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Palestine Polytechnic University



College of Engineering and Technology

Electrical and Computer Engineering Department

Graduation Project

The Effect of Soft Handover Threshold on Data Loss and Delay in UMTS Network Using Simulation "OPNET Simulator"

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Based on the requirements of college of engineering and technology and the supervision of the immediate supervisor of the project and the approval of members of the committee discussion of this project was submitted to the department of electrical engineering and computer in order to meet the requirements of bachelor's degree in engineering for Telecommunications and Electronics Engineering

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Abstract

UMTS network is one of the most communication network widespread in the world , and there is continuously increasing of number of mobile users , but increasing the number of users causes problems in the network ,and we need ways to solve this problem, one of these ways is decreasing the coverage area of the Node-B's and increasing its number , this lead to several problems , one of this problems is increase the number of soft handover, and this reason has effect of the QoS parameters .

In this project we decided to study the relation between the soft handover threshold and the two main parameters from QoS which are loss and delay using OPNET simulation, to take these results during planning for any network.

According to the results that we obtained, we found that increasing soft handover threshold , produce more connection established in the system and more system resources are consumed , this lead to overhead of extra connection caused by soft handover and more loss will be produced.

In case of delay, by decreasing the soft handover threshold , the value of the throughput will increase, so that a packet queuing will be produced, and more delay will happen over the network , in the other hand, by decreasing the soft handover threshold the mobile will remain connect with the Node-B for time and distance higher than it at higher threshold before begin executing the handover algorithm , so the higher distance of connection will increase delay between the transmitter and receiver .

شكر وتقدير

الحمد لله الذي علم بالقلم ، علم الإنسان ما لم يعلم ، والصلاة والسلام على المعلم الأول ،
صلى الله عليه وعلى آله وصحبه وسلم .

﴿رَبِّ أَوْزِرْ عَنِّي أَنْ أَشْكُرَ نِعْمَتَكَ الَّتِي أَنْعَمْتَ عَلَيَّ وَعَلَىٰ وَالِدَيَّ وَأَنْ أَعْمَلَ صَالِحًا تَرْضَاهُ
وَأَدْخِلْنِي بِرَحْمَتِكَ فِي عِبَادِكَ الصَّالِحِينَ﴾ (النمل: ١٩)

يا ربّي . . . توفيقنا في بحثنا هذا من عندك والنقص فيه من عند أنفسنا
فلك الحمد والشكر كما ينبغي لجلال وجهك وعظيم سلطانتك .

ثم بكل الود تتقدم بالشكر للأستاذ الفاضل أيمن ونرونر

على ما قدمه لنا من جهد مبارك ، نسأل الله أن يجزيه عنا خير الجزاء وأن يوفقه لكل خير .

قال حبيبنا صلى الله عليه وسلم : (إن الله وملائكته وأهل السماوات والأرض حتى النملة

في جحرها ، وحتى الحوت ، ليصلون على معلمي الناس الخير)

الإهداء

﴿ وَقَضَىٰ رَبُّكَ أَلَّا تَعْبُدُوا إِلَّا إِيَّاهُ وَبِالْوَالِدَيْنِ إِحْسَانًا إِمَّا يَبْلُغَنَّ عِنْدَكَ الْكِبَرَ أَحَدُهُمَا أَوْ كِلَاهُمَا فَلَا تَقُلْ لَهُمَا آفٌ وَلَا نَهْمًا وَقُلْ لَهُمَا قَوْلًا كَرِيمًا . وَخَفِضْ لَهُمَا جَنَاحَ الذُّلِّ مِنَ الرَّحْمَةِ وَقُلْ رَبِّ ارْحَمْهُمَا كَمَا رَبَّيْتَنِي صَغِيرًا ﴾ (الإسراء: ٢٤، ٢٣)

أمهاتنا وآباؤنا يستحقون أن نبذل لأجلهم الغالي والنفيس فكيف لا نهديهم بحشنا ابتداءً!!

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Acronyms

1G	1st Generation
2G	2nd Generation
3G	3rd Generation
UMTS	Universal mobile telecommunication system
NMT	Nordic Mobile Telephone
AMPS	American Mobile Phone System
GSM	Global System for Mobile Communications
WCDMA	Wide code division multiple access
UTRA	Universal Terrestrial Radio Access
FDD	Frequency Division Duplex
TDD	Time Division Duplex
IMT	International Mobile Telecommunications
UE	User equipment
SIM	Subscriber Identity Module
RNC	Radio Network Controller
RRC	Radio Resource Control
BTS	base transceiver station
SGSN	Serving GPRS support node
MAP	mobile application protocol
RA	routing area
IP	Internet protocol
PLMN	public land mobile network
GGSN	Gateway GPRS Support Node
QOS	quality of service
HSS	Home Subscriber Server
CSCF	Call session control function
CDRs	call detail records
MGW	Media gateway
MGCF	Media Gateway Control Function
TS	3GPP technical specifications
CN	core network

UTRAN	UMTS terrestrial radio access network
RNS	radio network subsystems
RNC	radio network controller
HC	handover control
AC	admission control
LC	load control
PS	packet scheduling
PC	power control
HLR	home location register
VLR	visitor location register
MSC	mobile services switching center
GMSC	gateway MSC
PCH	paging channel
RACH	random access channel
AGCH	access grant channel
DS-CDMA	Direct-Sequence Code Division Multiple Access
BoD	Bandwidth on Demand
FDD	Division Duplex
TDD	Time Division Duplex
AGCH	access grant channel
PCH	paging channel
RACH	random access channel
DCH	dedicated channel
CCCHs	Common Control Channels
DCCHs	Dedicated Control Channels
FACCH	fast associated control channel
SACCH	slow associated control channel
ITU	International Telecommunications Union
IMT	International Mobile Telephony
BER	Bit error rate
FER	Frame error rate
MDHO	Macro diversity handover
UPM	UMTS performance modeler

Chapter One

1

Overview

1.1 Introduction

1.2 General Idea About The Project

1.3 Objectives

1.4 Problem Statement

1.5 Proposed Solutions

1.6 Related Work

1.1 Introduction

In this chapter , we will discuss the basic idea of the project which is studying the effect of soft handover threshold on the network losses and quality of service (QOS) , then we will talk about the objectives of the project , problem statement , proposed solutions , and related works.

Chapter 2 will provide two main parts, the first part about UMTS network, and the second part about the OPNET Modeler.

Chapter 3 consists of two main parts , the first part discusses the soft handover concept and study the impact of soft handover threshold on losses and end to end delay on the quality of Service , the second section presents the models built for the several simulations and case studies used and include some general considerations around the network modeling done.

Chapter 4 including the network modeling with different scenario and simulations .

Finally, chapter 5 is the concluding part which focuses on the general remarks and results, and discusses some open issues and the future work.

1.2 General Idea about the Project

The idea of this project is to improve the QOS in UMTS (universal mobile telecommunication system) using simulation by OPNET simulator , we will discuss the challenges and will study UMTS system , as well as we will clarify the objectives of the project and we will show the plan of the project that describe what we will do in this project .

The main principle of our project to Reduce the losses and end to end delay in UMTS system by studying the UMTS network , soft handover threshold, traffic types, path loss model in the network ,This method overcomes many of the challenges and improves the good quality of the information transmission.

In our work , we will study the UMTS system and we will make a simulation of this system by using OPNET program which will be presented to find the effect of soft handover threshold and traffic types on the losses and probability a user in soft handover, and which threshold should give the lowest losses ,lower delay ,and high performance of the system by comparing the different traffic types for different thresholds .

1.3 Objectives

1. To better understand the main concepts of UMTS system and the problems in this system.
2. To study the soft handover threshold and how we can reduce the losses and end to end delay in the UMTS network.
3. To detect the effect of soft handover threshold on the soft handover probability.
4. To measure QOS using simulation - OPNET program - for several different cases from soft handover threshold and traffic type, then finding out the best threshold to overcome the losses problem and delay and soft handover overhead to improve the transmission quality and QOS .

1.4 Problem Statement

UMTS (universal mobile telecommunication system) is a digital mobile telephony system that is widely used in the world. The UMTS subjected to several problems; in our project we will discuss the quality of service in UMTS network under two main parameters, The first one is throughput and then we will discuss the end to end delay at different threshold and different traffic (16,96,256,512 byte) to prove the effect the soft handover threshold on the quality of service .

The quality of service parameters are :

- **Throughput**

Throughput is measure of average rate of successful transmission of packets in a communication channel Which is often measured in packet per second.

- **Delay in UMTS Network**

Network delay is an important design and performance characteristic of a computer network or telecommunications network. The delay of a network specifies how long it takes for a bit of data to travel across the network from one node or endpoint to another. It is typically measured in multiples or fractions of seconds. Delay may differ slightly, depending on the location of the specific pair of communicating nodes. Although users only care about the total delay of a network ,engineers need to perform precise measurements. Thus, engineers usually report both the maximum and average delay .

1.5 Proposed Solutions

In this research we want to study the relation between the soft handover threshold and the quality of service at different environment like different distribution and different traffic . as we said in Problem Statement the QOS has many parameter here we discuss two terms of them, the loss and the delay .

The expected result for the first term (loss) is when the threshold increase the loss will increase . so we suggest that at the place where we have a large number of handovers we can use new node-B or move the node-B to cover this place for example “ at wad alharea in Palestine Polytechnic University , we have node B at C building , because this will make many handover when the student move from B building to C building or to A building , the solution for this is , put the node B in B building and this will decrease number of hand over . so the loss at this area will decrease . and this solution will make some good result on the second term (delay) because when the number of handover decrease that will decrease the delay .

1.6 Related Work

The wireless communication is a key technology in today's information age. Despite the ongoing improvements in equipment design , QOS a limiting factor for the use of radio communication. Therefore, there is a lot of research that has examined this problem and has developed proposals for the resolution and in this section will recall some of these publication :

1. A paper titled " ENABLING UMTS END-TO-END PERFORMANCE ANALYSIS", the authors have presented the end-to-end performance modeling tool, which helps operators optimize their application data networks over UMTS technology. The key to this simulation platform, UMTS performance modeler (UPM) is its unique modeling capabilities. This is a valuable asset for optimizing existing UMTS networks, assessing new application performances, assessing a subscriber base increase, optimizing terrestrial links bandwidth, and increasing throughput. By modeling the entire UMTS protocol stack, radio resources management functions and all network elements, the accuracy of UPM is one step closer to real-time field performance.

Finally, the accuracy of this tool would not be complete without matching to the real network layout and radio environment. As such, Motorola's developers have facilitated a linkage between RF prediction and the end-to-end simulator. Comparisons of simulation results with real measurements collected during drive tests prove to be accurate and very reliable. Our engineers continue to enhance UPM, which is seen as a great value to Motorola's customers. Increased optimization work based on reliable simulations accelerates the optimization cycle-time, hence decreasing the optimization delivery cost. [1]

2. A paper titled "Analysis and Simulation of Radio Resource Management for Quality of Service in Universal Mobile Telecommunications System", the power control algorithm adjust the transmission power required by the mobile device in accordance with the environment changes such as line of sight and the rate of the bit energy noise ratio, avoiding that the user could bring out on line to other users or block the cell, this reduce the interference with . Soft Handover offers a better QOS than Hard Handover because like the RNC receives a copy of the data of Node-B it choose the packet with the better quality, besides guarantee that if occurs any failure in the connection the user can continue with the sending of information through the other Node-B in active set. However, it implies an increment of the reserve in the resources for many interfaces, increasing the processing load of the recurrent data that arrives from the set in the RNC and the signaling time. By contrast, in Softer Handover the Node-B is commissioned to manage the traffic in sectors and to send the frame with the best quality to the RNC .[2]

3. A paper titled ("Evaluation of QOS in UMTS Backbone Network Using Differentiated Services)" focuses on investigating an optimized UMTS Quality of Service provisioning strategy in anE2E scenario to supply QOS guarantees as well as to improve system performance. A basic model for deploying Differentiated Services in UMTS backbone networks to support the core network's QOS requirements is presented. The study addressed two implementation related issues: the structure of a Differentiated Services-aware UMTS backbone router and QOS mapping related issues.

The router utilizes the Differentiated Services functional elements with novel algorithms to build two data paths for two different PHBs. The scheduling block is based on WFQ service discipline

that is Suitable for Differentiated Services network. A simulation model of the backbone network has been used to evaluate the overall performance of the system when treating a packet according to its PHB group, mapped from its UMTS traffic class. We have presented simulation results on the end-to-end delay, throughput and end-to end delay variation to show the effectiveness of the prototype in providing service differentiation in the backbone network. Also, it was found that the hybridized model (Differentiated Services/RSVP) improves the end-to-end delay and end-to-end variation compared with Differentiated Services model only, also (Differentiated Services/RSVP) is superior to Differentiated Services regarding the throughput and utilization. [3]

4. A paper titled "Soft Handover Performance for UMTS Operations" , present satisfactory QOS level is essential for facilitating UMTS service penetration. Lasting service continuity and high radio link performance under a variety of operation conditions belong to the natural expectations of end-users of 3G systems. With this background, effective and efficient handover procedures deal as key enablers for meeting the requirements on and the challenges of UMTS networks.

This under has shown the results of an analysis aimed at optimizing the control parameters of the soft handover procedure for UMTS , the studied parameters have a major bearing on the network traffic handling capacity . their optimized has considered aspects relevant to both the appreciation of the service by the end-users, such as dropped calls and failed handovers, and the management of the radio access infrastructure by the network operators, such as signaling traffic. For operating conditions representative of an urban, high user density environment, the analysis has identified the optimum setting of the control parameters. [4]

5. A paper titled “Analyzing Quality of Service in UMTS”, Universal Mobile Telecommunications Service system is advancement over second generation system with enhanced data rates, capacity, security and much more .This paper gives an overview out of the UMTS system with its architecture and emphasizing to the Quality of Service in the UMTS network. UMTS is considered as evolution step from 2G to advance. The introduction of new WCDMA based air interface imposed new requirements for UMTS Radio Access Network.

The Quality of Service was analyzed by changing the value of the precedence bit of the CBR application. The values of the precedence bits that have been taken are 0, 1, 4 and 6. It was found that maximum throughput was achieved with precedence bit 4. The minimum average end-to-end delay was also achieved with precedence bit 4.[5]

Chapter Two

2

Theoretical background

2.1: UMTS

- 2.1.1 History of UMTS
- 2.1.2 UMTS Bandwidth Allocation
- 2.1.3 Architecture of the UMTS network
- 2.1.4 UMTS channel types
- 2.1.5 Sharing the Electromagnetic Spectrum
- 2.1.6 UMTS Cell structure
- 2.1.7 power control
- 2.1.8 Handover control

2.2 OPNET Modeler

- 2.2.1 OPNET software
- 2.2.2 The concept of simulation
- 2.2.3 About OPNET Modeler

2.1 UMTS

UMTS is one of the major new third generation mobile communications systems being developed within the framework, which has been defined by ITU and known as IMT-2000. UMTS facilitates convergence between telecommunications, IT, media and content industries. It has potential to provide end users with data rates up to 2 Mbps, and it lends itself to give individuals the freedom to choose among a wide range of services currently in existence or soon to exist. Some examples of the new services are video telephony and quick access to information and fast download of data, for instance, on Internet directly for people on the move. [7]

2.1.1 History of UMTS

Nowadays, it is widely recognized that there are three different, implemented generations as far as mobile communication is concerned (Figure 2.1). The first generation, 1G, is the name for the analogue or semi-analogue (analogue radio path, but digital switching) mobile networks established in the mid-1980s, such as the NMT system and the AMPS. These networks offered basic services for users and the emphasis was on speech and speech related services. 1G network were developed with national scope only and very often .

The main technical requirements were agreed between the governmental telecom operators and the domestic industry without wider publication of the specifications. Due to national specifications, 1G network were incompatible with each other and mobile communication was considered at that time to be some kind of curiosity and added value service on top of the fixed networks.

Because the need for mobile communication increased, also the need for a more global mobile communication system arose. International specification bodies started to specify what the second generation, 2G; mobile communication system should look like. The emphasis for 2G was on compatibility and international transparency; the system should be regional) or semi-global and the users of the system should be able to access it basically anywhere within the region. From the end-user's point of view, 2G networks offered a more attractive "package" to buy; besides the traditional speech service these networks were able to provide some data

services and more sophisticated supplementary services. Due to the regional nature of standardization, the concept of globalization did not succeed completely and there are some 2G systems available on the market. Of these, the commercial success story is the GSM and its adaptations: it has clearly exceeded all the expectations set, both technically and commercially.

The third generation, 3G, is expected to complete the globalization process of mobile communication. Again, there are national and regional interests involved and difficulties can be foreseen. Anyway, the trend is that 3G will mostly be based on GSM technical solutions for two reasons: GSM technology dominates the market and the great investments made in GSM should be utilized as much as possible. Based on this, the specification bodies created a vision about how mobile telecommunication will develop within the next decade.[6]

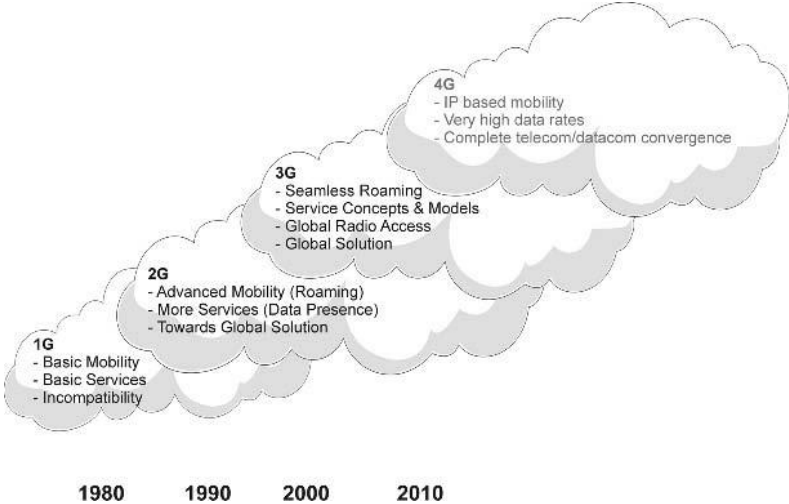


Figure 2.1 : Cellular generations

2.1.2 UMTS Bandwidth Allocation

According to "WARC-92 frequencies for IMT-2000" resolution: "The bands 1885-2025 MHz and 2110-2200 MHz are intended for use, on a worldwide basis, by administrations wishing to implement International Mobile Telecommunications-2000 (IMT-2000). Such use does not preclude the use of these bands by other services to which they are allocated."

Here is the summary of UMTS frequencies:

1. *UMTS FDD*: uplink: 1920–1980 MHz; downlink: 2110–2170 MHz .
2. *UMTS TDD*: uplink: 1900–1920 MHz; downlink: 2010–2025 MHz .

2.1.3 Architecture of the UMTS network

UMTS network architecture will be an evolution of GSM and GPRS network, thus resembling very much of their architecture. It consists of two parts: UTRAN and CN. UTRAN provides the air interface for UMTS terminals and core network is responsible for switching and routing of calls and data connections to external networks. The UMTS system architecture with the interfaces is depicted in Figure 2.2. The interfaces are defined open to allow the equipment at the endpoints to be from two different manufacturers. A complete description of the network architecture and the interfaces between the logical network elements can be found in TS [8].

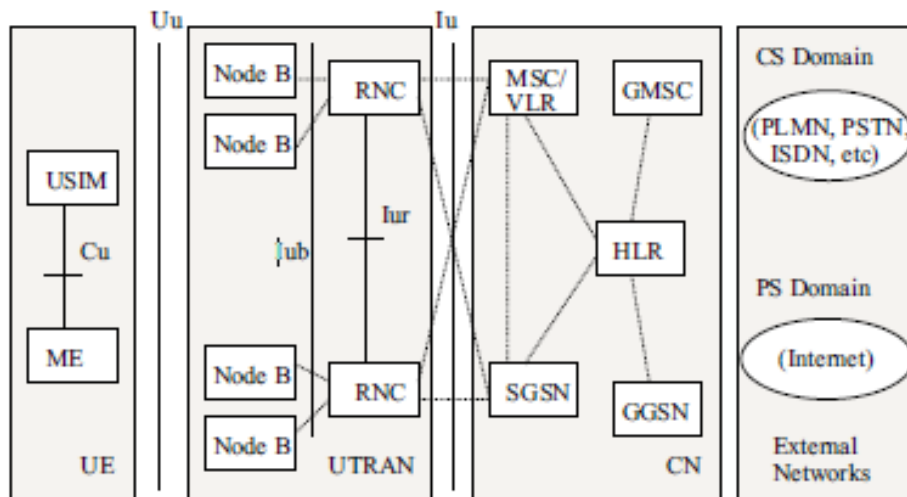


Figure 2.2: General architecture of a UMTS network

2.1.3.1 UMTS Radio Access Network

UTRAN consists of one or more RNS. RNS consists of RNC, several node Bs (UMTS base stations) and UE. The RNC is responsible for the control of radio resources of UTRAN. It plays a very important role in PC, HC, AC, LC and PS algorithms, which are at least partially located at RNC. RNC interfaces the core network via Iu interface and uses Iub to control one node B.

The Iur interface between RNCs allows soft handover between RNCs. Node B is equivalent to the GSM base station.

2.1.3.1.1 UE

The UE is a combination of terminal equipment and subscriber data. The terminal equipment as such is called ME and the subscriber's data is stored in a separate module called SIM. Figure 2.3 shows the component of the UE. Therefore, $ME + USIM = UE$.

The SIM card contains the identification numbers of the user and a list of available networks. The SIM card also contains tools needed for authentication. Depending on the type of the card, there is also storage space for messages, such as phone numbers. A home operator issues a SIM card when the user joins the network by making a service subscription.[7]

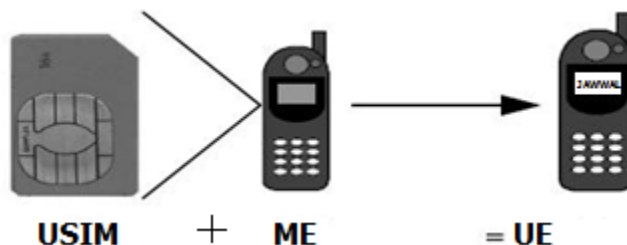


Figure 2.3: component of UE

2.1.3.1.2 Node B

Is a term used in UMTS equivalent to the BTS description used in GSM. It is the hardware that is connected to the mobile phone network that communicates directly with mobile handsets. In contrast with GSM base stations, Node B uses WCDMA/TD-SCDMA as the air interface technology. As in all cellular systems, such as UMTS and GSM, the Node B contains radio frequency transmitter and the receiver used to communicate directly with mobile devices, which move freely around it. In this type of cellular network, the mobile devices cannot communicate directly with each other but have to communicate with the Node B.[9]

2.1.3.1.3 RNC

The RNC is the network element responsible for the control of the radio resources of UTRAN. It interfaces the CN (normally to one MSC and one SGSN) and also terminates the RRC protocol that defines the messages and procedures between the mobile and UTRAN. It logically corresponds to the GSM BSC.

2.1.3.2 Core Network

UMTS is based on an evolved core GSM network integrating circuit and packet switched traffic. The entities of CN, shown in Figure 2.2, are HLR, MSC/VLR, GMSC, SGSN and GGSN.

2.1.3.2.1 HSS

HSS serves as the master database for a given user. It contains the subscription related information, to support the network entities actually handling calls /sessions . it could provide support for the call control servers to complete routing/roaming procedures by solving authentication, authorization, naming/ addressing resolution, location dependencies, etc.[10]

The HSS holds the following user related information:

1. user identification, numbering, addressing and security information (i.e. network access control information for authentication and authorization).
2. user location information at inter-system level ; the HSS handles the user registration, and stores inter-system location information, etc.
3. the user profile (services, service specific information. etc.). Based on the above information, the HSS also supports the CC/SM entities of the different control systems (CS domain control, PS domain control, IP multimedia control ,etc.) offered by service provider or an operator.

2.1.3.2.2 SGSN

The SGSN serves the mobile devices within its BSS/RAN, and provides authentication, and mobility management, which are derived as much as possible from the GSM MAP. It is the connection point between the BSS/RAN and the CN, and at a high level the SGSN provides a similar role for the packet switched network as the MSC/VLR provides to the circuit switched network. When a mobile device is packet switch attached, the SGSN is said to provide a mobility management context and it then keeps track of the mobile device to a RA or specific cell. The SGSN connects to GGSNs and also to other SGSNs via an IP network. When a mobile device is furnished with a session management context a connection is established between the SGSN and corresponding GGSN so that the mobile device may transfer data to and from an external network. An SGSN is not restricted to communication with one single GGSN and will in practice communicate with many GGSNs, which may not even be within the same PLMN as the SGSN. The SGSN has a dynamic database which stores information about the current mobile devices it is serving. This database will contain the location of the device to an RA or specific cell, security information, such as the ciphering key, charging information, current connections and the QoS being used, etc.[10]

2.1.3.2.3 GGSN

The Gateway GPRS Support Node supports the edge routing function of the packet switched GPRS network. To external packet data networks the GGSN performs the task of an IP router. Firewall and filtering functionality, to protect the integrity of the GPRS core network, are also associated with the GGSN along with a billing function.[11]

2.1.3.2.4 MSC

The MSC constitutes the interface between the radio system and the fixed networks. The MSC performs all necessary functions in order to handle the circuit switched services to and from the mobile stations. A UE roaming in an MSC area is controlled by the visitor location register in charge of this area. GMSC is the switch at the point where UMTS PLMN is connected to external circuit switched networks. All incoming and outgoing circuit switched connections go through GMSC.[12]

2.1.3.2.5 HLR

The HLR is a database used for storage and management of subscriptions. The HLR is considered the most important database, as it stores permanent data about subscribers, including a subscriber's service profile, location information, and activity status. When an individual buys a subscription from one of the PCS operators, he or she is registered in the HLR of that operator. [8]

2.1.3.2.6 VLR

The VLR was devised so that the HLR would not be overloaded with inquiries on data about its subscribers. Like the HLR, a VLR contains subscriber data, but only part of the data in the HLR and only while the particular subscriber roams in the area for which the VLR is responsible.

When the subscriber moves out of the VLR area, the HLR requests removal of the data related to a subscriber from the VLR. The geographic area of the VLR consists of the total area covered by those BTSs that are related to the MSCs for which the VLR provides its services. [13]

2.1.4 UMTS channel types

WCDMA is the main air interface standard for the 3G UMTS mobile network. The mobile station and base station communicate by means of several physical channels that are transmitted on a given frequency assignment. The "Downlink" refers to a radio link for the transmission of signals from the base station to a UE (mobile station) while the "Uplink" refers to a radio link for the transmission of signals from a UE (mobile station) to the base station.

There are three types of channels in the WCDMA technologies: Physical Channel, Transport Channel and Logical channel.

The Transport Channels are interface between MAC and Layer 1, while Logical Channels are interface between MAC and RLC. The logical and transport channels define WHAT data are

transported, while the physical channels define HOW and with what physical characteristic the data are transport.

2.1.4.1 Transport Channels

A transport channel is defined by how and with what characteristics data is transferred over the air interface. There exist two types of transport channels:

1. Dedicated channels.
2. Common channel.

There is one dedicated transport channel, the DCH, which is a downlink or uplink transport channel. The DCH is transmitted over the entire cell or over only a part of the cell using beam-forming antennas. The DCH is characterized by the possibility of fast rate change (every 10 ms), fast power control, and inherent addressing of mobile stations. [14]

2.1.4.1.1 CCCHs

The common control channels are used in both downlinks and uplinks between the MS and the BTS. These channels provide access to the network and convey information from the network to MSs .

The UMTS common control channels are used to inform mobile stations of incoming calls and to request and grant channels. The UMTS PCH, which exists only on the downlink, informs the UE of an incoming call. The UMTS AGCH, which only exists on the downlink; allocate a stand-alone dedicated control channel or traffic channel to a mobile station. The UMTS RACH, which exists only on the uplink, allows the UE to request allocation of a stand-alone dedicated control channel. Unlike other UMTS channels, for which capacity is allocated by the network, the RACH allows random access. Collisions can therefore occur if multiple mobile stations attempt to transmit at the same time. [15]

2.1.4.1.2 DCCHs

The DCCH are used on both downlinks and uplinks. The DCCHs are responsible for roaming, handovers, and encryption . GSM dedicated control channels carry data used during connection establishment and for handover decisions. The GSM stand-alone SDCCH is used for signaling between base station and mobile station during call setup .

The GSM SACCH carries measurement reports required for handover decisions. The GSM FACCH has the same purpose as the stand-alone dedicated control channel , but borrows capacity from a traffic channel rather than having capacity specifically allocated by the base station. [16]

2.1.4.2 Logical Channels

The MAC layer provides data transfer services on logical channels. A set of logical channel types is defined for different kinds of data transfer services as offered by MAC. Each logical channel type is defined by the type of information that is trans-ferred. Logical channel types are depicted in Figure 2.4 Logical channels are classified into two groups: [17]

- Control channels for the transfer of control plane information .
- Traffic channels for the transfer of user plane information.

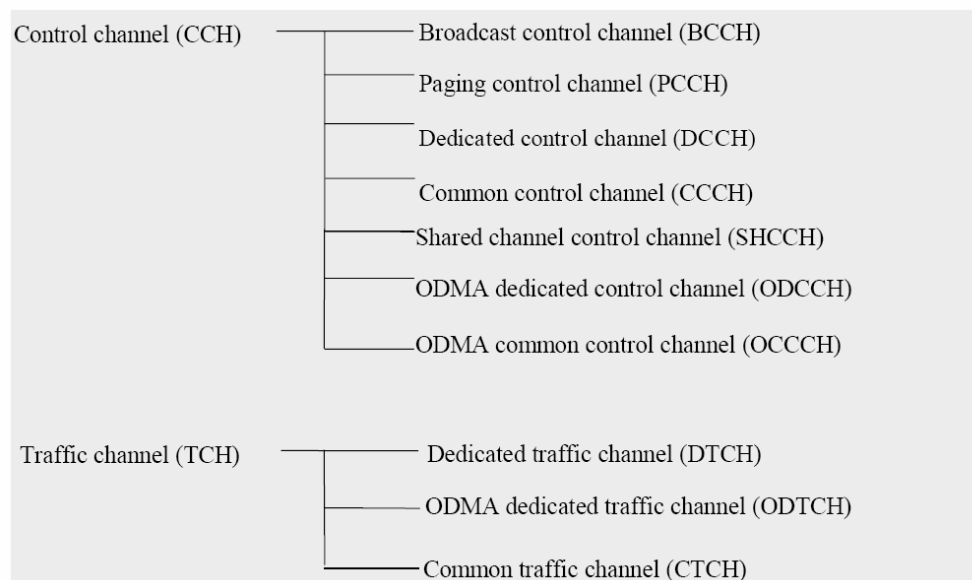


Figure 2.4 Logical Channel Structure

2.1.4.3 Physical Channels

The Transport Channels are received by the physical layer and mapped onto Physical Channels. Physical Channels define how the Transport Channels use the physical medium (i.e. chips and codes). A Physical Channel is structured in frames and slots. A frame lasts 10 ms and consists of 15 slots. Since UMTS works with a chip rate of 3.84 Mega chips/s, this translates into 2560 chips per slot. The frame and slot structure allows organizing the information on the Physical Channels, e.g. into control information and payload. illustrates the structure of Physical Channels. dependent on the terminal capabilities [18].

2.1.5 Sharing the Electromagnetic Spectrum

The electromagnetic spectrum is a scarce resource that is shared by many technologies. In order to separate the different technologies from each other, each is assigned a particular frequency band. Mobile Telecommunication Networks and mobile Computer Networks are located typically in the frequency range between hundreds of MHz to tens of GHz. Lower frequencies are assigned to television broadcasting and AM/FM radio broadcasting. Frequencies adjacent to 300 GHz correspond to infrared and visible light.

Separating technologies, however, is not sufficient. Within one technology, the spectrum resource is shared by different companies and—for mobile Communication Networks—by different users, as well as by the two communication directions for each user, downlink (i.e. network towards user) and uplink (i.e. user towards network), see Figure 2.5. If all senders were use the entire available frequency band indiscriminately it would be impossible for the receiver to distinguish the signal intended for her. Many techniques exist for dividing the available frequency band. Often, they are used in combination, for example, one technique is used for separating uplink and downlink, and another technique is used for separating users.[19]

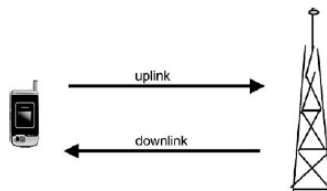


Figure 2.5 : Uplink and downlink

2.1.5.1 WCDMA

WCDMA is a wideband DS-SS-CDMA system, i.e. user information bits are spread over a wide bandwidth by multiplying the user data with quasi-random bits (called chips) derived from CDMA spreading codes. In order to support very high bit rates (up to 2 Mbps), the use of a variable spreading factor and multi-code connections is supported. The chip rate of 3.84 Mps leads to a carrier bandwidth of approximately 5 MHz . The wide carrier bandwidth of WCDMA supports high user data rates and also has certain performance benefits, such as increased multipath diversity. WCDMA supports highly variable user data rates, in other words the concept of obtaining BOD is well supported. The user data rate is kept constant during each 10 ms frame. However, the data capacity among the users can change from frame to frame. This fast radio capacity allocation should typically be controlled by the network to achieve optimum throughput for packet data services. WCDMA supports two basic modes of operation: FDD and TDD. In the FDD mode, separate 5 MHz carrier frequencies are used for the uplink and downlink respectively, whereas in TDD only one 5 MHz is timeshared between the uplink and downlink. Uplink is the connection from the mobile to the base station, and downlink is from the base station to the mobile. [20]

2.1.5.1.1 UMTS FDD

Like any CDMA system, UMTS needs a wide frequency band in which to operate to effectively spread signals. The defining characteristic of the system is the chip rate, where a chip is the width of one symbol of the CDMA code. UMTS uses a chip rate of 3.84 MChips/s and this converts to a required spectrum carrier of 5 MHz wide. Since this is wider than the 1.25 MHz needed for the existing CDMA One system, the UMTS air interface is termed wideband CDMA. There are actually two radio technologies under the UMTS umbrella: UMTS FDD and TDD.

FDD stands for frequency division duplex, and, like GSM, separates traffic in the uplink and downlink by placing them at different frequency channels. Therefore an operator must have a pair of frequencies allocated to allow it to run a network, hence the term 'paired spectrum'. TDD or time division duplex requires only one frequency channel, and uplink and downlink traffic are separated by sending them at different times.

The ITU-T spectrum usage, as shown in Figure 2.6, for FDD is 1920–1980 MHz for uplink traffic, and 2110–2170 MHz for downlink. The minimum allocation an operator needs is two paired 5 MHz channels, one for uplink and one for downlink, at a separation of 190 MHz. However, to provide comprehensive coverage and services, it is recommended that an operator be given three channels. Considering the spectrum allocation, there are 12 paired channels available, and many countries have now completed the licensing process for this spectrum, allocating between two and four channels per license. This has tended to work out a costly process for operators, since the regulatory authorities in some countries, notably in Europe, have auctioned these licenses to the highest bidder. This has resulted in spectrum fees as high as tens of billions of dollars in some countries. [21]

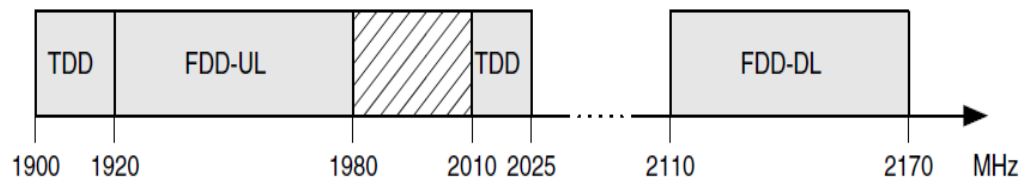


Figure 2.6: UMTS frequency allocation

2.1.5.1.2 UMTS TDD

The TDD system, which needs only one 5 MHz band in which to operate, is often referred to as unpaired spectrum. The differences between UMTS FDD and TDD are only evident at the lower layers, particularly on the radio interface. At higher layers, the bulk of the operation of the two systems is the same. As the name suggests, the TDD system separates uplink and downlink traffic by placing them in different time slots.

As will be seen later, UMTS uses a 10 ms frame structure which is divided into 15 equal time slots. TDD can allocate these to be either uplink or downlink, with one or more breakpoints between the two in a frame defined. In this way, it is well suited to packet traffic, since this allows great flexibility in dynamically dimensioning for asymmetry in traffic flow.

The TDD system should not really be considered as an independent network, but rather as a supplement for an FDD system to provide hotspot coverage at higher data rates. It is rather unsuitable for large-scale deployment due to interference between sites, since a BTS may be trying to detect a weak signal from a UE, which is blocked out by a relatively strong signal at the same frequency from a nearby BTS. TDD is ideal for indoor coverage over small areas. Since FDD is the main access technology being developed currently, the explanations presented here will focus purely on this system.[22]

2.1.5.2 Code Division

Since code division is the technique of choice for UMTS, at least originally, we will go into greater detail. This technique for dividing the resources on the radio interface is less straightforward than the previous ones. Each sender can utilize the same frequency band, time slot and space as all the others. Each sender-receiver pair is, however, assigned a unique CDMA code. Codes are sequences of .one. and .minus one., so-called chips. The sender multiplies the bit sequence by the code before sending. The receiver, in turn, multiplies the received sequence of chips again with the code, thereby obtaining back the original sequence of bits. Of course, because of the non-zero travelling time between sender and receiver, the receiver must apply the code with the right time-shift, i.e. we need synchronization between sender and receiver.[23]

2.1.5.2.1 Orthogonality of Codes

Code division works because codes assigned to different sender receiver pairs have a high auto-correlation, and a very low cross-correlation. Mathematically speaking, they are orthogonal or quasi-orthogonal. Therefore, when the receiver multiplies the total of all received signals with the right code it filters out the signal destined to itself.

2.1.5.2.2 Spreading and Dispersing

The chip rate is much higher than the bit rate. In other words, each bit is multiplied by many chips, this results in a spreading of the bandwidth of the signal, as illustrated in Figure 2.6 The receiver, when multiplying the received sequence of chips with the right code obtains back the

original lower-rate bit sequence and simultaneously the narrow-band signal. The entire process is illustrated in Figure 2.7 The reader is invited to test what happens when the received signal is multiplied with the wrong code: the result is not a meaningful bit sequence. While code division is more complex to realize than the previous techniques, it is also more flexible: because there is no shortage of codes, user and load shifts between cells can be easily accommodated .

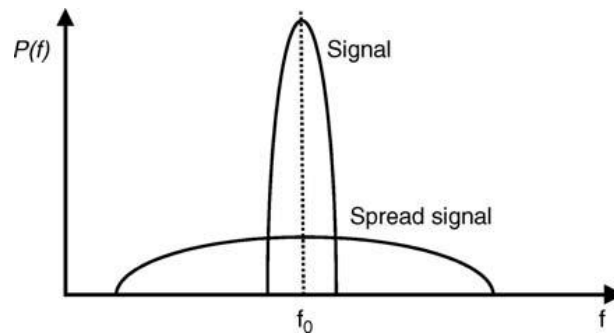


Figure 2.7: Spectrum spreading as a result of code division

2.1.6 UMTS Cell structure

During the architecture design of the UMTS system also more attention was drawn to the diversity of the user environment. Indoor, outdoor urban and outdoor rural environments are supported besides different mobility models ranging from stationary users through pedestrian up to very high vehicular speeds. To offer worldwide coverage and enable global roaming hierarchical layer structure of zones with varying coverage was developed for UMTS.

The highest layer consists of satellites covering the whole planet; the lower layers form the terrestrial radio access network – UTRAN. Each layer is built up of cells, the lower the layer, the smaller the geographical area covered by the cell. Therefore small cells have been implemented to support higher user density. Macro-cells offering land wide coverage are combined with micro cells increasing capacity in more densely populated areas and Pico-cells installed in so-called hot spots requiring high capacity in a very limited area (airports...). This follows two well-known design principles in deploying cellular networks; smaller cells can be used to increase the available capacity per geographical area, larger cells can extend the coverage area. As it is obvious the needs and characteristics of an indoor office environment are different to the requirements of a user cruising rural areas at high speed, the UMTS forum has developed six

operational environments. For each model the density of potential users per km² and the foreseen cell types have been identified for low, medium and high mobility scenarios (see Figure 2.8) . [24]

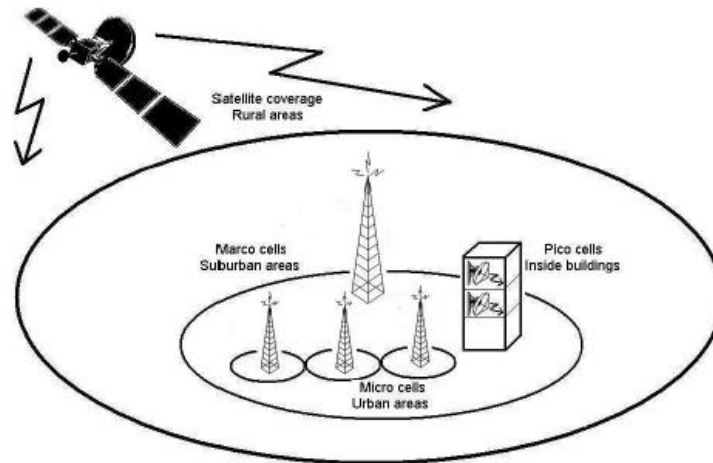


Figure 2.8: UMTS mixed cell structure

2.1.7 power control

Power control in a WCDMA system is crucial to its successful operation. This is because each handset transmits on the same frequency and at the same time as other handsets. Each of the handsets therefore generates interference, raising the overall noise level in the cell, and the base station has to be able to distinguish a particular user out of this interference. If a single mobile device is transmitting with too much power, or is physically closer to the BTS, this may drown out the other UEs. Conversely, if a UE is transmitting with too little power, or is physically further away, the base station will never hear it. This is commonly referred to as the near-far problem. There are two main concerns regarding power control: distance from the base station and fast fading.

The key goals of power control are to:

1. provide each UE with sufficient quality regardless of the link condition or distance from the BTS;
2. compensate for channel degradation such as fast fading and attenuation;
3. optimize power consumption and hence battery life in the UE.

Power Control is important both in the uplink and the downlink directions. In the uplink direction control is required in the situations where UEs are located very close to the Node Bs and transmitting with excessive power. This is called the near-far effect and can result in blocking the whole cell, with UEs that are close to the cell edge possibly overlooked. If the uplink power is too high interference in neighboring cells (inter-cell interference) may also be a direct result of the near-far effect. In the downlink direction, Power Control directly affects system capacity. System capacity is determined by the total downlink transmission power for each cell i.e. when total downlink transmission power is minimized then the Node B can accept more UEs and the capacity is increased. Therefore, it is essential to keep the transmission at a minimum level while ensuring adequate signal quality and level at the receiving end (UE) [24] [25].

There are three types of Power Control algorithms that are normally implemented in a mobile network. The Open-loop Power Control is responsible for setting the initial uplink and downlink transmission powers when a mobile terminal is accessing the network. The Inner-loop Power Control, also called fast closed-loop power control, adjusts the transmission powers dynamically at very small time intervals, based on SIR targets. The third Power Control algorithm is called Outer-loop Power Control and it estimates the received quality and adjusts the target SIR, in both the uplink and downlink directions. It operates at longer time intervals than the inner loop and aims at keeping the system operating stably.

2.1.8 Handover control

The freedom to be able to make and receive calls anywhere, at any time, creating a totally new dimension in human communications has frequently been advertised as the main advantage of new wireless systems. Handovers are a key concept in providing this mobility. It makes it possible for a user to travel from one cell to another while having a seamless connection (see Figure 2.9).

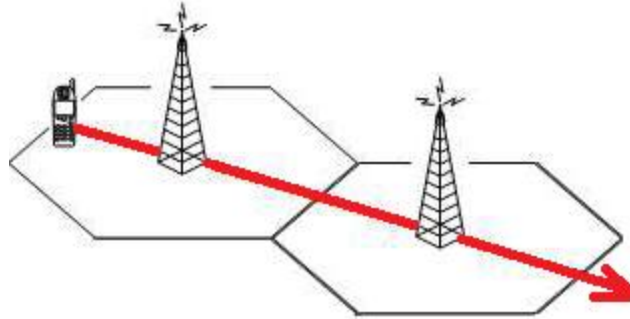


Figure 2.9: Handover

Generally a handover is performed when the quality of the link between the base station and the mobile terminal on the move is decreasing. The term “handover” refers to the whole process of tearing down an existing connection and replacing it by a new connection in the cell into which the user is handed over – the so called target cell [26].

From the information about the radio link quality contained in measurement reports, the network controller is able to decide whether a handover to another cell is needed. Knowledge about radio resource allocation in the target cell and the correct release of channels after the handover is completed are vital for a successful handover. The inability to establish a new connection in the target cell is referred to as a “handover failure”. Handover failures occur when no new resources are available in the target cell or when the radio link quality has decreased below acceptable levels before the call could be handed over. The latter scenario being common in GSM networks results into dropped calls.

As the effect of a handover request in the target cell is similar to that of an incoming call, optimization of the resource utilization is crucial in order to minimize call blocking and call dropping probabilities. But it is commonly accepted that the forced dropping of an existing call is more desirable than the blocking of a new call. Therefore various handover prioritization algorithms have been studied [27]. Some schemes suggest allocating a portion of the total number of channels to handover users. The main disadvantage of this strategy is that fewer channels can be granted to new calls, resulting in rapidly increasing blocking probabilities for new calls. In order to improve the handover performance (or reduce the high dropped call

probabilities in GSM systems) and to accommodate for future capacity increase in 3G systems, advanced handover protocols have been developed. Soft handover enables two simultaneous links between a mobile terminal and two base stations in a different cell. Also the case of a user having two concurrent connections with one base station exists, this is called softer handover. Both operational modes will be discussed in next chapter.

As expanding markets demand increasing capacity there is a trend towards reducing the size of cells in mobile communications systems (besides increasing the used frequency band). This results in more frequent handovers and it is important to remark that this makes a reliable handover mechanism more than ever desirable for efficient operation of any future cellular mobile network.

2.2 OPNET Modeler

OPNET[®] Modeler provides a graphical user interface, which enables modeling and simulating networks. The modeling environment consists of different hierarchical layers for developing communication structures. OPNET[®] provides the flexibility to build very detailed customized models as well to perform general system analysis. Systems are built up in an object oriented way, compiling the models automatically generates discrete event simulations in C language [28]. After simulation it is possible to gather and analyze results with some of the built-in performance statistics features provided by this package.

2.2.1 OPNET software

OPNET solutions incorporate a high fidelity software model that accurately simulates the behavior of a real-world network. By changing the configuration, link capacity, traffic volumes, and characteristics of this virtual network model, professors and students can accurately predict the impact of these changes on the real network. This capability enables a broad range of studies including:

- Studying various wired and wireless routing protocols
- Visualizing TCP/IP mechanisms and variations

- Understanding LAN/WAN/MAN network architectures
- Designing reliable wireless networks
- Implementing efficient network security

Simulator options:

There is two options : Option 1: Full-Feature Software , and Option 2: IT'S Guru Academic Edition which we used in our project .

2.2.2 The concept of simulation

The concept of simulation, computer networking, is based on; modeling computer networks in real world Networks on a computer screen using a computer program Software is dedicated to this purpose. It is intended, the real computer networks, networks are already implemented on the ground, or networks that wish to implement in the future. The benefit of this idea, that, as long as possible to model these networks by using the computer, all the characteristics of components and everything related to it, it is possible to change or control. The process of modeling this or simulation, using computer software, is the process of low-cost compared with the implementation of the network on the ground without the previous study, taking into account, all the trials may be, parts and equipment that may be changed, and perhaps more than once until we reach the goal ... etc)

Consider a simple example of this: Imagine that the company wants to expand its network wired or wireless LAN, is required, add more computers, wires, and other pieces such as Access Points if we are talking about WLANs, any wireless local area networks. But, have you after all these additions and changes you will get the best performance of the company's Performance, or rather the best performance? Let's remember that this process of change is a costly process, and that the cost increases as the increased size of the network and equipment used, it can be implemented simply through the simulation program. Through this program, the network can be built on the computer screen, and then make the required changes, the collection of statistics that we wish to study, such as The Average Network Throughput and The Average Network Delay and The Server Status ... etc. Let us remember always that, through simulation programs developed, we

can download the network to Traffic that we use in the network realism, which may include, for example, access to e-mail, or surf the Web, or use an FTP server or print jobs, or access to databases ... etc. In the last stage before we run the Simulator, and finally after the completion of the simulation we will read, study and analyze the results. After that, we will decide whether these changes that we wish to make meaningful or not!

2.2.3 About OPNET Modeler

If we want to make simulation for any network with OPNET, we must begin to implement the project step by step, as shown in Block Diagram (Fig. 2.10), And to achieve this, the program is available in a number of editors. Each editor is described in detail on the following pages.

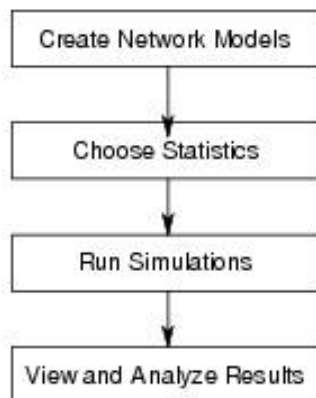


Figure 2.10: Block diagram of steps of implementation of the project

2.2.3.1 The Project Editor

The Project Editor is the main staging area for creating a network simulation. From this editor, you can build a network model using models from the standard library, choose statistics about the network, run a simulation, and view the results. (See Fig. 2.11).

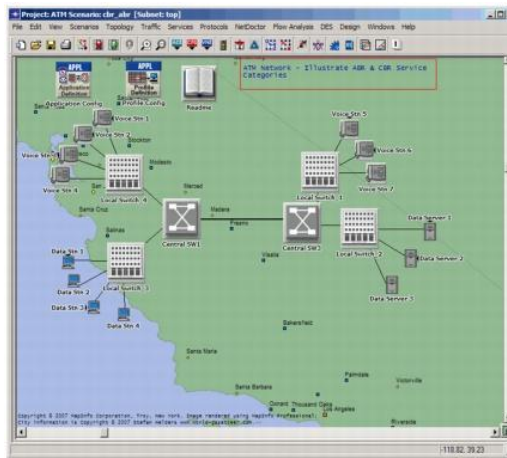


Figure 2.11: Network Model in the Project Editor

You can also create node and process models, build packet formats, and create filters and parameters, using specialized editors that you can access from the Project Editor.

2.2.3.2 The Node Editor

The Node Editor lets you define the behavior of each network object. Behavior is defined using different modules, each of which models some internal aspect of node behavior such as data creation, data storage, etc. Modules are connected through packet streams or statistic wires. A network object is typically made up of multiple modules that define its behavior. (See Fig. 2.12).

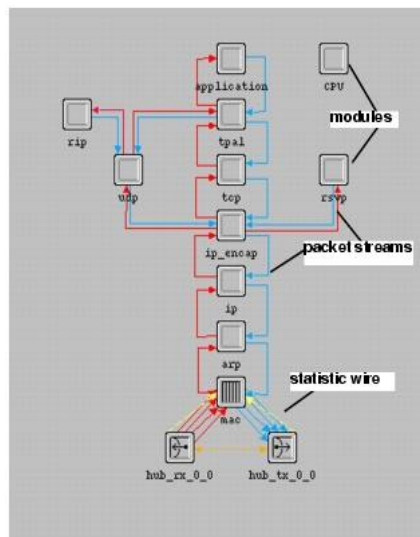


Figure 2.12: Node Editor

2.2.3.3 The Simulation Sequence Editor

Although you can run simulations from within the Project Editor, you might want to specify additional simulation constraints in the Simulation Sequence Editor. Simulation sequences are represented by simulation icons, which contain a set of attributes that control the simulation's run-time characteristics (See Fig. 2.13) .

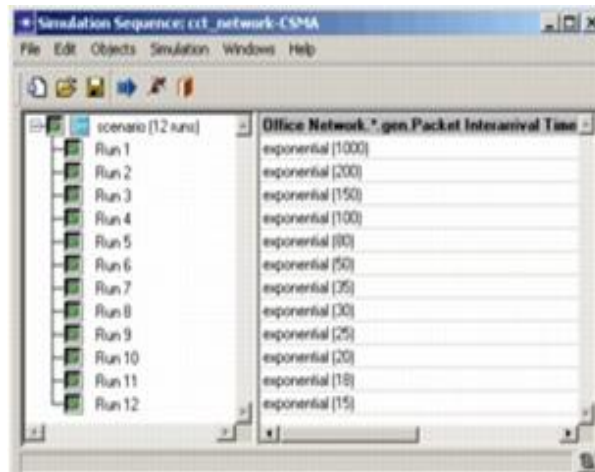


Figure 2.13: Simulation Sequence Editor

2.2.3.4 The Antenna Pattern Editor (with Wireless Functionality)

In OPNET Modeler/Wireless, the Antenna Pattern Editor lets you model the direction-dependent gain properties of antennas. OPNET Modeler can use these gain patterns to determine gain values, given knowledge of the relative positions of nodes. (See Fig. 2.14)

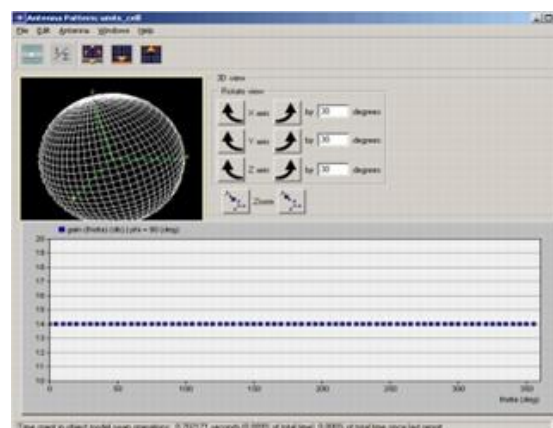


Figure 2.14: Antenna Pattern Editor

2.2.3.5 Path loss model

This model [34], is applicable for the test scenarios in urban and suburban areas outside the high rise core where the buildings are of nearly uniform height:

$$L=40(1-4\times 10^{-3} \Delta h_b)\log_{10} R-18\log_{10} \Delta h_b+21\log_{10} f+80 \text{ dB} \quad \text{Eq : 2.1}$$

where:

R : base station – mobile station separation (km)

f : carrier frequency of 2 000 MHz

ΔhB : base station antenna height (m), measured from the average rooftop level.

To quantitatively evaluate each RTT, the base station antenna height is fixed at 15 m above the average rooftop ($\Delta hB = 15$ m). Each proponent has an option to specify an alternate base station antenna height to optimize coverage and spectrum efficiency in their proposal. (See Fig. 2.15)

NOTE 1 – L shall in no circumstances be less than free space loss. This model is valid for NLOS case only and describes worse case propagation. Log-normal shadow fading with 10 dB standard deviation are assumed in both urban and suburban areas.

NOTE 2 – The path loss model is valid for a range of ΔhB from 0 to 50 m

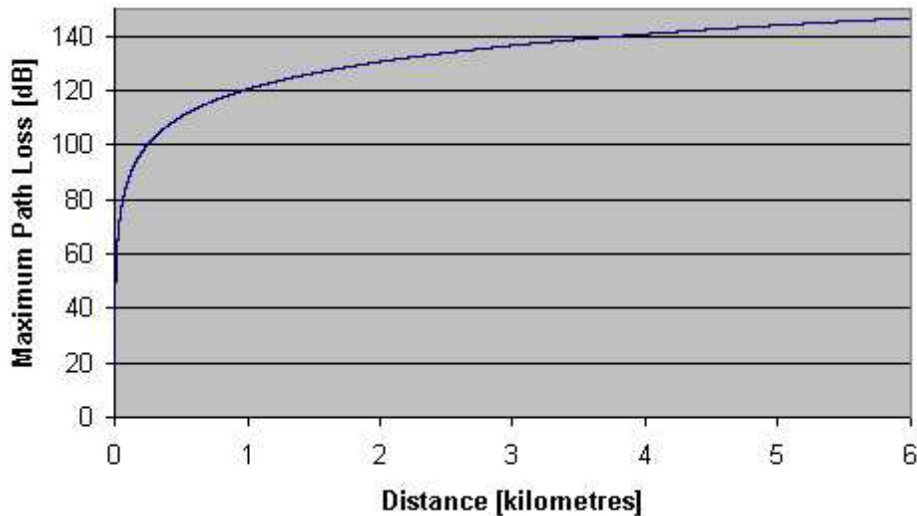


Figure 2.15: ITU Outdoor Vehicular path loss model

Chapter Three

3

Conceptual Design

- 3.1 System Overview
- 3.2 Handover in UMTS
- 3.3 QOS for UMTS
- 3.4 Network Modeling
- 3.5 General

3.1 System Overview

The previous chapter introduced the UMTS system technology described in the 3GPP. The goal of this project is to analyze the soft handover process, end to end delay, the loss, and study the impact of soft handover on the probability a user in soft handover, delay, and on issues as network losses and quality of (QOS).

This chapter consists of two main parts. ; The first part discusses the soft handover concept and analyses the probability that the user is in soft handover, and study the impact losses and end to end delay on the quality of service.

The second section presents the models built for the several simulations and case studies used and includes some general considerations around the network modeling done.

3.2 Handover in UMTS

Handover (handoff) means the action of switching a call in progress between radio channels in the same cell or switching a call from one cell to another without interruption of the call. It is essential to guarantee the mobility of a subscriber, handovers can generally be divided into soft handovers and hard handovers. [29]

Handover aims to provide continuity of mobile services to a user travelling over cell boundaries in a cellular infrastructure. For a user having an ongoing communication and crossing the cell edge, it is more favorable to use the radio resources in the new cell – also called the target cell – because the signal strength perceived in the “old” cell worsens as the user penetrates the target cell. The whole process of tearing down the existing connection in the current cell and establishing a new connection in the appropriate cell is called “handover”. The ability of a cellular network to perform efficient handovers is crucial to offer attractive services as real-time applications or streaming media as planned in third generation networks. Especially the number of “handover failures” – the situation in which the handover procedure cannot be completed –has to be further reduced compared to previous generation cellular communication systems as GSM.

The cause for a handover failure ranges from signaling failures to the lack of resources in the target cell, making it impossible for a new user to be accommodated. In high performance networks where there is a trend towards the use of smaller cells to increase the capacity, the handover process becomes even more important as more frequent handovers are needed . In this chapter we will discuss two type of handover , soft handover and hard handover .

3.2.1 Hard Handover

Hard handover can be further divided into intra-frequency and inter-frequency. All of these mechanisms are provided by the UMTS system.

If the old connection during the handover process is released before making the new connection it is called a hard handover. Therefore, there are not only lack of simultaneous signals but also a very short cut in the connection, which is not distinguishable for the mobile user.

In the case of inter-frequency hard handover the carrier frequency of the new radio access is different from the old carrier frequency to which the UE was connected. On the other hand, if the new carrier, through which the UE is accessed after the handover procedure, is the same as the original carrier, then there is an intra-frequency handover in question.[30]

Figures 3.1 and 3.2 show hard handover situations in which neighboring BSs may transmit with the same frequency or with a different frequency, respectively. In Figure 3.1, the neighboring RNC is not connected to the Iur interface due to the radio network planning strategy or for transmission reasons and, hence, inter-RNC soft handover is not possible. Under these circumstances, intra-frequency hard handover is the only handover to support seamless radio

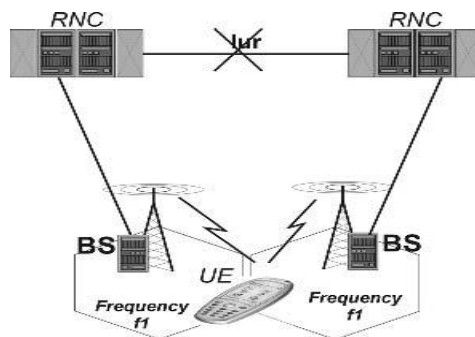


Figure 3.1 : Inter-frequency hard handover with same frequency

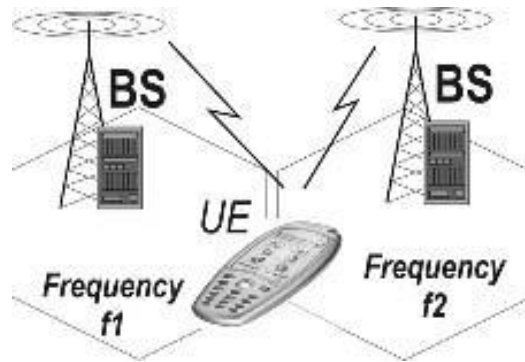


Figure 3.2: Inter-frequency hard handover with different frequency

access connection and subscriber mobility from the old BS to the new BS. In fact, this leads to an inter-RNC handover event, in which the MSC is also involved

3.2.2 Soft Handover

While there is hard handover for carrier change or hierarchical cell transition, and intersystem hand over to pass from FDD to TDD or GSM, in WCDMA two types of soft handovers characterize the cell transition process , these include and *Soft* handovers.

In the 1st case, a UE finds itself in the overlapped cell coverage area of two adjacent sectors of a BS. The UE communicates simultaneously with BS through two channels (2 DL codes) corresponding one to each sector. The UE's rake receives and processes the two signals, where its fingers generate the necessary de-spreading codes for each sector. The UL process occurs in the BS, where the BS receives the UE's channel in each sector and routes them to the same rake receiver for the typical maximal ratio combining process under one active power control loop per connection.[31]

In the 2nd case, i.e. soft handover, a UE finds itself in the overlapping cell coverage area of two sectors corresponding to different BSs. Communications between UE and BS occur simultaneously through two channels, one from each BS. In the DL, the UE receives both signals for maximal ratio combining. In the UL, the UE code channel arrives from both BS, and is routed to the RNC for combining, in order to allow the same frame reliability indicator provided

for outer loop power control when selecting the best frame. Two active power control loops participate in soft handover, i.e. one for each BS (see Figure 3.3) .

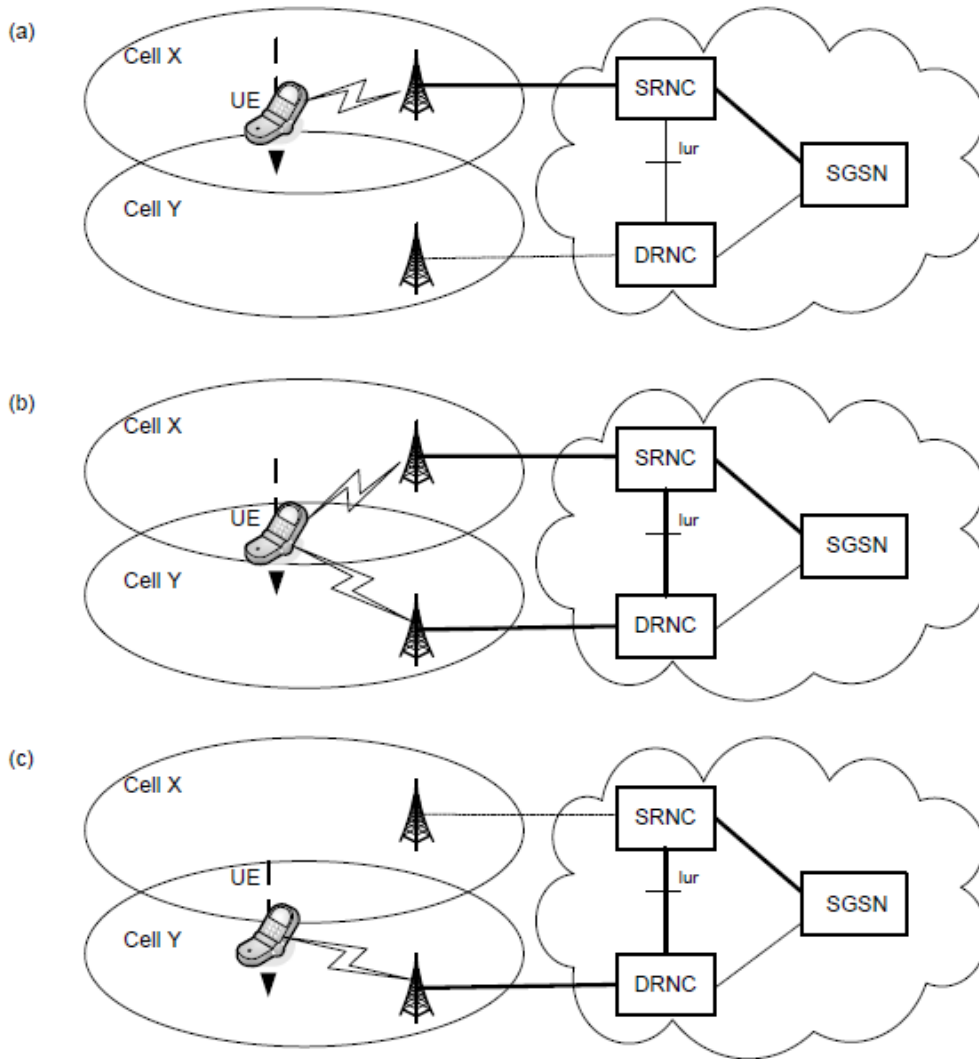


Figure 3.3 : Soft handover. (a) the UE is still in cell X. (b) the UE moves from cell X to cell Y.
(c) the UE arrives in cell Y

3.2.2.1 Soft Handover Algorithm

This paragraph discusses the handover process as described in TR 25.922 of the 3GPP specifications [37]. Basically the soft handover is composed of two main functions:

1. Acquiring and processing measurements .
2. Executing the handover algorithm .

Before starting the in-depth analysis of these functions some terms used for describing the handover process have to be defined:

1. Set: list of cells or Node B's .
2. Active set: list of cells having a connection with the mobile station .
3. Monitored set: list of (neighboring) cells whose pilot channel E_c/I_0 is continuously measured but not strong enough to be added to the active set.

- Measurements

Accurate measurements of the E_c/I_0 of the pilot channel (CPICH) form the main input for obtaining the RRC measurement report, necessary for making handover decisions. Mainly three parameters can be measured. Besides the E_c/I_0 of the CPICH also the received signal code power (RSCP) and the received signal strength indicator (RSSI) are measured. RSCP is the power carried by the decoded pilot channel and RSSI is the total wideband received power within the channel bandwidth. E_c/I_0 is defined as:

$$\frac{E_c}{I_0} = \frac{RSCP}{RSSI} \quad \text{Eq: 3.1}$$

It is important to apply filtering on the handover measurements to average out the effect of fast fading. Measurement errors can lead to unnecessary handovers. Appropriate filtering can increase the performance significantly. As long filtering periods can cause delays in the handovers, the length of the filtering period has to be chosen as a trade-off between measurement accuracy and handover delay. Also the speed of the user matters, the slower the user equipment is moving the harder it is to average out the effects of fast fading. Often a filtering time of 200ms is chosen. Other essential information needed during the so-called intra-mode handovers – soft

and softer handover – is timing information. As the WCDMA network is of asynchronous nature there exist relative timing differences between the cells. To allow easy combining in the Rake receiver and avoid delays in the power control loops, the transmissions have to be adjusted in time. After the UE has measured the timing difference between the CPICH channels of the serving cell and the target cell, the RNC sends DCH timing adjustment info to the target cell.

Based on the E_c/I_0 measurements of the set of cells monitored, the mobile station decides which of three basic actions to perform; it is possible to add, remove or replace a node B in the active cell. These tasks are respectively called Radio Link Addition and Radio Link Removal, while the latter is Combined Radio Link Addition and Removal. The example below is directly taken from the original 3GPP specifications. Discussing this scenario gives a good insight into the algorithm itself and forms an introduction to the illustrating simulations included in the next paragraph. This scenario can be based on a user following a trajectory as shown Figure 3.4 below.

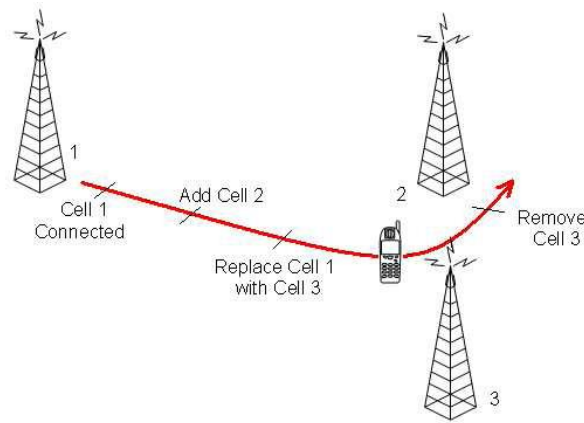


Figure 3.4: soft handover scenario

At the start of the scenario the user is connected to cell number 1 which has the strongest pilot signal. Due to the user moving or to slow fading the perception of the signal strengths to the mobile user can change and following actions are taken:

1. Event A: cell 2 is added .
2. Event B: cell 1 is replaced with cell 3 .
3. Event C: Cell 3 is removed from the active set .

This example could be based on a mobile user following a path similar to the Figure 3.4. The main parameter in the soft handover algorithm is the threshold for soft handover **As_Th**. As will be shown in the following chapters the value of this figure is a crucial design parameter, it determines the amount of users being in soft handover mode and hence influences the system capacity and coverage. Roughly stated it is the maximum difference in SIR two pilot signals can have so their cells can coexist in the active set. **As_Th_Hyst** is the hysteresis for the **As_Th** threshold and **As_Rep_Hyst** is the replacement hysteresis (see Figure 3.5 below. [28])

The actual algorithm is as follows:

- a. Adding: If **Meas_Sign** is greater than $(\text{Best_Ss} - \text{As_Th} + \text{As_Th_Hyst})$ for a period of T and the Active Set is not full, the Best cell outside the Active Set is added to the Active Set.
- b. Removing: If **Meas_Sign** is below $(\text{Best_Ss} - \text{As_Th} - \text{As_Th_Hyst})$ for a period of T remove Worst cell in the Active Set.
- c. Replacing: If Active Set is full and **Best_Cand_Ss** is greater than $(\text{Worst_Old_Ss} + \text{As_Rep_Hyst})$ for a period of T add the Best cell outside the Active Set and Remove the Worst cell in the Active Set.

Where:

- a. **Best_Ss**: the best measured cell present in the Active Set .
 - b. **Worst_Old_Ss**: the worst measured cell present in the Active Set .
 - c. **Best_Cand_Set**: the best measured cell present in the monitored set .
- Meas_Sign**: the measured and filtered E_c/I_0 of the pilot channel of the monitored cell .

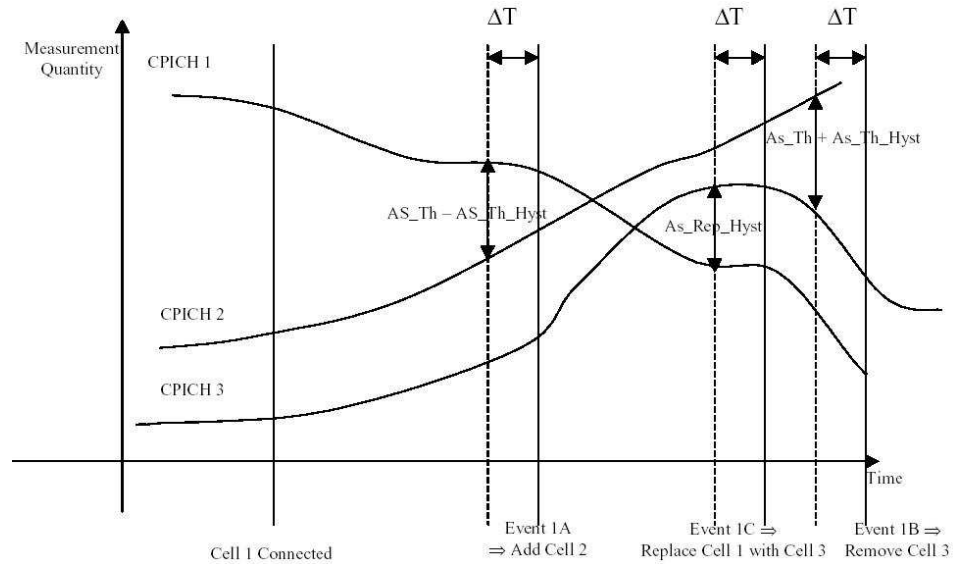


Figure 3.5 : WCDMA handover algorithm

3.2.2.2 Soft Handover window

The soft handoff window is the zone in the network where soft handovers are possible. This implies that in this zone the strengths of the pilot signals from the two Node B's differ less than the soft handover threshold used in the system. When the Node B's are placed closer to each other, the so-called handoff window becomes smaller for the same threshold value. This is shown on the picture below. Hence the soft handover probability for users in the cell edge area decreases with the cell size (see Figure 3.6).[31]

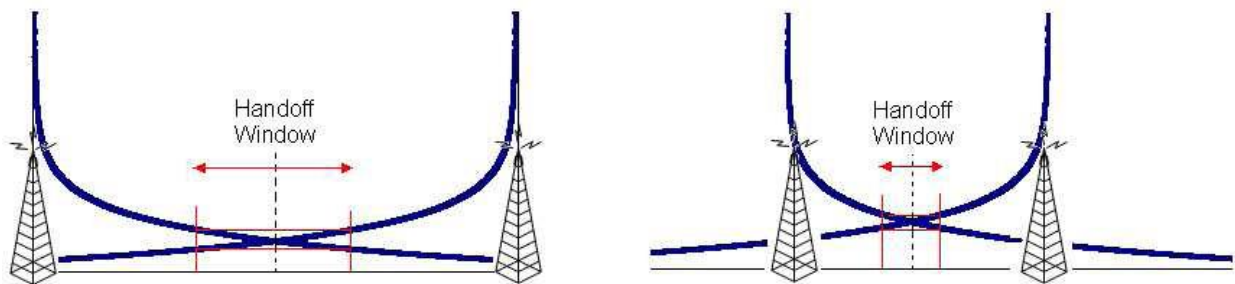


Figure 3.6: comparison of handoff windows for different Node B spacing

3.2.2.3 Soft Handover Probability

The probability a user is in soft handover mode is an important parameter for radio network planning. As an excessive amount of soft handovers causes an overhead on system resources used, it is important to be able to set system parameters to an appropriate level resulting in a number of handovers that optimizes network performance.

To verify the results obtained by simulation, this section introduces a mathematical model that makes it possible to calculate the average soft handover probability in a cell for a given threshold. This probability can be calculated by taking the ratio of the surface area of the part of the network where soft handovers are possible, relative to the total network surface. Using the Figure 3.7 below, due to the symmetry present in the network this can be simplified to:

$$SHO - PROB = \frac{A_{shaded-area}}{A_{triangle}} \quad \text{Eq :3.2}$$

where $A_{shaded-area}$ is the surface of the shaded area in the picture below and $A_{triangle}$ is the surface of the red triangle.

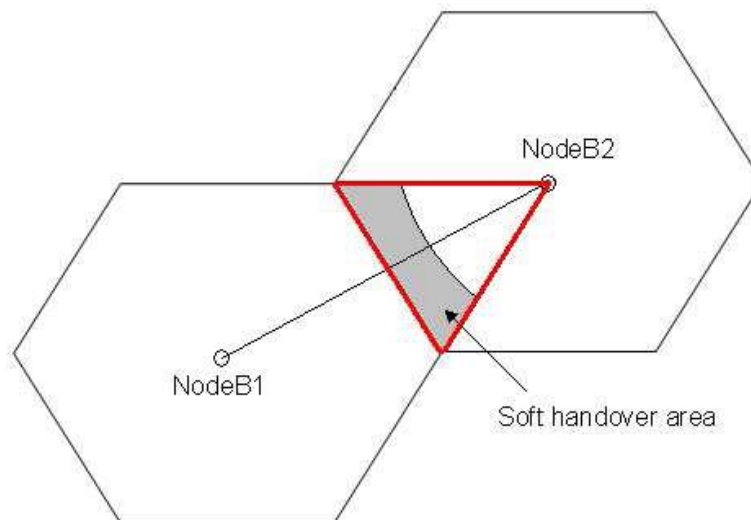


Figure 3.7 : calculation of soft handover probability using surface ratios .

The shaded area is formed by the edges of the triangle and the curve for which this relation holds:

$$\text{path loss1} - TH = \text{path loss2} \quad \backslash \quad \text{Eq: 3.3}$$

as we will use in the section (4.3) Results Authenticity an antenna height of 40 meters and carrier frequency of 1940 MHz the formula becomes:

$$\text{path loss2} = 33.6 \log_{10} X2 + 120.2 \quad \text{Eq : 3.4}$$

Using the vehicular path loss model this can be transformed to:

$$33.6 \log_{10} X1 + 120.2 - TH = 33.6 \log_{10} X2 + 120.2 \quad \text{Eq: 3.5}$$

where x_1 and x_2 represent the distance to NodeB1 and NodeB2 respectively. Simplifying this equation gives:

$$\frac{x_1}{x_2} = 10^{\frac{TH}{33.6}} = K \quad \text{Eq: 3.6}$$

Using the so-called circle of Apollonius it can be proven that the locus of the points in the plane, for which the ratio of the distances to two fixed points – in this case the two Node B's – is constant, is a circle (see Figure 3.8) [38]. Using the intuitive notion of the shape of the handoff area the following situation from which the surface of the shaded area can be calculated is obtained:

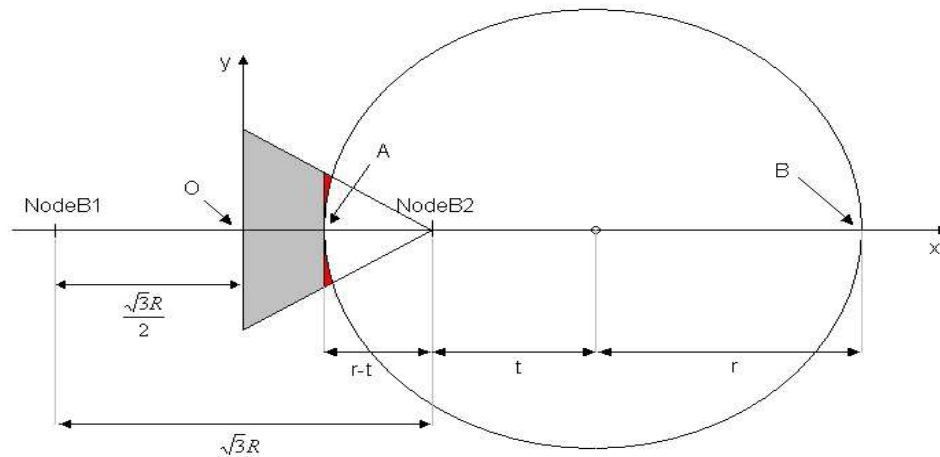


Figure 3. 8: mathematical model used for calculation of formula (3.10)

Expressing the relation $\frac{x_1}{x_2} = K$ in the two points where the x-axis and the circle intercept – the points A and B on Figure 3.5 the following two relations are obtained:

$$\frac{\sqrt{3} R - (r - t)}{r - t} = \frac{\sqrt{3} R + (t + r)}{t + r} = k \quad \text{Eq: 3.7}$$

where R represents the cell radius. Solving this for r give:

$$r = \frac{\sqrt{3} R \cdot k}{k^2 - 1} \quad \text{Eq: 3.8}$$

The surface of the handoff window is given by the surface of the grey plus the red shaded area on the picture below. Seen the fact that the values obtained for r are significantly higher than the cell radius, the handoff area can be approximated by the surface of the grey area.

This surface can be integrated as follows:

$$\begin{aligned} 2 \cdot \int_0^{|OA|} y \cdot dx &= 2 \cdot \int_0^{\frac{\sqrt{3}R - (r-t)}{2}} \left(R - \frac{2x}{\sqrt{3}} \right) \cdot dx \\ &= 2 \cdot \int_0^{\frac{\sqrt{3}R}{2} - \frac{\sqrt{3}R}{k+1}} \left(R - \frac{2x}{\sqrt{3}} \right) \cdot dx \end{aligned} \quad \text{Eq: 3.9}$$

where $|OA|$ represents the distance from point O to A as shown on the picture above and y is given by the equation of the edge of the red triangle. Calculating this integral gives for the surface of the shaded area:

$$R^2 \cdot \left(\frac{\sqrt{3}}{4} - \frac{\sqrt{3}}{k+1} \right) \quad \text{Eq: 3.10}$$

The soft handover probability is given by the ratio of this surface area with the surface of the triangle:

$$SHO - PROB = \frac{R^2 \cdot \left(\frac{\sqrt{3}}{4} - \frac{\sqrt{3}}{k+1} \right)}{\frac{\sqrt{3}R^2}{4}} = 1 - \frac{4}{(K+1)^2} \quad \text{Eq: 3.11}$$

Substitution of the value for k gives:

If the cell radius is equal in the network as we assume in the section Results Authenticity as spatial case the the formula become :

$$SHO - PROP = 1 - \frac{4}{\left(10^{33.6} + 1\right)^2} \quad \text{Eq: 3.12}$$

So in this spatial case , this relation shows again that the soft handover probability in a UMTS network is independent of the cell size used. The number of handover increases no longer linearly although a linear would give good results.

3.3 QOS for UMTS

UMTS has been designed to support a variety of quality of service (QOS) requirements that are set by end users and end-user applications. The third generation services will vary from simple voice telephony to more complex data applications including voice over IP (VoIP), video conferencing over IP (VoIP), web browsing, email and file transfer. 3GPP has identified four different main traffic classes for UMTS according to the nature of traffic: conversational class, streaming class, interactive class and background class[32].

The best-known use of conversational class is telephony speech. With Internet and multimedia, a number of new applications, for example, VoIP and video conferencing tools will require this scheme. Real time conversation is always performed between peers of human end users. This is the only traffic type where the required characteristics are strictly imposed by human perception. Real time conversation is characterized by the fact that the transfer time and time variation between information entities must be low and preserved.

Streaming class is applied when the transferred data is processed as a steady and continuous stream. Accordingly, the streaming class is characterized by the preserved time variation between information entities of the stream, but it does not have any requirements on low transfer delay. Thus, the acceptable delay variation over transmission media, that is, jitter is much higher than in the conversational class.

3.3.1 Throughput in UMTS

The throughput is one of the main parameter that limiting the network quality because its tell us the amount of the loss between the transmitter and the receiver , This is illustrated by the next paragraph .

At any network if we sketch the curve for the load and throughput in ideal mode as shown in Figure 3.9 , the throughput will be increases proportional with increasing the load to reach the bandwidth of the link without any losses . after that when the load increases the throughput still constant , so the different between the load and the throughput will be the loss .

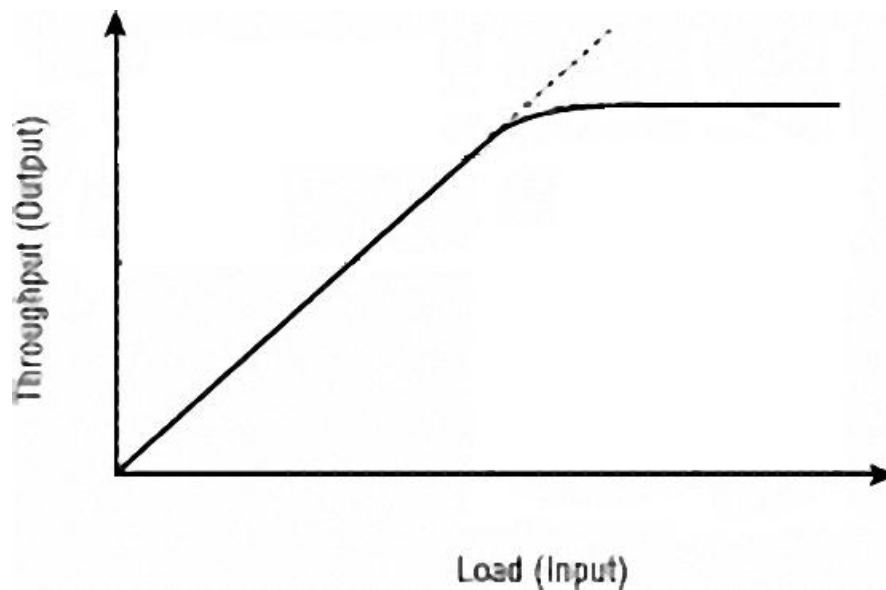


Figure 3.9 : The Relation Between The Load And Throughput .[33]

3.3.2 end to end delay

The End System Delay within a VoIP service is the sum of the encoding, decoding, jitter buffer, and other data handling delays that occur within a typical IP phone or gateway. The encoding delay is the time taken to accumulate and encode a voice packet, and will always be at least as large as the packet size, typically 10 to 30 milliseconds. The decoding delay is the time taken to decode and start to play out a received voice packet. This delay can be quite short. IP phones and

gateways use jitter buffers to remove short-term packet delay variations from the received packet stream by inserting some additional delay that allows the system to re-insert late-arriving packets in the proper order before they are decoded and played out. Jitter buffers are often adaptive and can grow in size to several hundred milliseconds. The End System Delay can therefore typically range from 10-20 milliseconds up to several hundred milliseconds and can potentially form a major component of overall perceived delay .

3.4 Network Modeling

The soft handover threshold is the parameter used in the WCDMA soft handover algorithm and is also commonly referred to as the soft handover margin. In OPNET this parameter is incorporated as an attribute of the RNC model and is called the macro-diversity margin. In the soft handover algorithm this threshold value determines the maximum difference in measured quality there can exist between the two pilot signals of cells in the active set of one mobile station. When this value increases it is clear that for one given cell a larger population of candidate signals will exist as the constraints for the signal quality of the cells to be added to the active set become less strict when a larger difference in E_b/N_0 is allowed.

During this project a total of 28 simulation series were build and run in order to obtain the desired results. To draw the conclusions about the effect of the soft handover threshold with different traffic on the throughput (packet/second), load (packet/second) ,loss, end to end delay, soft handover probability, and quality of service .we will use seven scenario with four cases for each and compare between the results, for these scenario we will study the impact of soft handover threshold on issues as network losses and quality of (QOS) (see Figure 3.10) .

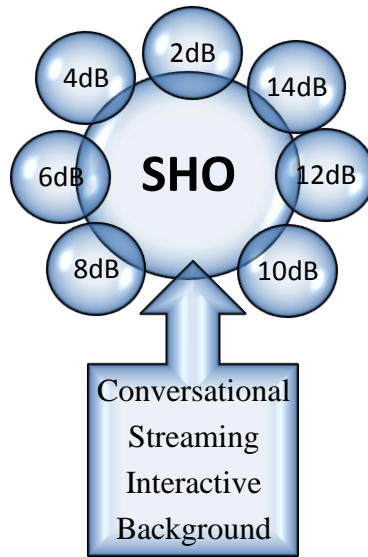


Figure 3.10: Scenarios

3.5 General

During the modeling phase of this report it was important to analyze the trade-off between building simple models and simulating real network cases. Simple network models as used in the scenario may produce results in a reasonable amount of time but they should provide reliable information applicable to real network situations and reflect characteristics recognizable in real life systems. Simulation of real networks on the other hand results in accurate results but the issue is if the increase in complexity and computing time is worthwhile.

The following iterative process has been used to obtain the end-results:

1. Define goal :

The scope of this project is to study the overall impact of soft handovers on the system performance. During the early stages of this project it has been decided that mainly four aspects of soft handovers are to be examined: effect of the soft handover threshold with different traffic on the throughput (packet/second), load (packet/second) ,loss, soft handover probability, end to end delay .

2. Simulate :

The simulations are discrete event, continuous time simulations and are run in OPNET. The runtime 10 minutes for the simple models used in the seven scenarios.

3. Analyze results

The results on this scenarios are presented in chapter 4, while chapter 5 analyze the result in the UMTS network.

Some UTRAN-specific modeling choices made are listed below:

- **Cell state :**

As the dedicated channels are the only transport channels supporting soft handovers only users in Cell DCH state have been modeled.

- **Path loss model:**

For all the simulations carried out ; the Vehicular Outdoor environment is used, The vehicular model is generally applicable for the user speeds and the cell sizes used in the simulations carried out. Besides setting one path loss model for all the models makes it more reliable to compare results.

The formula on which the model is based is as follows:

$$L_{PM_{ax}} = 40(1 - 4 \cdot 10^{-3} \cdot \Delta h_B) \cdot \log_{10} R - 18 \cdot \log_{10} freq + 80 \quad \text{Eq: 3.14}$$

where R is the distance between mobile station and base station in kilometers, Δh_B is the base station antenna height in meters and $freq$ is the carrier frequency in MHz

- **QOS**

Some services, particularly real-time services might not deliver acceptable quality to the user when sharing resources. Networks supporting multimedia services such as voice and video conversations and high speed Internet require different methods to handle applications with

diverse characteristics. This includes both the implementation of quality of service (QoS) classes and enabling different data rates.

- **Signal to noise ratio (E_c / I_0)**

The ratio of signal power to the noise power corrupting the signal .

- **Uplink transmission power**

Power transmitted from the user to base station .

- **Downlink transmission power**

Power transmitted from base station to the user .

Chapter Four

4

Modeling and Simulation

- 4.1 OPNET UMTS Model .
- 4.2 Statistical Analysis Procedure .
- 4.3 Results Authenticity
- 4.4 Network Modeling
- 4.5 scenarios

4.1 OPNET UMTS model

OPNET Modeler provides a graphical user interface, which enables modeling and simulating networks. The modeling environment consists of different hierarchical layers for developing communication structures. OPNET provides the flexibility to build very detailed customized models as well to perform general system analysis. Systems are built up in an object oriented way, compiling the models automatically generates discrete event simulations in C language . After simulation it is possible to gather and analyze results with some of the built-in performance statistics features provided by this package.

4.1.1 Object Palette Tree

To build any UMTS network , we need number of node-b's , number of RNC , and one SGSN , and number UE which one can find from Figure 4.1 .

This window contain all parts to build any UMTS network :

network

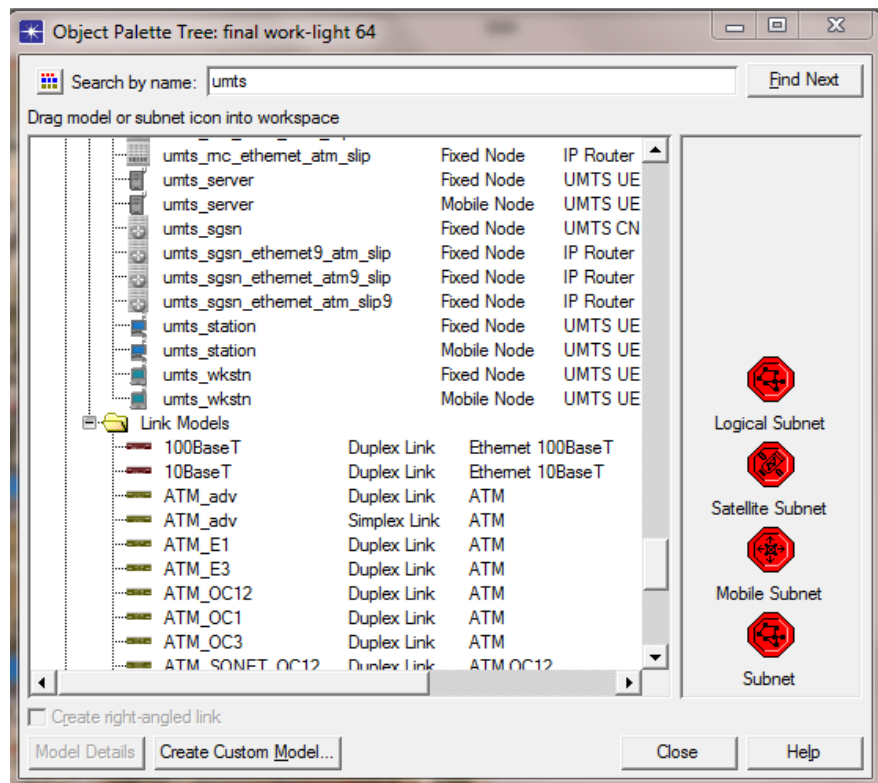


Figure 4.1 :object palette tree window

4.1.2 Node-B Attribute :

This window contain all properties that can be modified for node-b , you can modify on the name of node -b ,x- position , y - position , threshold ,... etc (see Figure 4.2) .

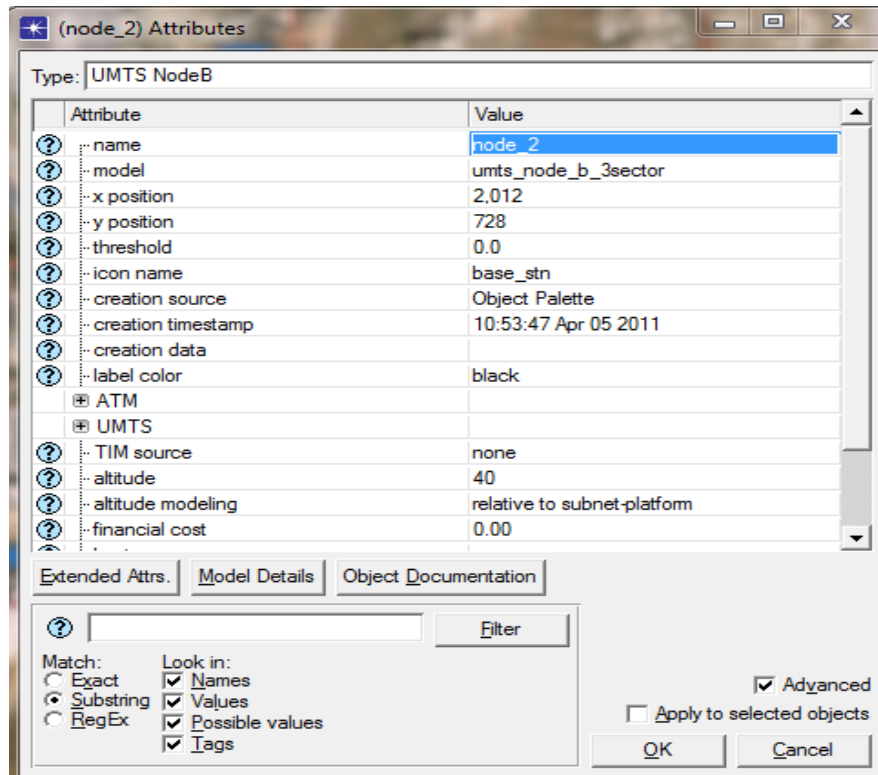


Figure 4.2 Node-B attribute

4.1.3 Mobile Node Attribute :

The Figure 4.3 below is a window attribute for Mobile node , this widow contain all parameters for mobile node , for example this window contain :

- **Start time** : Start Time of sessions of type "Traffic Class" .
- **Setup time** : end of simulation .
- **Session parameters** : Specifies the inter-arrival time between sessions and the duration of each session.

- a) Session inter arrival rate (second) : Specifies the inter-arrival time distribution name and arguments to be used for generating random outcomes to determine inter-arrival time between sessions.
- Exponential (1) : mean one event for each second .
- b) Session duration (second) : Specifies the distribution name and arguments to be used for generating random outcomes to determine duration of the session.
- Exponential (120) : average duration call per second is 120.
- **On state parameters** : Specifies the attributes used in the ON state of the client child process model. For a voice call, the ON and OFF states represent speech and silence periods respectively. For an e-mail application, only the ON state should be used for the duration of the session. The ON state duration would be set to infinity in that case and the OFF state duration would be set to 0.
 - **Packet size** : The packet size has the most profound effect on the number of packets sent across the network.

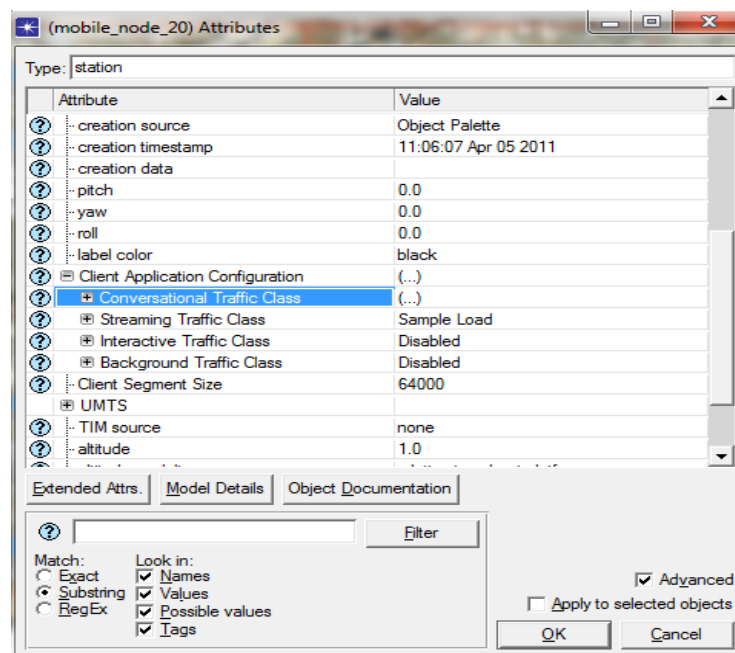


Figure 4.3 : Mobile Node Attribute

- **QOS Component**

In Network Services are considered end-to-end, this means from a Terminal Equipment (UE) to another UE. An End-to-End Service may have a certain Quality of Service QOS which is provided for the user of a network service. It is the user that decides whether he is satisfied with the provided QOS or not. To realize a certain network QOS a Bearer Service with clearly defined characteristics and functionality is to be set up from the source to the destination of a service .

There are four different QOS classes (see table 4.1) :

- conversational class : packet size (16bytes) .
- streaming class : packet size (96bytes) .
- interactive class : packet size (256bytes) .
- Background class : packet size (512bytes) .

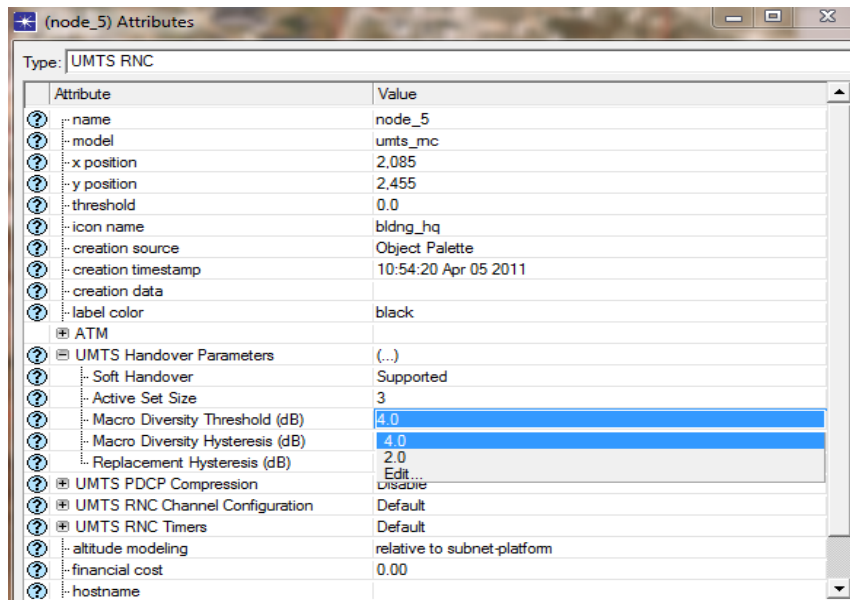
Traffic class	Conversational class	Streaming class	Interactive class	Background class
	Real Time	Real Time	Best Effort	Best Effort
Fundamental characteristics	- Preserve time relation (variation) between information entities of the stream - Conversational pattern (stringent and low delay)	- Preserve time relation (variation) between information entities of the stream	- Request response pattern -Preserve payload content	-Destination is not expecting the data within a certain time -Preserve payload content
Example of the application	voice	streaming video	web browsing	telemetry, emails

Table 4.1 : UMTS QOS Classes

4.1.4 UMTS RNC Attribute :

The window below 4.4 contain all parameter that can be modify for RNC , for example in this widow you can change :

- **Macro diversity threshold :** When MDHO (macro diversity handover) is supported by UE and by node-b, the “Diversity Set” is maintained by UE and node-b. Diversity set is a list of the node-b’s, which are involved in the handover procedure. Diversity set is defined for each of UE’s in network. UE communicates with all node-b’s in the diversity set .For downlink in MDHO, two or more node-b’s transmit data to UE such that diversity combining can be performed at the UE. For uplink in MDHO, UE transmission is received by multiple node-b’s where selection diversity of the received information is performed. The node-b, which can receive communication among UE’s and other node-b’s, but the level of signal strength is not sufficient is noted as “Neighbor node-b”. [40]
- **Active set size :** Maximum number of Node-B's that can exist in the "Active Set" of a connected UE at a given time.
- **Macro-diversity hysteresis**
- **Replacement hysteresis**



Attribute	Value
name	node_5
model	umts_mc
x position	2.085
y position	2.455
threshold	0.0
icon name	bldng_hq
creation source	Object Palette
creation timestamp	10:54:20 Apr 05 2011
creation data	
label color	black
ATM	
UMTS Handover Parameters	(...)
Soft Handover	Supported
Active Set Size	3
Macro Diversity Threshold (dB)	4.0
Macro Diversity Hysteresis (dB)	4.0
Replacement Hysteresis (dB)	2.0
UMTS PDCP Compression	Edit...
UMTS RNC Channel Configuration	Disable
UMTS RNC Timers	Default
altitude modeling	relative to subnet-platform
financial cost	0.00
hostname	

Figure 4.4 : UMTS RNC attribute

4.1.5 Configuration Run Window :

After the completion of building a network of UMTS and press the button of simulation will see the following window (Figure 4.5) , this window contain :

- **Duration** : the time take to simulation .
- **Seed** : random number generators .
- **simulation set name** : the name of senario or simulation .
- **Run** : Launch the simulation .

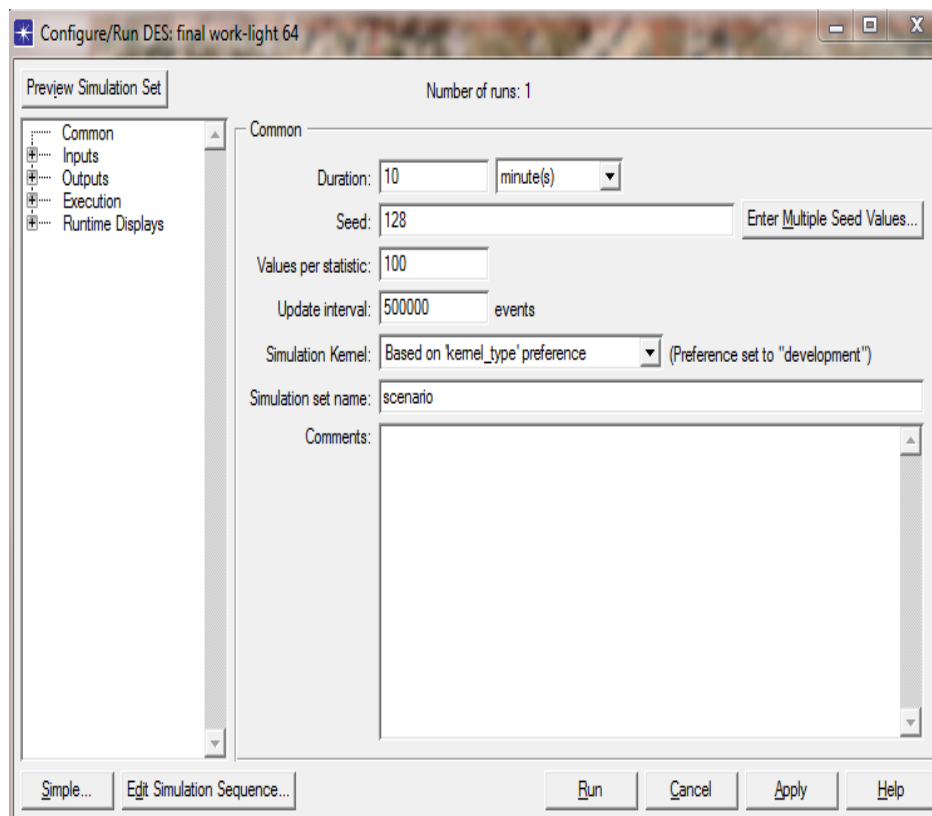


Figure 4.5 : Configuration Run Window

4.1.6 Simulation Progress

After pressing the button run, it will appear list called Simulation Progress (see Figure 4.6) , this window contain:

- **Elapsed time** : pass away time of the simulation .
- **Estimate remaining time** : The remaining time of the simulation .
- **Simulation speed** : number of operation for one second .
- **Messages** : Description of the simulation process at each stage .

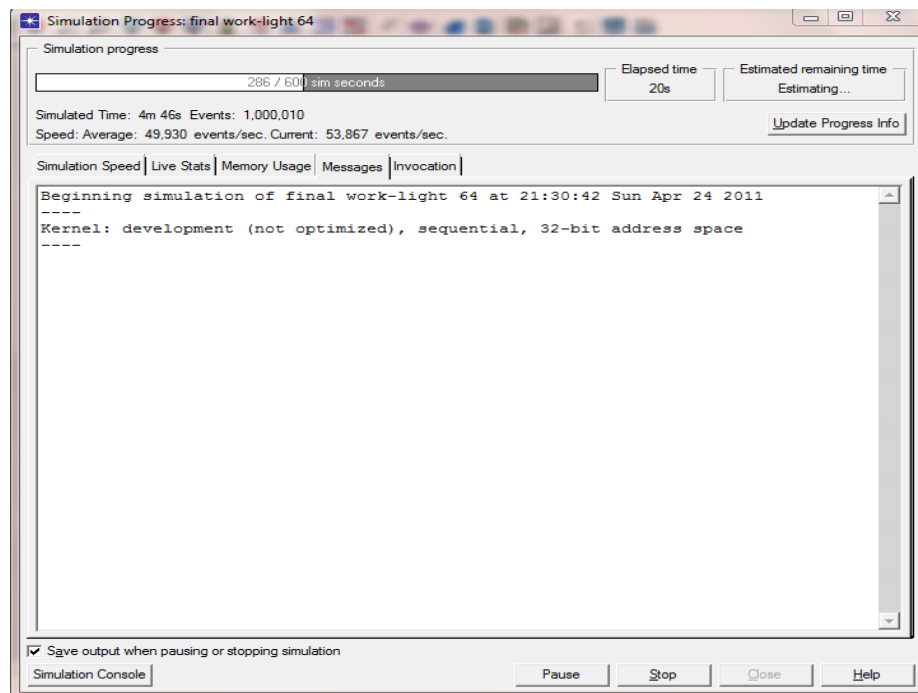


Figure 4.6 : Simulation Progress

4.1.7 Result browser

After the simulation is finished ; will see this window (Figure 4.7) , this window contain :

- a) all users in the network , each user has number of Figure (for example : total uplink transmission power , total received (packet /second) , total throughput....etc) .
- b) all node- b's in the network has number of Figure (for example : total down link transmission power , total received (packet /second) , total throughput....etc)

Each Figure has some of options such :

- a) **As is** : the figure without modification.
- b) **Adder** : Collect two or more graphics on the same graphic
- c) **Average** : is a measure of the "middle" value .

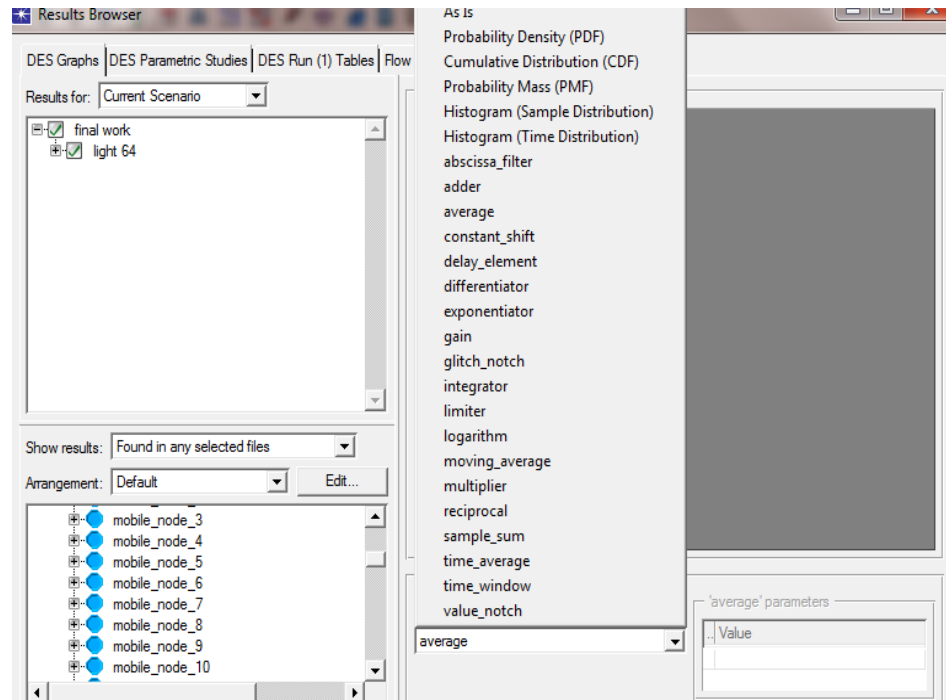


Figure 4.7: Result browser

4.2 Statistical analysis procedure

- **The arithmetic mean**

In mathematics and statistics, the arithmetic mean, often referred to as simply the mean or average when the context is clear, is a method to derive the central tendency of a sample space. The term “arithmetic mean” is preferred in mathematics and statistics because it helps distinguish it from other means such as the geometric and harmonic mean.

Suppose we have sample space $\{a_1, \dots, a_n\}$. Then the arithmetic mean A is defined via the equation :

$$A = \frac{1}{n} \sum_{i=1}^n a_i \quad \text{Eq: 4. 1}$$

- **Standard Deviation**

A measure of the dispersion of a set of data from its mean. The more spread apart the data, the higher the deviation. Standard deviation is calculated as the square root of variance.

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^n (X_i - \mu)^2} \quad \text{Eq: 4. 2}$$

- **Confidence intervals**

A term used in inferential statistics that measures the probability that a population parameter will fall between two set values. The confidence interval can take any number of probabilities, with the most common being 95% or 99%. In other words, a confidence interval is the probability that a value will fall between an upper and lower bound of a probability distribution.

Confidence intervals : [lower : $a - \frac{z \sigma}{\sqrt{n}}$, upper: $a + \frac{z \sigma}{\sqrt{n}}$]

Where :

a : Average value of the experiments (the average of the 10 values) .

σ : The standard deviation of the values .

n : the number of experiments (here it is 10 times) .

z : the normal distribution parameter .

- **Normal distribution :**

The normal (or Gaussian) distribution, is a continuous probability distribution that is often used as a first approximation to describe real-valued random variables that tend to cluster around a single mean value. The graph below is probability density function is known as the *Gaussian function* or *bell curve* (see Figure 4.8) .

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad \text{Eq: 4.3}$$

where parameter μ is the *mean* (location of the peak) and σ^2 is the *variance* (the measure of the width of the distribution). The distribution with $\mu = 0$ and $\sigma^2 = 1$ is called the standard normal.

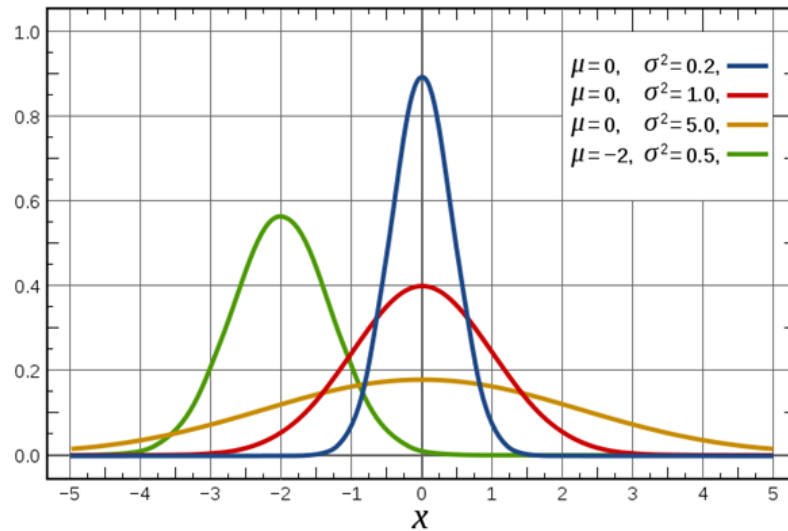


Figure 4.8 : probability density function with different mean and variance .

- **Exponential distribution** : is a family of continuous probability distributions. It describes the time between events in a Poisson process (see Figure 4.9). probability distributions function given by :

$$f(x) = \lambda e^{-\lambda x} \quad \text{Eq: 4.4}$$

Where λ is the duration call/ second .

The mean or expected value of an exponentially distributed random variable X with rate parameter λ is given by :

$$\mu = \frac{1}{\lambda} \quad \text{Eq: 4.5}$$

In light of the examples given above, this makes sense: if you receive phone calls at an average rate of 2 per hour, then you can expect to wait half an hour for every call.

The variance of X is given by :

$$Var = \frac{1}{\lambda^2}$$

Eq: 4.6

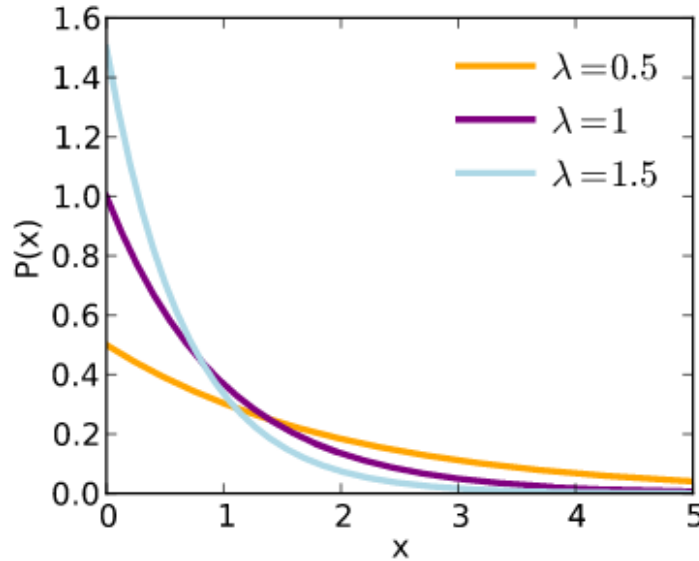


Figure 4.9 : Exponential probability distributions function with different λ .

4.3 Results Authenticity

at First, we will design network contains a number of mobiles ; to verify the authenticity of the results that will take from the program, for this experience we will compute the probability of soft handover with different threshold by OPNET , then compute the probability through equations that mention in the previews chapter , then compare between the two outcomes(see Figure 4.10) .



Figure 4.10 : Simple UMTS Network

The model of this UMTS network as shown in Figure 4.10 contain two node-b , one RNC , and one SGSN , and two communicated UE which one of them move with trajectory for distance 1 Km from node 1 to nod 0 . the table 4.2 explain the attribute for the node's that we use it the network ,like what the type of traffic , explain the property for the trajectory ,distance ,speed of mobile and the time taken to complete the trajectory . we deicide five threshold to the simulation with ten minute duration , and analysis the ten seed result by excel .

Variable	Value
Distance	1 Km
User Speed	10 Km/h
Trajectory Time	6.27 minute
Path loss model	Vehicular model
Threshold Handover	2,7,9,11,12
Duration	10 minutes
Traffic type	Conversational sample load

Table 4.2: parameter used for the simulation

4.3.1 Simulation

At OPNET; we simulate different ten seeds for each threshold , and the result which obtained for a signal to noise ratio , show Figure 4.11 . We can see from this Figure that the S/N for node 1 in maximum at the first ; then decrees when the mobile go far away from it , and vice versa on the other node . and when the difference between S/N for node-0 and S/N for node-1 equal the threshold then the window for soft handover will start , and when the window is finished this mean the user disconnect with node -0 and connect with node -1 , when S/N is constant the mobile end the trajectory and stop moving .

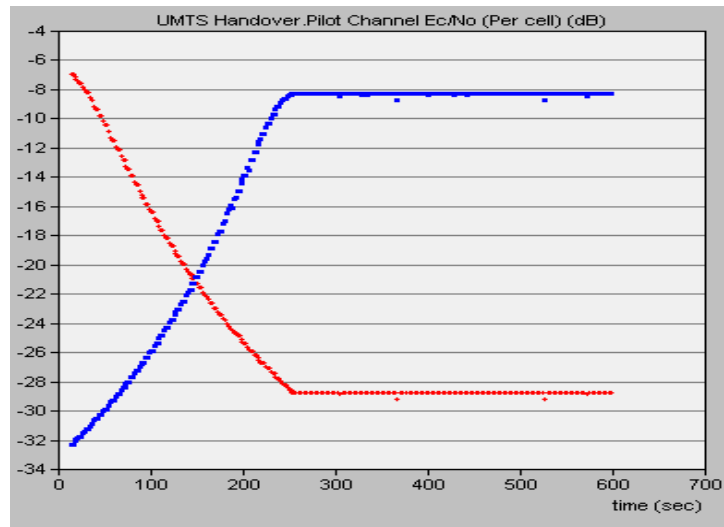


Figure 4.11 : Pilot channel (SIR) at 12dB

The other results which obtained from OPNET is uplink transmission power for a different threshold (2,4,7,9,12) dB , we noticed that the handover window different from threshold to another , i.e : when we increase the threshold , the handover window will be increased (see Figure 4.12) , and this increase of the handover window make an effect on the probability of soft handover.

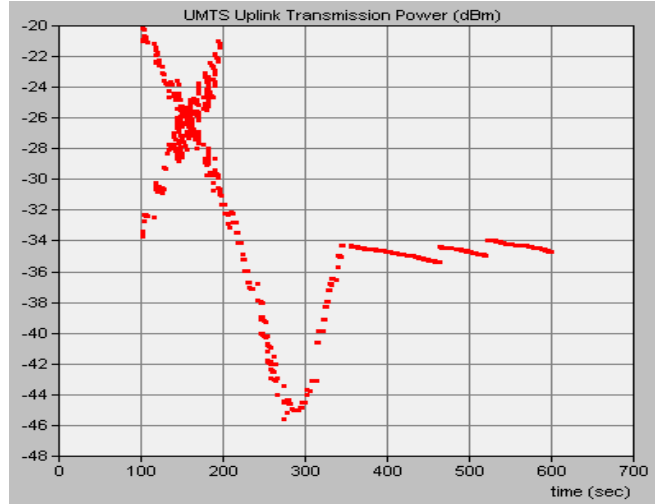


Figure 4.12 : uplink transmission power at 12 dB

4.3.2 Analysis

We exported the data for the result which obtained in OPNET to the Microsoft excel program ,then we take the S/N at time 48 seconds at 10 different seeds for node (0) and node (1) (see table 4.3) , then we analyzed the data to find average , standard deviation , confidence interval at 99% and 95 % , and plot the normal distribution for the results which shown in the below :

seed	1	2	3	4	5	6	7	8	9	10	avg	St.de v	Con at 95%		Con at 99%	
Nod 0	15.22023	18.80991	22.86524	14.94711	14.27654	13.9743	17.3084	13.33146	21.27741	20.63731	17.26479	3.432026	15.1376	19.39198	14.47014	20.05944
Nod 1	42.78992	41.06857	47.94941	46.97607	39.65601	38.88917	41.18456	47.44584	45.87037	45.43128	43.72612	3.400986	41.61817	45.83408	40.95674	46.4955

Table 4.3: S/N for node (0) and node (1) at time 48s in dBm .

Figure 4.13 shows the normal distribution at 95% from node 0 , which explain that the mean is 17.26479 , the standard deviation is 3.432026 , the lower confidence value at 95% is 15.1376 , and the higher confidence value at 95% is 19.39198 .

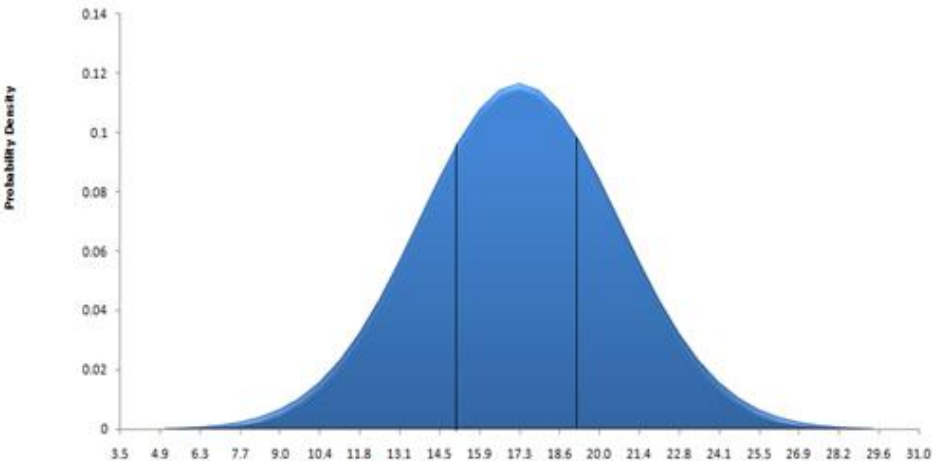


Figure 4.13 : normal distribution at 95% from node 0

Figure 4.14 shows the normal distribution at 99% from node 0 , which explain that the mean is 17.26479 , the standard deviation is 3.432026 , the lower confidence value at 95% is 14.47014 , and the higher confidence value at 95% is 20.05944 .

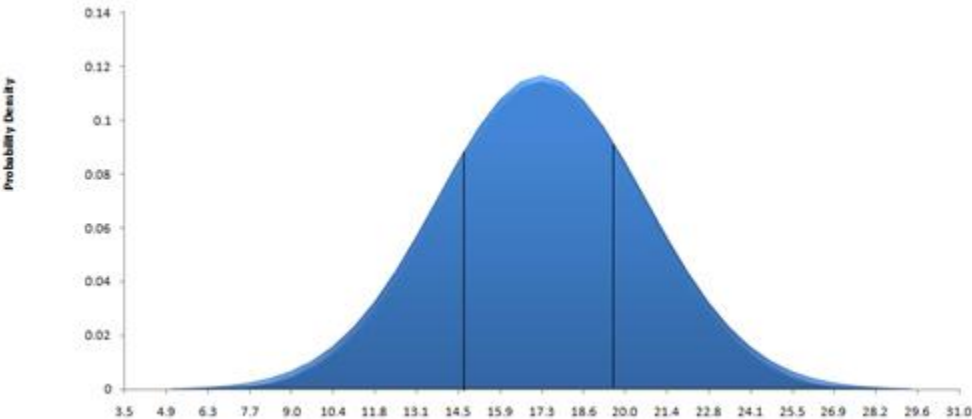


Figure 4.14: normal distribution at 99% from node 0 .

To find the handover window we need the graph of the S/N to see when the different between two signals reach the threshold (see Figure 4.15) , then find the probability of soft handover by the equation :

$$SHO - PROB = \frac{\Delta t_{SHO}}{\Delta t_{total}} \quad Eq: 4. 7$$

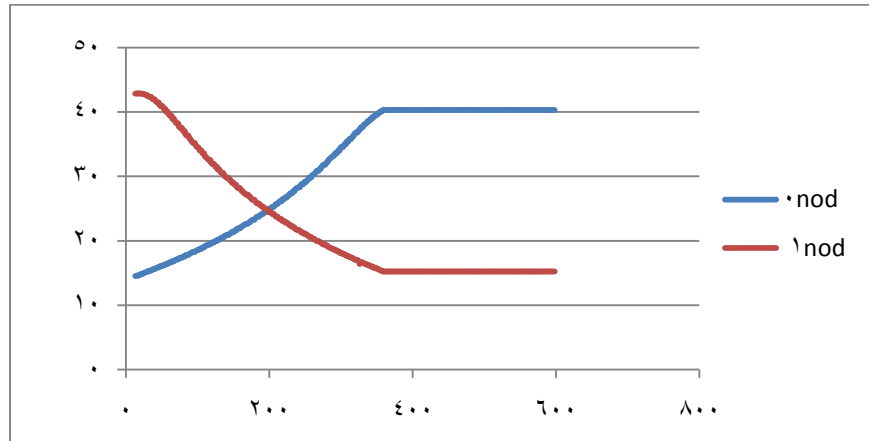


Figure 4.15 : S/N for node 0 and node 1 at 2dB

From this graph we find Δt_{SHO} the time where the different between the two S/N is equal to threshold .Then as this equation $SHO_PROB = \frac{\Delta t_{SHO}}{\Delta t_{total}}$ Where Δt_{total} is the time of the trajectory Δt_{SHO} is the time of the window, this was explained in chapter 3 :

$$SHO_PROB = \frac{\Delta t_{SHO}}{\Delta t_{total}} = \frac{212-165}{6.27*60} = 0.124934.$$

After we find the SHO Probability by OPNET , we want to find it using the equation 3.11 :

$$SHO_PROB = 1 - \frac{4}{(10^{33.6}+1)^2} = 1 - \frac{4}{(10^{33.6}+1)^2} = 0.132163 .$$

The error between the two result is 5.786544% .

4.3.3 Result

This table 4.4 explain the comparison between the probability of soft handover by OPNET and by the calculations and find the percentage error , we notice from the comparison that the probability of soft handover by OPNET close to the probability of soft handover by the calculation .

Threshold dB	Window (s)		Δt	Time of trajectory	Probability of soft handover by OPNET	Probability of soft handover By equation	Err%
2	212	165	47	376.2	0.124934	0.132163	5.786544
7	288	128	160	376.2	0.425306	0.41532	2.347799
9	299	112	187	376.2	0.497076	0.508549	2.308101
11	317	102	215	376.2	0.571505	0.590428	3.311211
12	322	91	231	376.2	0.614035	0.627254	2.152785
14	341	79	262	376.2	0.696438	0.693092	0.480409

Table 4.4: probability of SHO with different threshold .

4.3.4 Soft Handover MATLAB Code :

This code is the soft handover probability using MATALAB , this code from the equation 3.11 in chapter three :

```

x=[2 7 9 11 12 14 ]           % threshold 2dB 7dB 9dB 11dB 12dB 14dB
y=1-((4./((10.^(x./33.6)+1).^2) % mathematical equation for probability of sho
p1=((212-165)/376.2);         % OPNET result for 2dB
p2=((288-128)/376.2);         % OPNET result for 7dB
p3=((299-112)/376.2);         % OPNET result for 9dB
p4=((317-102)/376.2);         % OPNET result for 11dB
p5=((322-91)/376.2);          % OPNET result for 12dB
p6=((341-79)/376.2);          % OPNET result for 14dB
OPNET=[p1 p2 p3 p4 p5 p6]
err=abs(OPNET-y)./OPNET      % calculate error
plot (x,y,'r',x,OPNET,'b')
xlabel('SHO Threshold (dB)')
ylabel('SHO Probability')
title('SHO Probability as a function of the Threshold Value')
grid

```

by simulating this code in the MATLAB program the relationship between the threshold and soft handover probability with OPNET program and by calculation as shown in the Figure 4.16 below :

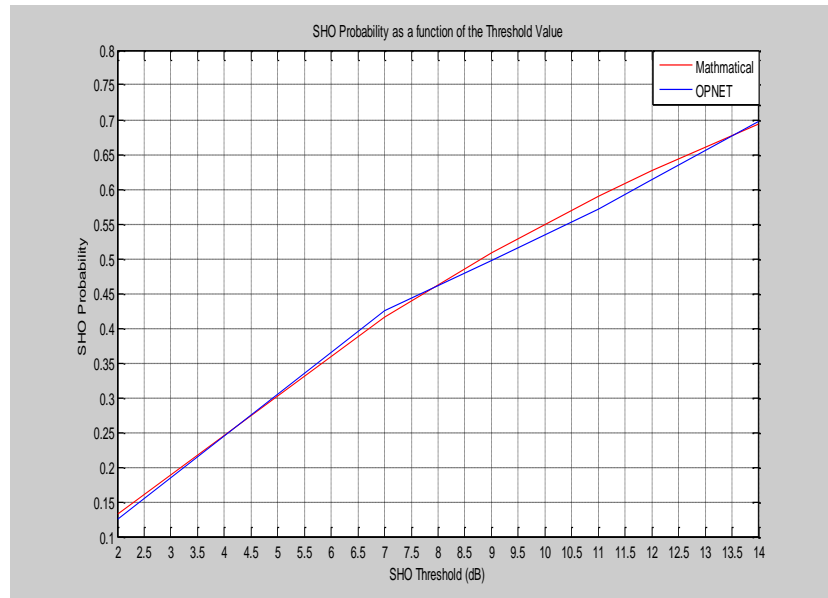


Figure 4.16 : simulation and mathematical SHO Probability as a function of the Threshold value

We see that by the figure the relationship between the threshold and soft handover probability is proportional when the threshold increase the probability for soft handover will increase and vice versa .

4.4 Network modeling

During the project we will simulate a real network, so we will give real locations and real distances and real results . The location of the network is Wad-Alharia in the Hebron city. And the network has five base-stations called A,B,C, and D as shown in Figure 4.17 below.

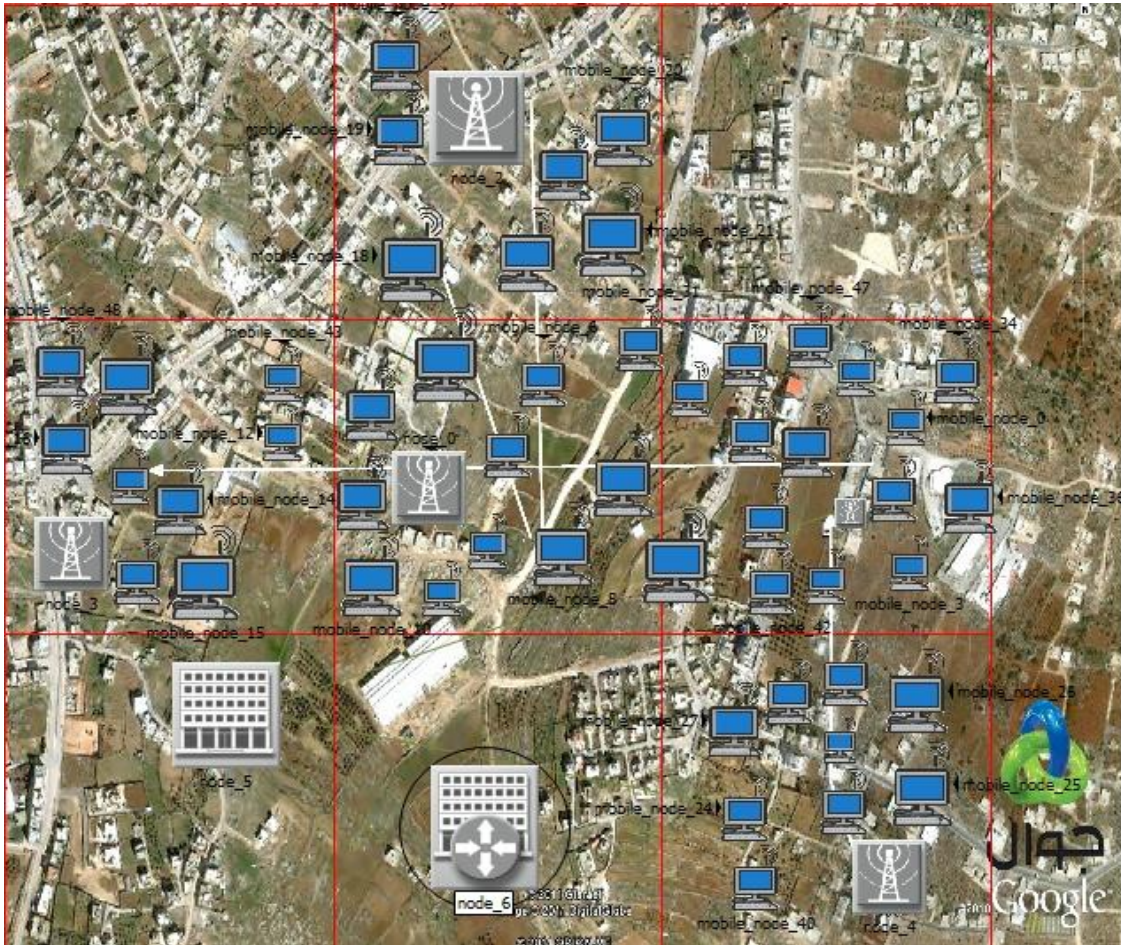


Figure 4.17 : Wad-Alharia Network

The network has 50 users, and the average user velocity is 10 km/h ,and we will use two base stations for the soft hand over (the active set size) with a micro-diversity threshold (2,4 , 6,8,10,12,14) dB .

The model will be a random distribution for the users. and we will use Vehicular model of the path loss because it's generally applicable for the user speed. And the transmission speed will be 15000 bps (see table 4.5) .

After all of these illustrations we have to specify the following we will record a ten minute of the network operating period for every simulation scenario, and there would be 28 different

scenarios ,for each scenario we will take 10 seeds. And the result for each simulation will be Total Transmit Load , Total Received throughput , end to end delay ,SNR VS time.

Variable	Value
Network Location	Wad-Alharia in Hebron city
Number of Node-B's	Five node-b called A,B,C,D and E
Number of users	50 users
User Speed	10 Km/h
Active set size	2 Node-B's
Path loss model	Vehicular model
Micro diversity threshold	(2,4, 6,8,10, 12,14) dB .
The transmission speed	15000 bps
Number of scenario	28 different scenarios
Number of seeds	10 seeds
Duration	10 minutes
Traffic type	conversational class streaming class interactive class Background class

Table 4.5 : parameter using for simulation

- **Total Transmit Load (packets/sec)** : Total transmit throughput on the downlink, i.e. from UTRAN to UE in bits/second.

- **Total Received Throughput (packets/sec)** : Total received throughput on the uplink, i.e. from UE to UTRAN in packets/second.
- **Total uplink power** : This statistic represents the transmission power used by the UE while transmitting uplink packets over the physical channels. The statistic is collected separately for each physical channel that is established with the Node-B of the current primary cell. The dimension indices refer to uplink signaling channel and 4 QoS channels, respectively.
- **SNR** : Pilot Channel Ec/No (dB) for cells in the active set of this UE. Active set will change as the UE moves, so the Ec/No does not correspond to one particular cell.
- **End-to-end delay** : refers to the time taken for a packet to be transmitted across a network from source to destination.
- **Throughput**: Throughput is measurement of average rate of Successful transmission of packets in a communication channel Which is often measured in bits per second.

Then the loss will be found from the formula, the loss :

$$\text{Loss} = \text{TTL} - \text{TRT} \quad \text{Eq: 4.8}$$

Where :

TTL : Total Transmit Load (packets/sec)

TRT : Total Received Throughput (packets/sec)

And the probability of any soft hand over :

$$\text{SHO} - \text{PROP} = 1 - \frac{4}{\left(10^{\frac{TH}{33.6}} + 1\right)^2} \quad \text{Eq : 4.9}$$

In our project we decide to make simulation for seven scenarios to measure the loss in the modeled network , this scenarios forms seven different threshold , in every one there is four packet size in two distribution normal and exponential .

4.5 Scenarios

In our project we decide to make simulation for seven scenarios to measure the loss and the End to End delay in the modeled network, this scenarios forms seven different threshold, in every one there is four packet size in two distribution, normal and exponential.

4.5.1 Packet Loss

The seven scenario below are form the packet loss with different traffic load, each scenario has a certain threshold with different packet size (16 , 96 , 256 , 512 byte), in addition to that, each scenario contains:

- Uplink transmission power at certain threshold which form the soft handover for a certain trajectory.
- Table consist of packet loss with two distribution (exponential and normal), average total transmit load and average total received throughput (packet / sec) to measure the loss for each threshold.
- Figure of average total transmit power, average total received throughput for the two distributions.

4.5.1.1 Scenario One "Threshold 2dB "

This scenario take 2 dB soft handover threshold, we take results from OPNET for uplink transmission power to explain the size of the soft handover window that shown from Figure 4.7, then we take the load and throughput to calculate the loss from table 4.6.

The Figure 4.18 is uplink transmission power for mobile passing three node B's, B to C, and C to D this Figure simulated at 2 dB, at begins the mobile start moving from the center of node B away to the node C, then the uplink transmission power from mobile will increase as the mobile away from node B, at time equal approximately 470 seconds; the window of soft handover between node B and node C will start, and will finished at point equal approximately 480s, at this point the mobile disconnect from node B and connect with node C, when the mobile continuously moving toward node C, the uplink transmission power continuously decrease until

the mobile reached at the center of node C at time equal 700s, at this point the uplink transmission power is the minimum , after this time the mobile continuously moving away from node C and the uplink transmission power from mobile continuously increases until the mobile reach to the time equal approximately 1000 s , at this point the soft handover window will start and finished at point equal 1010s ,at this point the mobile disconnect from node C and connect with node D, then the mobile completely moving toward node D , and the uplink transmission power continuously decreases until reach the center of node D at time equal 1400s , at the end the mobile complete the trajectory at point equal 1500s ,we note that ; the size of soft handover window in the Figure explained between the two red lines is small and that tell us the probability a user soft handover is small so there is a few numbers of handover in the network because the threshold is small .

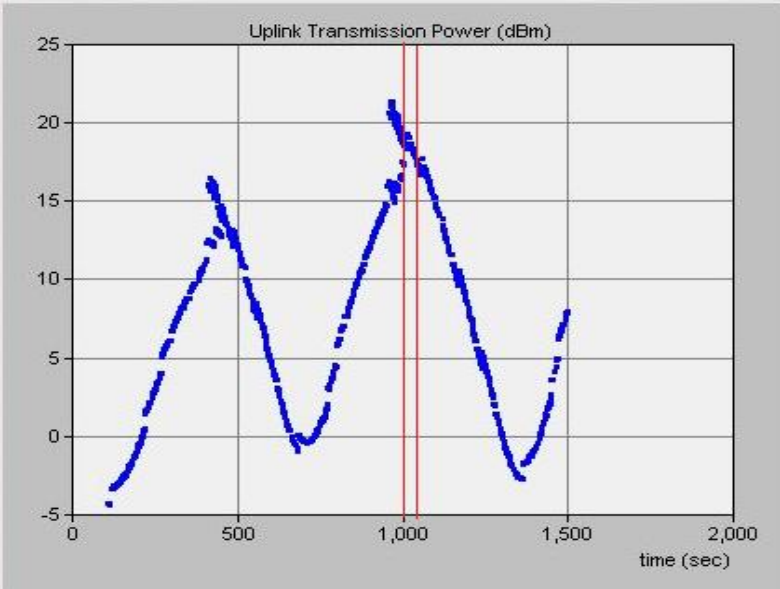


Figure 4.18 : Uplink Transmission Power At 2 dB

Table 4.6 explain the average total transmit load (packets/sec) , the average total received throughput (packets/sec) , and the loss (packets /sec) at different packet size for exponential and normal distribution at 2dB.

	packet size (byte)	Average Total Transmit Load (packets/sec)	Average Total Received Throughput (packets/sec)	Loss (packets/sec)
Exponential	16	41.551667	33.931667	7.62
	96	132.66	115.28833	17.37166667
	256	280.31333	250.96833	29.345
	512	539.195	326.95	212.245
Normal	16	44.67833	34.58167	10.09667
	96	140.05	101.4233	30.62667
	256	281.4483	201.7483	79.7
	512	445.0633	300.66	144.4033

Table 4.6 : packet loss for two distribution at 2dB .

Figure 4.19 has four curves for average total transmit load and average total received throughput in two distributions for traffic as we discuss before , the different between transmitted and received is the loss in the network , from the curve for each distribution if the load increase , the throughput will be increase with lower rate , so the difference between the transmit and received will increase , and the loss will be increase , that's for many reasons : first the arrival rate is not uniform so the buffer size in the term of link capacity are not enough to cope with high load so that lead to drop some packet .the second reason is “ leaky bucket protocol” , the explanation of this protocol is : when the data arrival in high load that make queuing in stations for every part of the network and the processor take the maximum data can deal with and drop the other data ,for example at packet size equal (16 bytes) for exponential distribution the packet loss is 7.62 packets compared with the packet size equal (512) packets the loss is 212.245 packets , so that make large loss at high load depending on the previous explanation .

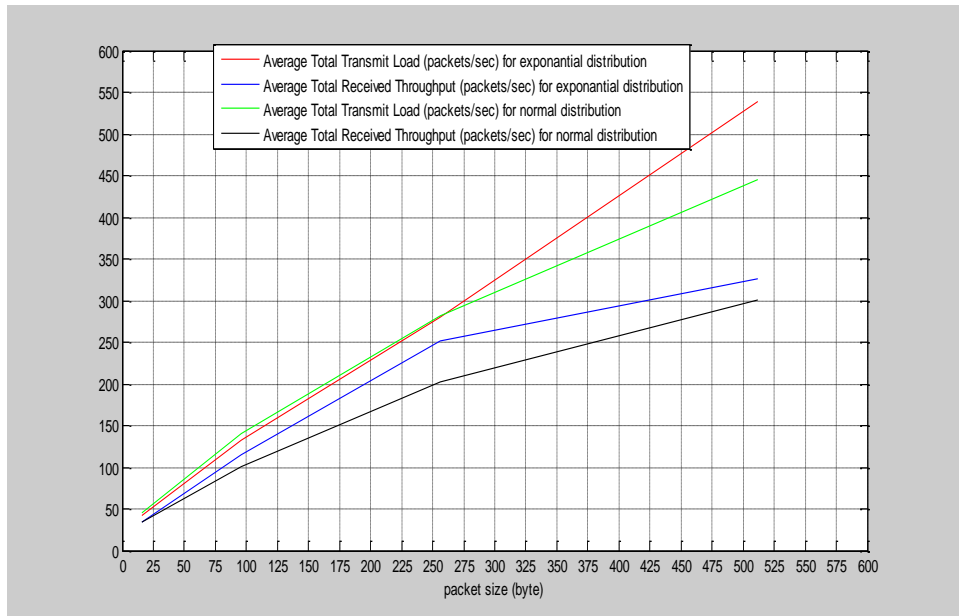


Figure 4.19 : Average Total Transmit Load And Total Received Throughput For Normal And Distribution at 2dB .

4.5.1.2 Scenario Two "Threshold 4dB "

This scenario take 4 dB soft handover threshold , we take results from OPNET for uplink transmission power to explain the size of the soft handover window shown in Figure 4.9 , then we take the load and throughput to calculate the loss as shown in table 4.7 .

The Figure 4.20 is uplink transmission power for mobile passing three node B's, B to C, and C to D, this Figure simulated at 4 dB ,at begins the mobile start moving from the center of node B away to the node C, then the uplink transmission power from mobile will increase as the mobile away from node B, at time equal approximately 450 seconds; the window of soft handover between node B and node C will start , and will finished at point equal approximately 500s, at this point the mobile disconnect from node B and connect with node C , when the mobile continuously moving toward node C, the uplink transmission power continuously decrease until the mobile reached at the center of node C at time equal 700s, at this point the uplink transmission power is the minimum , after this time the mobile continuously moving away from node C and the uplink transmission power from mobile continuously increases until the mobile

reach to the time equal approximately 990s , at this point the soft handover window will start and finished at point equal 1150s ,at this point the mobile disconnect from node C and connect with node D, then the mobile completely moving toward node D , and the uplink transmission power continuously decreases until reach the center of node D at time equal 1400s , at the end the mobile complete the trajectory at point equal 1500s ,we note that the figure below explained between the two red lines_ is larger than the size in 2 dB and that tell us the probability is larger than the probability in 2 dB so the numbers of handover in the network here is more than the numbers soft handover in 2 dB .

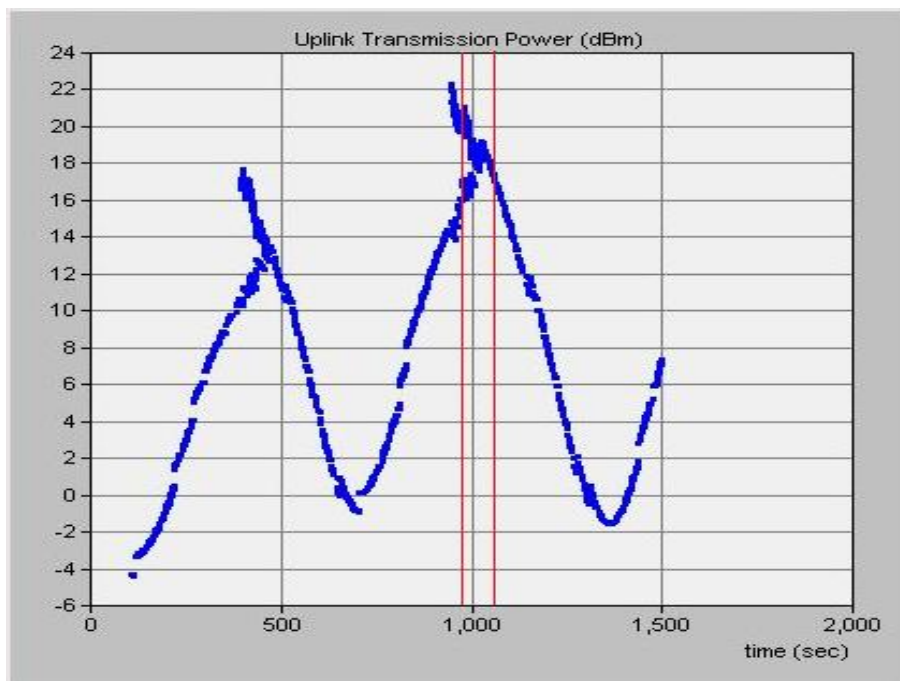


Figure 4.20 : Uplink Transmission Power At 4 dB

Table 4.7 explain the average total transmit load (packets/sec) , the average total received throughput (packets/sec) , and the loss (packets /sec) at different packet size for exponential and normal distribution at 4 dB .

	packet size (byte)	Average Total Transmit Load (packets/sec)	Average Total Received Throughput (packets/sec)	Loss (packets/sec)
Exponential	16	43.45	35.971667	7.478333
	96	135.19167	109.36	25.831667
	256	274.01333	208.47	45.543333
	512	481.55667	286.22667	225.33
Normal	16	44.61167	33.59667	11.015
	96	140.86	108.8033	32.05667
	256	266.5517	155.4017	111.15
	512	523.7133	364.4967	159.2167

Table 4.7 : packet loss for two distribution at 4dB

Figure 4.21 has four curves for average total transmit load and average total received throughput in two distributions for traffic at 4dB, as we discuss before, the difference between transmitted and received is the loss in the network, from the curve for each distribution if the load increase, the throughput will be increase with lower rate, so the difference between the transmit and received will increase, and the loss will be increase, and the reason for this is the same reason that discuss in the first scenario; but the loss will increase higher than the loss for 2 dB, for example at packet size equal (16 bytes) for exponential distribution the packet loss is 7.478333 packets compared with the packet size equal (512) packets the loss is 225.33 packets, so that make large loss at high load depending on the previous explanation.

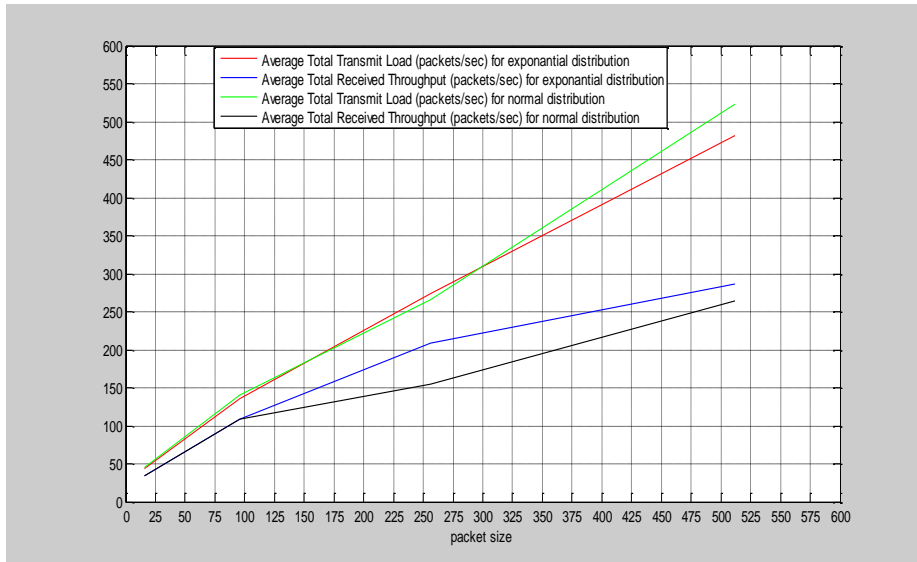


Figure 4.21 : Average Total Transmit Load And Total Received Throughput For Normal And Distribution at 4 dB .

4.5.1.3 Scenario Three "Threshold 6 dB "

This scenario take 6 dB soft handover threshold , we take results from OPNET for uplink transmission power to explain the size of the soft handover window as shown in Figure 4.11 , then we take the load and throughput to calculate the loss , table 4.8 .

The Figure 4.22 is uplink transmission power for mobile passing three node B's, B to C, and C to D this Figure simulated at 6 dB ,at begins the mobile start moving from the center of node B away to the node C, then the uplink transmission power from mobile will increase as the mobile away from node B, at time equal approximately 400 seconds; the window of soft handover between node B and node C will start , and will finished at point equal approximately 530s, at this point the mobile disconnect from node B and connect with node C , when the mobile continuously moving toward node C, the uplink transmission power continuously decrease until the mobile reached at the center of node C at time equal 700s, at this point the uplink transmission power is the minimum , after this time the mobile continuously moving away from node C and the uplink transmission power from mobile continuously increases until the mobile reach to the time equal approximately 1000s , at this point the soft handover window will start and finished at point equal 1250s ,at this point the mobile disconnect from node C and connect with node D, then the mobile completely moving toward node D , and the uplink transmission power continuously decreases until reach the center of node D at time equal 1400s , at the end

the mobile complete the trajectory at point equal 1500s ,we note that the figure explained between the two red lines_ is larger than the size in 4 dB and that tell us the probability is larger than the probability in 4 dB so the numbers of handover in the network here is more than the numbers in 4 dB and 2dB.

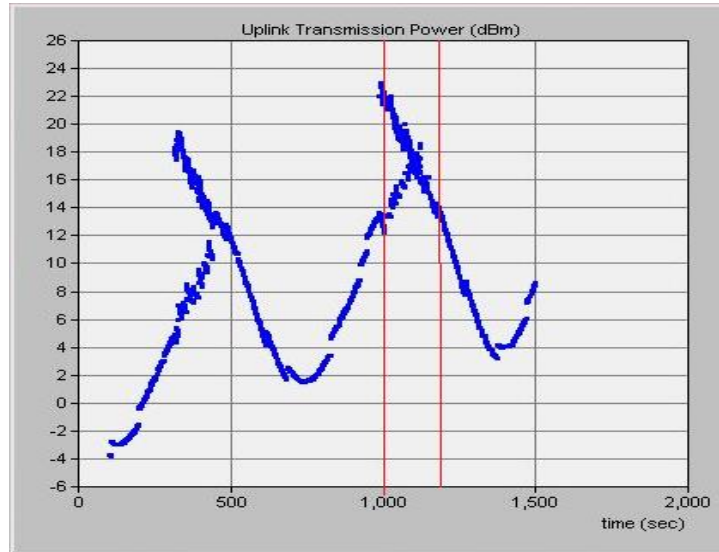


Figure 4.22: Uplink Transmission Power At 6 dB .

Table 4.8 explain the average total transmit load (packets/sec) , the average total received throughput (packets/sec) , and the loss (packets /sec) at different packet size for exponential and normal distribution at 6dB.

	packet size (byte)	Average Total Transmit Load (packets/sec)	Average Total Received Throughput (packets/sec)	Loss (packets/sec)
Exponential	16	40.99667	33.20333	7.793333
	96	131.35	113.575	17.775
	256	276.34167	224.11167	52.23
	512	588.78833	320.58833	268.2
Normal	16	47.43833	35.27667	12.16167
	96	137.78	99.31667	38.46333
	256	276.1901	152.9892	123.2008
	512	494.8867	300.66	194.2267

Table 4.8 : packet loss for two distribution at 6dB .

Figure 4.23 has four curves for average total transmit load and average total received throughput in two distributions for traffic at 6dB, as we discuss before, the difference between transmitted and received is the loss in the network, from the curve for each distribution if the load increase, the throughput will be increase with lower rate, so the difference between the transmit and received will increase, and the loss will be increase, and the reason for this is the same reason that discuss in the first scenario; but the loss will increase higher than the loss for 4 dB, for example at packet size equal (16 bytes) for exponential distribution the packet loss is 8.77933333 packets compared with the packet size equal (512) packets the loss is 268.2 packets, so that make large loss at high load depending on the previous explanation.

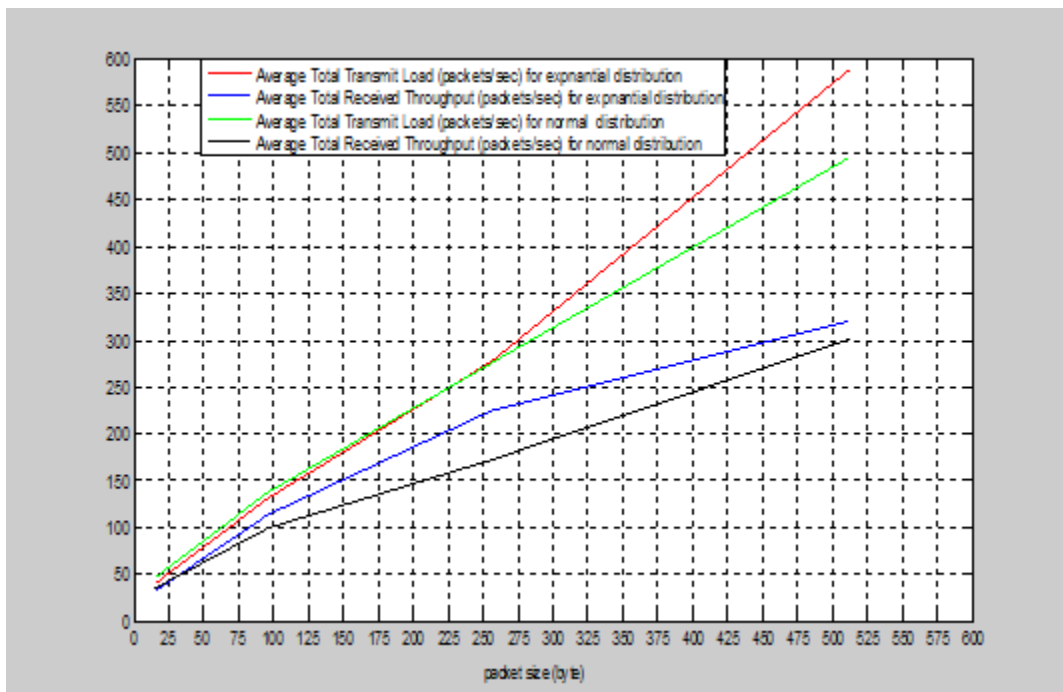


Figure 4.23 : Average Total Transmit Load And Total Received Throughput For Normal And Distribution at 6 dB .

4.5.1.4 Scenario Four "Threshold 8dB "

This scenario take 8 dB soft handover threshold, we take results from OPNET for uplink transmission power to explain the size of the soft handover window as shown in Figure 4.13, then we take the load and throughput to calculate the loss, see table 4.9.

The Figure 4.24 is uplink transmission power for mobile passing three node B's, B to C, and C to D this Figure simulated at 8 dB ,at begins the mobile start moving from the center of node B away to the node C, then the uplink transmission power from mobile will increase as the mobile away from node B, at time equal approximately 390 seconds; the window of soft handover between node B and node C will start , and will finished at point equal approximately 540s, at this point the mobile disconnect from node B and connect with node C , when the mobile continuously moving toward node C, the uplink transmission power continuously decrease until the mobile reached at the center of node C at time equal 700s, at this point the uplink transmission power is the minimum , after this time the mobile continuously moving away from node C and the uplink transmission power from mobile continuously increases until the mobile reach to the time equal approximately 900s , at this point the soft handover window will start and finished at point equal 1300s ,at this point the mobile disconnect from node C and connect with node D, then the mobile completely moving toward node D , and the uplink transmission power continuously decreases until reach the center of node D at time equal 1400s , at the end the mobile complete the trajectory at point equal 1500s ,we note that at 8 dB the size of soft handover window _ in the Figure explained between the two red lines_ is larger than the size in 6 dB , and that tell us the probability is larger than the probability in 6 dB so the numbers of handover in the network here is more than the numbers of soft handover in 6 dB ,4 dB , and 2dB.

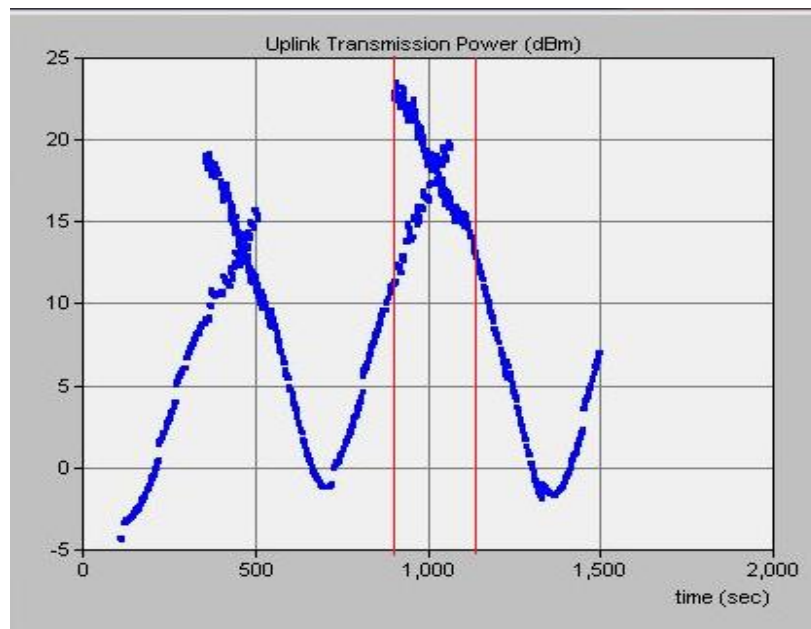


Figure 4.24 : Uplink Transmission Power At 8dB .

Table 4.9 explain the average total transmit load (packets/sec) , the average total received throughput (packets/sec) , and the loss (packets /sec) at different packet size for exponential and normal distribution at 8dB.

	packet size (byte)	Average Total Transmit Load (packets/sec)	Average Total Received Throughput (packets/sec)	Loss (packets/sec)
Exponential	16	43.745	35.178333	8.5666667
	96	140.54167	117.265	23.276667
	256	289.96833	226.885	63.083333
	512	623.13	336.44	286.69
Normal	16	46.625	34.04	12.585
	96	131.4533	72.29333	39.16
	256	310.6567	171.2263	139.4304
	512	506.9583	298.93	208.0283

Table 4.9 : packet loss for two distribution at 8dB .

Figure 4.25 has four curves for average total transmit load and average total received throughput in two distributions for traffic at 8dB, as we discuss before , the different between transmitted and received is the loss in the network , from the curve for each distribution if the load increase , the throughput will be increase with lower rate , so the difference between the transmit and received will increase , and the loss will be increase , and the reason for this is the same reason that discuss in the first scenario ; but the loss will increase higher than the loss for 6 dB, for example at packet size equal (16 bytes) for exponential distribution the packet loss is 8.5666667 packets compared with the packet size equal (512) packets the loss is 286.69 packets , so that make large loss at high load depending on the previous explanation .

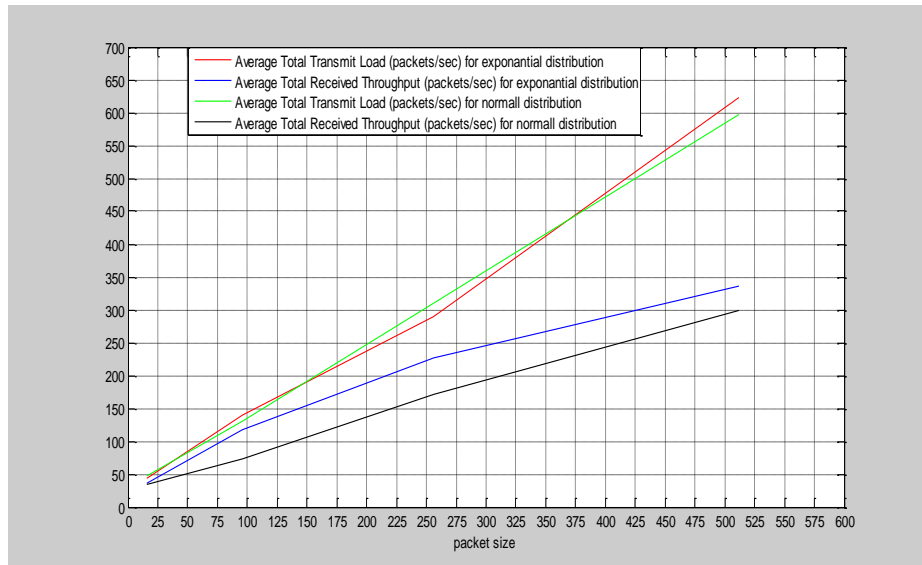


Figure 4.25 : Average Total Transmit Load And Total Received Throughput For Normal And Distribution at 8 dB .

4.5.1.5 Scenario Five "Threshold 10dB "

This scenario take 10 dB soft handover threshold , we take results from OPNET for uplink transmission power to explain the size of the soft handover window , Figure 4.15 , then we take the load and throughput to calculate the loss ,see table 4.10 .

The Figure 4.26 is uplink transmission power for mobile passing three node B's, B to C, and C to D (see Figure 4.7), this Figure simulated at 10 dB ,at begins the mobile start moving from the center of node B away to the node C, then the uplink transmission power from mobile will increase as the mobile away from node B, at time equal approximately 350 seconds; the window of soft handover between node B and node C will start , and will finished at point equal approximately 550s, at this point the mobile disconnect from node B and connect with node C , when the mobile continuously moving toward node C, the uplink transmission power continuously decrease until the mobile reached at the center of node C at time equal 700s, at this point the uplink transmission power is the minimum , after this time the mobile continuously moving away from node C and the uplink transmission power from mobile continuously increases until the mobile reach to the time equal approximately 890s , at this point the soft

handover window will start and finished at point equal 1310s ,at this point the mobile disconnect from node C and connect with node D, then the mobile completely moving toward node D , and the uplink transmission power continuously decreases until reach the center of node D at time equal 1400s , at the end the mobile complete the trajectory at point equal 1500s ,we note , at 10 dB the size of soft handover window _ in the figure explained between the two red lines_ is larger than the size in 8 dB and that tell us the probability is larger than the probability in 8 dB so the numbers of handover in the network here is more than the numbers in 8dB .

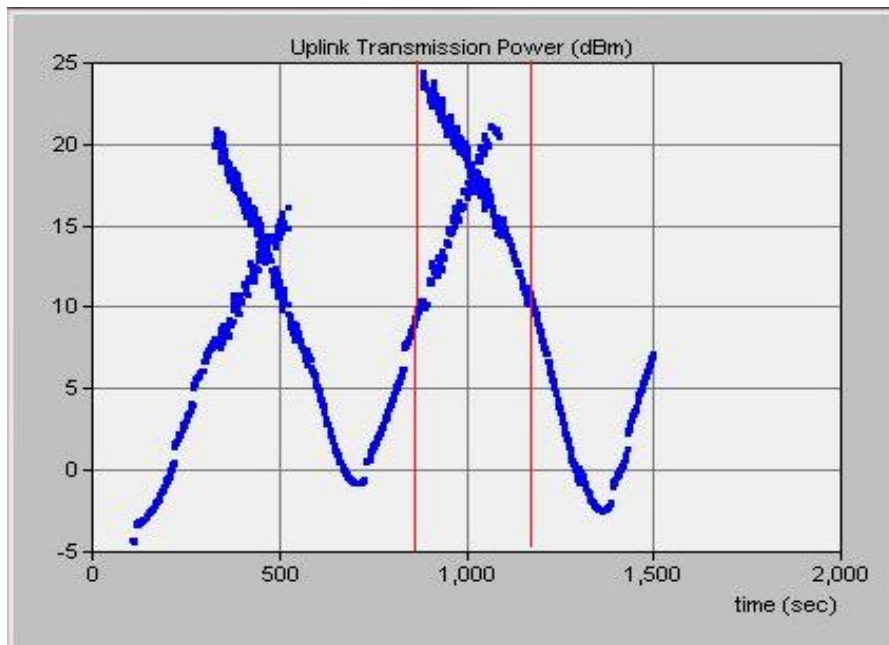


Figure 4.26: Uplink Transmission Power At 10dB .

Table 4.10 explain the average total transmit load (packets/sec) , the average total received throughput (packets/sec) , and the loss (packets /sec) at different packet size for exponential and normal distribution .

	packet size (byte)	Average Total Transmit Load (packets/sec)	Average Total Received Throughput (packets/sec)	Loss (packets/sec)
Exponential	16	43.755	34.94	8.815
	96	139.81	115.425	24.385
	256	289.3133	223.9683	65.345
	512	615.2867	343.1383	272.1483
Normal	16	49.925	36.46333	13.46167
	96	142.0333	96.865	45.16833
	256	316.775	175.0217	141.7533
	512	515.9683	273.82	242.1483

Table 4.10: packet loss for two distribution at 10dB .

Figure 4.27 has four curves for average total transmit load and average total received throughput in two distributions for traffic at 10 dB, as we discuss before, the difference between transmitted and received is the loss in the network, from the curve for each distribution if the load increase, the throughput will be increase with lower rate, so the difference between the transmit and received will increase, and the loss will be increase, and the reason for this is the same reason that discuss in the first scenario; but the loss will increase higher than the loss for 8 dB, for example at packet size equal (16 bytes) for exponential distribution the packet loss is 8.815 packets compared with the packet size equal (512) packets the loss is 272.1483 packets, so that make large loss at high load depending on the previous explanation.

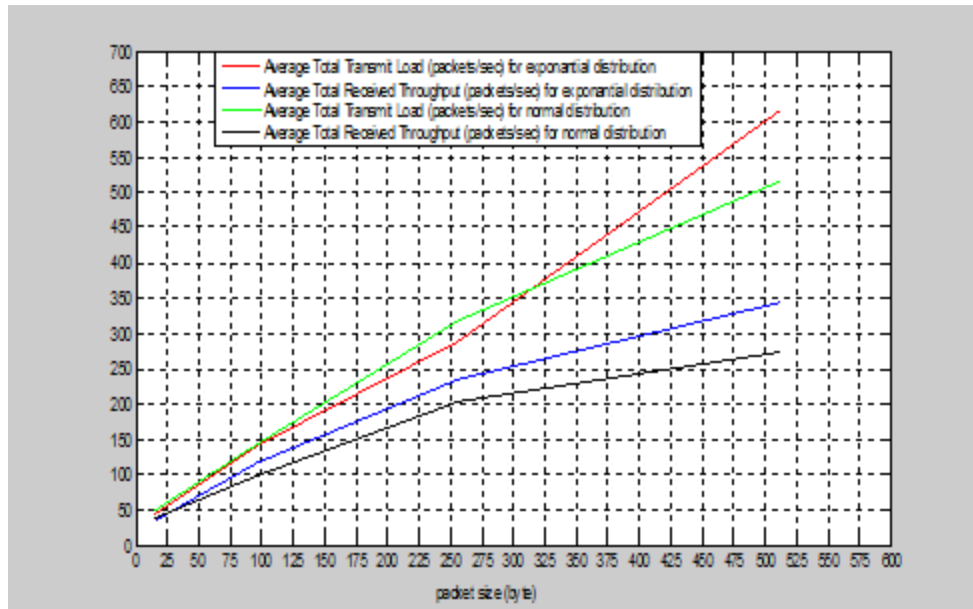


Figure 4.27: Average Total Transmit Load And Total Received Throughput For Normal And Distribution at 10dB .

4.5.1.6 Scenario Six "Threshold 12dB "

This scenario take 12 dB soft handover threshold , we take results from OPNET for uplink transmission power to explain the size of the soft handover window , Figure 4.17 , then we take the load and throughput to calculate the loss , table 4.11 .

The Figure 4.28 is uplink transmission power for mobile passing three node B's, B to C, and C to D this Figure simulated at 12 dB ,at begins the mobile start moving from the center of node B away to the node C, then the uplink transmission power from mobile will increase as the mobile away from node B, at time equal approximately 360 seconds; the window of soft handover between node B and node C will start , and will finished at point equal approximately 560s, at this point the mobile disconnect from node B and connect with node C , when the mobile continuously moving toward node C, the uplink transmission power continuously decrease until the mobile reached at the center of node C at time equal 700s, at this point the uplink transmission power is the minimum , after this time the mobile continuously moving away from node C and the uplink transmission power from mobile continuously increases until the mobile reach to the time equal approximately 880s , at this point the soft handover window will start and

finished at point equal 1320s ,at this point the mobile disconnect from node C and connect with node D, then the mobile completely moving toward node D , and the uplink transmission power continuously decreases until reach the center of node D at time equal 1400s , at the end the mobile complete the trajectory at point equal 1500s ,we note , at 12 dB the size of soft handover window _ in the figure explained between the two red lines_ is larger than the size in 10 dB and that tell us the probability is larger than the probability in 10 dB so the numbers of handover in the network here is more than the numbers in 10 dB .

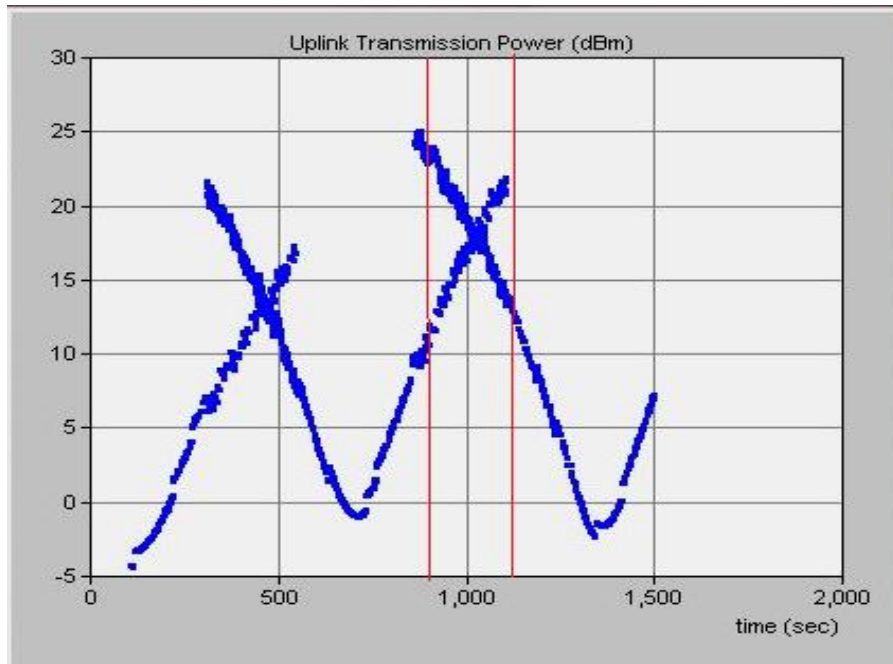


Figure 4.28: Uplink Transmission Power At 12dB .

Table 4.11 explain the average total transmit load (packets/sec) , the average total received throughput (packets/sec) , and the loss (packets /sec) at different packet size for exponential and normal distribution .

	packet size (byte)	Average Total Transmit Load (packets/sec)	Average Total Received Throughput (packets/sec)	Loss (packets/sec)
Exponential	16	45.76167	35.23333	10.52833
	96	146.7867	116.6633	30.12333
	256	313.28	229.6167	83.66333
	512	626.975	329.4767	297.4983
Normal	16	46.53667	32.83833	13.69833
	96	144.055	97.28	46.775
	256	319.6283	174.9817	144.6467
	512	604.955	308.6217	296.3333

Table 4.11: packet loss for two distribution at 12dB .

Figure 4.29 has four curves for average total transmit load and average total received throughput in two distributions for traffic at 12 dB, as we discuss before , the different between transmitted and received is the loss in the network , from the curve for each distribution if the load increase , the throughput will be increase with lower rate , so the difference between the transmit and received will increase , and the loss will be increase , and the reason for this is the same reason that discus in the first scenario ; but the loss will increase higher than the loss for 10 dB, for example at packet size equal (16 bytes) for exponential distribution the packet loss is 10.52833 packets compared with the packet size equal (512) packets the loss is 297.4983 packets , so that make large loss at high load depending on the previous explanation .

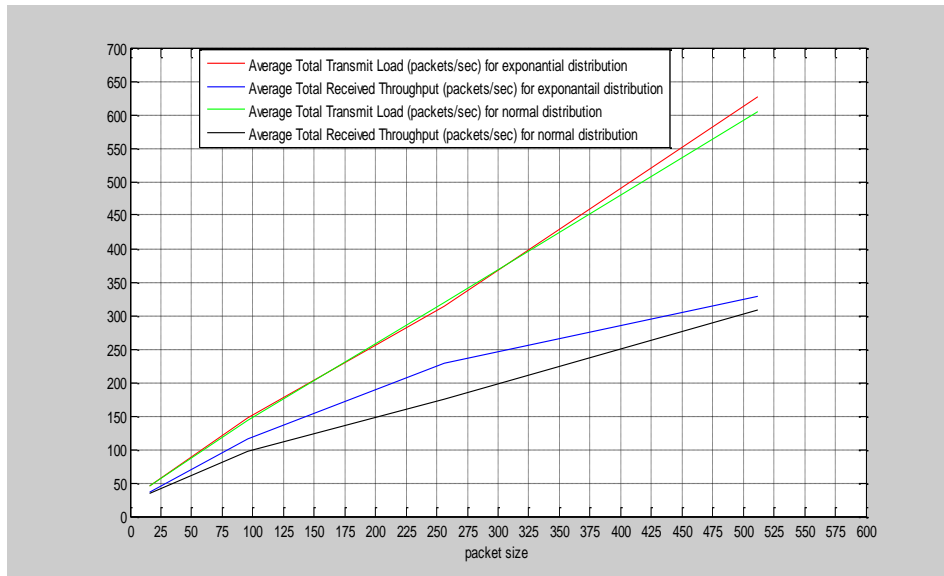


Figure 4.29: Average Total Transmit Load And Total Received Throughput For Normal And Distribution at 12 dB .

4.5.1.7 Scenario Seven "Threshold 14dB "

This scenario take 14 dB soft handover threshold , we take results from OPNET for uplink transmission power to explain the size of the soft handover window , Figure 4.19 , then we take the load and throughput to calculate the loss , see table 4.12 .

The Figure 4.30 is uplink transmission power for mobile passing three node B's, B to C, and C to D, this Figure simulated at 14 dB ,at begins the mobile start moving from the center of node B away to the node C, then the uplink transmission power from mobile will increase as the mobile away from node B, at time equal approximately 360 seconds; the window of soft handover between node B and node C will start , and will finished at point equal approximately 560s, at this point the mobile disconnect from node B and connect with node C , when the mobile continuously moving toward node C, the uplink transmission power continuously decrease until the mobile reached at the center of node C at time equal 700s, at this point the uplink transmission power is the minimum , after this time the mobile continuously moving away from node C and the uplink transmission power from mobile continuously increases until the mobile

reach to the time equal approximately 880s , at this point the soft handover window will start and finished at point equal 1320s ,at this point the mobile disconnect from node C and connect with node D, then the mobile completely moving toward node D , and the uplink transmission power continuously decreases until reach the center of node D at time equal 1400s , at the end the mobile complete the trajectory at point equal 1500s ,we note , at 14 dB the size of soft handover window _ in the figure explained between the two red lines_ is larger than the size in 12 dB and that tell us the probability is larger than the probability in 12 dB so the numbers of handover in the network here is more than the numbers in 12 dB .

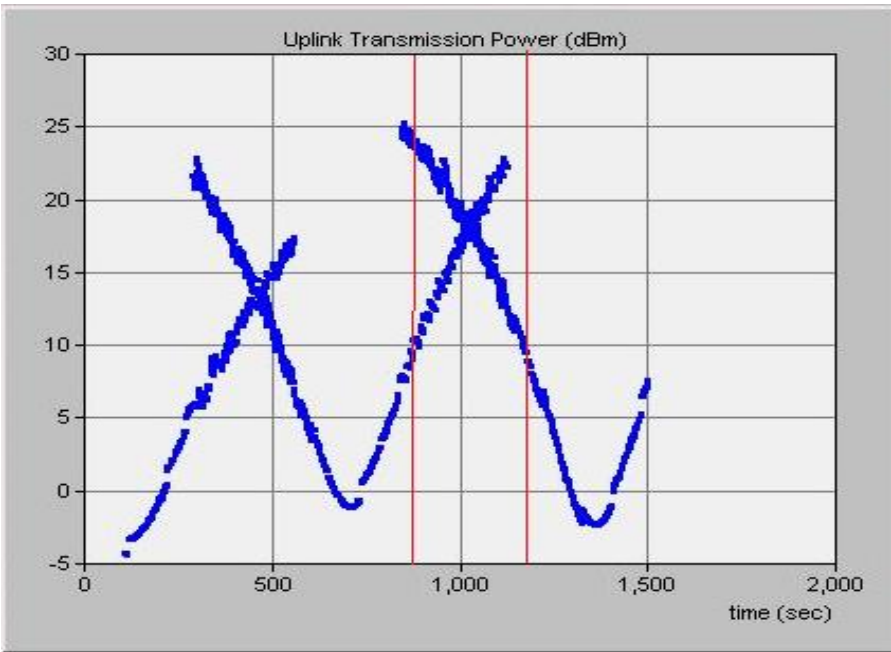


Figure 4.30: Uplink Transmission Power At 14dB .

Table 4.12 explain the average total transmit load (packets/sec) , the average total received throughput (packets/sec) , and the loss (packets /sec) at different packet size for exponential and normal distribution .

	packet size (byte)	Average Total Transmit Load (packets/sec)	Average Total Received Throughput (packets/sec)	Loss (packets/sec)
Exponential	16	45.76167	35.23333	10.52833
	96	146.7867	116.6633	30.12333
	256	313.28	229.6167	83.66333
	512	626.975	329.4767	297.4983
Normal	16	48.78667	33.84333	14.94333
	96	144.5567	97.83833	46.71833
	256	309.0033	160.485	148.5183
	512	615.9067	300.8467	315.06

Table 4.12: packet loss for two distribution at 14dB .

Figure 4.31 has four curves for average total transmit load and average total received throughput in two distributions for traffic at 14dB, as we discuss before, the different between transmitted and received is the loss in the network, from the curve for each distribution if the load increase, the throughput will be increase with lower rate, so the difference between the transmit and received will increase, and the loss will be increase, and the reason for this is the same reason that discuss in the first scenario; but the loss will increase higher than the loss for 12 dB, for example at packet size equal (16 bytes) for exponential distribution the packet loss is 10.52833 packets compared with the packet size equal (512) packets the loss is 297.4983 packets, so that make large loss at high load depending on the previous explanation.

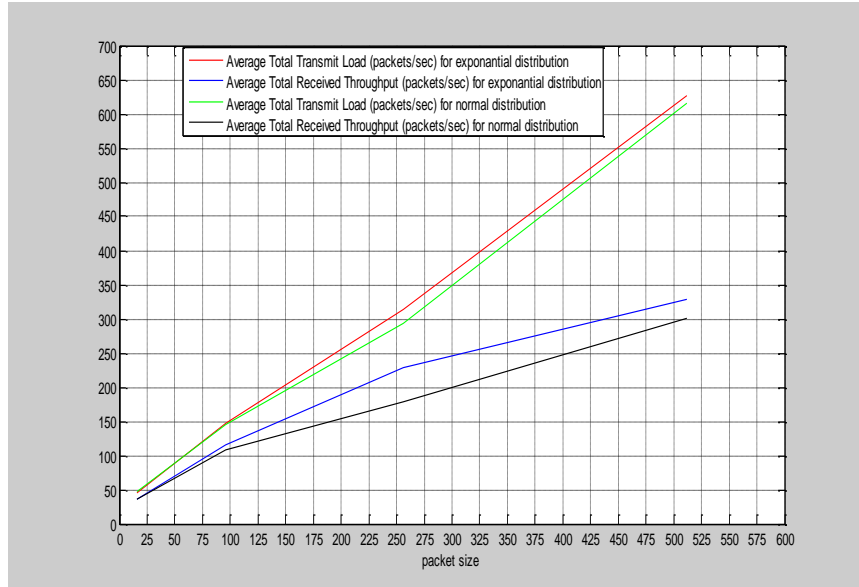


Figure 4.31: Average Total Transmit Load And Total Received Throughput For Normal And Distribution at 14 dB .

4.5.2 End to End delay

The second term we discuss is End to End delay , this is the other factors that determine the quality of the network , is the good case the delay must be few of millisecond , in this scenarios we will make simulation for the modeled network at different threshold and different load .

So this will give us an overview about The behavior of any UMTS network at different threshold load , the table 4.13 give the result for twenty scenario for four load and five threshold .

Load (Byte)	16 byte	96 byte	256 byte	512 byte
End-to-End delay (s) 2 dB	0.45691	0.56418	0.716587	1.092834
End-to-End delay (s) 4 dB	0.430543	0.56418	0.71336	1.030024
End-to-End delay (s) 6 dB	0.430225	0.446722	0.696912	1.001707
End-to-End delay (s) 8 dB	0.430225	0.448822	0.67252	1.008397
End-to-End delay (s) 12 dB	0.25366	0.386031	0.616154	0.958867

Table 4.13 : End-to-End delay for different threshold with different load .

Figure 4.32 is the curves of the end to end delay at different threshold for every curve, as we see at any threshold the delay will increase with increasing the load, and that for many reason, first one is queuing if we send data than the presses can deal with so that causes some of the data will wait. the second reason is the time that the processor take at anywhere in the UMTS network for example at the node B the data will take time before sending to RNC and so that for all station before reach the receiver.

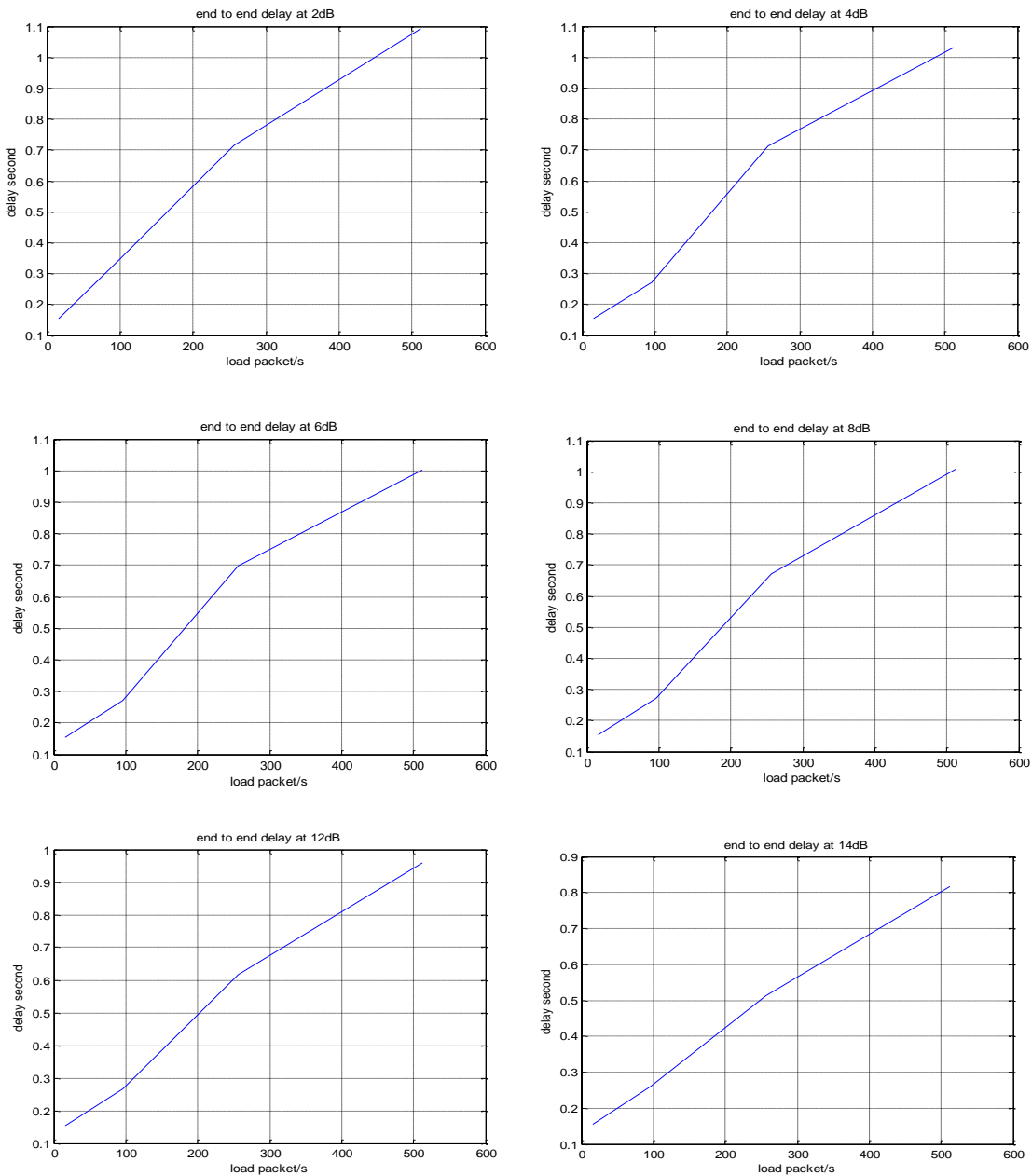


Figure 4.32 : End To End delay at different threshold

Chapter Five

5

Conclusions and Future Work

5.1 Conclusions On The Experiments' Results

5.2 Conclusion Remark

5.3 Future work

5.1 Conclusions On The Experiments' Results

- **The relation Between Throughput and Loss with Soft Handover Threshold**

The main objective in this project to find the relation between threshold and QOS , the first parameter in QOS is the throughput , Figure (5.1) represent the throughput Figure shows the result of the previous seven scenarios , it has seven curves , each curve has one threshold with different load .

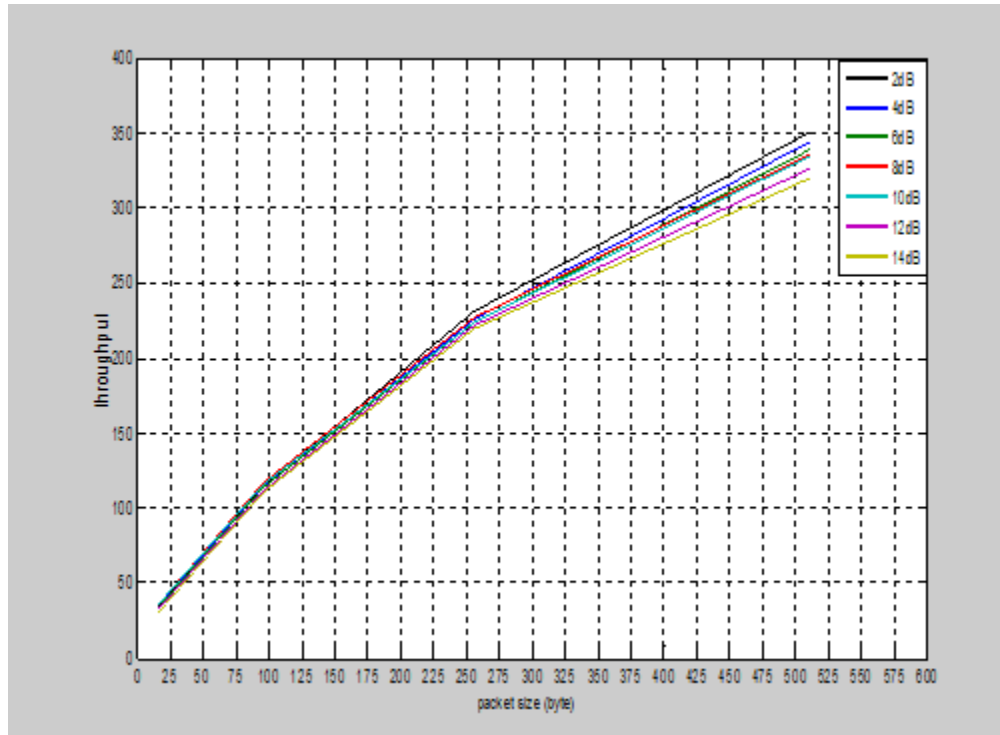


Figure 5.1 : average throughput at different threshold

As the previous shows when the threshold increase the throughput will decrease , the reason of that is at low threshold there is few number of soft handover , so there is no extra connection for exulting the handover algorithm , so we harness the network for more throughput ; and vice versa for high threshold .

And as we explain in previous chapters if throughput increase the loss will decrease the next two figures (5.2) and (5.3) represent the loss in normal and exponential distribution. We know that at low threshold the mobile will remain connected with the node-B at high distance compared with high threshold , so the mobile remains connected with the node-B for short

distance under high threshold, this leads to increase the soft handover probability which increase the number of soft handover in the network, so there is overhead will became on the network, and then increase the loss in the network

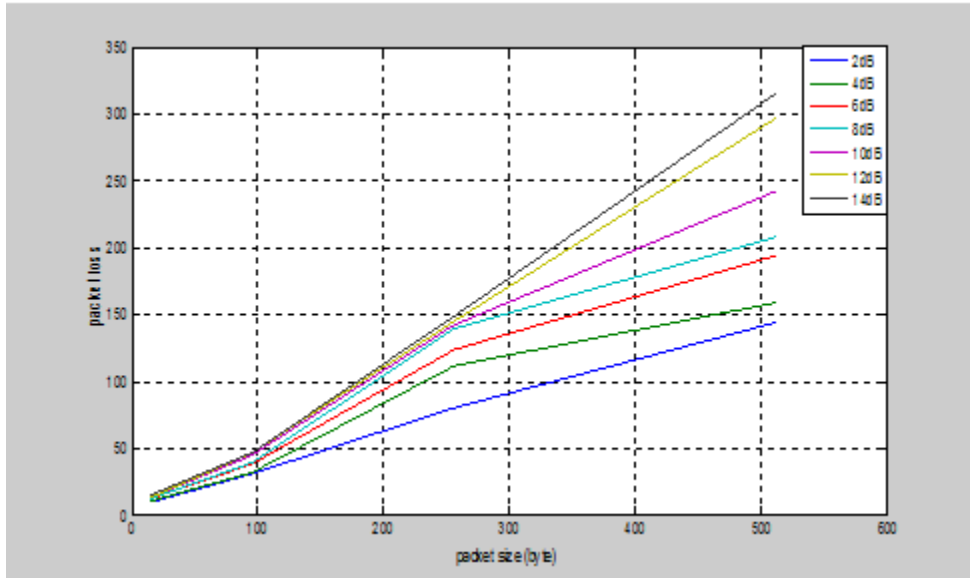


Figure 5.2: average packet loss at different threshold (normal distribution) .

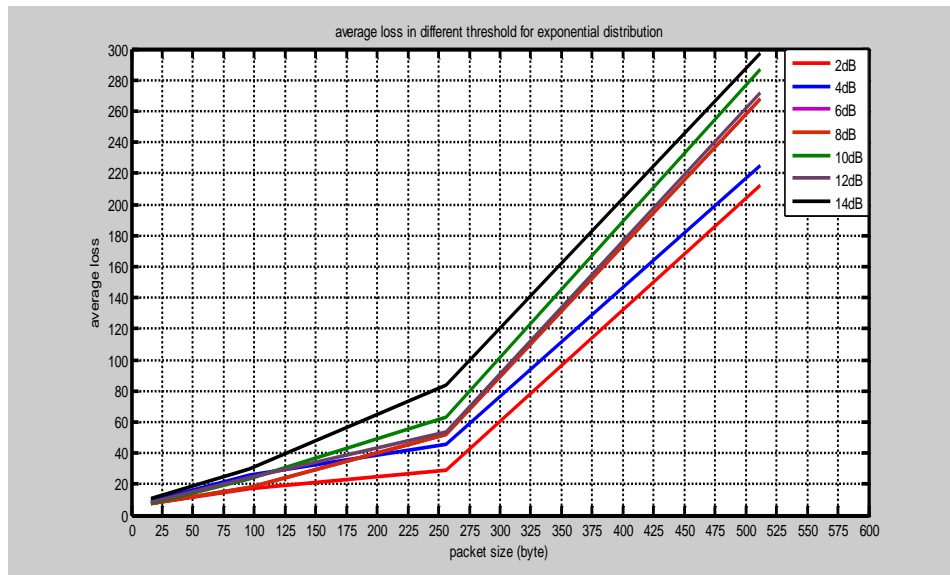


Figure 5.3 : average packet loss at different threshold (exponential distribution).

Depending on this result , the packet loss is high at high threshold, for example : from Figure 5.3 , at packet size equal 250 Byte , the loss equal 30 packets at 2 dB , but the packet loss for 4 dB at the same packet size is 60 packets .

We note that the loss at 4 dB is higher than the loss for 2 dB and this is normal ; because at threshold 4 dB the soft handover probability is more than it at 2 dB , so the number of handover at 4 dB threshold higher than it at 2 dB .

At threshold 14 dB , the packet loss at the same packet size is 80 packets , this value is very high compared with 2 dB and 4 dB ; at 14 dB the soft handover probability is much more than it at 2 dB and 4 dB , so the number of handover at 14 dB threshold much higher than it at 2 dB and 4 dB .

In Figure 5.4 below represent two mobiles connect with low and high threshold , The right side of the Figure represent mobile connect with high soft handover threshold and the left side represent mobile connect with low soft handover threshold , at the case for mobile moving from node 1 to node 2 , the mobile will begin connect with node 2 at distance higher than the distance for left side of the Figure at low threshold , this makes it possible to use a connection with lower quality , hence the loss will drop because the noise will be high and this is the main reason for this relation .

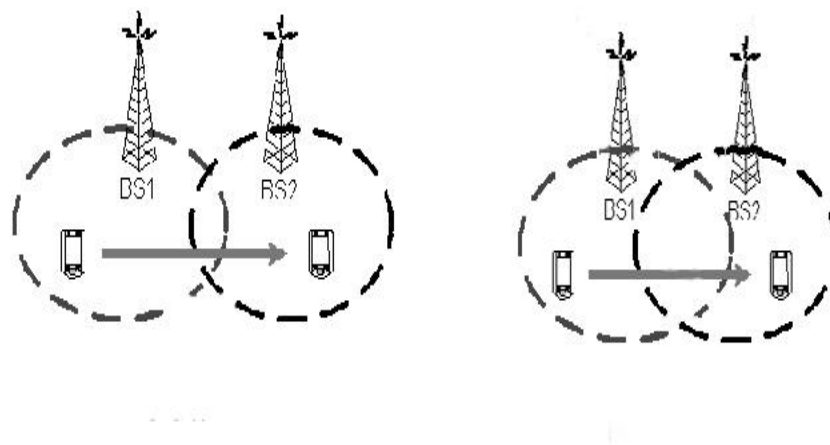


Figure 5.4: low and high threshold overlap area

There are several other reasons like , at high threshold the soft handover probability will increase this lead to increase number of soft handover in the network and this effect on two parameters , the first one high number of handover lead more connection establish in the system so it increase the overhead in the network , so some of packet will drops by buffer size limitation (leaky bucket protocol) .

The probability a user is in soft handover is very important parameter must be taken into account for radio network planning ; because an excessive amount of soft handover in the network leads to overhead in the system on the network and increase the additional hardware resources required for implementation of soft handover , so increase the soft handover probability leads to increase the number of soft handover in the network , and thus it is important to be able to set system parameters to appropriate level resulting in a number of handover that optimized network performance .

Depending on our result , when increase the threshold for soft handover , the soft handover probability will increase and this leads to increase the number of soft handover and consuming additional resources and causing interference , and this leads to increase the loss in the network .

“ so the final result is the loss will be at its minimal value when the threshold is at its minimal value also , consequently the throughput will be at its possible maximum value ” .

- **The Relation Between End To End Delay And Soft Handover Threshold**

Figure 5.5 below shows the end to end delay between the sender and receiver at different threshold under different traffic load , form this figure we note when increase the threshold for soft handover the end to end delay will decrease , for example at packet size equal 200 bytes the delay is 0.52 seconds at 12 dB threshold , but for 2 dB threshold the delay is 0.67 seconds , we note from figure ; for low threshold the delay is higher than it for high threshold , the reason for that at low threshold there is high throughput and that make queuing according the buffer size limitation so that make high delay at low threshold , and at low threshold the mobile will remains connected with node-B for time and distance higher than it at higher threshold before began executing the handover algorithm , so this distance will increase the delay between the

mobile and node-B , this leads to increase the delay for sending information between the user's and node-B's .

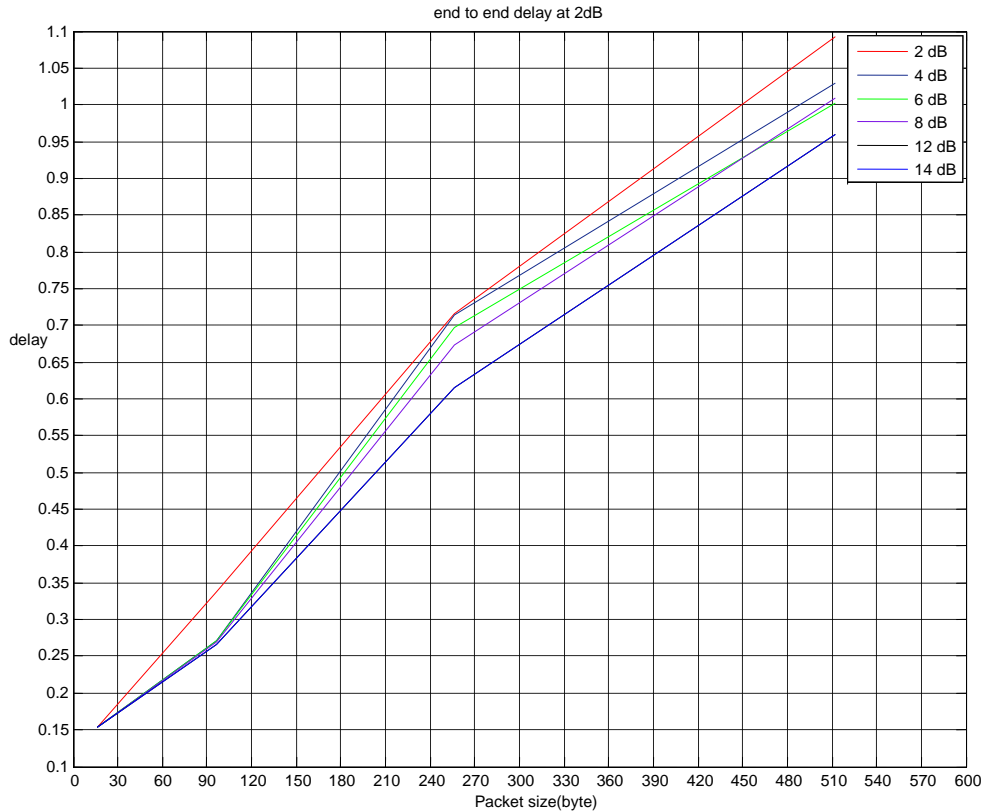


Figure 5.5: End To End Delay At Different Threshold

5.2 Conclusion Remark

In this work, the proposed design and implementation were used to enhance the performance of the UMTS network , we used some information from JAWWAL company to represent the performance of Wadi AL-harea network , in our project mainly focus on enhance the quality of service parameters (packet loss , end to end delay), by comparing between different scenarios with different threshold , each threshold has different packet size (different traffic load) .

By comparing between this scenario we have reached to some results :

1. The Relation between the packet loss and threshold :

The number of packet loss is directly proportional with the soft handover threshold , as we increase the soft handover threshold , the number of packet loss will increase , because the soft handover probability will increase and this leads to increase the number of soft handover in the network , so this lead to increase the additional hardware resources require for implementation of soft handover in the network ,this leads to make overhead on the network and increase the number of packet loss .

2. Relation between end to end delay and threshold :

We know that at lower threshold, the mobile will remain connected with the node –B at distance higher than it at higher threshold , this make it possible to use a connection with lower quality because the noise is very high , then the signal to noise ratio will decrease , in addition to that the data take time to reach to the node-B at lower threshold compared with the higher threshold , depending on this reason , the delay will high at low threshold and it is minimum at high threshold .

5.3 Future work

The quality of service contains many parameters , we study the relation between two of them (loss and delay) with threshold , there is many parameters we didn't study it such as : errors , latency , jitter , and out-of-order delivery .

There is many important parameters we must know the relation between it and the soft handover threshold such as coverage area , capacity , and data rate .

We advise the researchers to study the last mentioned parameters and compare the result with real data for full network of mobile company such as JAWWAL and WATANIYA , to increase the credibility of the researches .

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Appendices

- Packet size 16 byte “ exponential distribution “

time (sec)	2 dB		4 dB		6 dB		8 dB		10 dB		12 dB		14 dB	
	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)
100	16.56	64.55	7.174	66.14	20.21	68.56	29.05	60.69	39.86	99.42	40.67	72.88	72.75	71.23
110	13.15	18.91	22.76	31.19	14.26	27.34	30.76	39.17	26.77	44.89	22.73	31.13	24.92	38.45
120	38.19	39.59	33.84	44.17	39.2	50.76	25.66	32.32	32.99	44	34.79	46.17	36.29	52.44
130	35.34	79.72	45.44	89.29	35.12	67.84	36.74	51.27	32.15	71.31	32.65	61.53	38.46	50.4
140	37.96	44.41	34.35	45.93	37.61	39.59	47.86	57.01	34.15	41.95	30.77	35.26	42.42	53.9
150	70.52	78.3	36.63	45.64	31.85	31.83	48.96	55.8	35.22	41.73	34.26	48.51	42	55.28
160	50.25	88.08	49.05	67.57	37.95	67.84	37.13	45.18	34.97	50.03	34.83	65.68	46.64	50.98
170	33.33	38.86	40.69	53.32	39.19	47.02	33.24	40.46	35.23	46.7	44.59	61.08	36.42	50.89
180	31.12	40.82	44.47	59.89	40.87	43.01	44.58	52.81	42.03	54.94	30.77	48.44	29.39	50.06
190	38.35	78.28	34.29	60.4	37.29	58.6	49.23	59.93	39.56	61.62	39.41	72.38	40.73	49.77
200	50.25	52.36	52.39	63.97	53.75	75.38	42.04	57.41	57.04	65.01	48.54	74.04	56.67	78.42
210	43.46	43.85	54.93	70.16	55.72	62.84	48.16	63.09	59.7	78.08	46.07	67.79	41.76	56.48
220	36.71	64.17	38.72	58.37	30.56	59.82	41.88	44.85	41.35	60.53	33.43	53.26	33.81	42.89
230	40.18	54.95	33.99	43.78	32.64	37.59	40.36	44.62	34.25	39.25	42.36	51.54	34.13	42.87
240	29.33	30.36	37.25	52.47	33.11	40.39	47.82	51.61	45.96	52.01	25.3	38.98	44.47	60.29
250	42.06	58.89	39.03	49.57	35.71	43.42	25.75	36.77	35.42	46.07	31.96	38.48	34.96	42.57
260	36.74	38.35	45.23	50.51	31.26	34.01	29.24	34.92	26.15	32.33	30.76	41.4	41.84	49
270	36.15	40.23	30.56	45.04	30.9	35.72	48.45	51.8	43.19	54.36	28.55	42.71	42.74	54.95
280	40.52	54.47	35.15	43.71	30.2	36.2	40.01	49.65	31.22	44.66	39.64	40.82	39.95	46.85
290	27.21	30.84	34.92	40.04	41.45	39.56	50.03	53.74	49.48	57.48	32.78	42.83	46.51	57.66
300	35.5	41.73	43.17	62.47	34.15	47.88	55.87	79.42	42.19	56.35	36.63	57.4	56.68	79.23
310	42.98	54.39	39.08	45.81	29.7	34.43	45.57	54.94	30.6	42.07	43.5	55.82	47.99	56.14
320	38.68	39.67	46.11	60.49	38.62	38.75	34.74	37.51	30.26	37.12	33.68	46.22	36.28	46.96
330	35.75	34.99	44.84	48.47	30.52	37.08	33.01	41.12	32.24	38.53	37.28	43.45	35.86	43.12
340	35.99	48.82	35.07	46.86	30.66	35.66	42.19	49.32	40.48	49.36	35.54	42.47	39.02	45.52
350	41.55	39.56	43.29	47.08	32.19	35.02	32.62	38.26	40.65	44.64	32.03	38.12	34.98	43.04
360	36.62	38.94	34.21	34.59	34.78	40.51	29.77	33.43	32.88	36.34	33.31	41.19	31.13	37.7
370	39.54	50.82	43.2	48.91	37.35	42.43	36.01	39.39	39.55	43.12	32.07	38.77	40.71	45.09
380	36.47	36.78	37.47	43.28	45.53	52.38	48.29	54.23	38.88	43.98	32.8	43.33	39.48	46.3

390	35.08	35.77	39.48	42.94	39.28	48.22	56.54	62.86	36.08	42	32.39	38.84	38.7	47.32
400	49.7	51.03	33.46	38.89	35.23	39.68	41.9	46.1	42.32	46.33	37.71	45.59	43.87	49.15
410	33.81	40.63	41.68	46.19	28.6	31.22	38.04	43.81	33.77	35.17	32.51	42.6	39.1	47.47
420	33.77	39.76	39.54	45.9	35.05	41.08	40.97	46.1	31.97	39.33	31.48	35.7	38.79	53.91
430	47.61	53.44	45.46	49.25	40.39	44.01	37.66	39.6	38.3	43.64	27.8	31.14	42.21	56.36
440	29.96	33.75	45.37	51.01	38.45	45.76	45.47	48.66	42.22	52.89	33.25	46.61	39.01	51.24
450	40.94	43.12	39.02	43.74	45.36	53.92	44.88	43.94	40.22	52.09	41.36	54.11	45.92	53.87
460	42.81	46.9	41.92	48.49	39.55	43.41	46.28	49.61	38.22	37.35	40.89	47.11	33.56	40.4
470	41.11	38.66	31.46	37.9	37.92	42.93	40.34	45.36	43.81	45.13	31.02	46.54	45.61	51.16
480	38.8	39.17	46.59	51.18	32.31	33.08	36.66	39.85	37.45	42.32	31.07	38.67	38.49	43.68
490	35.39	39.61	37.53	42.91	27.58	34.36	42.27	45.27	38.38	43.95	39.03	44.56	34.35	41.13
500	41.91	47.23	48.64	51.98	35.51	41.47	42.9	49.14	40.07	45.51	35.94	38.43	36.68	50.36
510	35.18	36.34	35.22	40.37	30.11	37.33	34.46	39.27	34.25	39.94	32.54	45.2	37.52	49.16
520	33.01	37.54	26.67	36.52	39.09	45.05	38.9	44.48	42.01	50.78	40.79	53.09	51.5	58.06
530	41.85	44.67	52.68	51.86	38.19	47.61	34.56	40.64	47.59	52.78	33.54	44.13	40.17	53.94
540	43.27	41.88	34.76	39.49	32.54	38.88	38	42.16	40.47	46.57	31.42	42.34	45.47	57.1
550	40.89	38.98	36.11	41.44	42.09	45.64	44.31	45.56	41.02	44.47	37.82	48.14	36.2	45.14
560	37.96	43.23	36.76	40.1	34.77	40.11	43.25	48.12	45.24	51.48	41.7	58.5	34.26	47.64
570	45.44	45.44	48.67	51.53	30.28	33.17	44.04	46.19	31.49	36.84	41.54	47.24	46.08	52.95
580	35.24	36.45	32.54	37.82	30.79	35.7	40.34	41.4	33.56	39.94	35.73	42.24	39.04	46.72
590	42.66	43.99	36.11	43.04	32.14	35.07	42.69	43.07	43.35	43.71	40.14	54.49	43.02	51.54
600	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

• Packet size 96 byte “ exponential distribution “

time (sec)	2 dB		4 dB		6 dB		8 dB		10 dB		12 dB		14 dB	
	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)
100	16.2656	64.2328	7.10809	66.0921	20.1877	68.8334	29.3611	61.1338	39.8393	99.364	40.8119	73.4169	71.4083	81.5758
110	46.1275	85.9366	92.4559	136.357	19.9154	103.257	48.212	97.051	47.4133	107.816	64.7447	103.574	116.106	171.344
120	388.71	293.185	123.082	134.898	141.971	171.124	183.47	173.79	141.816	149.051	92.3768	128.411	147.659	210.125
130	154.03	227.759	71.855	118.441	128.51	149.001	109.369	168.155	94.3396	170.407	133.006	171.135	143.619	162.859
140	136.548	144.876	106.008	148.661	131.071	149.033	168.843	233.183	160.68	159.282	129.997	159.719	135.867	170.359
150	119.961	141.237	109.55	161.051	149.21	179.533	142.787	160.697	140.806	170.035	120.221	139.78	154.449	217.378
160	163.11	219.019	128.799	185.983	141.904	171.217	121.192	153.11	107.236	171.231	116.241	184.527	158.41	176.355
170	140.14	168.7	142.248	165.901	113.154	125.459	117.829	129.698	92.3346	138.076	105.083	138.267	167.276	232.591
180	166.238	155.993	154.472	202.319	141.178	132.51	152.7	192.338	106.907	136.63	116.797	166.664	100.16	144.495
190	114.719	159.699	135.138	163.075	139.666	171.16	124.31	162.223	115.736	145.155	107.595	149.05	143.232	169.034
200	133.752	171.255	155.341	178.318	132.681	155.475	174.205	205.594	143.557	158.61	148.445	165.859	156.377	233.492
210	170.943	169.767	168.189	209.954	122.995	147.536	156.609	191.108	148.725	180.989	98.971	134.988	169.598	245.353
220	141.335	191.12	129.158	173.525	146.371	199.16	129.279	154.787	152.856	188.824	80.8454	126.478	122.676	171.057
230	111.443	112.65	136.325	175.467	123.952	157.694	165.704	225.066	120.299	150.843	109.672	144.2	122.689	159.211
240	133.512	155.584	120.475	146.815	173.972	169.502	166.142	198.113	89.1911	96.3667	121.529	154.344	141.78	192.36
250	127.789	146.036	102.588	124.018	132.596	139.834	96.9335	133.631	90.4191	143.183	83.5425	115.594	89.2151	127.765
260	156.211	165.256	128.767	162.825	124.651	158.891	105.5	134.045	120.717	177.992	110.784	121.939	131.497	169.497
270	73.0863	185.399	110.671	143.725	112.057	153.667	132.779	186.193	169.284	225.01	119.99	139.219	138.246	176.329
280	98.8684	112.687	173.327	195.876	120.007	118.007	109.407	133.571	147.787	191.275	131.213	168.029	110.796	131.099
290	185.853	176.985	136.931	146.118	142.112	162.379	115.004	121.345	163.278	185.588	105.007	134.418	154.618	178.033
300	157.38	190.473	147.857	187.378	146.832	161.551	138.929	174.869	178.697	195.636	124.648	151.048	165.545	210.828
310	119.911	151.001	138.909	177.326	95.486	119.338	163.492	194.147	136.268	143.843	104.049	151.44	122.815	139.097
320	152.811	159.052	135.701	171.611	144.655	155.644	172.476	188.703	122.486	153.844	115.109	158.715	139.845	156.853
330	127.597	142.784	140.052	142.749	124.954	158.163	141.418	158.978	139.887	174.379	126.162	131.307	124.826	164.116
340	136.187	166.671	155.865	193.782	128.78	134.868	142.574	149.63	179.078	194.125	127.169	171.799	107.035	167.592
350	134.037	143.692	119.186	145.677	142.247	168.203	134.83	149.32	147.713	181.144	113.63	115.592	166.283	161.992
360	136.662	132.676	138.469	167.478	147.609	164.701	133.156	178.492	158.448	187.156	116.702	146.16	128.023	141.272
370	123.455	136.209	148.528	166.425	118.239	137.914	121.248	140.992	109.751	150.525	148.18	177.3	133.412	166.918
380	147.555	175.356	125.691	148.566	140.321	139.493	137.44	150.847	128.171	162.01	113.719	152.809	101.307	135.062
390	138.954	160.945	104.231	140.24	140.66	135.886	148.222	149.464	146.071	159.606	124.237	167.764	131.982	154.807
400	118.33	133.719	155.151	198.623	129.496	152.314	140.458	148.28	117.512	130.552	144.378	181.909	144.207	157.54
410	120.56	117.791	119.107	164.319	130.907	136.286	129.252	166.076	207.837	222.929	130.714	152.721	144.348	192.227

420	132.856	143.226	137.626	164.25	180.055	181.825	136.271	178.024	146.539	163.61	99.4378	125.816	138.592	185.244
430	153.115	146.516	142.73	189.52	151.927	166.457	149.295	164.417	127.875	154.828	120.958	131.929	147.055	157.48
440	132.783	141.586	102.765	125.41	140.421	145.168	155.751	159.296	114.224	134.649	103.682	121.428	114.224	165.601
450	174.76	168.544	134.429	153.483	130.955	128.796	140.381	184.267	116.889	141.724	96.316	116.89	134.493	151.515
460	104.993	115.652	136.757	143.021	148.707	143.991	114.858	115.443	108.256	135.627	96.6467	122.086	188.967	231.25
470	111.278	140.567	162.036	191.066	132.04	121.46	145.451	152.551	108.014	121.986	85.0591	115.011	115.882	137.842
480	160.404	152.835	128.933	158.69	155.58	159.544	88.4518	114.468	140.319	176.191	121.998	151.254	153.194	180.303
490	120.258	136.434	137.959	136.892	121.198	149.479	121.096	167.112	157.625	215.283	98.2587	105.933	114.739	147.896
500	147.09	160.516	90.7566	130.531	124.736	115.326	148.572	183.757	83.6002	129.049	160.98	175.549	145.699	163.568
510	113.479	133.58	125.777	140.91	126.895	168.774	175.845	198.042	152.354	169.09	118.989	157.085	146.638	168.186
520	155.065	207.239	125.629	139.71	131.886	147.624	146.376	167.103	172.004	198.471	98.0923	155.139	140.3	179.67
530	155.576	158.533	140.076	180.45	128.962	140.962	129.507	136.249	165.263	199.289	100.166	110.722	108.903	134.837
540	148.723	168.789	100.776	140.361	133.619	132.662	147.579	179.055	138.785	173.879	110.504	164.898	147.587	202.247
550	168.951	188.183	145.01	151.731	168.801	196.549	142.246	175.963	151.149	162.227	154.737	162.505	154.754	173.596
560	181.288	187.533	147.929	188.314	116.825	134.374	168.956	196.174	140.969	164.635	73.5485	109.083	113.232	129.666
570	143.848	139.557	141.813	174.295	142.418	147.431	114.872	121.096	142.885	178.154	154.763	168.118	116.808	133.63
580	145.604	140.061	131.276	143.786	103.789	127.247	111.639	120.083	114.423	141.371	122.212	154.091	128.203	173.051
590	164.548	156.625	139.142	171.106	168.154	186.695	104.37	132.291	153.81	172.728	108.705	153.377	174.303	183.971
600	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

- Packet size 256 byte “ exponential distribution “

time (sec)	2 dB		4 dB		6 dB		8 dB		10 dB		12 dB		14 dB	
	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)
100	16.63	64.64	7.154	66.12	20.21	68.9	29.36	61	40.02	99.65	40.73	73.05	71.3	89.11
110	114.6	230.1	50.86	169.8	179.4	298.9	106.9	205.1	70.68	210.5	176.2	246	255.8	337.5
120	302.6	346	321.8	350.6	319.5	354.2	265.6	326.5	246.5	357.7	220.4	375.7	254.9	331.7
130	200.4	367	175.6	355.7	263.8	357.9	176.4	281.1	202.1	351.4	243.3	318.9	263.7	344.4
140	285.6	256.4	207.7	282.7	237.7	295.9	183.6	263.4	245.9	358.2	260.2	375.3	299.1	368.9
150	315.8	286.8	225.3	298.8	257.9	412.7	301.4	342	265.2	307.6	297.6	351.7	336.7	463.6
160	305.9	341.3	291.1	364.9	291.1	448.1	256.3	292.1	229.9	336.6	226.8	329.5	298.4	384
170	295.7	313.9	273	366.2	227	284.9	306.3	303.1	310.6	374.3	218.1	255.6	219.1	328.6
180	241.3	261.1	284.6	404.5	266.8	329.4	225.8	306.7	139	265.7	281.5	417.8	228.4	407
190	276.8	290.7	238.1	351.5	266.7	315.9	207.4	267.6	267.6	278.7	286.7	291.6	339.7	372.8
200	244.4	263.9	253.9	326.4	288.6	324.7	300.8	307.2	302.8	408.3	255.8	359.7	312.4	398.7
210	307.2	345.2	275.9	306.6	180.5	313.5	353.1	515.6	237.8	318.8	202.7	274.2	269.6	347.3
220	334	411.5	254	338.2	245.6	339.9	223.4	256.8	285.5	401.6	155.5	217.4	295.9	383.9
230	231.7	410.9	283.3	309.1	353.8	410	252.8	364.3	242.9	315.2	255.2	349.2	253.3	473.3
240	256	266.5	206	392	266.3	344.3	242.5	301.9	245.4	240.2	308.4	443.1	255.3	306.4
250	275.3	320.7	230.7	281.4	226.9	284.9	285.9	344	329.2	430.2	187	316.2	214	409.7
260	255.8	263.9	209.8	301.3	249.4	313.6	249.3	404.6	220.4	263.7	278.9	368.1	274.9	315.4
270	56.53	280.6	95.34	316.7	118.3	321.1	153.3	373	347.2	448.4	209.5	268.1	300	409.9
280	167.6	365.8	310.8	353.3	97.09	295	194.6	335.5	322.2	299.3	152.2	253.3	355.6	417.6
290	89.71	313.5	194.9	308.5	357.2	429.5	241.2	358.4	347.5	347.5	266.3	374.7	378.6	465.6
300	180.4	345.1	313.1	351	282.5	326.8	187.1	294.1	317.9	324.8	237.8	307.4	268.8	319.5
310	70.99	224.1	280.1	300.1	302.6	353.8	218.6	363.7	221.4	278.5	190.5	292.3	299.1	325.7
320	76.15	319.5	322.5	388.9	274.3	319.1	198.3	399.5	317.4	386.6	256.4	331.5	258.1	364.1
330	71.5	237.7	248.6	312.4	233.2	311.3	181.7	314.2	319.7	446.7	131.5	332.6	251.1	362.8
340	149.9	332.7	215.7	278.9	299.7	324.8	205.8	328.8	332.8	397.7	269.7	370.4	286.3	414.9
350	56.4	186.9	214.2	251.9	330.5	368.8	208.5	320.5	328.6	356.1	315.3	379.7	220.3	308
360	71.5	277.7	286.9	348.3	252.4	282.9	177.7	284.2	309.3	397.2	216.1	287	270.4	316.1
370	170	348.5	191.3	223.5	324.4	364.5	208.6	368.2	236.7	267.9	186.2	227.7	230.8	351.4
380	161.4	330.6	208.6	309.3	331.1	376.7	236.8	323.6	333.1	330.9	214.6	267.9	321.1	386.4
390	183.7	357.1	221.1	310.3	329.5	426.7	241.9	327.8	303.6	363.2	196.5	298	310.2	340.9
400	214.2	332.4	226.5	259.7	340.3	356.1	206.1	322.9	128.5	209	184.2	245.1	338.2	394.4
410	181.4	436.8	248.4	360.9	328.1	284.1	212.8	320.6	319.3	383.7	227.2	311.7	270.3	396.1

420	112.6	337.2	274.1	316.1	244.4	276.5	223.5	305.3	331.7	380.8	230.3	312.7	282.9	416.4
430	134.5	298.3	269.4	363.7	268.3	293.3	153.7	312.1	329.6	384	230.3	341.8	303.4	390.3
440	211.9	309.9	214.2	329.9	239.1	366.3	219.8	361.7	309.4	376.4	235.8	364.2	338	458.8
450	194.1	426.3	298	435.5	390.4	372.1	193.9	439.4	236.8	278.9	291	363.6	295.5	453.9
460	185.4	332.4	232.5	310.2	257.8	267.1	212.8	315.9	204.8	336.8	317.2	393.3	249.5	340.2
470	151.6	329.5	247	373.9	271.2	363.3	196.4	286.3	330.1	401.8	224.3	296.9	238.7	273.3
480	216.3	356.2	239.3	298.1	242.4	273.7	177.3	286.5	315	330.3	308.3	330.6	307.6	358.7
490	125.2	348.1	283.5	348	310.5	338.7	167.9	362.7	315.7	339	269.6	356.6	258.8	327.9
500	189.1	364.7	346.5	414.5	285.7	396.7	160.2	307	279.8	366.3	199.2	273.5	257.6	353.4
510	183.4	391	201.2	208	274.6	329.2	237.7	327.7	293.7	327.8	236	326.5	259.9	349.4
520	167.9	342	280	346.2	238.8	257.5	237.8	392.1	323.2	304.2	162.1	305.6	283.2	345.2
530	231	302.2	250.6	313.9	287.4	316.6	296.1	375.4	288.5	325.6	311.4	369.8	244.8	333.8
540	96.93	314.5	251.2	327.1	235	260.5	238.1	338.5	329.7	308	239.5	326.7	305.6	408.4
550	167	420.7	162.6	237	302.7	358.5	280.4	396.8	205.6	314.6	242.8	307.3	270.7	304.4
560	130.8	353.7	251.8	313	241.7	250.2	245.9	380.3	321.4	360.3	270.3	328.3	259.2	386.9
570	144.8	371.3	310.2	336.7	358.4	376.9	224.8	319.6	302.7	335	240.1	321.1	286.9	408
580	120.7	325.3	271.7	324.2	243.4	320.1	246.8	426.6	341.7	386.5	238.2	321.6	327.3	426.6
590	194.9	323.8	296.7	373.7	226.2	345.4	218.3	351.9	390	446.9	227.2	322.6	320.8	430.5
600	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

- Packet size 512 byte “ exponential distribution “

time (sec)	2 dB		4 dB		6 dB		8 dB		10 dB		12 dB		14 dB	
	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)
100	26.53	55.19	7.128	66.11	41.01	68.38	24.85	59.5	46.82	73.49	40.96	73.41	71.32	89.74
110	66.73	385.7	84.13	359.2	100.6	403.1	88.49	369.9	268.5	609.7	253.4	500.8	374.9	728.5
120	539.8	671.5	391.4	599.4	446.4	695.5	257.5	528	300.4	679.5	390.7	648.3	305.4	890.6
130	473.7	691.8	398.1	594.5	354.4	712	245.3	598.6	438.8	814.8	416.6	513.1	550.8	760.7
140	442.3	719.4	279	428.7	562.8	673.1	370.7	681.3	517.9	694.7	422.8	560.5	551.5	851.4
150	137.7	565.2	292.3	538.1	565.9	854.5	507.1	773	400.2	730.4	482.1	611.4	520.7	998.2
160	413.3	636.5	421.5	527.1	581.7	783	425.6	726.2	628.8	787.3	372.8	690.1	573.9	700.3
170	505.9	692.9	421	517.8	483.4	744.4	514.5	729.1	548.7	796.9	465.1	630.3	521.8	716
180	392	593.8	518.4	690.2	392.9	550.2	619.2	951.4	589.5	688.1	426.8	880.6	431.6	584.4
190	377.9	643.3	459.3	652.4	569.1	630.1	653.3	903.7	368.5	514.9	452.8	758	488.5	649.6
200	565.3	694.2	456.9	736	402.1	873.2	591.3	827.3	573.1	804.1	377.3	607.3	564.2	826.4
210	524.4	666.2	343.7	630.4	415.8	551	458.1	720.3	599.9	774.4	307.2	587.7	493.7	847.6
220	506.5	793.5	511.7	644.2	570.5	716.5	436.8	615.5	514.9	724.2	285.8	571	394.5	790.4
230	604.1	779.9	357.7	465.9	458.3	752.9	470.3	666.7	480.7	617.6	440.5	758.9	406.3	742.4
240	538.6	556	398.5	631.3	502.5	615.9	526.9	723.2	440.8	767.2	252.4	463.8	444.2	806.1
250	449.6	635.1	364.1	461.7	496.8	698.7	557.2	592.8	430.8	761.8	297.9	662.1	396.6	905.6
260	672.2	832.6	513.9	589	654	1008	217.9	691.3	239.8	854.3	432.9	766.9	379.2	748.3
270	407.8	684.2	106.3	444.9	204.2	789.5	349.5	943	285.2	775	248.8	682.7	198.4	589.4
280	172.6	595.5	450.8	565.5	239.6	608.4	364.7	754.4	201.3	582.9	380.6	872.9	263.2	773.6
290	296.3	649.1	350.5	774.3	656.6	809.3	366.2	701.3	364.3	885.6	428.1	737.5	194.5	582.3
300	410.5	698.4	146.5	533.9	536.7	705.7	166	708.6	315.8	696.6	420.7	515.5	392.9	862.2
310	363.5	690.1	234.4	626	642	610.9	317.3	767	380.3	871.5	574.1	704.4	448.7	715.9
320	509.2	731.6	291.2	587.4	510.2	666.8	439.6	750.2	371.5	857.9	251.2	782.4	312.4	730.1
330	299.7	566	199.3	558.5	566.2	691	581.4	1075	208.9	737.6	415.4	593.4	344.5	788.6
340	333.2	770	539.4	636.4	509.1	499.4	504.4	673.3	271.8	819.8	598.1	723.7	318.9	762.1
350	187.3	599.3	380.8	540.4	711.2	820.6	392.6	693.7	404.4	721.1	473.6	664.5	418	833.7
360	357.9	605	354.9	553.8	533.5	568.8	489.9	985.5	332.9	726	469.4	757.8	220.2	719.9
370	440	711.3	317.5	644.5	551.8	578.8	369.7	656.1	495.4	861.9	512.9	716.1	429.7	763.1
380	461.7	750.6	502.8	605.7	629.5	891.1	448.6	859.1	360.4	601.1	420.4	596.2	355	662.5
390	451.1	664.3	234.5	456.9	505.2	669.2	370.5	651.1	306.4	643.3	471	822	354.4	659.7
400	415.3	620	365.3	669.6	582.7	802.2	535.9	920.5	445.8	840.3	511	765.2	405.9	742.2
410	246.4	668	369	577	544.9	706.8	264	854.7	396.4	844.4	535.6	768.9	305.8	537.9

420	361.7	700.4	309.8	632.5	520.5	751.1	474.6	824.7	342.7	631	440.8	535	395	653.1
430	424.8	692.9	340.1	545	567.9	783.9	400.1	952.9	391.9	915.6	404.8	816.5	398.3	971.4
440	489.3	783.4	319.7	642.4	496.7	524.7	351.2	815.6	568.9	886	371.3	630.8	372.9	914.8
450	565	700.1	252	537.3	604.2	781.9	342.6	792.4	425.4	657.7	349.9	565.1	479.3	769.3
460	436	752.7	213.9	480.3	487	581.9	460	796.2	288.7	669.2	412.9	478.4	151.3	616.2
470	318.3	613.5	300.7	578.2	587.6	759.1	543.8	801.8	342.2	630.9	417.2	657.9	371.9	656.1
480	473.4	684.9	295.4	592.3	691.6	680.8	330.8	696	471.4	737	425	566.3	447.7	696.9
490	345.5	727.6	368	756.8	603.1	782.6	445.4	695.8	289.6	704.6	377.4	575.5	284.3	518
500	456.5	700	299.2	583.3	496.3	692.2	345.3	931.9	271.1	803.5	484.3	781.4	520.3	772.6
510	244.7	742.7	360.7	584.5	548.9	726.5	643.7	1069	426.3	726.9	416.2	743.1	304.8	510.2
520	412.7	578.5	309.5	670.3	556.5	705.6	434.9	823	375.6	835.4	433.4	510.4	279.9	734.5
530	239.8	389.9	243.6	626.7	483	762.5	499.8	737.9	424.1	720	571.3	785.9	342.8	663.9
540	488.6	624	352.5	539.1	586.1	673.8	345.7	614.8	593.2	917.9	385.9	543.8	359.7	710.4
550	425.1	673.2	278.7	602.7	466.1	766.6	420.7	766	408.5	645.9	465.7	573.8	379.2	826.5
560	420.2	560.9	319.7	583.1	496.2	866	312.7	614.2	629.3	962.7	551.6	925.4	502.3	860.2
570	371.3	623.5	359.8	537.9	544.5	744.9	227	697.4	448.7	685.2	552	862.9	364.8	671.8
580	344	567.6	173	529.5	554.7	696.7	307.1	672.3	390	818.7	484.7	857.8	340.8	755.3
590	313.7	508.5	359.5	608.1	511.9	618.2	302.9	662.6	440.2	620	484	796.5	369.4	717
600	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

- Packet size 16 byte “ normal distribution”

time (sec)	2 dB		4 dB		6 dB		8 dB		10 dB		12 dB		14 dB	
	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)
100	7.138	24.66	19.73	20.49	22.05	37.59	14.59	28.9	11.87	26.17	14.02	24.78	23.88	37.44
110	13.22	20.18	36.3	46.09	24.54	37.36	8.345	34.13	18.97	27.17	22.39	32.62	54.67	50.78
120	90.72	102.1	107.9	67.53	72.52	82.21	31.18	37.64	42.86	48.82	43.17	53.23	55.18	62.54
130	36.69	48.21	40.38	58.08	42.49	59.55	41.54	51.31	42.64	48.47	41.77	49.91	38.23	41.02
140	50.81	63.6	36.02	36.58	38.89	45.61	42.8	47.29	35.03	49.59	35.02	44.48	38.77	46.1
150	39.32	47.27	33.43	37.96	38.8	48.62	35.68	43.64	38.07	46.73	35.95	48.88	34.51	40.3
160	38.56	52.56	38.47	46.84	41.06	65	40.31	48.1	43.71	49.84	40.64	55.12	41.2	58.74
170	37.5	42.72	39.92	44.37	37.46	43.01	33.86	47.74	49.07	56.55	45.09	51.44	47.14	52.06
180	33.94	43.84	39.46	45.95	25.29	40.9	44.21	57.96	40.28	46.48	43.06	55.9	45.31	55.25
190	40.46	55.4	44.57	47.75	29.26	44.65	35.36	43.88	40.99	52.85	31.65	49.32	36.88	47.91
200	42.83	47.24	40.47	56.02	50.38	70.9	50.03	68.04	49.18	66.7	45.73	70.64	52.53	74.77
210	40.1	51.39	39.13	52.09	50.41	75.89	45.53	68.38	30.35	48.5	32.96	43.23	38.65	50.75
220	38.37	53.42	36.85	47.96	38.87	62.07	37.41	47.74	41.39	41.42	37.64	47.24	37.4	42.4
230	40.36	49.39	27.83	45.02	41.12	53.57	31.97	47.34	35.11	57.34	40.26	57.27	34.99	48.01
240	39.67	46.4	39.66	61.71	35.31	55.89	32.36	48.82	30.05	49.79	40.01	50.95	34.94	51.38
250	30.12	42.72	28.52	39.35	36.05	46.79	41.57	48.68	41.81	52.59	40.46	50.21	31.95	40.87
260	42.79	48.77	44.29	50.54	32.32	43.02	39.53	44.82	30.38	42.75	38.92	52.69	42.1	55.76
270	41.21	44.89	37.9	48.79	37.94	55.16	41.04	54.61	46.24	50.88	40.08	53.45	41.38	49.83
280	35.85	42.27	30.6	44.81	30.67	37.51	46.7	51.59	37.22	47.42	31.09	44.36	39.63	48.96
290	34.66	40.02	38.95	49.3	48.25	52.32	36.38	40.7	44.42	51.93	42.21	49.07	36.39	46.79
300	37.94	43.7	44.68	54.84	37.04	57.6	53.71	72.5	57.76	77	46.42	61.92	46.86	63.57
310	42.87	45.76	39.09	49.12	35.48	44.18	39.35	50.84	38.14	55.4	42.43	52.64	43.07	52.57
320	52.09	58.57	38.91	50.93	46.23	60.72	35.77	41.35	40.18	56.07	31.87	42.21	38.15	49.69
330	30.53	39.31	35.13	50.88	27.01	50.58	29.97	42.42	41.76	52.42	34.3	43.53	43.32	55.95
340	22.37	29.86	38.54	46.76	29.09	40.72	33.52	43.85	37.79	46.25	35.21	40.28	40.25	50.22
350	45.22	48.62	31.68	43.39	34.03	45.97	45.16	50.09	42.89	50.91	39.24	50.02	45.74	62.66
360	36.76	46.14	40.1	44.82	37.55	42.66	39.03	45.85	40.1	43.03	37.77	45.39	38.98	51.4
370	33.03	43.13	37.42	41.85	35.42	50.05	46.41	48.14	39.33	47.35	38.49	49.17	52.88	62.8
380	43.44	47.69	42.79	54.78	36.9	57.07	34.2	44.68	53.14	59.83	36.75	43.94	32.62	39.42
390	31.11	35.94	35.69	41.14	43.17	47.62	33.05	48.7	43.98	50.27	38.08	49.16	49.39	55.87

400	43.02	45.03	43.07	54.42	30.14	45.48	44.35	47.48	47.27	57.52	39.24	40.8	46.61	52.27
410	35.09	42.99	40.84	50.07	38.47	48.9	37	45.46	47.21	55.72	36.55	46.15	53.03	58.42
420	29.66	35.86	35.69	42.67	43.16	55.87	39.62	59.76	40.41	46.43	35.83	48.66	41.71	52.44
430	40.93	44.6	31.34	41.19	38.48	48.93	37.91	51.01	48.37	59.75	29.63	40.23	47.91	53.39
440	46.85	47.84	37.6	51.31	40.08	54.89	43.18	56.41	34.97	43.53	39.54	46.49	41.47	47.26
450	40.57	45.33	41.62	52.05	41.19	46.3	37.04	46.98	47.84	53.09	39.13	48.29	39.57	51.47
460	31.25	39.92	32.4	40.63	42.52	49.29	28.78	42.96	41.39	50.41	28.81	37	38.82	44.61
470	40.6	48.71	31.45	43.44	42.47	44.85	37	44.64	34.32	50.85	34.3	38.76	38.01	41.44
480	41.38	45.23	34.02	42.61	39.23	47.31	37.59	44.44	49.2	58.39	33.62	41.22	36.39	39.21
490	38.43	37.89	34.53	38.44	44.99	53.89	35.78	46.98	51.37	57.09	34.11	50.74	38.37	52.74
500	40.47	49.68	45	56.47	45.33	51.72	41.9	56.63	42.96	51.73	39.42	44.48	54.36	63.29
510	51.61	56.2	33.2	46.82	37.14	51.25	46.78	54.15	43.83	53.29	39.91	45.26	36.06	46.43
520	34.29	39.97	47.69	51.86	38.8	46.31	43.77	56	53.68	60.96	43.3	52.47	40.78	50.27
530	36.96	41	39.32	48.72	42.26	53.47	44.41	48.4	39.43	46.76	33.13	39.86	45.73	53.25
540	30.85	40.46	34.72	42.92	53.74	61.5	40.57	52.07	38.91	53.06	40.04	46.33	33.85	43.62
550	40.59	48.96	39.93	45.38	51.43	57.19	45.67	56.09	41.49	54.11	49.6	65.29	34.14	42.34
560	28.22	31.65	41.62	46.34	42.86	59.21	38.63	43.16	38.59	47.1	39.7	47.08	43.63	52.28
570	32.97	39.1	33.95	51.19	35.16	44.66	39.28	45.46	54.78	59.82	46.33	54.51	41.84	53.89
580	29.62	33.51	33.55	38.37	40.91	47.13	41.62	50.72	46.82	54.05	30.19	35.73	35.11	46.98
590	34.21	42.89	37.8	45.69	41.74	52.78	39.04	52.82	35.24	46.53	34.17	40.9	37.09	45.54
600	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

- Packet size 96 byte “normal distribution”

time (sec)	2 dB		4 dB		6 dB		8 dB		10 dB		12 dB		14 dB	
	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)
100	7.047	24.56	19.82	20.55	22.9	41.34	14.48	28.75	11.53	26.06	13.96	24.69	23.99	37.56
110	19.62	72.39	51.14	71.49	28.5	98.95	100.6	138.9	34.33	75.67	65.97	108.5	146.5	165.1
120	364.4	356.9	302	340.1	256.4	189.9	122.1	234.1	254	134.3	315.8	260.7	104.9	155.8
130	175.2	201	100.2	160.7	144.7	185	115.3	145.4	123.6	162	147.1	157.6	105.3	121.1
140	124.9	138.1	98.76	116.5	145.1	159.1	76.35	135	193.1	192.5	157.4	178.5	115.6	141.4
150	186.7	168.7	177.1	156.5	135.7	141.8	126.2	161.7	125.8	150	126.7	164.9	151	165.8
160	152.8	194.2	146.3	165	161.3	223.8	123.1	169.9	113.2	131.2	128.8	186.1	148.7	198.9
170	179.8	185.9	148.3	178.2	103.3	140.2	72.84	154.1	115.3	146.7	163.2	194.9	146	166.2
180	91.75	129.4	134.3	163.8	116.5	160.2	73	116.7	121.1	139	57.17	85.7	133.5	151.2
190	159.2	181.1	143	139.3	134.9	180.4	86.54	143.2	143.3	168	112.9	149.5	143.4	165.7
200	112.2	155.5	122.1	209.6	119.8	197.2	69.72	140.3	126.8	191.4	130.9	214.3	125.1	164.5
210	107.9	138.8	134.3	194	104.9	169	80.77	175.2	112.2	155.2	104.4	181.2	123.1	184.7
220	133.4	170.3	108.2	140.3	122.8	176.7	74.15	133.2	142.7	164.5	95.29	149.1	137.1	167.6
230	120.6	182.6	160.7	205.7	108.5	156.2	60.03	130.4	117.4	148	93.42	148	139.7	195.8
240	160.2	198.1	130.3	185.2	144.4	165.2	18	122.7	109.6	146.2	79.68	144.1	165.8	214.9
250	103.7	157.8	115.5	152.2	152.3	229.8	43.32	127	113.9	166.6	103.7	188.3	149	192.6
260	92.47	184.8	116.7	165	129	165.4	73.84	129.5	115	161.4	88.89	187.8	189	252.6
270	65.95	165.5	94.68	138.7	80.78	152.5	57.56	122.1	81.37	107.3	95.5	179.2	122.7	166.7
280	97	141.3	111.6	183.4	103.6	197	74.75	141.8	145.4	205.6	132.3	162.3	136.1	150.1
290	114.1	156.8	139	158.2	115.3	168.6	100.8	148.7	190.2	223.4	125.8	161.2	166.9	192.1
300	79.26	158	107.6	147.3	138.2	209.8	101.8	178.1	68.16	164.9	126.7	201.7	140.1	212.3
310	102.7	142.5	104.2	150	101.2	175.3	88.39	137.5	97.18	158.4	106.7	179.1	122.6	144.1
320	141.1	187.8	79.21	144.6	79.02	110.8	78.08	161.4	112.8	177.8	126	170.9	124.5	168.1
330	143.7	202.9	115.5	141.2	103.5	137.8	95.47	158.2	81.89	145.2	126.6	189.1	109	146.2
340	98.14	156.4	128.4	155.9	92.34	115.7	103.5	156.8	105.3	127.1	164.6	199.3	150	176.7
350	103.6	139.9	158.6	178.1	119.1	137.6	103.8	138.7	113.3	144.1	78.75	148.4	122.4	137.8
360	107.6	134.4	160.9	191.1	105	167.9	111.9	173.8	83.52	149.6	110.7	148.6	126.4	178.2
370	124.3	179.1	174.8	143.9	79.82	123.2	86.35	186.9	96.42	143.9	122.9	188.2	107.8	140.2
380	116.4	155.9	123.2	168.4	97.47	152.2	91.06	136.6	134.9	207.4	111.9	198.4	112.5	149.9
390	139.1	187.2	173.3	181.5	125.9	174.1	87.86	157.8	123.6	180.5	155.7	185.5	119.8	198.5
400	113.4	166.3	128.7	192.4	114	155.9	106.5	148.8	133.6	156.6	149	177.5	146.6	161.8
410	155.1	214.9	111.5	133.9	84.19	105.2	63.72	140.4	105.9	181.7	126.3	165.3	127.2	181.2

420	143.9	184.9	109.7	153	126.1	170	107.2	173.7	108.7	174.3	134.3	192.7	150.4	203.6
430	121.4	184.5	137.5	144.5	126	172.6	77.68	161.4	86.2	170.1	110.9	156.3	116.9	147.1
440	133.5	157.4	163.7	209	110.6	157.8	82.45	191.8	77.75	155.3	92.59	138.3	114.1	156.8
450	89.3	128.2	152.6	188.7	97.63	147	70.1	139.8	116.4	144	75.27	132.6	107.3	142.3
460	87.02	132.3	116.6	152.8	82.88	153	77.64	143.8	89.22	149	100.8	153.2	119.1	147.2
470	119.5	188.4	95.91	122.2	94.88	153.6	84.6	149.7	105.8	156.3	98.28	144.4	133.3	151.1
480	94.87	121	127.3	166.6	112.5	148.6	76.87	125.3	107.6	145.8	120.1	183.9	102.3	149.4
490	123.7	159.6	132.1	132.4	103.7	181.5	103.3	184.6	90.41	161.5	143.4	190.5	107	123.8
500	116.3	183.7	124.6	154	142.1	191.2	76.79	133.8	96.49	150.9	122.7	190.1	125.9	156.2
510	122.8	151.7	140.5	159.9	89.51	148.4	105.1	170.5	75.36	149.7	145.2	189.8	117.1	148.6
520	152.2	188	140.2	172.4	149.1	224.9	95.7	127.8	98.69	207.9	71.05	106.5	113.4	198.6
530	139.1	158.4	133.1	189.1	152.8	166.9	60.78	131.1	102.7	165	137.2	186	124.2	155.3
540	104.8	124.2	122.8	142.2	120.2	165.7	67.21	155.3	103.4	162.9	121.1	168.4	130.9	149.6
550	144.6	178.9	161.5	172	123	183.8	94.82	183.4	109.4	202.8	114.2	173.1	111.8	166.6
560	105.7	135.3	141.6	194.9	128.6	185.8	113	185.6	88	171.5	125.4	159.5	111.5	178.6
570	146.9	189.5	138.9	177.8	127.1	167.9	87.23	129.5	85.7	177.6	137.6	186.9	117.3	171.4
580	115.9	158.4	110.2	131.4	107.1	133.6	79.16	129.3	90.1	197.7	150.4	193.2	97.73	133
590	135.5	177.5	104.2	129.5	109.3	148.5	62	107.5	96.62	155.8	95.25	159.2	118.2	160.4
600	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

• Packet size 256byte “ normal distribution”

time (sec)	2 dB		4 dB		6 dB		8 dB		10 dB		12 dB		14 dB	
	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)
100	7.155	24.71	19.96	20.73	22.88	44.01	14.37	28.81	11.74	26.05	13.74	24.48	23.78	37.42
110	34.71	83.43	36.95	68.96	99.32	272.1	124.4	259.3	157.7	266.1	142.1	231	251.2	401.5
120	335.3	455.9	421.7	482.4	314.6	411.8	505.9	506.2	437	385.3	258.6	437.2	287.6	282.2
130	323.7	410.2	212.5	292.2	219.3	234.6	202.2	338.3	198.8	349	174.3	314.7	261.7	287.1
140	326.6	342.5	250.3	335.2	329.1	354.3	145.1	422.6	318.4	452.1	194.8	406.8	260.3	378.3
150	193	256.6	325	386.6	307.5	432.6	245.3	422.8	341.7	473.5	192.1	329.9	328.5	402
160	277.8	347.9	256.4	337.3	311.9	356.3	309.1	389.3	364.6	459.7	259.4	487.7	331	438.9
170	231.2	271.3	227.2	272.6	282	326.9	249.1	443.6	315.4	377.8	122.2	366.3	256.3	330.4
180	257.1	326.1	250.8	373.4	252.2	432.7	147.8	382.2	239.7	360.3	217.5	358.7	173.7	323.9
190	262.5	350.4	263.3	294.2	269.6	282.5	249.8	452.8	361.5	577.8	247.1	472.2	249.7	345.1
200	358.4	457.8	161.9	309.1	210.2	248.5	199	388.3	303.4	397.6	148.5	321.9	190.7	344.5
210	280.1	374.1	163	295.4	206.6	311.6	212.8	412	211.4	358.2	226.2	405.7	243.4	391
220	225	274.9	173.8	304.4	175.5	269.7	186.5	416.4	170.4	267.9	219.2	362.6	228.6	329
230	201	309.3	213.5	313.8	305.6	410.9	118.9	341.7	211.3	397.7	245.4	386.9	194.9	377
240	274.7	408.5	187.1	297.4	225.8	436	136.7	400	193.1	341.4	159.1	368.9	144.8	324.8
250	199	293.3	121.5	266.2	265.1	410.4	176.7	458.5	111.8	289.1	252.8	521.9	174.1	325.1
260	192.9	326.9	204.6	342.3	328.1	413.5	272.3	385.7	228.6	336.2	207.3	377.8	235.5	347.4
270	185.7	323.3	188.2	361.9	181.3	415.5	159.2	285.8	264.1	473.1	186	312	72.99	361.3
280	196.2	347.1	156.2	274.6	205.8	375.2	259	360.1	205.8	415.4	201.9	480.7	108.1	289.5
290	210.1	305.3	201.2	362.8	264.3	336.6	283.9	387.2	229.4	353.2	117.6	375.1	163.7	330.5
300	125.7	262.1	153.7	380.5	225.7	409.8	269	441.9	196.7	336.4	145.2	336	246.8	345.6
310	122.2	301.3	219	364.9	193.9	277.9	233.2	389.7	218.2	366.9	180.6	371.2	139.1	286.1
320	166.5	351.7	160	279.1	273.4	298	134.6	332.4	203.5	392.7	128.1	339	271.6	365
330	186	363.1	165.7	297.9	153.3	306.5	195	433.1	243.3	371.2	147.9	406.1	261.2	418.8
340	221.8	317.5	85.47	150.9	198	277.7	151.6	256.8	175.7	339.5	177.3	302.4	239.5	404.2
350	167	310.4	144	239.7	263.4	395.4	231.3	357.3	259.6	360.8	232.2	479.4	182.2	323.5
360	228.5	428.4	239.7	313.4	172	356	250.3	372.1	186.5	329.8	197.4	402.3	130.1	323.2
370	215.4	352.5	209.9	403.6	201.1	331.9	197.7	371.2	194.4	368.8	222.4	321.2	286.2	339
380	133.8	276.3	215.9	326	205.8	395.1	228.8	405.1	230.2	447	140.6	296.3	206.9	295.7
390	178.9	313.4	139.3	288.6	214.9	345.9	166.5	348.1	258.6	390.6	193.3	465.6	115.1	256.3
400	145.8	317	145.9	290.2	158.2	324.8	128.6	374.2	250.1	364.4	162.4	223.9	238.7	340.7
410	212.1	345.7	184.4	331.9	243	356.3	243.2	397.3	172.5	396	249.5	388.6	218.6	288.7
420	234.9	267	154.2	296.8	142.4	294.5	188.8	371.1	238.3	334.5	278.5	485.5	184.1	309.1

430	185.4	312.6	206.2	343.6	228.9	366.8	138.1	359	245	369.6	246.6	418	183.4	242.7
440	166	277.6	190.9	269.1	160.3	269	281.5	433	139	355	271.8	345.3	204.5	403.9
450	251	285.8	170.1	270.2	205	382.4	217.7	355.5	272.4	361.1	198	417.6	140	273.4
460	147.3	233.7	202.1	323.6	228.2	413.5	268.4	367.1	133.5	322.8	223.6	375.9	261.3	396.6
470	192	327	158	307.4	248.1	348.9	259.1	387.3	200.6	358.3	243.5	395.7	231.8	289.7
480	138	294.5	148.6	300.5	204.2	355.3	243.8	366.5	308.6	460.9	256.3	353	252.1	357.7
490	135.2	289.7	200	314.7	213.6	271.7	225.7	474.4	170.4	287.9	298.9	369	231.6	412
500	250.8	332.1	147.1	310.9	254.3	488.6	172.3	364.7	251.9	308.1	284.2	330.2	169.7	319.4
510	225.8	314.4	216.1	306	205	382.4	230.2	407.6	241.2	402	127.1	321.6	249	370.7
520	172.5	288.3	155.3	315.4	228.2	413.5	181.3	327.5	221.1	269.5	198.9	351.1	221.4	333.4
530	233	322.4	186.3	295.8	248.1	348.9	250.5	395.1	278.4	352.9	228.5	343.4	258.1	338.3
540	183.5	332.3	196.1	371.7	204.2	355.3	281.5	433	320.5	347.6	253.2	413.2	250.6	381.8
550	300.1	337.3	156.9	332.9	213.6	271.7	217.7	355.5	346	417.8	222.1	377.3	201.9	380.1
560	181.8	286.9	185.4	384.6	254.3	488.6	268.4	367.1	257.7	409.7	146.8	328.1	235.3	401
570	137.7	313.4	230.8	316	196	331.2	259.1	387.3	219.1	320.6	241.3	362.6	218.8	417.3
580	259.8	405.3	141.2	320	181.1	330.6	243.8	366.5	259.1	365.8	162.9	308.2	279.7	328.9
590	183.4	311.8	184.2	358	180.7	344.4	225.7	474.4	299.4	429.4	178.8	327.3	255.4	343.8
600	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

• Packet size 512byte “ normal distribution”

time (sec)	2 dB		4 dB		6 dB		8 dB		10 dB		12 dB		14 dB	
	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)	Total Received Throughput (packets/sec)	Total Transmit Load (packets/sec)
100	23.04	24.68	7.138	20.58	23.04	44.01	14.4	28.68	11.5	26.07	13.74	24.48	23.68	37.34
110	257.6	241	84.91	317.7	257.6	451.5	63.12	359.4	141.8	313	166.9	602.9	287.9	547
120	425.7	540	214.8	528.8	425.7	556.5	419.6	879.6	539.7	612.4	379.4	619.6	481	745.3
130	405.4	425.7	143.7	433.9	405.4	582.2	259.2	643	246.3	577.7	362.6	656	423.9	570.8
140	381.6	677.8	495.5	721.2	381.6	543.7	233.1	775.9	493.7	780	428.7	676.7	388.3	691.7
150	178.4	571.7	416.4	643.7	178.4	689.4	406.4	715.1	293.7	587	537.9	851.9	220.7	757.5
160	487.9	693.7	436.4	684.2	487.9	804.3	237.9	792.9	215.8	560.1	510.6	725.9	513.7	665.9
170	576.5	487.2	475.1	740.6	576.5	607.3	333.4	713	166.3	761	520.6	716.1	550.3	862.4
180	344	584.1	388	681.7	344	623.9	388.9	851.8	226.1	474.2	491.4	619.2	197.9	842.2
190	477.5	569.5	318.3	614	477.5	597.9	227.7	693.8	334.5	644.9	294.2	573.3	376	808.7
200	450.2	552.3	359.6	719	450.2	526.2	109.7	555.1	339.7	578.3	404.9	725	311.4	787.8
210	368.3	634.6	280.5	437.2	368.3	505.2	388.3	576.7	369.8	644	368.4	741.2	387.8	577.6
220	399.4	584.4	342.2	667.6	399.4	762.4	504.8	913.3	396.1	778.5	322.5	659.6	341.5	804.6
230	337.8	554.4	298.3	668.7	337.8	674.9	317.5	798.7	236.1	717.4	266.9	786.5	337	849.5
240	248.7	594.9	402	592.4	248.7	591.2	366.6	865.4	387.7	618.3	329.5	765.9	242	693.9
250	510.9	568.4	274.9	625.9	510.9	628.9	308.5	646.4	291.7	694.5	163.8	676.6	211.3	711.8
260	301.6	515.2	383.8	583.8	301.6	644.1	340.9	723.9	338.3	646.1	256.9	767.3	353.4	866.1
270	495.2	509.6	196	603.4	495.2	821	255.1	748.2	297.3	589.5	411.2	803.4	416.1	878.3
280	414.3	602.1	227.9	497.2	414.3	755.4	354.4	683.6	271.4	621.8	276.3	635.9	626.9	1024
290	514.8	528.2	158.1	653.3	514.8	819.8	271.4	620.2	310.6	557.6	453.3	736.4	552	862.1
300	308.6	545.8	215.9	720.5	308.6	608.6	344.4	739.6	286.9	668.3	501	651.6	393.7	827.2
310	554	499.9	237.5	706.2	554	797.6	426.9	608.3	472.6	816.2	433	711.9	449.3	748.8
320	367.7	619.3	217.5	626.8	367.7	488.4	399.7	724	412.8	570.5	257	696.1	327.1	631.8
330	433	576.4	259	623.2	433	710.8	517.3	711.6	379	725.8	270	633.3	452.9	850.3
340	343.6	502.1	273.2	691.5	343.6	619.7	344.2	774.4	380.8	653.1	180.5	484.1	238.3	816.3
350	366.1	494.6	210.3	546.3	366.1	612	277	792.3	212.8	602.8	449.4	797.2	298.3	754.4
360	291.2	533.7	354	663.3	291.2	450.8	452.2	725.2	394.2	609.7	401.6	829.8	405.6	803.7
370	267.3	671.3	331	608	267.3	621.1	493.8	651.5	553	632.4	331.8	591	397	592.1
380	435.2	748.9	450	633.7	435.2	562	356.6	731.9	181.5	590.3	506	933.2	562.1	861.8
390	309.3	470.8	141.5	731.7	309.3	566.5	428.7	826.5	471.4	683.2	248.9	692.4	485.5	764.3
400	262.1	513.1	318.1	684	262.1	509.7	477.9	801.4	246.9	560.7	398.6	748	439.6	710.3
410	381	554.1	260.9	579.3	381	600.9	259	526.3	392.3	594.9	320.2	672	325.3	834
420	414.7	548.5	327.4	629.9	414.7	673.1	516.2	855.9	291.6	616.1	266.2	683.5	384	984.1

430	279.4	623.7	309.8	653.6	279.4	573.9	345.4	721.6	310.9	612.7	441.8	691.6	369.4	684.4
440	382	621.3	364.3	557.4	382	596	307.4	653.1	189.7	451.5	412	819.3	351.8	741.7
450	371.6	460.4	279.6	630.4	371.6	371.5	454.8	800.1	346.3	508.3	234.9	659.8	474.1	785.8
460	241.8	564.3	246.3	496.1	241.8	505.2	340.1	629.9	295.8	546.7	405.5	772.7	372.1	750.7
470	249.3	622.3	404.8	511.4	249.3	639.2	516.1	775.8	137.3	541.3	292.3	738.2	264.4	656.7
480	256	706.7	444.9	564.2	256	448.2	299.4	414.2	365.1	640.1	516.3	764	255	613.6
490	282.8	543.4	344.1	726.3	282.8	579.8	343.6	759.7	402.4	548.3	377.4	813	414.1	619.1
500	441.9	467	421	643.6	441.9	537.5	429.7	837.3	528.1	683.1	399.5	597.8	502.8	896.8
510	563.5	382.8	271.3	688	563.5	524.4	375.5	727.8	372.5	598.2	390.8	650.1	419.1	815.6
520	364.7	504.2	348.6	565.3	364.7	563.1	433.9	628.2	254	395	412.3	882.4	403.3	834.2
530	387	614.2	416.4	838.6	387	671.4	212.7	492.2	357.2	598.3	443.6	797.3	397.5	868.8
540	267.2	677	437.1	635.5	267.2	486.8	516.4	967	335.8	637	448.5	864.1	340.3	754.2
550	339.2	396.3	230.4	553.7	339.2	609.7	420.6	679.2	364.5	653.3	354.5	720.7	437.5	755
560	436.2	537.7	391.5	727.1	436.2	726.3	561.2	730	401.8	545.9	301.5	588.6	385.3	583.5
570	236.8	582.1	418.4	703.7	236.8	431.3	411.6	766.3	224.5	593.8	365.8	749	283.7	512.2
580	546.3	348.2	220.5	512.9	546.3	646	531.6	652.4	288.1	580.1	262.5	749	279.4	654.4
590	376.1	478.2	289.7	754.5	376.1	556	269.1	666.2	420.8	630.8	306.9	668.7	288.9	637
600	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

• End-to-End Delay

time (sec)	16					96					256					512				
	12 dB	2 dB	4 dB	6 dB	8 dB	12 dB	2 dB	4 dB	6 dB	8 dB	12 dB	2 dB	4 dB	6 dB	8 dB	12 dB	2 dB	4 dB	6 dB	8 dB
120	1.45	0.15	0.15	0.15	1.49	0.85	1.21	0.81	0.26	1.38	1.61	0.62	1.36	0.48	0.55	0.96	1.85	2.16	1.44	2.52
126	0.16	0.15	2.51	0.16	8.36	2.18	1.57	2.89	0.27	6.33	0.46	0.95	0.47	2.4	0.47	4.64	1.08	0.82	0.97	1.05
132	9.82	5.68	8.45	1.66	5.62	8.05	5.43	5.45	3.71	6.34	7.27	7.63	4.61	3.14	4.02	3.4	2.68	1.23	2.14	5.53
138	0.15	0.16	0.15	0.15	0.16	0.27	4.22	0.27	0.28	0.28	0.49	1.28	0.41	0.37	0.52	0.44	0.97	0.97	0.92	0.87
144	8.5	12.9	3.94	0.15	0.15	7.86	8.64	5.05	2.64	0.27	3.81	1.6	0.45	0.4	6.52	1.77	5.52	0.92	2.51	3.51
150	0.15	0.15	0.15	0.15	0.16	0.27	0.28	0.28	0.27	0.27	0.48	0.43	0.42	0.39	0.47	2.58	0.93	0.85	0.97	0.94
162	0.15	12.8	0.15	4.53	11.7	4.98	4.55	0.28	0.26	12.6	3.12	0.51	0.38	8.31	0.5	0.87	0.97	2.68	1.09	0.8
174	0.15	0.15	0.15	0.16	0.15	0.27	0.27	0.26	0.26	0.27	0.49	0.5	0.46	0.45	0.53	0.82	0.98	1	0.87	0.66
180	0.15	13.5	0.15	0.15	0.15	0.28	0.28	0.27	0.27	0.27	0.42	0.46	0.51	0.48	4.19	0.68	0.94	0.85	1.02	0.58
186	0.15	0.15	0.16	0.15	0.16	0.27	0.28	0.27	0.27	0.26	0.44	0.45	0.47	0.51	2.39	0.56	0.89	0.89	0.89	0.62
192	0.15	0.15	0.15	0.15	0.15	0.27	0.28	0.26	0.26	0.27	0.46	0.49	0.44	0.47	0.5	0.77	0.88	0.92	0.86	0.69
198	0.15	0.15	0.15	0.15	0.15	0.26	0.28	0.25	0.26	0.27	0.47	0.46	0.46	0.47	0.47	0.99	0.86	0.92	1.07	0.96
210	0.15	0.15	0.15	0.15	0.16	0.28	0.27	0.27	0.27	0.27	0.45	0.45	1.68	0.44	0.47	1	0.89	0.85	0.88	0.86
216	0.15	0.15	0.15	0.15	0.15	0.27	0.27	0.27	0.27	0.26	0.47	0.46	0.48	0.43	0.46	0.8	0.97	0.78	0.79	0.73
222	0.15	0.16	0.16	0.15	0.16	0.28	0.27	0.27	0.27	0.27	0.45	0.44	0.5	0.4	0.45	0.72	0.94	0.85	1.1	0.83
234	0.15	0.15	0.16	0.16	0.15	0.25	0.27	0.27	0.26	0.26	0.47	0.45	0.42	0.5	0.4	0.6	0.71	0.86	0.82	2.01
246	0.15	0.16	0.15	0.15	0.16	0.26	0.26	0.28	0.27	0.25	0.49	0.45	0.46	2.62	0.48	0.67	0.8	1.01	0.85	1.08
252	0.16	0.16	0.15	0.15	0.15	0.28	0.26	0.27	0.26	0.27	0.41	0.51	0.41	0.47	0.49	0.67	0.87	0.92	0.76	0.88
258	0.15	0.16	0.15	0.15	0.15	0.27	0.27	0.27	0.26	0.26	0.44	0.52	0.43	0.45	0.5	0.97	1.09	0.98	0.69	0.74
270	0.15	0.15	0.15	0.15	0.15	0.28	0.27	0.26	0.25	0.86	0.45	0.45	0.47	0.45	0.62	0.76	0.93	0.98	0.75	0.76
276	0.15	0.15	0.15	0.15	0.15	0.28	0.26	0.26	0.26	0.27	0.46	0.45	0.46	0.49	0.42	0.9	0.97	0.99	0.49	0.66
288	0.15	0.16	0.15	0.15	0.16	0.27	0.28	0.26	0.27	0.27	0.51	0.45	0.46	0.5	1.34	0.78	0.78	0.89	1.11	0.82
294	0.16	0.16	0.15	0.16	0.15	0.27	0.28	0.27	0.27	0.28	0.45	0.49	0.45	0.5	0.45	0.8	0.9	1.12	0.99	0.66
306	0.15	0.16	0.15	0.15	0.16	0.27	0.26	0.27	0.28	0.28	0.46	0.5	0.45	0.47	0.5	0.82	0.92	0.98	1.01	0.84
312	0.15	0.16	0.16	0.16	0.15	0.27	0.28	0.27	0.27	0.27	0.89	0.49	0.43	0.44	0.49	0.92	0.95	1.06	0.9	0.95
318	0.15	0.15	0.16	0.15	0.15	0.26	0.27	0.26	0.27	0.27	0.41	0.49	0.46	1.72	0.45	0.86	7	1.09	0.86	0.96
324	0.15	0.16	0.15	0.15	0.15	0.27	0.27	0.27	0.27	0.27	0.37	0.43	0.47	0.5	0.47	0.8	0.87	1.18	0.82	0.94
330	0.16	0.16	0.15	0.15	0.15	0.27	0.26	0.27	0.26	0.27	0.38	0.47	0.5	0.49	0.47	0.73	0.87	1.2	0.87	1.15
336	0.15	0.15	0.16	0.15	0.16	0.28	0.26	0.26	0.26	0.28	4.17	0.46	0.47	0.48	0.52	0.66	0.95	1.05	0.94	1
342	0.15	0.15	0.15	0.16	0.16	0.28	0.27	0.26	0.26	0.27	0.37	0.47	0.46	0.45	0.54	0.77	0.89	1.07	0.82	0.96
348	0.16	0.16	0.15	0.16	0.15	0.28	0.26	0.27	0.26	0.27	0.4	0.45	0.49	0.43	0.45	0.82	0.92	0.84	0.84	0.9
360	0.15	0.16	0.16	0.15	0.15	0.27	0.26	0.27	0.28	0.26	0.46	0.61	0.5	0.41	0.46	1	1.27	0.8	0.9	0.75
366	0.15	0.16	0.15	0.15	0.15	0.27	0.27	0.28	0.28	0.26	0.47	0.44	0.46	0.45	0.49	1.06	0.93	0.8	0.97	0.76
372	0.15	0.15	0.16	0.16	0.15	0.26	0.29	0.28	0.27	0.25	0.47	0.45	0.44	0.43	0.48	0.96	0.85	0.9	0.85	0.71
378	0.15	0.15	0.15	0.15	0.15	0.27	0.28	0.28	0.27	0.26	0.63	0.47	0.43	0.44	0.47	0.84	1.02	0.97	0.83	0.84
384	0.15	0.16	0.15	0.15	0.15	0.27	0.27	0.28	0.27	0.26	0.57	0.45	0.49	0.43	0.46	0.97	0.98	0.83	0.84	0.81
390	0.16	0.15	0.16	0.15	0.15	0.27	0.27	0.27	0.28	0.27	0.5	0.5	0.48	0.46	0.48	0.95	1	0.78	0.86	0.92

396	0.15	0.16	0.16	0.16	0.15	0.26	0.28	0.27	0.27	0.27	0.5	0.51	0.45	0.46	0.48	1.03	1.07	0.87	0.78	1.05
402	0.16	0.16	0.15	0.15	0.15	0.27	0.28	0.28	0.27	0.26	0.5	0.45	0.43	0.45	0.48	1.13	1.21	0.82	0.84	0.86
408	0.16	0.15	0.15	0.16	0.15	0.27	0.28	0.27	0.27	0.28	0.47	0.53	0.45	0.47	0.47	0.94	0.98	0.62	1.05	0.89
414	0.15	0.15	0.15	0.16	0.16	0.27	0.27	0.28	0.28	0.28	0.48	0.5	0.44	0.45	0.48	0.84	0.95	0.8	0.98	0.99
420	0.15	0.15	0.15	0.16	0.15	0.27	0.27	0.27	0.27	0.28	1.61	0.47	0.43	0.49	0.48	1.01	1.04	0.95	0.93	0.75
426	0.15	0.15	0.15	0.15	0.16	0.27	0.26	0.27	0.27	0.27	0.52	0.48	0.5	0.51	0.5	0.83	1.06	0.94	0.82	0.86
432	0.15	0.16	0.15	0.15	0.16	0.27	0.25	0.28	0.27	0.27	0.49	0.52	0.44	0.45	0.5	0.94	1.01	0.98	0.88	0.83
438	0.16	0.16	0.15	0.15	0.15	0.28	0.26	0.28	0.26	0.27	0.52	0.5	0.42	0.45	0.47	0.89	1.02	0.71	0.99	0.92
444	0.15	0.15	0.16	0.16	0.15	0.28	0.27	0.27	0.24	0.27	0.51	0.49	0.42	0.47	0.46	0.77	0.93	0.98	0.95	0.83
450	0.15	0.16	0.16	0.16	0.15	0.27	0.27	1.61	0.24	0.27	0.45	0.47	0.45	0.48	0.46	0.9	0.99	4.32	1.02	0.78
456	0.15	0.15	0.15	0.15	0.16	0.27	0.27	0.26	0.25	0.27	0.48	0.51	0.5	0.52	0.51	1.05	0.97	0.86	0.76	1.02
462	0.16	0.15	0.15	0.15	0.15	0.27	0.26	0.26	0.26	0.28	0.5	0.44	0.47	0.49	0.45	0.79	0.96	0.9	0.85	0.85
468	0.16	0.15	0.15	0.15	0.15	0.26	0.27	0.27	0.27	0.27	0.48	0.4	0.48	0.48	0.48	0.98	0.94	0.88	0.83	0.97
474	0.16	0.15	0.16	0.15	0.15	0.27	0.26	0.26	0.26	0.27	0.47	0.44	0.43	0.47	0.51	0.87	0.91	0.77	0.88	0.82
480	0.15	0.15	0.15	0.15	0.15	0.28	0.26	0.27	0.27	0.27	0.47	0.47	0.43	0.5	0.52	0.91	0.9	0.78	1.1	0.85
486	0.15	0.15	0.15	0.15	0.16	0.28	0.26	0.28	0.28	0.28	0.47	0.47	0.44	0.48	0.47	0.93	0.83	0.96	1	0.71
492	0.16	0.15	0.15	0.15	0.15	0.27	0.28	0.26	0.27	0.27	0.47	0.48	0.44	0.46	0.47	0.96	0.91	0.97	1.02	0.63
504	0.15	0.15	0.15	0.16	0.15	0.26	0.28	0.26	0.27	0.28	0.48	0.44	0.43	0.46	0.48	0.91	1.01	0.87	0.86	0.93
510	0.15	0.15	0.16	0.15	0.15	0.26	0.28	0.26	0.26	0.28	0.45	0.48	0.41	0.48	0.47	0.98	0.86	1.05	0.81	0.74
516	0.16	0.16	0.15	0.16	0.15	0.27	0.28	0.27	0.26	0.27	0.44	0.49	0.43	0.46	0.46	1.29	0.89	0.82	1.06	0.67
522	0.15	0.15	0.15	0.15	0.15	0.27	0.28	0.26	0.27	0.27	0.5	0.51	0.48	0.45	0.4	0.78	1.03	0.99	1.06	0.69
528	0.16	0.15	0.15	0.15	0.15	0.28	0.29	0.26	0.26	0.28	0.52	0.48	0.52	0.47	0.44	0.78	0.91	0.85	1.14	1.01
540	0.16	0.15	0.15	0.15	0.15	0.28	0.28	0.27	0.28	0.27	0.5	0.51	0.5	0.48	0.46	0.85	0.86	0.87	0.95	0.79
546	0.15	0.15	0.15	0.16	0.16	0.27	0.27	0.26	0.27	0.27	0.47	0.51	0.44	0.5	0.48	1.07	0.85	0.91	0.88	0.8
552	0.15	0.15	0.15	0.16	0.15	0.28	0.27	0.26	0.28	0.27	0.5	0.46	4.22	0.49	0.42	1.1	0.97	1.06	0.92	0.72
558	0.16	0.15	0.15	0.15	0.15	0.28	0.28	0.25	0.27	0.26	0.52	0.49	0.5	0.48	0.46	0.99	0.96	0.96	1.02	0.83
564	0.15	0.15	0.16	0.15	0.15	0.28	0.27	0.27	0.26	0.27	0.48	0.51	0.45	0.44	0.47	0.97	1	0.9	0.79	0.85
570	0.16	0.15	0.15	0.15	0.15	0.27	0.27	0.27	0.28	0.27	0.49	0.48	0.42	0.43	0.46	0.93	0.92	0.85	1.05	0.89
576	0.15	0.15	0.15	0.15	0.15	0.27	0.26	0.26	0.27	0.27	0.49	0.49	0.42	0.48	0.46	0.92	0.93	1.02	0.86	1.08
582	0.15	0.15	0.15	0.16	0.15	0.27	0.27	0.27	0.26	0.26	0.49	0.48	0.42	0.45	0.46	0.78	1.01	1.11	0.83	0.92
588	0.15	0.15	0.16	0.15	0.15	0.26	0.27	0.26	0.26	0.26	0.42	0.5	0.45	0.4	0.46	0.71	1	0.95	0.83	1.02
594	0.15	0.15	0.15	0.15	0.15	0.28	0.27	0.26	0.27	0.26	0.44	0.5	0.42	0.47	0.44	0.79	0.9	1.05	1.02	0.89
600	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A