	500
12.9707648	79.1597933	-85	550
12.9706595	79.1597907	-83	580

Figure 6. Practical Measurement: Done in TT second Floor and 1st Floor

Figure 7. Tower Location Measurement

D. *Estimation of distance between UE and BS from RSRP samples*

In practice, the pathloss between the BS and UE depends on the scenario such as Urban Micro (UMi), Urban Macro (UMa), and Rural Macro (RMa) and Line-of-Sight (LoS) and Non-line of sight (NLoS) conditions. The pathloss formula has to be selected based on the above mentioned scenarios. Since, our measurements are taken in Urban scenario, let us consider pathloss formula for NLoS condition in UMi scenario given by

$$PL(d) = 36.7 \log d + 22.7 + 26 \log f_c, \qquad (5)$$

where f_c is carrier frequency in GHz and d is distance in meters. From (5) and (4), the distance (d) in meters can be calculated as

$$\hat{d} = 10^{\frac{PL(d)-22.7-26\log f_c}{36.7}}. \qquad (6)$$

Tables II and III show the estimated distance from (6) for scenarios as shown in Figures 4 and 5, respectively, with transmit power, P_t = 41 dBm. The RSRP values are collected using the smartphone which is connected to Vodafone network with carrier frequency f_c = 2320 MHz . For checking your carrier frequency search **in** **www.frequencycheck.com**. The pathloss and the distance for each RSRP sample are calculated using Equations 5 and 6, respectively. From Tables II and III, it can be observed that the pathloss varies from 106 dB to 156 dB. For example, the pathloss formula for LoS condition can be used if the measurement is taken in front of a tower (i.e. no building in between the tower and the measurement location). Therefore, we have to physically verify the location by visiting the tower locations. After finding the tower locations, we can verify the distances obtained using Equation (6).

Distance calculator:

1. Download **Cell tower Location Finder : Network cell Info lite**

2. Turn on the mobile data and select the correct SIM. Check Figure 7

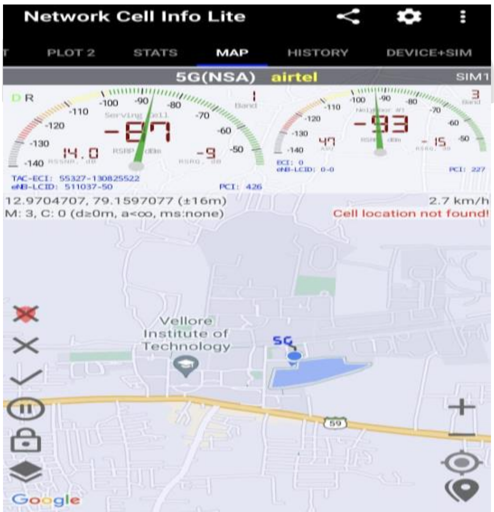


Figure : 7 Sim and Network details in Cell tower Location Finder : Network cell Info lite

3. click on plots2 to check the RSRP graph as shown in Figure 8

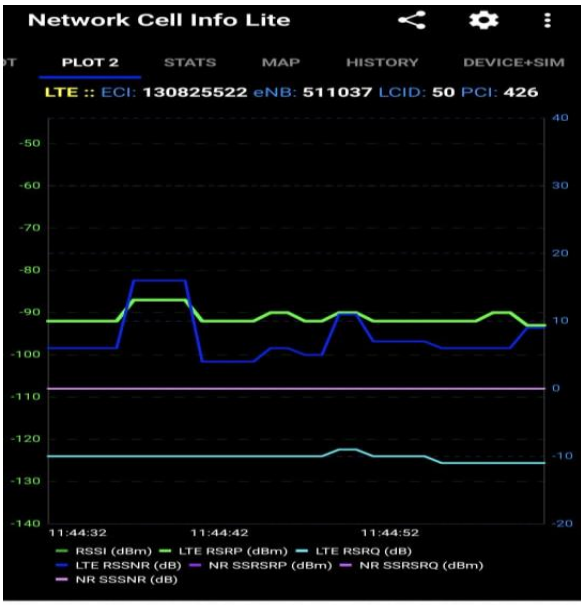


Figure 8 : RSRP reading as per the measurement sequence

5. Go to **https://www.geodatasource.com/distance-calculator.** In place origin Latitude and Logitude, use the value as obtained from Cell tower Location Finder : Map Tower Locator, and in place of destination substitute values of latitude and Longitude as obtained from Trai Myspeed App. Figure 10.

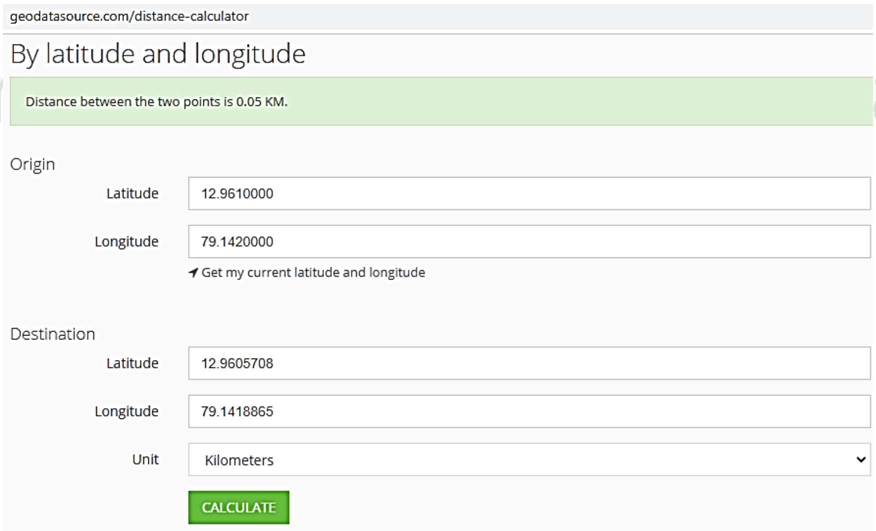


Figure 10 : Estimated Distance based on the origin and destination address.

TABLE II

DISTANCE CALCULATION FROM RSRP VALUES WITH MEASUREMENT SCENARIO 1; P_t = 41 DBM, f_c = 2.32 GHz

Latitude	Longitude	RSRP (dBm)	$P_L(d)$ (dB)	$\hat{d}$ (m)
13.0801679	80.2260928	-109	150	1581
13.0801522	80.2260598	-115	156	2332
13.0804893	80.2260314	-86	127	376
13.0803774	80.225859	-84	125	345
13.080398	80.2254994	-86	127	388
13.0804202	80.2254112	-89	130	462
13.0802461	80.2251972	-88	129	428
13.0803134	80.2252857	-88	129	437
13.0804581	80.2256027	-88	129	442
13.0804357	80.225761	-81	122	277

TABLE III

Distance calculation from RSRP values with Measurement Scenario 2; $P_t = 41$ dBm, $f_c = 2.32$ GHz

Latitude	Longitude	RSRP (dBm)	$P_L(d)$ (dB)	$\tilde{d}$ (m)
13.0801464	80.2260452	-101	142	981
13.0804985	80.2257557	-75	116	192
13.0805631	80.2255582	-79	120	247
13.0808002	80.2254647	-87	128	408
13.0812191	80.2254888	-79	120	247
13.0819614	80.225355	-89	130	462
13.0815274	80.2254982	-91	132	524
13.0815553	80.225979	-87	128	408
13.0815046	80.226252	-85	126	360
13.0804931	80.2260634	-79	120	247
13.0800177	80.2268996	-73	114	170
13.0802885	80.2268616	-95	136	673
13.0796643	80.2269571	-71	112	149
13.080351	80.2265585	-89	130	462
13.0795623	80.2267914	-77	118	218
13.0797573	80.2265138	-83	124	317
13.0797832	80.2255705	-69	110	132
13.0797705	80.2260777	-65	106	103
13.0780113	80.2259357	-87	128	408
13.0785264	80.225988	-85	126	360
13.0776225	80.225624	-95	136	673
13.0774578	80.2250176	-95	136	673
13.0780228	80.2241998	-99	140	866
13.0776462	80.224294	-87	128	408
13.0786936	80.2241142	-79	120	247
13.0791813	80.2242534	-89	130	462
13.0797125	80.2249236	-69	110	132
13.0798296	80.2245243	-91	132	524
13.080434	80.2256389	-89	130	462
13.0802891	80.2252336	-89	130	462
13.0803889	80.226053	-83	124	317
13.0810215	80.2262463	-91	132	524
13.0791252	80.2259602	-79	120	247

Observation:

The following results are obtained while plotted against the data in Table I and Table II

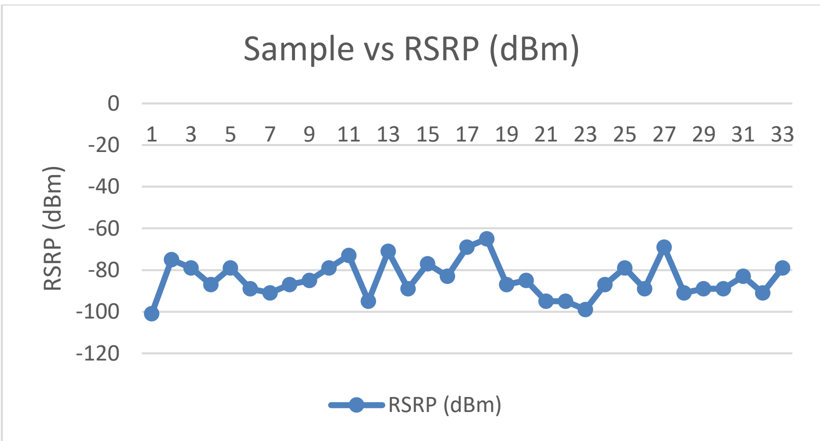


Figure 11. RSRP plot for Table I

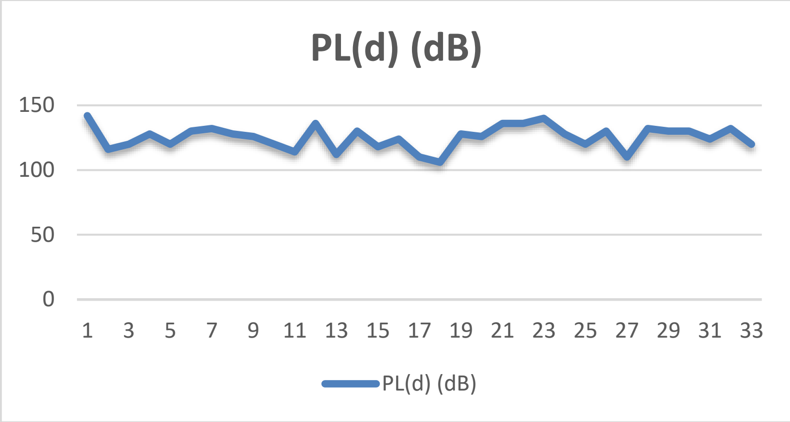


Figure 12 .Path loss plot for Table II

Inference

Task:

1. From your own location tabulate the RSRP data and create your own CRFO heatmap.
2. For the same set of reading as in Task 1, analyse Download speed statistics, Network Delay and Percentage Packet Loss for your network.
3. Write a MATLAB code to estimate Path Loss that incur for Urban Macro (UMa) LOS condition of the transmitter is 1.5 m and Height of the Receiver is 25 m. Compare your finding for the same scenario considering one other frequency other than 2.32 GHz.
4. Infer your results and show the analytical calculations involved for the same.
5. Observe and conclude if any significant changes are observed when you change the path loss models.

Experiment No: 7

Aim

MATLAB based comparative analysis between Outdoor Propagation Models – Okumura and HATA Model

Theory

The Okumura model for Urban Areas is a Radio propagation model that was built using the data collected in the city of Tokyo, Japan. The model is ideal for using in cities with many urban structures but not many tall blocking structures. The model served as a base for the Hata Model.

Okumura model was built into three modes. The ones for urban, suburban and open areas. The model for urban areas was built first and used as the base for others.

In wireless communication, the Hata Model for Urban Areas, also known as the *Okumura-Hata model* for being a developed version of the Okumura Model, is the most widely used radio frequency propagation model for predicting the behaviour of cellular transmissions in built up areas. This model incorporates the graphical information from Okumura model and develops it further to realize the effects of diffraction, reflection and scattering caused by city structures. This model also has two more varieties for transmission in Suburban Areas and Open Areas. Hata Model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications. This particular version of the Hata model is applicable to the radio propagation within urban areas. This model is suited for both point-to-point and broadcast transmissions and it is based on extensive empirical measurements taken.

Coverage for Okumura Model

Frequency = 150 MHz to 1920 MHz

Mobile Station Antenna Height (h_{re}): between 1 m and 10 m

Base station Antenna Height (h_{ete}): between 30 m and 1000 m

Link distance: between 1 km and 100 km

Coverage for Hata Model

Frequency: 150 MHz to 1500 MHz

Mobile Station Antenna Height: between 1 m and 10 m

Base station Antenna Height: between 30 m and 200 m

Link distance: between 1 km and 20 km.

Mathematical formulation for Okumura Model

The Okumura model is formally expressed as:

$$L = LFSL + AMU - HMG - HBG - \Sigma K_{CORRECTION}$$

where,

L = The median path loss. Unit: Decibel (dB),

LFSL = The Free Space Loss. Unit: Decibel(dB),

AMU = Median attenuation.Unit: Decibel(dB),

HMG = Mobile station antenna height gain factor, where

$$HMG = 20\log\left(\frac{h_{te}}{200}\right) \quad 1000m > h_{te} > 30m$$

HBG = Base station antenna height gain factor.

$$HBG = 10\log\left(\frac{h_{re}}{3}\right) \quad h_{re} \le 3m$$

$$= 20\log\left(\frac{h_{re}}{3}\right) \quad 10m > h_{re} > 3m$$

Kcorrection = Correction factor gain Okumura model does not provide a mean to measure the Free space loss. However, any standard method for calculating the free space loss can be used.

Mathematical formulation for Hata Model

Hata Model for Urban Areas is formulated as:

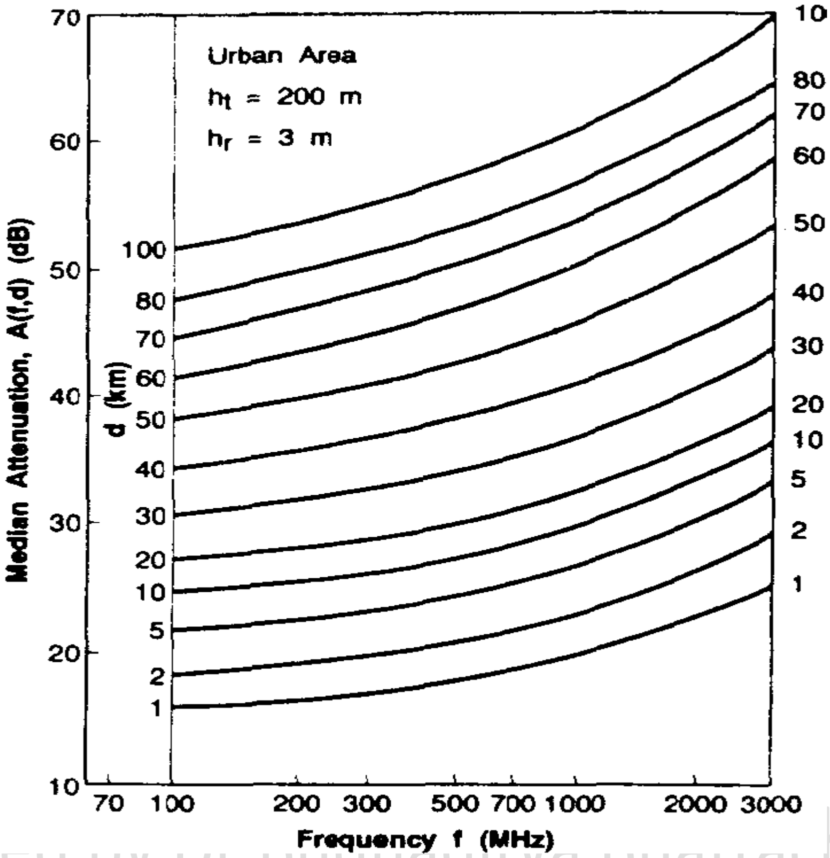
LU = 69.55 + 26.16 log f – 13.82 log h_{te} – **CH** + [44.9 – 6.55 log h_{te}] log d.

For small or medium sized city,
CH = 0.8 + (1.1 log f – 0.7) hre – 1.56 log f.

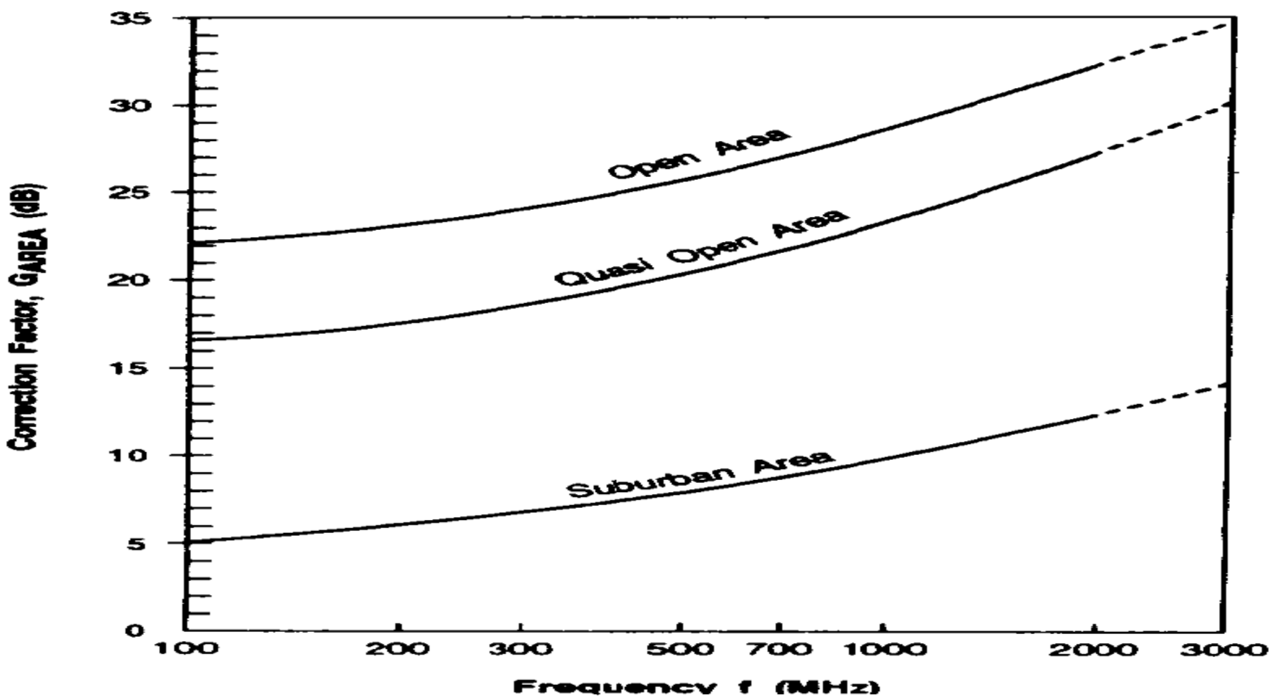
and for large cities,
CH = 8.29 (log (1.54 hre))2 – 1.1 , if 150 ≤ f ≤ 200

CH = 3.2 (log (11.75 hre))2 – 4.97 , if 200 ≤ f ≤ 1500

Reference Plot : 1 Median attenuation Loss vs Frequency



Reference Plot : 2 Correction Factor vs Frequency



Sample Program for Okumura Model

```
clc;
clear all;
close all;
Lfsl=input('enter the free space loss:');
Amu=input('enter the median attenuation value:');
Hmg=input('enter the Mobile station antenna height gain factor:');
Hbg=input('enter the Base station antenna height gain factor:');
Kc=input('enter the Correction factor gain:');
L=Lfsl+Amu-Hmg-Hbg-Kc;  %calculating median path loss
disp(sprintf('%s %f %s','the median path loss:',L,'dB'));
```

Sample Program for Hata Model

```
clc;
clear all;
close all;
f=input('enter the frequency of transmisson in mhz:');
Hb=input('enter the height of base station Antenna in meter:');
Hm=input('enter the height of mobile station Antenna in meter:');
d=input('enter the distance between the base and mobile stations:');
n=input('enter 0 for small city and 1 for large city:');
```

Write the rest of the code here based on small city or large city

Results

For Okumura Model :

1. Plot a Graph : Frequency vs Loss (dB) for open area and comment on the finding.
2. Plot a Graph : Transmitter Antenna height vs Loss (dB) and comment on the finding.
3. Plot a Graph : Receiver Antenna height vs Loss (dB) and comment on the finding.
4. Plot a Graph : Compare the results for Frequency vs Loss (dB) for Open. Quasi and suburban area.

For HATA Model :

1. Plot a Graph : Frequency vs Loss (dB) for small city and comment on the finding.
2. Plot a Graph : Transmitter Antenna height vs Loss (dB) and comment on the finding.
3. Plot a Graph : Receiver Antenna height vs Loss (dB) and comment on the finding.
4. Plot a Graph : Compare the results of HATA model and Extended HATA model with respect to Frequency vs Loss (dB) for Large cities

Inference

Experiment Number 5

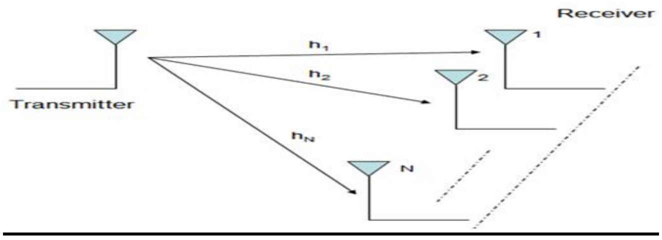
Aim

MATLAB based analysis of Bit Error probability with selection diversity

Theory

Selection Diversity

Receiver diversity is a form of space diversity, where there are multiple antennas at the receiver. The presence of receiver diversity poses an interesting problem – how do we use 'effectively' the information from all the antennas to demodulate the data. There are multiple ways to approach the problem. The three typical approaches to be discussed are – selection diversity, equal gain combining and maximal ratio combining. In this experiment we will discuss selection diversity. For the discussion, we will assume that the channel is a flat fading Rayleigh multipath channel and the modulation is BPSK. Consider a scenario where we have a single antenna for transmission and multiple antennas at the receiver (as shown in the figure below). At the receiver we have now N copies of the same transmitted symbol. With **selection diversity**, the receiver selects the antenna with the highest received signal power and ignores observations from the other antennas. The chosen receive antenna is one which gives $\max(\gamma_i)\ \forall i$



Let instantaneous SNR is denoted as γi and Avg SNR is given by Γ , then

$$SNR = \Gamma = \frac{E_b}{N_0}\overline{\alpha^2}$$

Where, Eb = Avg. Carrier Energy, N0 = Noise PSD, α = a random variable used to represent amplitude values of the fading channels wrt Eb/N0 =1. The mean SNR improvement is given by.

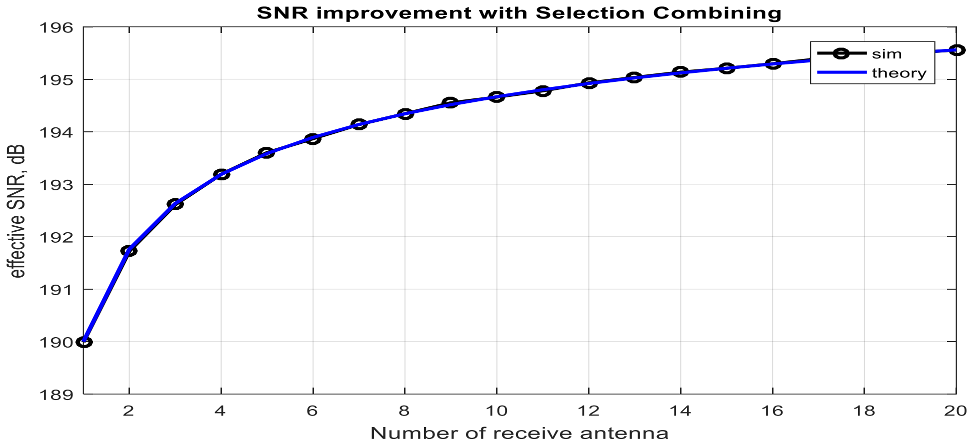
$$\bar{\gamma} = \Gamma \sum_{k=1}^{m} \frac{1}{k} = \Gamma\left(1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \cdots + \frac{1}{m}\right) > \Gamma$$

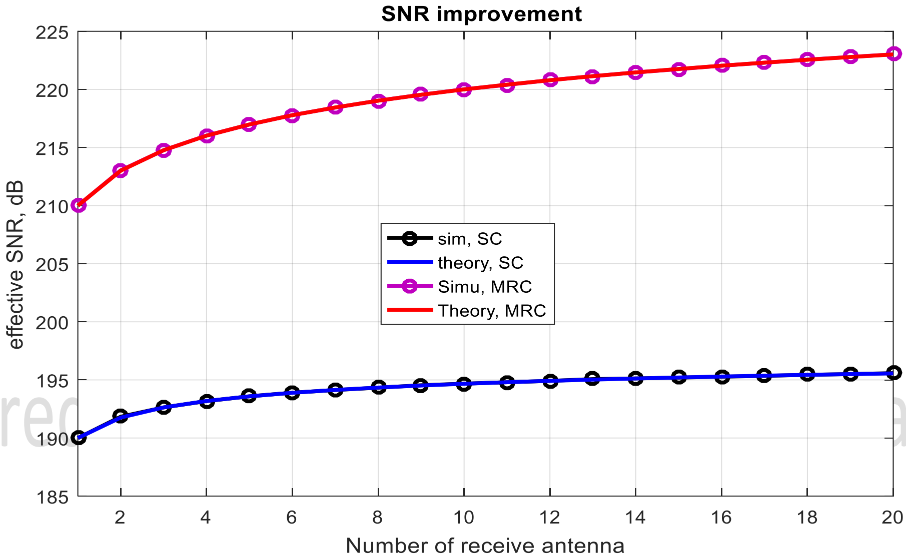
MATLAB Sample Codes

MATLAB Sample Codes

```
clc;clear all; %close all
N = 10^4; % number of bits or symbols

% Transmitter
% ip = rand(1,N)>0.5; % generating 0,1 with equal probability
% s = 2*ip-1; % BPSK modulation 0 -> -1; 1 -> 0

s=randsrc(1,N) % Random number generation

spower=1; % very similar to Eb = 1

nRx = [1:20]; % Number of Antenna or order of diversity
Eb_N0_dB =   [20]; % multiple Eb/N0 values
var_noise=spower/(10^(Eb_N0_dB)/10); % chaning it to linear scale as spower is in linear

for t = 1:length(nRx)

        n = sqrt(var_noise)*[randn(nRx(t),N) + j*randn(nRx(t),N)]; % white gaussian
noise, 0dB variance
        h = 1/sqrt(2)*[randn(nRx(t),N) + j*randn(nRx(t),N)]; % Theoritical Rayleigh
channel distribution
        % Channel and noise Noise addition
        sD = kron(ones(nRx(t),1),s);
        y = h.*sD + n;
        %y = h.*sD + 10^(Eb_N0_dB(ii)/10)*n;

        % finding the power of the channel on all rx chain
        h_Power = h.*conj(h);

        % finding the maximum power
        [hMaxVal ind] = max(h_Power,[],1);% Finding the exact antenna which one has
maximum signal strength
        hMaxValMat = kron(ones(nRx(t),1),hMaxVal); % Summary of all the branches

        % selecting the chain with the maximum power
        %ySel = y(h_Power==hMaxValMat);
        hSel = h(h_Power==hMaxValMat);

        % effective SNR
        EbN0EffSim(t) = mean(hSel.*conj(hSel));% calculating Sqare (hi)
        EbN0EffThoery(t) = sum(1./[1:nRx(t)]);
```

Results





Inferences

Task 1: Change the Eb_No to values 10, 15, 20, 30 and compare the effective SNR improvement.
Task 2: Vary the modulation from BPSK to QPSK and analyse effective SNR improvement.
Task 3: For diversity order of 20, find the effective SNR improvement for MRC technique.