2007-09

Analysis of Wideband Code Division Multiple Access (WCDMA) system with co-channel interference

Argyros, Andreas

Monterey, California. Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ANALYSIS OF WIDEBAND CODE DIVISION MULTIPLE ACCESS (WCDMA) SYSTEM WITH CO-CHANNEL INTERFERENCE

by

Andreas Argyros

September 2007

Thesis Advisor: Tri T. Ha
Co Advisor: David Jenn

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2007	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Analysis of Wideband Code Division Multiple Access (WCDMA) System with Co-Channel Interference			**5. FUNDING NUMBERS**
6. AUTHOR(S) Andreas Argyros			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Security Agency, Applied Technologies Division 9800 Savage Rd. Fort George G. Meade, MD 20755			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

The Wideband Code Division Multiple Access is a third generation air interface, initiated in European Union research projects at the start of the 1990s. The standard emerged by the end of 1999 as part of the 3GPP standardization process. It was designed to support multiple simultaneous services with high quality services through an increased data rate.

This research examines the properties and parameters of the WCDMA system to determine the feasibility of intercepting and exploiting this technology with known assets. It explores this possibility by looking at link analysis, adaptive antennas and co-channel interference canceling techniques to determine if the interception of WCDMA signals is possible.

14. SUBJECT TERMS Wide band Code Division Multiple Access (WCDMA)			**15. NUMBER OF PAGES** 127
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution unlimited

ANALYSIS OF WIDEBAND CODE DIVISION MULTIPLE ACCESS (WCDMA) SYSTEM WITH CO-CHANNEL INTERFERENCE

Andreas Argyros
Lieutenant Junior Grade, Hellenic Navy
B.S., Greek Naval Academy, 1998

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRONIC WARFARE SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September 2007

Author: Andreas Argyros

Approved by: Tri T. Ha
Thesis Advisor

David Jenn
Co-Advisor

Dan Boger
Chairman, Department of Information Sciences

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The Wideband Code Division Multiple Access is a third generation air interface, initiated in European Union research projects at the start of the 1990s. The standard emerged by the end of 1999 as part of the 3GPP standardization process. It was designed to support multiple simultaneous services with high quality services through an increased data rate.

This research examines the properties and parameters of the WCDMA system to determine the feasibility of intercepting and exploiting this technology with known assets. It explores this possibility by looking at link analysis, adaptive antennas and co-channel interference canceling techniques to determine if the interception of WCDMA signals is possible.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

The author would like to express his sincere appreciation to Dr. Tri Ha for his guidance. Without his supervision, this thesis would not have been possible. I would like to thank Professor David Jenn for agreeing to be a second reader for this thesis.

I would like to express my gratitude to my parents, Aristofanis and Niki, for their love and support.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. PURPOSE

The purpose of this thesis is to evaluate one of the flourishing Third Generation (3G) standards for mobile communications known as Wideband Code Division Multiple Access (WCDMA). It will examine the properties and parameters of the WCDMA system in order to determine the feasibility of intercepting and exploiting this technology with known assets**.**

B. BACKGROUND

The original objective of the International Telecommunication Union (ITU) was to define a single standard for 3G radio access technology (RAT); however, due to different existing 2G technologies and due to political reasons the best compromise was to create multiple technology modes. In 1985 the International Telecommunication Union (ITU) set up a standardization group (Task Group 8/1) to define the world standards for 3G mobile technologies, also known as International Mobile Telecommunications 2000 (IMT-2000). Figure 1 illustrates the extent of 3G technologies and the different terms that are commonly applied to define 3G. [1]

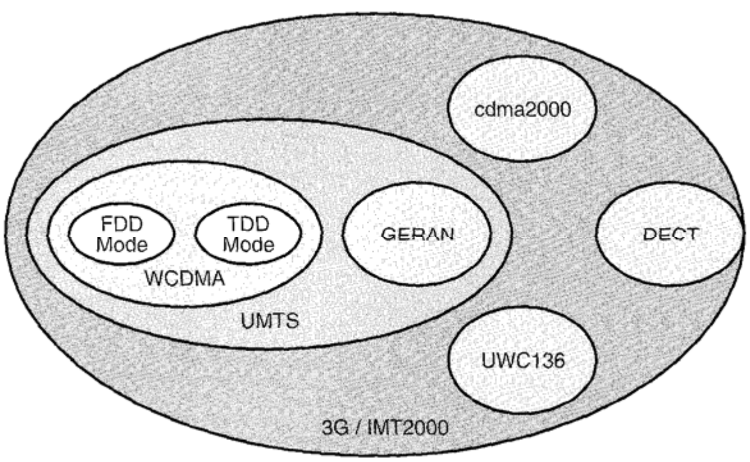

Figure 1 3G technology relationship. From [1]

In Europe, the research work started in 1988 with core industrial partners Nokia, Siemens, Ericsson, France Telecom and CSEM/Pro Telecom, and the proposed technologies were submitted to the European Telecommunications Standards Institute (ETSI) by June 1997. ETSI decided among different proposals in January 1998, selecting WCDMA as the standard for Universal Mobile Telecommunications System Terrestrial Radio Access (UTRA) for Frequency Division Duplex (FDD) operation and WTDMA/CDMA for Time Division Duplex (TDD) operation. [2]

In Japan, the Association for Radio Industries and Businesses (ARIB) selected the WCDMA standard in 1997 with FDD and TDD modes of operation. The ARIB's selection was made prior to the completion of the ETSI process, carrying more weight in ETSI selection as the global technological alternative. [2]

In the US, different second generation technologies existed (GSM 1900, US-TDMA, IS-95, IS-136), so a different evolution path had to be defined for each of these technologies to progress to third generation technology. The evolution of GSM 1900 was carried out by the Technical Subcommittee of Committee T1 and the result was W-CDMA N/A (N/A for North America). The proposals were very similar to ETSI and ARIB technologies since the same companies were involved in their selection process. The TR45.3 committee worked on the evolution of IS-136 towards the third generation. The result was a combination of narrowband and wideband TDMA technologies, where the narrowband part was similar to the Enhanced Date rates for GSM Evolution (EDGE) concept (the evolution of GSM in Europe) and the wideband part was similar to the WTDMA considered by ETSI. The CDMA 2000 was the proposal solution of the TR45.5 committee for the evolution of IS-95 towards the third generation. CDMA 2000 is based on the IS -95 principles; however, it is wideband with a bandwidth three times that of IS-95. [2]

In Korea, the Telecommunications Technology Association (TTA) evaluated two different technologies (TTA1 and TTA 2) based on synchronous and asynchronous wideband CDMA technologies respectively. TTA1 WCDMA was similar to the standard of ETSI, ARIB, and T1P1 while TTA2 was similar to CDMA 2000. [2]

In 1999 the standardization organizations from Europe, Japan, Korea, the US and China have partnered in 3rd Generation Partnership Project (3GPP) in order to define the WCDMA specifications. Within 3GPP, WCDMA is identified as UTRA (Universal Terrestrial Radio Access) FDD and TDD , the name WCDMA is used to cover both FDD and TDD operations. [2]

The first effort towards a single common global IMT air interface started in the 1992 meeting when the World Administrative Radio Conference (WARC), under the ITU, identified the frequencies around 2 GHz which were available for use by future third generation mobile systems, both terrestrial and satellite as shown in Figure 2. [2]

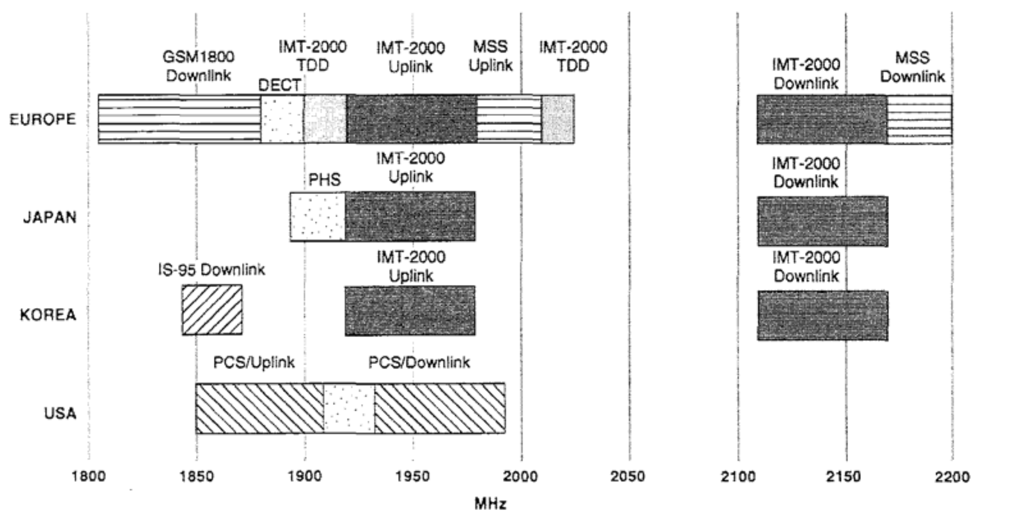

Figure 2 2 GHz band spectrum allocation in Europe, Japan, Korea, and US. From [2].

Therefore countries in Europe and Asia, including Japan and Korea, access the same air interface (WCDMA) using the frequency bands that WARC-92 allocated for the third generation. In North America, however, the spectrum was already occupied by the second generation systems, so the third generation services were implemented within the existing bands. [2]

The spectrum allocation for IMT-2000 bands of 2x60 MHz (1920-1980 MHz plus 2110-2170 MHz) is available in Europe, Japan and Korea and most Asian countries for WCDMA FDD operation. However, the availability spectrum for IMT-2000 TDD bands varies. In Europe and in Korea a 25 MHz band (1900-1920 MHz and 2020-2025

MHz) will be available for licensed TDD applications, and for unlicensed applications (SPA: Self Provided Applications) a 10 MHz band (2010-2020 MHz) is allocated. In Japan, part of the IMT-2000 spectrum TDD is used by cordless telephone system (PHS: Personal Handy Phone System). In the United States, at the time of the 1992 meeting, no new spectrum had yet been made available for third generation systems. In the United States, third generation services can be implemented using the existing PCS spectrum with alternative technologies, including EDGE, WCDMA, and CDMA 2000. At the ITU-R WRC-2000 in May 2000, the following additional frequency bands were also introduced for IMT-2000: 1710-1885 MHz, 2500-2690 MHz, and 806-960 MHz. According to [3], new third generation spectrums in the United States are expected to have 2x60 MHz (1710-1770 MHz and 2110-2170 MHz) assigned. These two spectrums can be efficiently used to carry third generation services with WCDMA. The new IMT-2000 spectrum 190 MHz (2500-2690 MHz) arrangement is still under discussion. [2]

The different air interfaces applied to each geographical area are shown in Figure 3; however, local exceptions are made to places where multiple technologies are being deployed. [2]

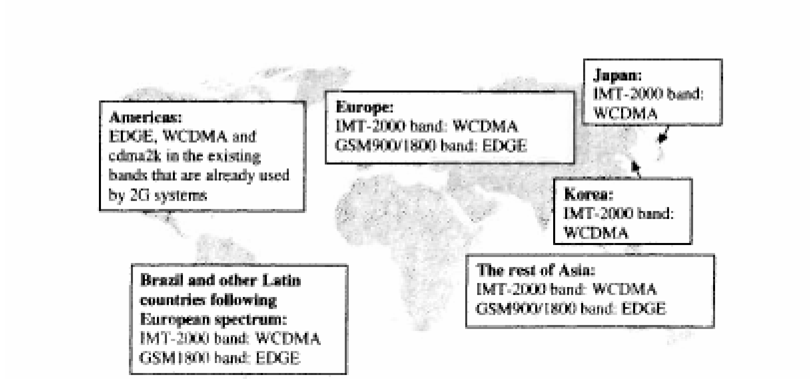

Figure 3 Expected air interfaces and spectrums for providing third generation services. From [2]

C. OUTLINE

This thesis is organized into the introduction and three chapters. In Chapter II, the basic theory of the physical layer of WCDMA is reviewed, including the basic parameters of the base station and the user equipment. Chapter III presents a link analysis of the WCDMA using several communication models. Finally, in Chapter IV the conclusions based on the results obtained from the analysis in the previous chapters are presented.

THIS PAGE INTENTIONALLY LEFT BLANK

II. PHYSICAL LAYER OF WCDMA

A. INTRODUCTION

The Wideband Code Division Multiple Access (WCDMA) is a third generation system which is not limited to a single service such as speech. Therefore its physical layer needs to have the flexibility to meet its varied requirements.

The functions of the physical layer are extensive and include RF processing aspects, chip rate processing, symbol rate processing and transport channel combination. In the forward link the data generated at higher levels (transport blocks via transport channels from Medium Access Control, MAC) are multiplexed and are carried over the air with transport channels, which are mapped in the physical layer to different physical channels. In the reverse link the physical layer receives the physical channels, extracts and processes the multiplexed data and delivers it up to the MAC. [1] The physical layer is required to support variable bit rate transport channels to offer bandwidth -on-demand services, and to be able to multiplex several services to one connection. [2] This chapter analyses the structure of the physical channels.

An important function of the physical layer is the RF aspects of the WCDMA transceiver. The transmitter and receiver specifications are presented in detail in this chapter, focusing on the FDD mode.

B. FORWARD LINK

1. Common Uplink Physical Channels: Physical Random Access Channel (PRACH)

An important aspect of UMTS is the random access procedure. It is required for mobile registration after power-up, initial call set up or location updating purposes. In UTRA these requirements are covered by an uplink transport channel called Random Access Channel. The RACH is mapped on the Physical Random Access (PRACH) at the physical layer. The PRACH has a specific feature, preambles that are sent prior to data transmission. [2] Once the preamble is detected and acknowledged by the Acquisition Indicator Channel (AICH) the 10 ms (or 20 ms) message part is transmitted. [2] The PRACH is based on a modified slotted aloha protocol with fast acquisition indication. [3-4]. In order to accommodate a large number of simultaneous users there are 16 special waveforms called access preambles. These waveforms have a spreading factor of 256, resulting in a total length of 4096 chips for the preamble as Figure 4 displays.

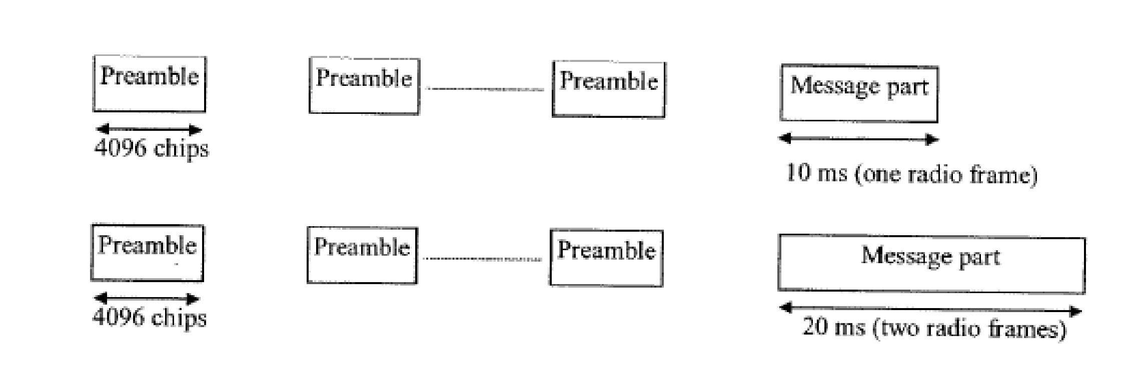

Figure 4 Structure of the random-access transmission. From [4]

Each access preamble is transmitted at well-defined time intervals, denoted as access slots. From Figure 5 it is easy to see that there are 15 access slots per two radio frames, spacing 5120 chips apart. Each radio frame has 10 ms duration [4]. The random access slots are distributed evenly within the radio frame structure. [1]

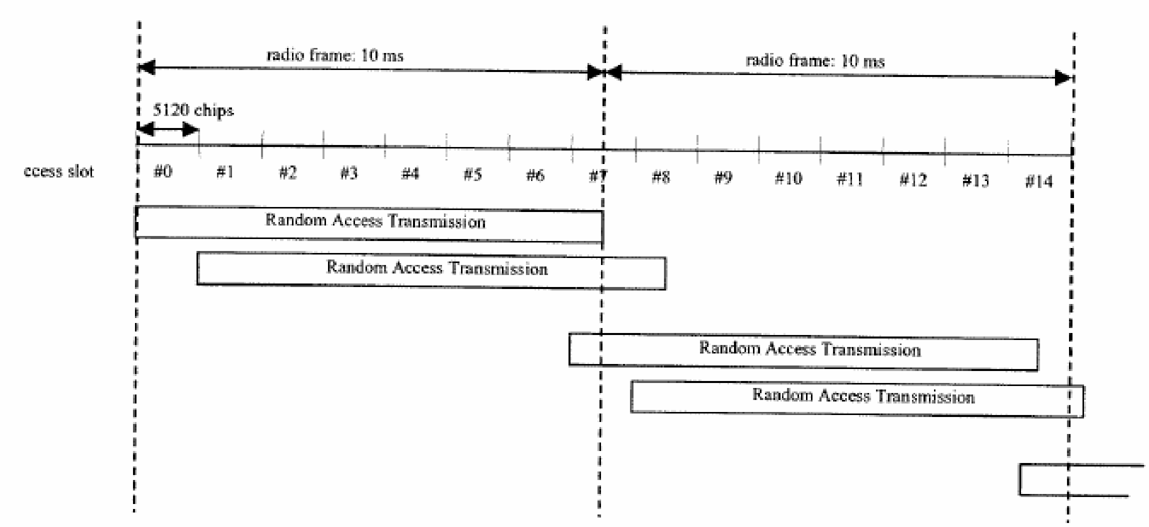

Figure 5 RACH access slot numbers and their spacing. From [4]

The basic structure of the radio-access message part radio frame is illustrated in Figure 6.

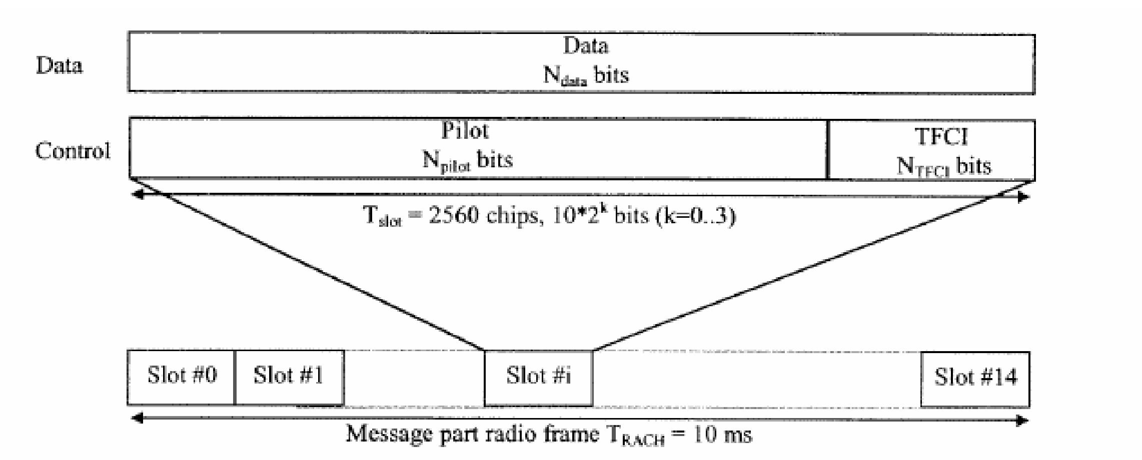

Figure 6 Structure of the random-access message part radio frame. From [4]

It is constructed from either a 10 ms frame or two 10 ms frames; however, both types have the same structure. [1] The message part of the radio frame is split into 15 slots, each of length T_{slot} =2560 chips. Each slot has two elements, the data and the physical control information, which are transmitted in parallel. The data part consists of

10×2^k bits, where k=0,1,2,3. Table 2.1 shows that the data rate ranges from 15 kb/s up to 120 kb/s corresponding to a spreading factor of 256, 128, 64 and 32 respectively. [4]

Slot Format #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{data}
0	15	15	256	150	10	10
1	30	30	128	300	20	20
2	60	60	64	600	40	40
3	120	120	32	1200	80	80

Table 1. Random-access message data fields. From [4]

The physical control part has a data rate of 15 kb/s corresponding to a spreading factor of 256. It consists of 8 pilot bits per slot and two Transport Format Combination Indicator (TFCI) bits per slot. The pilot bits are used to support channel estimation for coherent detection.

The TFCI bits are used to define the transport format of the RACH transport channel mapped to the simultaneously transmitted message part radio frame. [4] Each slot contains 2 TFCI bits; therefore, in a 10 ms frame of 15 slots are assigned 30 bits for the coded TFCI. These bits are used to define the transport format that is used in the PRACH. The selected TFCI is defined by a 10 bit codeword coded to 32 coded TFCI bits using a (32,10) Reed Muller. Two bits are punctured to reduce to a 30 bit codeword. The 30 bit codeword is divided to 15 segments of 2 bits per segment. Each segment is transmitted in the TFCI field of the physical control information part of the PRACH message [1].

2. Dedicated Physical Data Channel (Uplink DPDCH) and Dedicated Physical Control Channel (Uplink DPCCH)

The DPDCH is dedicated to transport the downlink channel. For each radio link there may be zero, one or several uplink DPDCHs (e.g., for multi-code transmission). The DPCCH carries the control information generated at Layer 1. On each radio link there is only one uplink DPCCH.

Figure 7 shows the uplink dedicated channel structure. Each radio frame of length 10 ms is split into 5 subframes, each of 3 slots, each of length T_{slot} =2560 chips, corresponding to one power-control period. The DPDCH and the DPCCH are transmitted in parallel. [4]

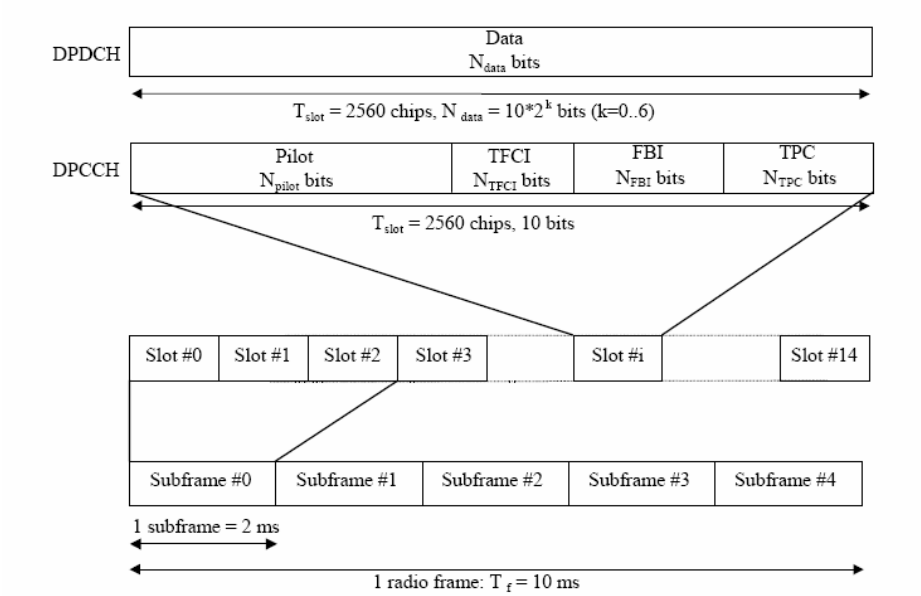

Figure 7 Uplink dedicated channel structure. From [4]

The number of bits per uplink DPDCH slot may vary from 10 to 640 bits with a spreading factor that may range from 256 down to 4. The spreading factor of DPCCH is always equal to 256; therefore, there are always 10 bits per uplink DPCCH slot. Table 2 and Table 3 show the exact number of bits in the uplink DPDCH and the different number uplink DPCCH fields ($N_{pilot}, N_{TFCI}, N_{FBI}, N_{TPC}$). Each DPCCH slot has four fields to be used for pilot bits, Transport Format Combination Indicator (TFCI) bits, Transmission Power Control (TPC) bits and Feedback Indicator (FBI) bits. [4]

Slot Format #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{data}
0	15	15	256	150	10	10
1	30	30	128	300	20	20
2	60	60	64	600	40	40
3	120	120	32	1200	80	80
4	240	240	16	2400	160	160
5	480	480	8	4800	320	320
6	960	960	4	9600	640	640

Table 2. DPDCH fields. From [4]

Slot Form at #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{pilot}	N_{TPC}	N_{TFCI}	N_{FBI}	Transmitted slots per radio frame
0	15	15	256	150	10	6	2	2	0	15
0A	15	15	256	150	10	5	2	3	0	10-14
0B	15	15	256	150	10	4	2	4	0	8-9
1	15	15	256	150	10	8	2	0	0	8-15
2	15	15	256	150	10	5	2	2	1	15
2A	15	15	256	150	10	4	2	3	1	10-14
2B	15	15	256	150	10	3	2	4	1	8-9
3	15	15	256	150	10	7	2	0	1	8-15
4	15	15	256	150	10	6	4	0	0	8-15

Table 3. DPCCH fields. From [4]

The pilot bits in DPCCH are used in the receiver for channel estimation, frequency tracking, time synchronization and trucking [4]. The TPC bits carry the power control commands for the downlink power control [2]. The FBI bits are used for closed loop transmission diversity in order to support techniques requiring feedback from UE to UTRAN Access Point. [4]

The TFCI bits are used for transport format detection by the receiver and hence they show how to decode, de-multiplex, and deliver the received data on the appropriate Transport Channels. [5] The TFCI bits may (e.g., for several simultaneous services) or may not (e.g., for fixed-rate services) be included in the DPCCH slot. The network determines if a TFCI should be transmitted, and all the UEs support the use of TFCI uplink. [4]. Each TFCI indicates the transport format for a specific frame, and the loss of the TFCI does not affect any other frames. However, this is a rare event due to its high reliability. [2]

3. Base Station (BS) Parameters

Next a consideration of the RF aspects of the base station is in order, focusing on the FDD mode. There are different specifications between the transmitting part and the receiving part of the base station due to their functions; therefore, each part will be analyzed separately.

The requirements in these specifications apply to Wide Area Base Stations, Medium Range Base Stations and Local Area base Stations. The Wide Area Base Stations are characterized by requirements derived from Micro Cell scenarios with BS to UE minimum coupling loss equal to 70 dB. The Medium Range Stations with a minimum coupling loss equal to 53 dB and for the Local Area Base Stations equals to 45 dB. [7] The UTRA/FDD is designed to operate based on a chip rate of 3.84 Mcps, as shown in the following Table 11. [6]

Operating Band	UL Frequencies UE transmit, Node B receive	DL frequencies UE receive, Node B transmit
I	1920 - 1980 MHz	2110 -2170 MHz
II	1850 -1910 MHz	1930 -1990 MHz
III	1710-1785 MHz	1805-1880 MHz
IV	1710-1755 MHz	2110-2155 MHz
V	824 - 849MHz	869-894MHz
VI	830-840 MHz	875-885 MHz
VII	2500 - 2570 MHz	2620 - 2690 MHz
VIII	880 - 915 MHz	925 - 960 MHz
IX	1749.9 - 1784.9 MHz	1844.9 - 1879.9 MHz
X	1710-1770 MHz	2110-2170 MHz

Table 4. Frequency Bands. From [6]

a. Base Station Transmitter Specifications

(1) Output Power. The output power is defined by the manufacturer, but in general it is in the range of 10 to 40 W. [1] The downlink total power dynamic range is at least 18 dB in steps of 1 dB mandatory or optional 0.5, 1.5, 2.0 dB. The rated output power (PRAT), which is the mean power level per carrier that the manufacturer has declared to available at the antenna connector, is are displayed in Table 5. In normal conditions, the Base station maximum output power shall remain within +2 dB and -2 dB of the manufacturer's rated output power [6].

BS class	PRAT
Wide Area BS	- (note)
Medium Range BS	$\leq$ +38 dBm
Local Area BS	$\leq$ + 24 dBm
NOTE: There is no upper limit required for the rated output power of the Wide Area Base Station like for the base station for General Purpose application in Release 99, 4, and 5.	

Table 5. Base Station rated output power. From [6]

(2) Error Vector magnitude (EMV). The EMV measures how closely the transmitter performs to an ideal transmitter. [1] It measures the difference between a reference waveform and a measured waveform which is called the error vector. These waveforms are passed through a Root Raised Cosine filter with bandwidth 3.84 MHz and roll-off factor $\alpha = 0.22$. In order to minimize the error vector both waveforms are modified by selecting the frequency, absolute phase, absolute amplitude and chip clock timing. [7] The EMV is defined by the following formula: $EMV = \sqrt{\frac{\sum_{i=1}^{n}(EMV_i)^2}{\sum_{i=1}^{n}(REF_i)^2}}$.

[1] When the base station is transmitting a composite signal using a QPSK modulation, the EMV should not be higher than 17.5 %. However if the base station is using 16QAM modulation, the EMV should not be higher than 12.5 %. [6] Figure 8 displays the effects that I / Q phase offset error contributes to the error vector. In order to achieve the ideal specification level of 17.5 %, the I/Q phase offset error should be much less than 20 degrees.

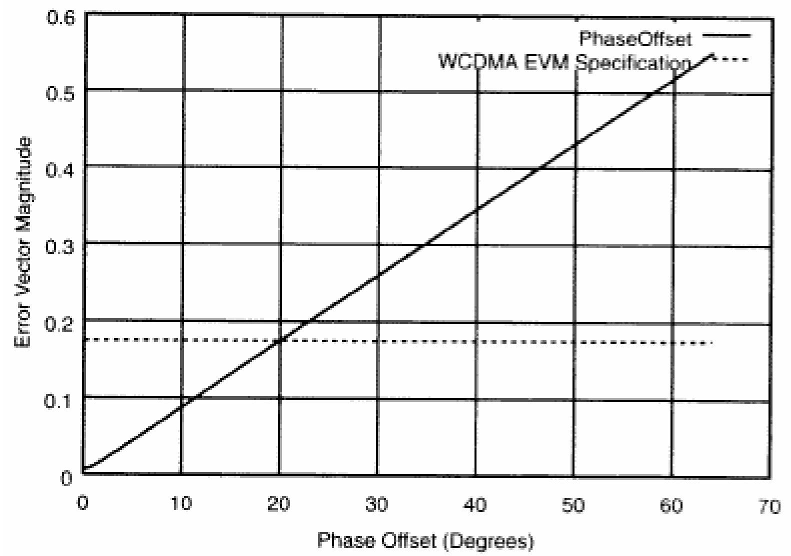

Figure 8 EMV versus I/Q phase offset. From [1]

Figure 9 illustrates the effects that the amplitude offset contributes to the error vector. From the curves, it is clear that I/Q amplitude balance should be much less than 3 dB to ensure that the EMV remains within the specification limits. [1]

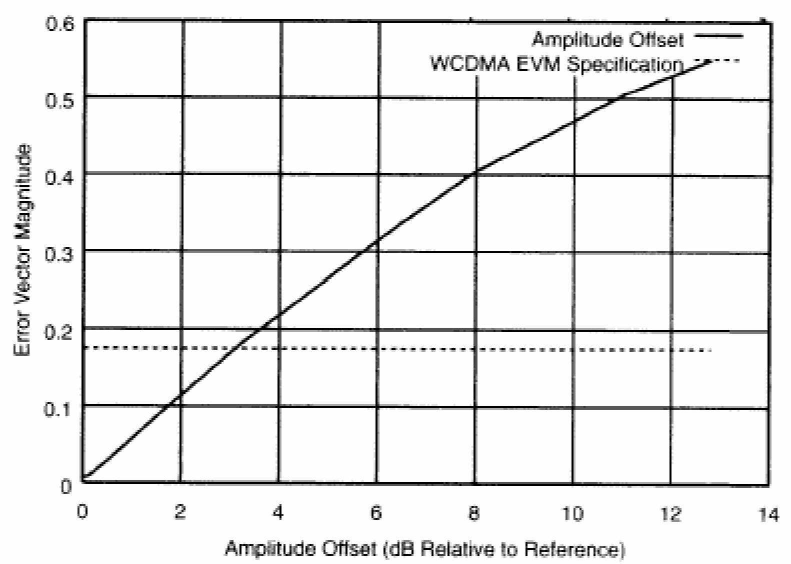

Figure 9 EMV versus I/Q amplitude offset. From [1]

(3) Peak Code Domain Error (PCDE). The PCDE measures the distortion of the transmit signal. [1] For every code in the domain a Code Domain Error is defined, which is the ratio of the mean power of the projection onto the code domain to the mean power of the composite reference waveform. The PCDE is the maximum value for the Code Domain Error for all codes, and it should not exceed -33 dB at spreading factor 256. [6]

(4) Adjacent Channel Leakage power Ratio (ACLR). The Adjacent Channel Leakage power Ratio (ACLR) is the ratio of the Root Raised Cosine filter (RRC) mean power centered on the assigned channel frequency to the RRC filtered mean power centered on an adjacent channel frequency. The specification defines two ACLR performance levels of 45 dB for a 5 MHz offset and 50 dB for a 10 MHz offset. [7] Factors that affect the ACLR are issues such as the length of the RRC filter. Figure 10 shows the 5 MHz and 10 MHz ACLR results obtained by a RRC filter whose length is increased from 4 to 32 chips. From the graph we can see a decreasing trend with an increasing filter length. The minimum length for the RRC filter should be 10 chips; therefore, a 16 chips length RRC filter provides a sufficient margin over the specification level. [1]

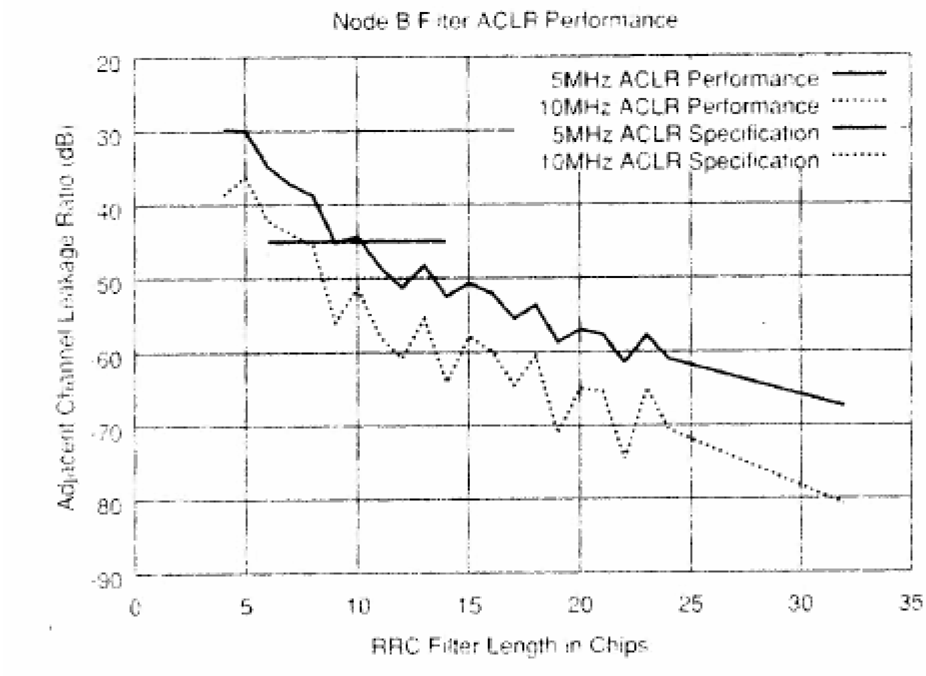

Figure 10 ACLR performance specifications. From [1]

(5) Spectrum Emission Mask. The mask is dependent on the carrier frequency, and along with ACLR characterizes the out-of-band emissions. These emissions are immediately outside the channel bandwidth, caused by the modulation process and non-linearity in the transmitter. Figure 11 illustrates the mask for powers from 31 dBm to greater than 43 dBm for measurement bandwidths based on either 30 kHz or 1 MHz. The close –to- carrier measurement bandwidths are 30 kHz, and the away-from-carrier ones are 1 MHz. [1]

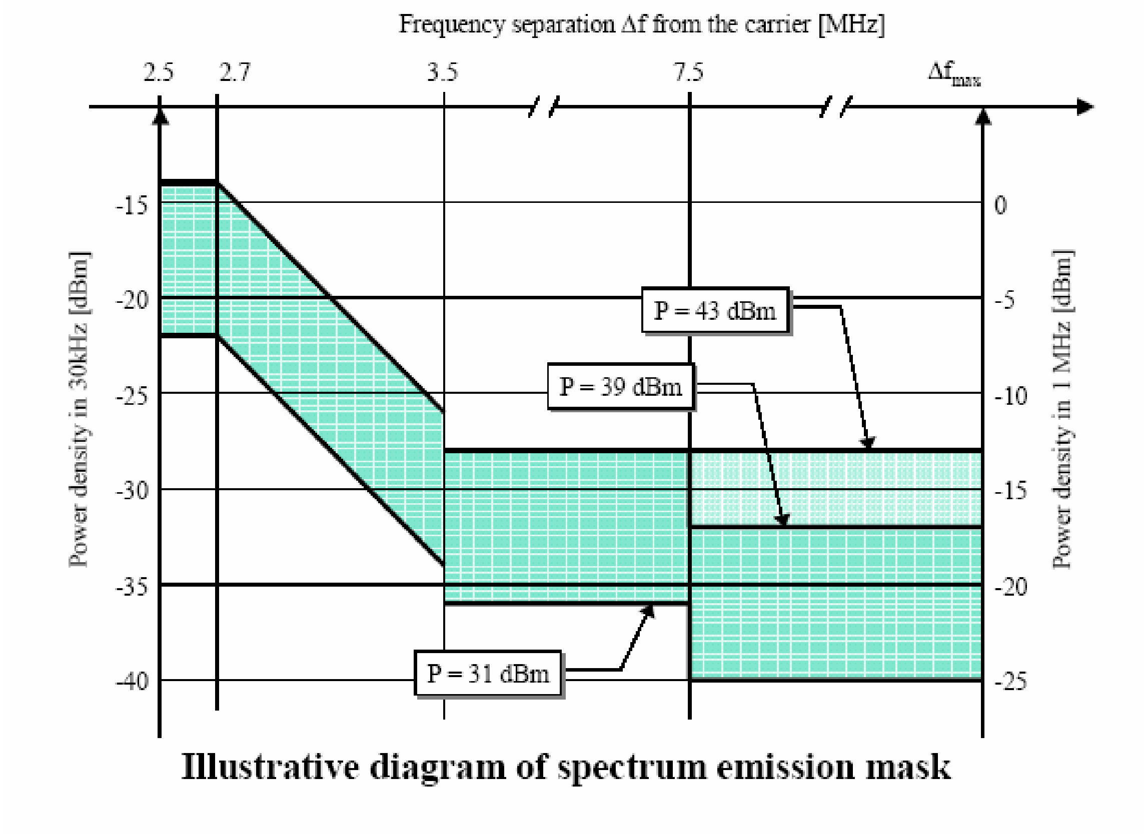

Figure 11 Spectrum emission mask. From [6]

(6) Spurious emissions. These are emissions which are caused by unwanted transmitter effects, such as harmonic emissions, parasitic emission, intermodulation products and frequency conversion products, but exclude out-of-band emissions. This effect is measured at the base station RF output port. [6] Table 6 illustrates the spurious emission specifications to which the transmitter must conform.

Band (MHz)	Usage	Maximum level	Measurement bandwidth
1920–1980	UTRA Rx Band I	−96 dBm	100 kHz
1850–1910	UTRA Rx Band II	−96 dBm	100 kHz
1710–1785	UTRA Rx Band III	−96 dBm	100 kHz
921–960	GSM 900 MS	−57 dBm	100 kHz
876–915	GSM 900 BTS	−98 dBm	100 kHz
1805–1880	DCS1800 MS	−47 dBm	100 kHz
1710–1785	DCS1800 BTS	−98 dBm	100 kHz
1893.5–1919.6	PHS	−41 dBm	300 kHz
1900–1920	UTRA-TDD	−52 dBm	1 MHz
2010–2025	UTRA-TDD	−52 dBm	1 MHz
1900–1920	UTRA-TDD (co-located)	−86 dBm	1 MHz
2010–2025	UTRA-TDD (co-located)	−86 dBm	1 MHz

Table 6. Spurious emission specifications. From [6]

These requirements apply whatever the type of transmitter (single carrier or multiple carriers) and at frequencies within the specified frequency ranges (more than 12.5 MHz above the last carrier frequency used or more than 12.5 MHz below the first carrier frequency used). [6]

b. Base Station Receiver Specifications

In this section we will explore the receiver RF characteristics for the base station which is not equipped with diversity. For receivers with diversity the requirements apply to each antenna connector separately if the other one(s) is/are terminated or disabled. [6]

(1) Receiver Sensitivity. The receiver sensitivity level is the minimum power received at the antenna connector at which the Bit Error Ratio (BER) shall not exceed a specific value, depending on the area that the base station is operating. [6] Table 7 illustrates the base station reference sensitivity levels and the performance of the base station.

BS Class	Reference measurement channel data rate	BS reference sensitivity level (dBm)	BER
Wide Area BS	12.2 kbps	-121	BER shall not exceed 0.001
Medium Range BS	12.2 kbps	-111	BER shall not exceed 0.001
Local Area BS	12.2 kbps	-107	BER shall not exceed 0.001

Table 7. BS reference sensitivity levels. From [6]

(2) Receiver Dynamic Range. The receiver dynamic range is the receiver ability to handle a rise of interference in the reception frequency channel. The receiver shall fulfill a specified BER requirement for the specified sensitivity degradation of the wanted signal in the presence of interfering AWGN signal in the same reception frequency channel. The BER shall not exceed 0.001, depending on the parameters that are specified in Table 8. [6]

Parameter	Level Wide Area BS	Level Medium Range BS	Level Local Area BS	Unit
Reference measurement channel data rate	12.2	12.2	12.2	kbps
Wanted signal mean power	-91	-81	-77	dBm
Interfering AWGN signal	-73	-63	-59	dBm/3.84 MHz

Table 8. Dynamic range. From [6]

Figure 12 illustrates the physical interpretation of the dynamic range test for a wide area base station. The interfering signal is attenuated by an amount equal to processing gain. The BER of 0.1% can be achieved as long as the resultant noise signal is $\frac{E_b}{N_0}$ plus margin below the desired signal. Therefore the receiver dynamic range is 18 dB [1].

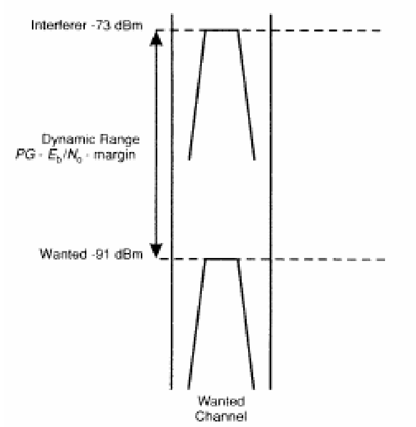

Figure 12 Node B receiver dynamic range calculations. From [1]

(3) Adjacent Channel Selectivity (ACS). As stated in [6], the adjacent channel selectivity is a measure of receiver ability to receive a desired signal at its assigned channel frequency in the presence of an adjacent channel signal at a given frequency offset from the center frequency of the assigned channel. The ACS is the ratio of the receiver filter attenuation on the assigned channel frequency to the receiver filter attenuation on the adjacent channel. For an average error rate BER of 0.001, the adjacent channel selectivity requirements are specified in Table 9.

Parameter	Level Wide Area BS	Level Medium Range BS	Level Local Area BS	Unit
Data rate	12.2	12.2	12.2	kbps
Wanted signal mean power	-115	-105	-101	dBm
Interfering signal mean power	-52	-42	-38	dBm
Fuw offset (Modulated)	5	5	5	MHz

Table 9. Adjacent channel selectivity. From [6]

Figure 13 shows the ACS filtering estimation. The interfering signal is attenuated by an amount equal to the ACS plus the processing gain (PG) less $\frac{E_b}{N_0}$ and the margins required for threshold sensitivity [1].

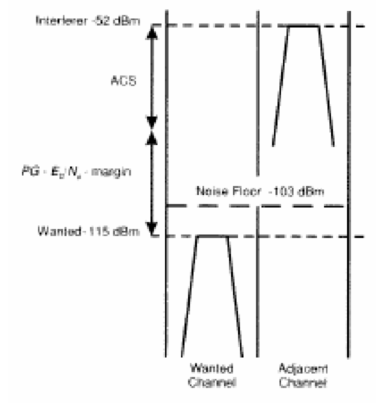

Figure 13 Node B receiver ACS filtering estimation. From [1]

In order to calculate the ACS we are using the distribution in Table 9 applied to each type of base station area. Therefore ACS= Interferer -Wanted Signal -PG + $\frac{E_b}{N_0}$ + margin. The processing gain is $PG = 10 \times \log_{10}(3.84e^6 / 12.2e^3)$ =25 dB. The value of $\frac{E_b}{N_0}$ is 5 dB and the margin is 2 dB. For each wanted signal, ACS is 45 dB [1].

(3) Blocking Characteristic. The blocking characteristic is a measure of the receiver's ability to receive a wanted signal at its assigned channel frequency in the presence of an unwanted interferer on frequencies other than those of the adjacent channels [6]. The physical process in the receiver and the method used to estimate the receiver blocking performance is illustrated in Figure 14 [1].

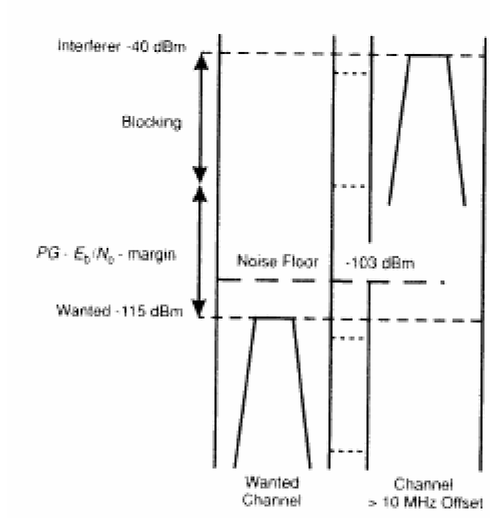

Figure 14 Node B receiver blocking calculations. From [1]

As with the ACS case, the blocking filter and the processing gain protect the receiver from the effects of the interference in the receiver. [1] Working similarly to ACS, we come up with the blocking calculations shown in Table 10 using two types of interfering signals, a WCDMA signal and a CW signal.

Type of Area	**Measurement Channel**	**Mean power of the wanted signal**	**Interfering mean power signal**	**Type of Interfering channel**	**Blocking**
Wide Area	12.2 Kbps	-115 dBm	-40 dBm	WCDMA signal	**57 dB**
Wide Area	12.2 Kbps	-115 dBm	-15 dBm	CW signal	**82 dB**
Medium Range	12.2 Kbps	-105 dBm	-35 dBm	WCDMA signal	**52 dB**
Medium Range	12.2 Kbps	-105 dBm	-15 dBm	CW signal	**72 dB**
Local Area	12.2 Kbps	-101 dBm	-30 dBm	WCDMA signal	**53 dB**
Local Area	12.2 Kbps	-101 dBm	-15 dBm	CW signal	**68 dB**

Table 10. Blocking calculations

The blocking specification extends the ACS specification into the adjacent bands. As a consequence, the interfering signal powers are greater than for the ACS specification. [1]

(4) Receiver Intermodulation Specification. Non–linear devices such as mixers can produce intermodulation products. Figure 15 presents a general analysis in the generation of n^{th} - order intermodulation products referred to the input of a non-linearity. [1]

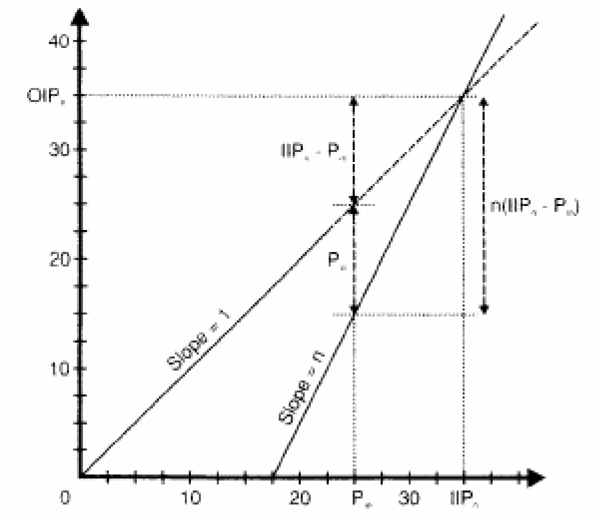

Figure 15 Node B receiver blocking calculations. From [1]

The receiver can be subject to two different interfering signals: the first one (10 MHz offset) is a CW signal and the second one (20 MHz offset) is a WCDMA signal. [1] For a narrowband intermodulation the two interfering signals are: 3.5 MHz offset signal for a CW signal and 5.9 MHz offset signal for a modulated Gaussian Minimum Shift Keying (GMSK) signal. [6] From the diagram we can derive the following formula: P_{in} = $n\times(\mathrm{II}P_n - P_{in})$- $(\mathrm{II}P_n - P_{in})$. The n^{th}- order input intermodulation product is $\mathrm{II}M_n$ is: $\mathrm{II}M_n = P_{in} - P_{in}$. We are interested in the third and higher order of mixing because the two interfering RF signals can produce an interfering signal in the band of the desired channel, so for n=3 the intermodulation product is $\mathrm{II}M_3 = 3P_{in} - \mathrm{II}P_3$. [1] The intermodulation response rejection is a measure of the capability of the receiver to receive a desired signal on its assigned channel frequency in the presence of two or more interfering signals which have a specific frequency relationship to the desired signal. [6] Figure 16 illustrates the physical processes that occur in an intermodulation test for a base station receiver operated in a wide area.

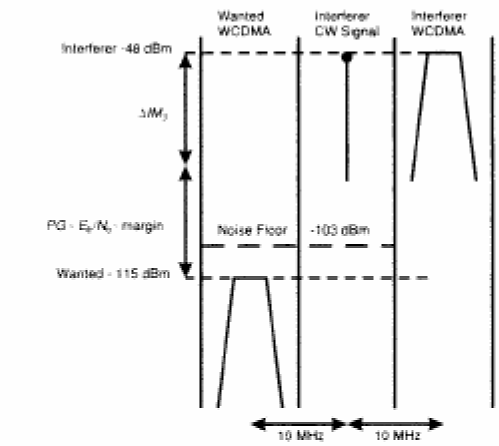

Figure 16 Intermodulation generation processes. From [1]

The two RF signals intermodulate due to non-linearities that are present at the front of the receiver producing components that are present in the receiver bandwidth. The maximum level for these intermodulation products can be derived from the formula $\Delta IM_3 \geq$ Interferer – Wanted – PG + $\frac{E_b}{N_0}$ + margin. The processing gain is again 25 dB, the value of $\frac{E_b}{N_0}$ is 5 dB, and the margin is 2 dB. The third order intercept point (IIP_3) is: $IIP_3 \geq P_{sig} + \frac{\Delta IM_3}{2}$. Tables 11 and Table 12 show the intermodulation rejection and the intercept point for a wideband and a narrowband interferer respectively. [1]

Type of Area	Measurement Channel	Mean power of the wanted signal	Interferer	Intermodulation rejection	Intercept point
Wide Area	12.2 Kbps	-115 dBm	-48 dBm	**≥ 49 dB**	**≥ -23.5 dB**
Medium Range	12.2 Kbps	-105 dBm	-44 dBm	**≥ 43 dB**	**≥ -22.5 dB**
Local Area	12.2 Kbps	-101 dBm	-38 dBm	**≥ 45 dB**	**≥ -15.5 dB**

Table 11. Intermodulation calculations for wideband interferer

ype of Area	Measurement Channel	Mean power of the wanted signal	Interferer	Intermodulation rejection	Intercept point
Wide Area	12.2 Kbps	-115 dBm	-47 dBm	**≥ 50 dB**	**≥ -22 dB**
Medium Range	12.2 Kbps	-105 dBm	-43 dBm	**≥ 44 dB**	**≥ -21 dB**
Local Area	12.2 Kbps	-101 dBm	-37 dBm	**≥ 46 dB**	**≥ -14 dB**

Table 12. Intermodulation calculations for narrowband interferer

C. REVERSE LINK

1. Common Downlink Physical Channels

a. Common Pilot Channel (CPICH)

The common pilot channel is used for channel estimation at the terminal for the dedicated channel and provides an additional phase reference in the use of adaptive antennas where hot spots are present. [2] The CPICH has a fixed rate (30 kbps, SF=256) with a predefined bit sequence (T_{slot} =2560 chips, 20 bits). Figure 17 shows the structure of the CPICH. [4]

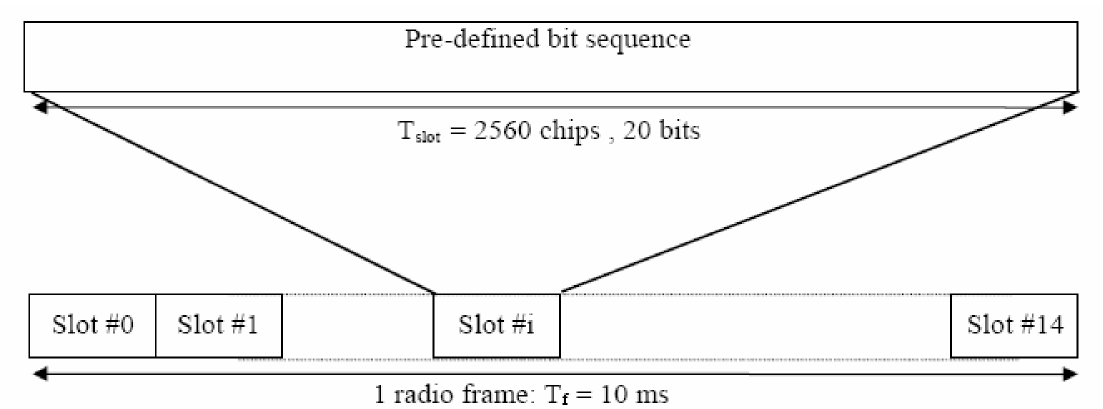

Figure 17 Frame structure for Common Pilot Channel. From [4]

An important aspect of the primary common pilot channel is the handover measurements and cell selection/reselection. Adjusting the CPICH power level at the terminal, the cell load can be balanced between different cells. If the CPICH power reduces, some of the terminals hand over to other cells. On the other hand, if it increases, more terminals are invited to hand over to the cell and to make their initial access to the network in that cell. [2]

There are two types of common pilot channel, primary and secondary. The primary CPICH is scrambled by the primary scrambling code using the same channelization code, and there is only one P-CPICH per cell broadcasted over the entire cell coverage area. The secondary CPICH is scrambled by either the primary or the secondary scrambling code using an arbitrary channelization code of SF 256, and there may be zero, one or several S-CPICH per cell. S-CPICH may be transmitted over the entire cell or only over a part of the cell. [4]

b. Synchronization Channel (SCH)

The Synchronization Channel (SCH) is a downlink signal needed for the cell search. It consists of two subchannels, the primary and the secondary synchronization channels. The primary and secondary SCH have a radio frame of 10 ms, divided into 15 slots each of length 2560 chips. [4] Figure 18 illustrates the structure of the SCH radio frame.

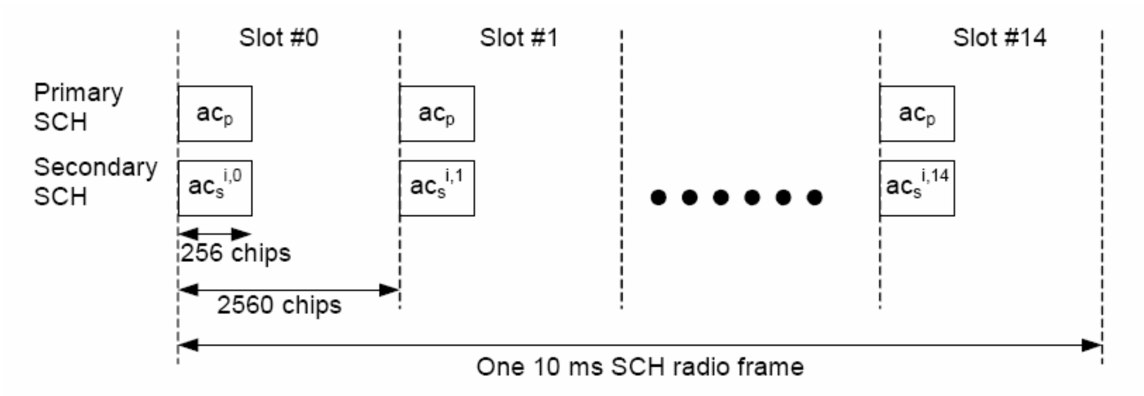

Figure 18 Structure of Synchronization Channel (SCH). From [4]

The Primary SCH consists of a modulated 256-chip code identical in every cell. The Primary Synchronization Code (PSC) is denoted c_p in Figure 18 and is transmitted once every slot. The Secondary SCH uses sequences with different code word combination possibilities representing different code groups. It is transmitted in parallel with the Primary SCH. The Secondary SCH helps the terminal obtain the frame and slot synchronization as well as information about the group that the cell belongs to. The 256 chip of the Secondary SCH is pointing to 64 different code groups. The Secondary Synchronization Code is denoted $c_s^{i,k}$ in Figure 16 where i=0, 1, 2,…, 63 is the number of scrambling group, and k =0, 1,…,14 is the slot number. [4]

c. Primary Common Control Physical Channel (P-CCPCH)

The P-CCPCH is the physical channel used to transmit the Broadcast Channel (BCH). The channel bit rate is 30 kbps with a SF=256. In this particular channel there is not any pilot information bits present since the P-CCPCH needs to be available over the whole cell area using the same antenna radiation pattern as the common pilot channel. [2] The P-CCPCH does not carry any power control information for any of the terminals, but is used to provide system-wide cell broadcast information which is used by the UE when first trying to locate the UTRA or any other subsequent communication with it. [1] The frame structure is shown in Figure 19.

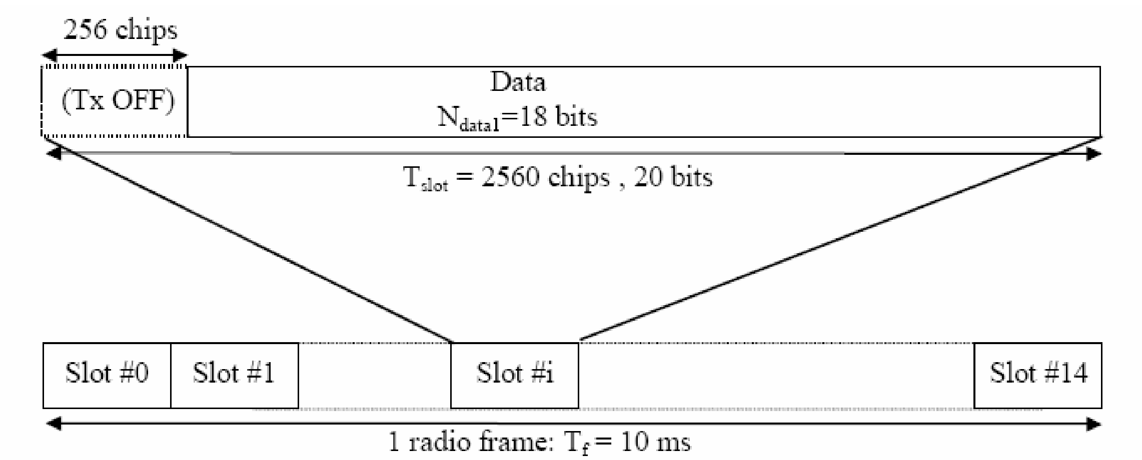

Figure 19 Frame structure for primary common control physical channel. From [4]

As shown in Figure 19, the P-CCPCH is switched off for the duration of 256 chips at the start of each slot in order to facilitate the transmission of the primary and secondary synchronization channels which occurs in this 256 chip part of the slot. [1]

d. Secondary Common Control Physical Channel (S-CCPCH)

The S-CCPCH is used to carry two different common control transport channels, the Forward Access Channel (FACH) and the Paging Channel (PCH). The FACH and PCH can be mapped to the same or separate S-CCPCHs. In a case of a single S-CCPCH, FACH and PCH are mapped to the same frame, reducing the degrees of freedom in terms of data rates, since all the terminals need to detect the FACH and PCH.

The motivation for multiplexing the channels together is the base station budget. Since both the channels need to be transmitted at full power for all the terminals to receive, avoiding the need to send them simultaneously obviously reduces the base station power level variations. For more than one FACH and PCH mapped to additional S-CCPCH, the data rates may vary [2]. The frame structure of the S-CCPCH is shown in Figure 20.

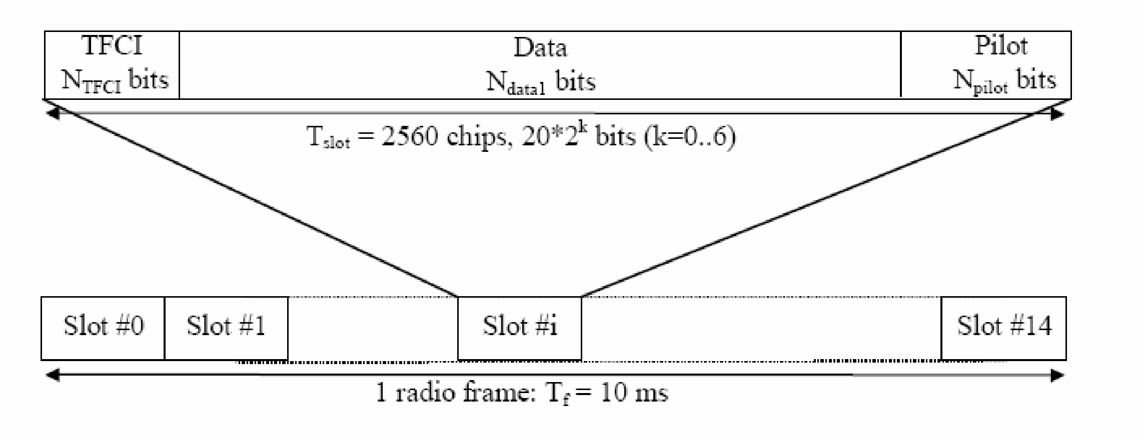

Figure 20 Frame structure for secondary common control physical channel. From [4]

e. Acquisition Indicator Channel (AICH)

The AICH is used to indicate the reception of the random access channel signature sequence from the base station responding to the PRACH sequence. The waveform that is selected for use on the AICH is in direct response to the waveform detected as being used on the PRACH. [1] Figure 21 illustrates the structure of AICH.

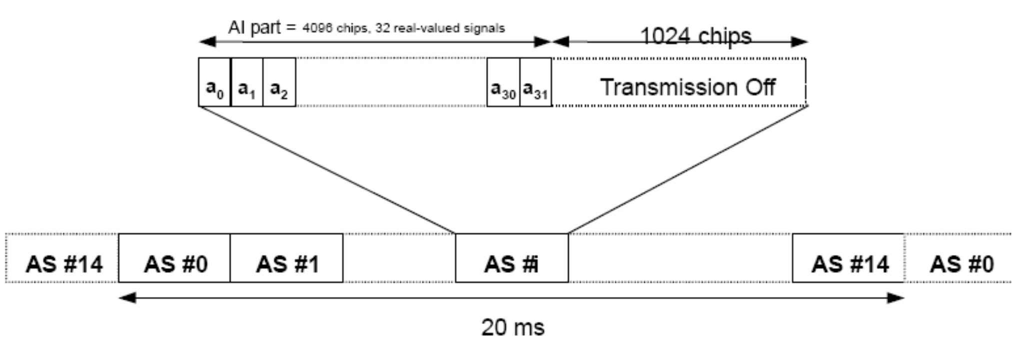

Figure 21 Structure of acquisition indicator channel. From [4]

The AICH structure has duration of 20 ms and consists of a repeated sequence of 15 consecutive access slots (AS), each of length 5120 chips. Each access slot consists of two parts, an Acquisition – Indicator (AI) part, which corresponds to 32 symbols, spread with a spreading factor of 256, and a part of four symbols with no transmission that is not formally part of AICH. The part of the slot with no transmission is reserved for possible future use by other physical channels.

In order to detect the AICH, the terminal obtains the phase reference from the primary common pilot channel (P-CPICH). All terminals must hear the AICH, so it is sent with high power level without power control. It is not visible to higher levels; however, it is controlled by the physical layer in the base station. [2]

f. Paging Indicator Channel (PICH)

The paging indicator channel (PICH) shown in Figure 22 is associated with an S-CCPCH to which a PCH transport channel is mapped to provide terminals with efficient sleep mode operation. [2]

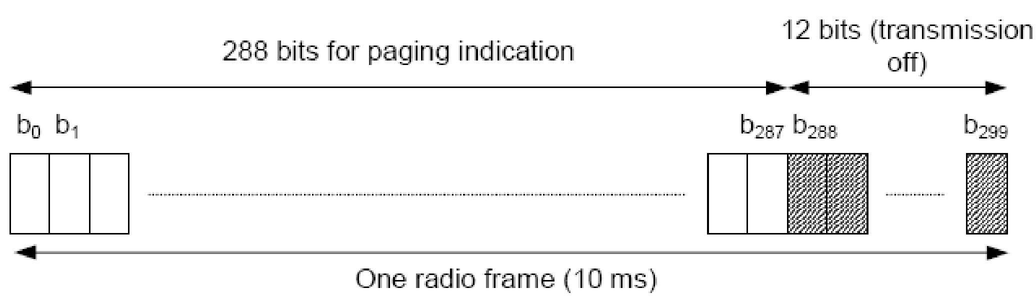

Figure 22 Structure of paging indicator channel. From [4]

The PICH consists of a 10 ms radio frame of 300 bits (b_0 ,b_1 ,…,b_{299}). Of these, 288 bits are used to carry paging indicators and the remaining 12 bits are reserved for possible future use. In each PICH frame, N_p paging indicators { P_0, …, P_{N_p-1} } are transmitted where N_p can be 18, 32, 72 or 144. The paging bits define whether or not there is a paging message present, and are associated with the value of the paging indicator P_q. The values of P_q can either be 1 or 0 depending on whether or not a paging message is present. [1].

2. Dedicated Downlink Physical Channels (DPCH)

The DPCH is used to carry the DPDCH and the DPCCH time-multiplexed together. The DPDCH is used to carry the dedicated data generated at Layer 2 and the DPCCH is used to carry the control information generated at Layer 1 (known pilot bits, TPC commands and optional TFCI). [4] Figure 23 shows the frame structure of the downlink DPCH.

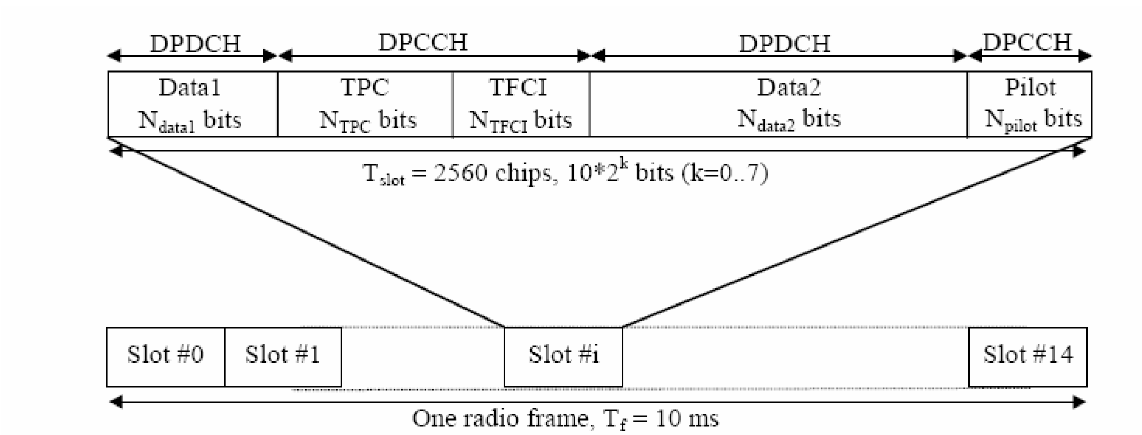

Figure 23 Frame structure for downlink DPCH. From [4]

As stated previously, the DPDCH and the DPCCH are transmitted together, within the same slot but separated in time. The DPDCH is divided into two parts, data 1 and data 2; the DPCCH is divided into three parts, the TFCI bits, the power control bits and the in-band pilot bits. In total there are 15 slots, each of length T_{slot} =2560 chips, per radio frame of duration 10 ms. [1]

3. User Equipment (UE) Parameters

As with the base station parameters, the RF aspects of the user equipment are considered, analyzing the transmitting part and the receiving part separately.

a. User Equipment Transmitter Specifications

(1) Output Power. The output power level will depend on the operating band. Normally it is +24 dBm with a tolerance of +1/-3 dB for power class 3 or +21 dBm with a tolerance of +2/-2 dB for power class 4. [7].

(2) Error Vector Magnitude (EMV). The UE has the same requirements as the base station specification that is less than 17.5 % with I/Q phase offset error much less 20 degrees. These measurements correspond to one time slot interval except when the mean power between the slots is expected to change. In this case the measurement interval is reduced by 25 ms at each end of the slot [7].

(3) Peak Code Domain Error (PCDE). The test signals include two coded channels each with SF=4 and a DPCCH. The peak code domain error should not exceed 15 dB below the transmitted signal power. [1] The measurement interval corresponds to one timeslot except when the mean power between the slots is expected to change, whereupon the measurement interval is reduced by 25 ms at each end of the slot. [7]

(4) Adjacent Channel Leakage (ACLR). The ACLR specification for the UE defines two performance levels of 33 dB for a 5 MHz offset and 43 dB for a 10 MHz offset. Figure 24 illustrates the 5 MHz and 10 MHz ACLR results obtained from an RRC filter whose length is increased from 4 to 32 chips. From the graph we can see that the minimum RRC filter length is 6 chips and 12 chips respectively, that provide sufficient margin over the specification levels. [1]

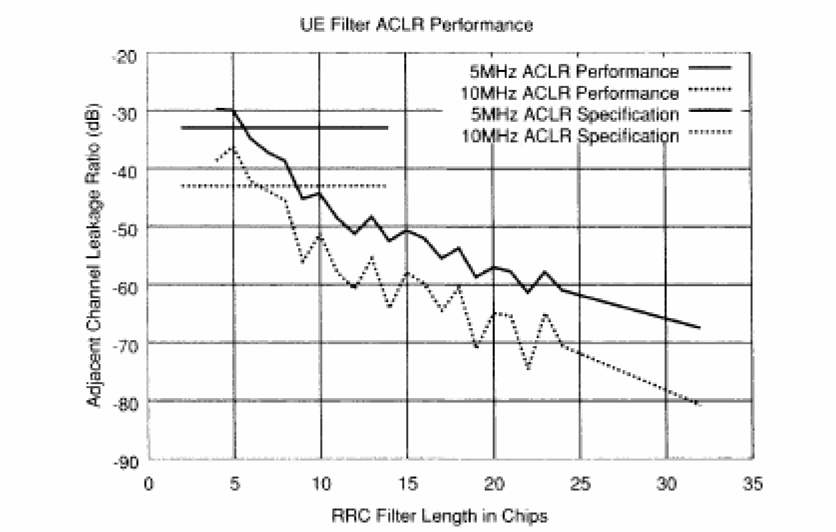

Figure 24 UE ACLR performance. From [1]

(5) Spectrum Emission Mask. In the case of spectrum emission mask the measurements are based on either the close-to-carrier measurements using 30 kHz bandwidth or the away-from-carriers using 1 MHz bandwidth. [1]

b. User Equipment Receiver Specifications

(1) UE Receiver Sensitivity. The minimum power received at the UE antenna port at which the bit error rate does not exceed 0.001 is defined at Table 13, and depends on the operating band of the UE.

Operating Band	Sensitivity (dBm)
I	-117
II	-115
III	-114
IV	-117
V	-115
VI	-117
VII	-115
VIII	-114
IX	-116
X	-117

Table 13. Reference sensitivity. From [7]

(2) UE Adjacent Receiver Selectivity (ACS). It is not possible to directly measure the ACS for all operating bands; therefore, a lower and an upper range of input signals are chosen in Table 13 where BER does not exceed 0.001. For a 12.2 kb/s measurement voice channel the lower and the upper range are shown in Table 14 [7].

Parameter	Lower range	Upper range
Wanted signal	-103 dBm	-73 dBm
Signal interferer	-52 dBm	-25 dBm
Signal offset	5 MHz	5 MHz

Table 14. Test parameters for adjacent channel selectivity. From [7]

Using the Table 14 and working in a manner similar to the ACS of the base station receiver, we calculate ACS to be approximately 33 dB. [1]

(3) UE Blocking Characteristics. There are two types of UE blocking characteristics: the in-band blocking and the out-of-band blocking. The in-band blocking is defined for an unwanted interfering signal falling into the UE receive band below or above 15 MHz. The out-of-band blocking is defined as an unwanted interfering signal falling more than 15 MHz below or above the UE receive band [7]. The blocking in-band specifications are summarized in Figure 25. Using the values of Figure 25 and calculating the base station receiver, the blocking in-band requirements for the UE receiver are shown in Table 15.

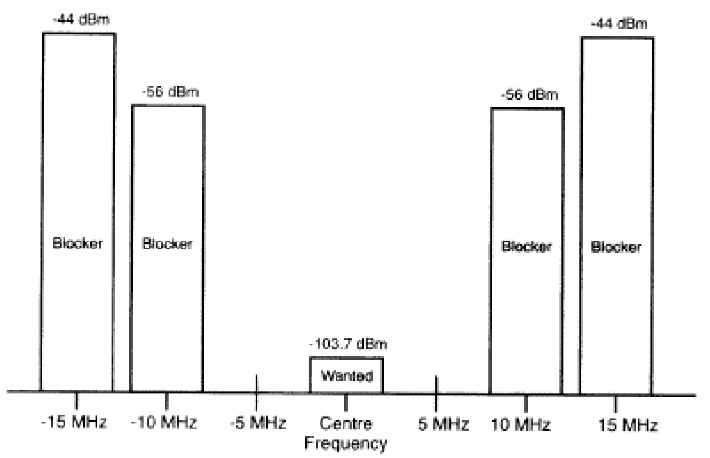

Figure 25 UE receiver in-band blocking specifications. From [1]

Wanted signal	Interfering signal	Interfering offset	Blocking
-114 dB	-56dB	10 MHz	**40 dB**
	-44 dB	15 MHz	**52 dB**
-113 dB	-56dB	10 MHz	**39 dB**
	-44 dB	15 MHz	**51 dB**
-112 dB	-56dB	10 MHz	**38 dB**
	-44 dB	15 MHz	**50 dB**
-111 dB	-56dB	10 MHz	**37 dB**
	-44 dB	15 MHz	**49 dB**

Table 15. The results for the blocking in band receiver

The results for blocking out-of-band UE receiver are shown in Table 16, taking into consideration Figure 26 specifications.

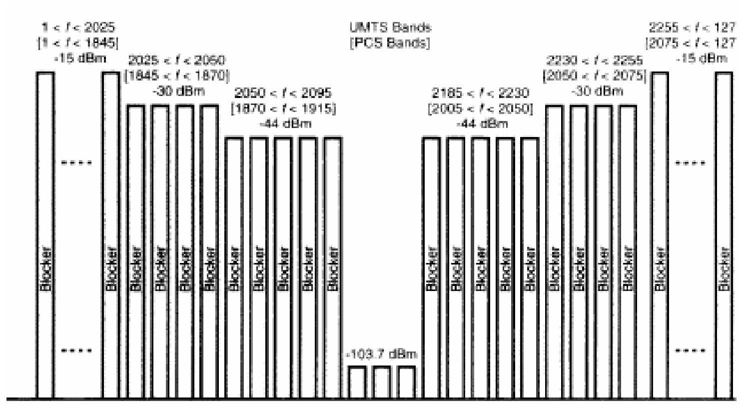

Figure 26 UE receiver out-of-band blocking specifications. From [1]

Wanted signal	Interfering signal	Interfering offset (MHz)	Blocking
-114 dB	-44 dB	2050<f<2095,1870<f<1915,2185<f<2230,2005<f<2050	**52 dB**
	-30 dB	2025<f<2050,1845<f<1870,2230<f<2255,2050<f<2075	**66 dB**
	-15 dB	1<f<2025,1<f<1845,2255<f<12750,2075<f<12750	**81 dB**
-113 dB	-44 dB	2050<f<2095,1870<f<1915,2185<f<2230,2005<f<2050	**51 dB**
	-30 dB	2025<f<2050,1845<f<1870,2230<f<2255,2050<f<2075	**65 dB**
	-15 dB	1<f<2025,1<f<1845,2255<f<12750,2075<f<12750	**80 dB**
-112 dB	-44 dB	2050<f<2095,1870<f<1915,2185<f<2230,2005<f<2050	**50 dB**
	-30 dB	2025<f<2050,1845<f<1870,2230<f<2255,2050<f<2075	**64 dB**
	-15 dB	1<f<2025,1<f<1845,2255<f<12750,2075<f<12750	**79 dB**
-111 dB	-44 dB	2050<f<2095,1870<f<1915,2185<f<2230,2005<f<2050	**49 dB**
	-30 dB	2025<f<2050,1845<f<1870,2230<f<2255,2050<f<2075	**63 dB**
	-15 dB	1<f<2025,1<f<1845,2255<f<12750,2075<f<12750	**78 dB**

Table 16. The results for the blocking out of band receiver

(4) UE Receiver Intermodulation Specification. In a manner similar to that used previously for the base station we can estimate the maximum level for the intermodulation products and the input IP_3 performance of the receiver. [1] Table 17 shows the results for the wideband interferer, and Table 18 shows the results for the narrowband interferer.

Wanted signal	**Interfering signal**	**Interfering offset**	**Intermodulation rejection**	**Intercept point**
-114 dB	-46 dB	10 MHz 20 MHz	**50 dB**	**-21 dB**
-113 dB	-46 dB	10 MHz 20 MHz	**49 dB**	**-21.5 dB**
-112 dB	-46 dB	10 MHz 20 MHz	**48 dB**	**-22 dB**
-111 dB	-46 dB	10 MHz 20 MHz	**47 dB**	**-22.5 dB**

Table 17. Intermodulation results for wideband interferer

Wanted signal	**Interfering signal**	**Interfering offset**	**Intermodulation rejection**	**Intercept point**
-107 dB	-44 dB	3.5 MHz 5.9 MHz	**42 dB**	**-21.5 dB**
-105 dB	-44 dB	3.5 MHz 5.9 MHz	**43 dB**	**-22.5 dB**
-104 dB	-43 dB	3.6 MHz 6.0 MHz	**43 dB**	**-21.5 dB**

Table 18. Intermodulation results for narrowband interferer

THIS PAGE INTENTIONALLY LEFT BLANK

III. ANALYSIS OF THE UMTS

A. INTRODUCTION

This chapter presents the analysis of the UMTS Terrestrial radio access network (UTRAN) using various communication models to explore the transmission intercept ability of the UTRAN as the number of users increases. The primary constraint limiting the interception of the UTRAN is the co-channel interference due to the use of microcells as well as the multi-access interference due to the number of users sharing the same wideband carrier.

1. Co-channel Interference

A cellular system relies on the allocation and the reuse of channels in a given coverage area. Therefore, it is broken down into hexagonally shaped small geographical areas called cells. Base stations in adjacent cells are assigned channel groups which contain completely different channels than those in neighboring cells. The design process of selecting and allocating channel groups for all the cellular base stations within a system is called frequency reuse. [2] Co-channel interference occurs when two different stations use the same frequency in a coverage area.

The co-channel interference may be decreased if directional antennas are used at the base station and a group of frequencies is reused in one direction only. The technique is called sectoring, and the factor by which the co-channel interference is reduced depends on the number of sectors into which the cell is divided. Co-channel interference is not likely to be a problem in a WCDMA system while the number of users is below its threshold, due to the spreading techniques. However, as the number of users increases interference may increase substantially.

2. Multi-Access Interference

Due to its spread spectrum techniques the UMTS has an inherent interference rejection capability. A user information signal bit is spread over a wider bandwidth by multiplying the user data bits by pseudo-random or pseudo-noise (PN) bits called chips. The number of PN chips per bit is defined as the spreading factor. The PN code of one user is approximately orthogonal to the PN codes of other users; thus, multiple access interference is generated at the receiver. [2] As the number of users increases the strength of multiple access interference increases.

The receiver can separate each user based on its PN codes even though the codes occupy the same spectrum at all times, because the correlation detection raises the desired user signal by the spreading factor from the interference present in the CDMA system. This effect is called processing gain, and it gives a CDMA system the robustness against multiple access interference or co-channel interference that is necessary to reuse the 5 MHz carrier frequency band over geographically close distances. However in any given channel bandwidth, a lower processing gain occurs for higher rate user than lower rate users. For example, for bit rate of 2 Mbps, the processing gain is less than 2 (3.84 Mcps/2Mbps=1.92), so some of the robustness of the WCDMA waveform against interference is clearly compromised depending on the type of bit rates. [2]

3. Channel Model

Prior to starting the actual analysis it is important to describe the model on which this thesis is based. A relay mobile station is capable of intercepting the signal from the UTRAN via an interceptor link (IL) and capable of transmitting it to a satellite via the satellite link (SL). The satellite is also capable of intercepting the signal directly. Figure 37 displays a comprehensive view of the channel model that is used throughout this analysis. This thesis examines various scenarios where the interception of a signal is feasible.

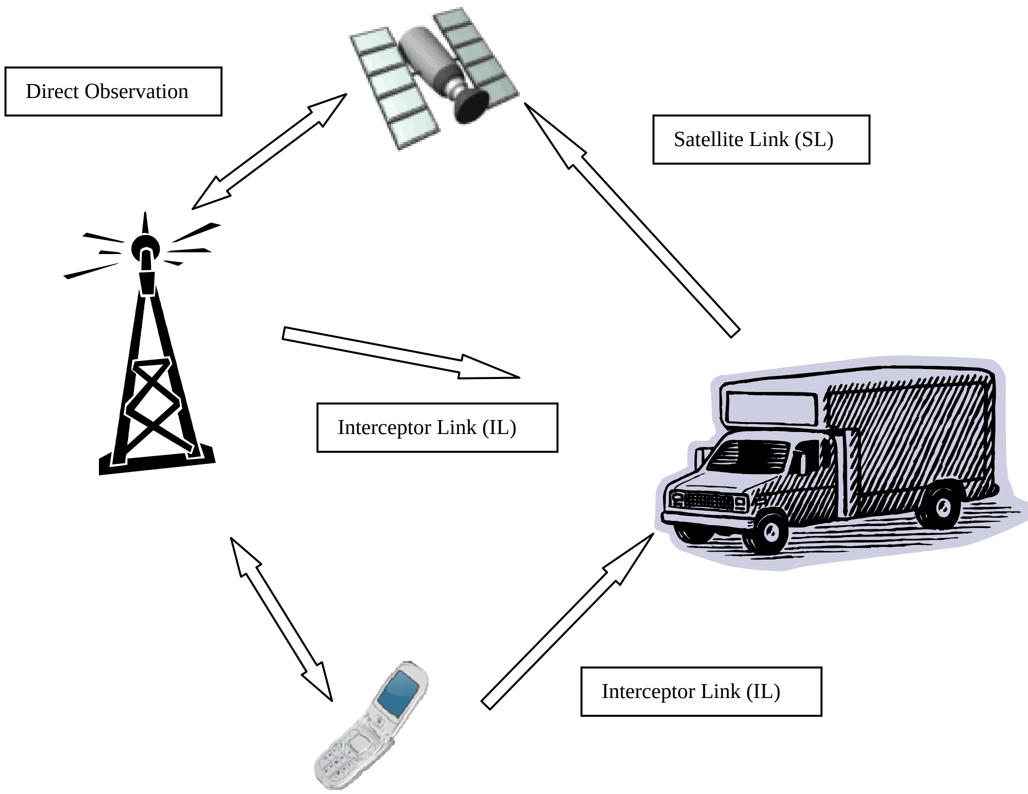

Figure 27 Channel model for the UMTS analysis

B. ANALYSIS USING FREE SPACE PROPAGATION MODEL

1. Free Space Model

The free space model is a simple theoretical model used to predict the received signal strength when there is only one clear line-of-sight (LOS) in ideal propagation conditions. It is used for satellite communications and microwave line-of-sight radio links. According to this model the received power (P_r) is inversely proportional to the squared distance (*d*) between the transmitter and the receiver [8]. The received power is given by the Friis free space equation as follows:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L_m} \qquad (1)$$

where P_t is the transmitted power, P_r is the received power, G_t and G_r are the gains of the transmitting and the receiving antennas respectively, λ is the wavelength of the signal in meters, d is the distance in meters between the transmitter and the receiver, and L_m the miscellaneous losses due to transmission line attenuation, filter losses and antenna losses in the communication system [8]. For simplicity, this thesis uses a value of $L_m = 1$ indicating no loses in the system hardware. The wavelength is related to the carrier frequency by

$$\lambda = \frac{c}{f} \tag{2}$$

The effective isotropic radiated power (EIRP) represents the maximum radiated power available from a transmitter in the direction of the maximum antenna gain, as compared to an isotropic radiator and it is defined as

$$EIRP = P_t G_t \tag{3}$$

In order to predict the signal attenuation at any distance from the transmitter, the term *Path Loss* (PL) is used. It is a positive quantity in dB, and is defined as the difference between the effective isotropic radiated power and the received power using an isotropic antenna. The path loss for the free space model is computed assuming isotropic antenna gains

$$PL(dB) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \tag{4}$$

2. Evaluation

The analysis now evaluates the performance of UTRAN by examining the simplest model, the free space propagation model, where the satellite attempts to intercept the WCDMA signal without the assistance of the signal relay mobile station. There are several assumptions made in order to evaluate the performance of UTRAN. The first assumption is that the satellite is located 3900 km above the surface of the earth.

The second assumption is that the satellite has a receiver gain-to-noise temperature ratio ($\frac{G_r}{T}$) of $10^{2.7}$. Based on the information of the Standard [6,7] the transmit power of the UE for the speech terminal is -9 dBW with antenna gain of 0 dB, and for the data terminal it is -6 dBW with the same transmit gain. The transmit power of the BS is 10 dBW for the speech terminal and 16 dBW for the data terminal. The data terminal has a bit rate of 144 kbps for real time data and 384 kbps for non-real time data. For sectoring, the antenna of the base station is assumed to be partitioned into three sectors with antenna gain of 18 dBi. Recall from Table 4 that there are different operating frequency ranges depending on the type of the operating band. For Band I the UE operates at the frequency range of 1920-1980 MHz. The E_b / N_0 for the UE, which measures the signal-to-noise ratio (SNR) of the digital communication link, can be derived using the above quantities.

Given the transmitter power in dBW, the EIRP is calculated using equation 1:

$$EIRP = P_t G_t = (\text{-9 dBW}) + (\text{0 dBi}) = \text{9 dBW} \qquad (5)$$

Next the receive power is calculated using the following formula, assuming the satellite is located at distance d from the transmitter

$$P_r = \frac{(EIRP)G_r}{L} \qquad (6)$$

where L is the path loss given by equation (7), d is 3900 km and the wavelength of the signal λ is 0.1515 meters for a frequency of 1980 MHz. Therefore

$$L = \left(\frac{4\pi d}{\lambda} \right)^2 = \text{170.2 dB} \qquad (7)$$

The carrier to noise density ratio (C/N_0) is determined by equation (8) where k is Boltzmann’s constant given as $1.38x10^{-23}$ Joules/ Kelvin, and T is the receiver noise temperature in Kelvin:

$$\frac{C}{N_0} = \frac{P_r}{N_0} = \frac{(EIRP)G_r}{kTL} = EIRP_{dBW} - L_{dB} + \left[\frac{G_r}{T}\right]_{dB/K} - [k]_{dBW/K-Hz}$$

$$= -9 - 170.2 + 27 - (-228.6) \qquad (8)$$

$$= 76.4 \text{dB-Hz}$$

Hence, E_b / N_0 received by the satellite is given as

$$\frac{E_b}{N_0} = \left(\frac{C}{N_0}\right)\left(\frac{1}{R_b}\right),\ R_b = 12.2 \text{ kbps for the voice channel.}$$

$$= (76.4 \text{ dB-Hz})-(40.86 \text{ dB}) \qquad (9)$$

$$= 35.54 \text{ dB.}$$

After determining this quantity, several iterations of this process were carried out for the different operating frequencies and EIRPs for the BS and UE of UTRAN to determine the E_b / N_0 received at the satellite for these stations. The results of these calculations are given in Table 19 through Table 22 for BS and UE, respectively, for the speech and data terminals.

User Equipment (UE)															
Frequency (MHz)	1980			1910			1785			1755			849		
Transmitter Gain	0			0			0			0			0		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
EIRP (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
Path Loss (dB)	**170.2**	**170.2**	**170.2**	**169.9**	**169.9**	**169.9**	**169.3**	**169.3**	**169.3**	**169.1**	**169.1**	**169.1**	**162.8**	**162.8**	**162.8**
$\frac{C}{N_o}$ (dB)	**76.4**	**79.4**	**79.4**	**76.1**	**79.7**	**79.7**	**77.3**	**80.3**	**80.3**	**77.5**	**80.5**	**80.5**	**83.7**	**86.8**	**86.8**
$\frac{E_b}{N_o}$ (dB)	**35.5**	**27.8**	**23.6**	**35.9**	**28.1**	**23.9**	**36.4**	**28.7**	**24.5**	**36.6**	**28.9**	**24.7**	**42.9**	**35.2**	**31**

Table 19. Link analysis of UE using the free space propagation model

User Equipment (UE)															
Frequency (MHz)	840			2570			915			1784.9			1770		
Transmitter Gain	0			0			0			0			0		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
EIRP (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
Path Loss (dB)	**162.7**	**162.7**	**162.7**	**172.5**	**172.5**	**172.5**	**163.5**	**163.5**	**163.5**	**169.3**	**169.3**	**169.3**	**169.2**	**169.2**	**169.2**
$\frac{C}{N_o}$ (dB)	**83.6**	**86.9**	**86.9**	**74.1**	**77.1**	**77.1**	**83.1**	**86.1**	**86.1**	**77.3**	**80.3**	**80.3**	**77.4**	**80.4**	**80.4**
$\frac{E_b}{N_o}$ (dB)	**43**	**35.3**	**31.1**	**33.3**	**25.6**	**21.3**	**42.2**	**34.5**	**30.3**	**36.4**	**28.7**	**24.5**	**36.5**	**28.8**	**24.6**

Table 20. Link analysis of UE using the free space propagation model

Base Station (BS)															
Frequency (MHz)	2170			1990			1880			2155			894		
Transmitter Gain	18			18			18			18			18		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**
EIRP (dBW)	**28**	**34**	**34**	**28**	**34**	**34**	**28**	**34**	**34**	**28**	**34**	**34**	**28**	**34**	**34**
Path Loss (dB)	**171**	**171**	**171**	**170.2**	**170.2**	**170.2**	**169.7**	**169.7**	**169.7**	**170.9**	**170.9**	**170.9**	**163.3**	**163.3**	**163.3**
$\frac{C}{N_o}$ (dB)	**112.6**	**118.6**	**118.6**	**113.4**	**119.4**	**119.4**	**113.9**	**119.9**	**119.9**	**112.7**	**118.7**	**118.7**	**120.3**	**126.3**	**126.3**
$\frac{E_b}{N_o}$ (dB)	**71.7**	**67**	**62.8**	**72.5**	**67.8**	**63.6**	**73**	**68.3**	**64.1**	**71.8**	**67.1**	**62.9**	**79.5**	**74.7**	**70.5**

Table 21. Link analysis of BS using the free space propagation model

Base Station (BS)															
Frequency (MHz)	885			2690			960			1880			2170		
Transmitter Gain	18			18			18			18			18		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**
EIRP (dBW)	**28**	**34**	**34**	**28**	**34**	**34**	**28**	**34**	**34**	**28**	**34**	**34**	**28**	**34**	**34**
Path Loss (dB)	**163.2**	**163.2**	**163.2**	**172.9**	**172.9**	**172.9**	**163.9**	**163.9**	**163.9**	**169.7**	**169.7**	**169.7**	**171**	**171**	**171**
$\frac{C}{N_o}$ (dB)	**120.4**	**126.4**	**126.4**	**110.7**	**116.7**	**116.7**	**119.7**	**125.7**	**125.7**	**113.9**	**119.9**	**119.9**	**112.6**	**118.6**	**118.6**
$\frac{E_b}{N_o}$ (dB)	**79.5**	**74.8**	**70.6**	**69.9**	**65.2**	**60.9**	**78.8**	**74.1**	**69.9**	**73**	**68.3**	**64.1**	**71.7**	**67**	**62.8**

Table 22. Link analysis of BS using the free space propagation model

Multi-access interference is generated by PN codes used to separate the sectors/cells that are not perfectly orthogonal codes [10]. From [8] the bit energy-to-noise and multi-access interference-density ratio is given by the following equation, assuming equal power for interfering BS

$$\frac{E_b}{\mathrm{N}} = \frac{1}{\frac{2(K-1)}{3N_c} + \frac{N_0}{E_b}} \tag{10}$$

where K is the number of multiple access users and N_c is the spreading factor. Based on information obtained from [2], for a free space model $\frac{E_b}{\mathrm{N}}$ should not be less than 5 dB for good reception. Using equation (8) we are able to use the spreading factor to find the maximum number of multiple access users (K) that the system can handle without too much mutual interference. The assumptions that were made in determining this factor include the evaluation frequency of UE at 1980 MHz with a spreading factor 16 in the speech terminal. Using equation (10) the maximum amount of multiple users is 9.

After determining this quantity, this process was carried out for the different operating frequencies and the different spreading factors for the BS and UE of UTRAN to determine the maximum number of multiple users that the system could handle. The results of these calculations are the same for BS and UE, given in Table 23, for the speech and data terminals.

Number Of Users		Voice Channel	Real time Data	Non Real Time Data
Spreading Factor	16	9	9	9
	32	16	16	16
	64	31	31	31
	128	61	61	61
	256	122	122	122

Table 23. Number of multi-access users for the BS and UE

C. ANALYSIS USING HATA MODEL

1. Hata Model

A model that is widely used for predicting path loss for mobile wireless systems operating in complex urban environments is the Hata model. It is an empirical model devised from the graphical path loss data provided by the Okumura model. The model has the following restricted parameters: the carrier frequency should be in the range of 150 MHz to 1500 MHz, the distance d from the base station ranges from 1 km to 20 km, the height of base station antenna (h_{te}) ranges from 30 m to 200 m, and the height of mobile antenna (h_{re}) ranges from 1 m to 10 m. The Hata model computes the median path loss in open rural areas, suburban areas and urban areas. [8] The standard formula for the median path loss in urban areas, L_{50} in dB, is given by the following equation

$$L_{50}(urban) = 69.55 + 26.16\log f_c - 13.82\log h_{te} - a(h_{re}) + (44.9 - 6.55\log h_{te})\log d \qquad (10)$$

where $a(h_{re})$ is the correction factor for effective mobile antenna height, which is a function of the coverage area. For a small to medium sized city, the mobile antenna correction factor $a(h_{re})$ in dB is defined by the following equation:

$$a(h_{re}) = (1.1\log f_c - 0.7)h_{re} - (1.56\log f_c - 0.8) \quad \text{dB} \tag{11}$$

and for a large city, it is given by

$$a(h_{re}) = 8.29(\log 1.54h_{re})^2 - 1.1 \text{ dB for } f_c \leq 300 \text{ MHz} \tag{12}$$

$$a(h_{re}) = 3.2(\log 11.75h_{re})^2 - 4.97 \text{ dB for } f_c \geq 300 \text{ MHz}$$

To obtain the path loss in a suburban area, in dB, the standard Hata formula in equation (10) is modified as

$$L_{50} = L_{50}(urban) - 2[\log(f_c / 28)]^2 - 5.4 \tag{13}$$

and for the open rural area the formula is modified as

$$L_{50} = L_{50}(urban) - 4.78(\log f_c)^2 + 18.33\log f_c - 40.94 \tag{14}$$

The European Cooperative for Scientific and Technical research (EURO-COST) formed the COST-231 working committee to develop an extended version of the Hata model. The committee proposed a formula that supported frequency range from 1500 MHz to 2000 MHz and matches the other limitations of the regular Hata model. [8] The extended Hata model for the path loss, L_{50} in dB, is defined in [8] by the following equation:

$$L_{50} = 46.3 + 33.9\log f_c - 13.82\log h_{te} - a(h_{re}) + (44.9 - 6.55\log h_{te})\log d + C_M \tag{15}$$

where

$$C_M = \begin{cases} 0 \text{ dB for medium sized city and suburban areas} \\ 3 \text{ dB for metropolitan areas} \end{cases} \tag{16}$$

In this thesis both the standard Hata model and the extended one are being used; however, some of the operating bands of the UTRAN violate the frequency range parameters. This assumption still provides a useful approximation that does not suffer much from violating these restrictions. For these calculations a base station with 120^0 sectoring and antenna height of 30 m are assigned. The height of the mobile station was chosen to be 1.8 m.

2. Evaluation

To begin the evaluation of UTRAN using the Hata model, first an approximation for the signal power–to-interference power ratio (*S/I*) needs to be defined. As stated, each base station has 120^0 sectoring, and the path loss exponent is selected to be 3 throughout the coverage area. The signal-to-interference ratio *S/I* is approximated based on the analysis from [8] by the formula

$$\left(\frac{S}{I}\right)_{120^0} = \frac{9N_c}{2K}\left[\frac{1}{2(\sqrt{7})^{-n} + 2(2)^{-n} + 2}\right] \tag{17}$$

where N_c is the spreading factor and K is the number of multiple access users. Based on information obtained from [9], the signal-to-interference ratio should not be less than 5 dB for good receptions. Using K=9 and N_c=16, the signal-to-interference ratio on the interceptor link is

$$\left(\frac{S}{I}\right)_{120^0} = \frac{9\times16}{2\times9}\left(\frac{1}{2(\sqrt{7})^{-3} + 2(\sqrt{2})^{-3} + 2}\right) = 3.39 = 5.3 \text{ dB}$$

Tables 24 through 27 provide the results for *S/I* using the above analysis for the UE and the BS of the UMTS for the voice channel and the data terminal.

User Equipment (UE) with 120 degrees sectoring											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.5	1770
Spreading Factor	Number of users	Signal -to-interference ratio (S/I) (dB)									
16	4	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**
32	8	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**
64	16	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**
128	32	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**
256	64	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**	**8.8**

Table 24. The Signal –to-Interference ratio at the UE with 120 degrees sectoring of the UMTS

Base Station (BS) with 120 degrees sectoring											
Frequency (MHz)		2170	1990	1880	2155	894	885	2690	960	1880	2170
Spreading Factor		Signal –to-interference ratio (S/I)(dB)									
16	Number of users	**9**	**9**	**9**	**9**	**8**	**8**	**9**	**8**	**9**	**9**
		5.3	**5.3**	**5.3**	**5.3**	**5.8**	**5.8**	**5.3**	**5.8**	**5.3**	**5.3**
32	Number of users	**19**	**19**	**19**	**19**	**16**	**16**	**19**	**16**	**19**	**19**
		5.1	**5.1**	**5.1**	**5.1**	**5.8**	**5.8**	**5.1**	**5.8**	**5.1**	**5.1**
64	Number of users	**38**	**38**	**38**	**38**	**33**	**33**	**38**	**33**	**38**	**38**
		5.1	**5.1**	**5.1**	**5.1**	**5.7**	**5.7**	**5.1**	**5.7**	**5.1**	**5.1**
128	Number of users	**77**	**77**	**77**	**77**	**67**	**67**	**77**	**67**	**77**	**77**
		5	**5**	**5**	**5**	**5.6**	**5.6**	**5**	**5.6**	**5**	**5**

Base Station (BS) with 120 degrees sectoring											
Frequency (MHz)		2170	1990	1880	2155	894	885	2690	960	1880	2170
Spreading Factor		Signal –to-interference ratio (S/I)(dB)									
256	Number of users	**154**	**154**	**154**	**154**	**134**	**134**	**154**	**134**	**154**	**154**
		5	**5**	**5**	**5**	**5.6**	**5.6**	**5**	**5.6**	**5**	**5**

Table 25. The Signal –to-Interference ratio at the BS Voice channel with 120 degrees sectoring of the UMTS

Base Station (BS) with 120 degrees sectoring											
Frequency (MHz)		2170	1990	1880	2155	894	885	2690	960	1880	2170
Spreading Factor		Signal –to-interference ratio (S/I)(dB)									
16	Number of users	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**
		5.3	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**
32	Number of users	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**
		5.3	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**
64	Number of users	**37**	**37**	**37**	**37**	**38**	**38**	**37**	**38**	**37**	**37**
		5.2	**5.2**	**5.2**	**5.2**	**5.1**	**5.1**	**5.2**	**5.1**	**5.2**	**5.2**
128	Number of users	**74**	**74**	**74**	**74**	**77**	**77**	**74**	**77**	**74**	**74**
		5.2	**5.2**	**5.2**	**5.2**	**5**	**5**	**5.2**	**5**	**5.2**	**5.2**
256	Number of users	**150**	**150**	**150**	**150**	**154**	**154**	**149**	**154**	**150**	**150**
		5.2	**5.2**	**5.2**	**5.2**	**5**	**5**	**5.2**	**5**	**5.2**	**5.2**

Table 26. The Signal –to-Interference ratio at the BS Real Time Data with 120 degrees sectoring of the UMTS

Base Station (BS) with 120 degrees sectoring											
Frequency (MHz)		2170	1990	1880	2155	894	885	2690	960	1880	2170
Spreading Factor		Signal –to-interference ratio (S/I)(dB)									
16	Number of users	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**
		5.8	**5.8**	**5.8**	**5.8**	**5.8**	**5.8**	**5.8**	**5.8**	**5.8**	**5.8**
32	Number of users	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**
		5.6	**5.6**	**5.6**	**5.6**	**5.6**	**5.6**	**5.6**	**5.6**	**5.6**	**5.6**
64	Number of users	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**
		5.4	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**
128	Number of users	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**
		5.4	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**
256	Number of users	**140**	**140**	**140**	**140**	**140**	**140**	**140**	**140**	**140**	**140**
		5.4	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**

Table 27. The Signal –to-Interference ratio at the BS Non Real Time Data with 120 degrees sectoring of the UMTS

Recall from earlier discussions on the Hata model that the median path loss on the interceptor link for small to medium sized cities is derived from equation 15 where C_M is equal to zero. For a large city the proposed path loss is derived from the same equation, but C_M is equal to 3 dB. The proposed path loss for a medium sized city is

$$L_{50} = 46.3 + 33.9\log(1990) - 13.82\log(30) - 0.94 + (44.9 - 6.55\log(30))\log 1 + 0 = 138 \text{ dB}$$

The median path loss on the interceptor link for the metropolitan sized city is given below:

$$L_{50} = 46.3 + 33.9\log(1990) - 13.82\log(30) - 0.94 + (44.9 - 6.55\log(30))\log 1 + 3 = 141 \text{ dB}$$

Since $L_{50}(urban) = \frac{P_t}{P_r}$ and the power of the received signal is, $P_r = (SNR)(kTB)$, the SNR is equal to

$$\frac{S}{N} = \frac{(EIRP)(G_r)}{L_{50}(urban)(kTB)} \tag{18}$$

Assuming the receiver system noise temperature *T*=500K and a transmit power of 400 mW per channel, then the signal to noise plus interference ratio is

$$\therefore \frac{S}{N} = EIRP_{dBW} - L_{50}(urban) + \left[\frac{G_r}{T}\right]_{dB/K} - [k]_{dBW/K-Hz} - (B)_{dB-Hz}$$

= 14-138-27-(-228.6)-40.86

=36.7 dB

The reverse channel is influenced by the co-channel interference and the multi-access interference. However, the co-channel interference is negligible compared with the multi-access interference; therefore, the signal-to-noise ratio for the UE would be equal to the bit energy-to-noise and multi-access interference-density ratio given by equation 10 for the same number of users found for the signal-to-interference ratio.

Tables 28 through 31 provide comprehensive results of the analysis of the BS and the UE of UTRAN, taking into consideration the above theory.

User Equipment (UE) with 120 degrees sectoring											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.9	1770
Spreading Factor		Signal -to-noise plus interference ratio (SNIR)(dB)									
16	Number of users	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
		9	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**
32	Number of users	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**
		8.4	**8.4**	**8.4**	**8.4**	**8.4**	**8.4**	**8.4**	**8.3**	**8.4**	**8.4**
64	Number of users	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**
		8.1	**8.1**	**8.1**	**8.1**	**8.1**	**8.1**	**8**	**8**	**8.1**	**8.1**
128	Number of users	**32**	**32**	**32**	**32**	**32**	**32**	**32**	**32**	**32**	**32**
		7.9	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**
256	Number of users	**64**	**64**	**64**	**64**	**64**	**64**	**64**	**64**	**64**	**64**
		7.8	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**

Table 28. Received SNIR at the signal relay mobile station due to a signal from UE of UMTS for Voice Channel with 120 degrees sectoring

User Equipment (UE) with 120 degrees sectoring											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.9	1770
Spreading Factor		Signal -to-noise plus interference ratio (SNIR)(dB)									
16	Number of users	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
		9	**9**	**9**	**9**	**9**	**9**	**8.9**	**9**	**9**	**9**
32	Number of users	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**
		8.3	**8.3**	**8.3**	**8.3**	**8.4**	**8.4**	**8.3**	**8.4**	**8.3**	**8.3**
64	Number of users	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**
		8	**8**	**8**	**8**	**8.1**	**8.1**	**8**	**8.1**	**8**	**8**
128	Number of users	**32**	**32**	**32**	**32**	**32**	**32**	**32**	**32**	**32**	**32**
		7.9	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**	**7.8**	**7.9**	**7.9**	**7.9**
256	Number of users	**64**	**64**	**64**	**64**	**64**	**64**	**64**	**64**	**64**	**64**
		7.8	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**

Table 29. Received SNIR at the signal relay mobile station due to a signal from UE of UMTS for Real Time Data with 120 degrees sectoring

User Equipment (UE) with 120 degrees sectoring											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.9	1770
Spreading Factor		Signal -to-noise plus interference ratio (SNIR)(dB)									
16	Number of users	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
		8.9	**8.9**	**8.9**	**8.9**	**9**	**9**	**8.8**	**9**	**8.9**	**8.9**
32	Number of users	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**
		8.2	**8.2**	**8.3**	**8.3**	**8.3**	**8.3**	**8.1**	**8.3**	**8.3**	**8.3**
64	Number of users	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**
		8	**8**	**8**	**8**	**8**	**8**	**7.9**	**8**	**8**	**8**
128	Number of users	**32**	**32**	**32**	**32**	**32**	**32**	**32**	**32**	**32**	**32**
		7.8	**7.8**	**7.8**	**7.8**	**7.9**	**7.9**	**7.7**	**7.9**	**7.8**	**7.8**
256	Number of users	**64**	**64**	**64**	**64**	**64**	**64**	**64**	**64**	**64**	**64**
		7.7	**7.7**	**7.8**	**7.8**	**7.8**	**7.8**	**7.7**	**7.8**	**7.8**	**7.8**

Table 30. Received SNIR at the signal relay mobile station due to a signal from UE of UMTS for the Non Real Time Data with 120 degrees sectoring

Base Station (BS) **with 120 degrees sectoring**										
Frequency (MHz)	2170	1990	1880	2155	894	885	2690	960	1880	2170
Medium City										
$a(h_{re})$	0.94	0.93	0.92	0.94	0.78	0.78	0.98	0.8	0.92	0.94
$L_{50}(urban)$	138.1	136.8	135.97	137.96	161	161	141.2	162	135.96	138.1
S/N (dB) Voice channel	**36.7**	**37.9**	**38.8**	**36.8**	**13.95**	**14.1**	**33.6**	**13.95**	**38.8**	**36.7**
S/N(dB) Real Time Data	**25.97**	**27.2**	**28.1**	**26.1**	**3.2**	**3.3**	**22.8**	**3.2**	**28.1**	**25.97**
S/N(dB) Non Real Time Data	**21.8**	**23**	**23.8**	**21.9**	**-0.99**	**-0.88**	**18.7**	**-0.99**	**23.8**	**21.8**
Large City										
$a(h_{re})$	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	065
$L_{50}(urban)$	141.3	140.1	139.2	141.2	160.92	160.8	144.5	161.7	139.2	141.3
S/N(dB)Voice channel	**33.4**	**34.7**	**35.5**	**33.5**	**13.8**	**13.9**	**30.2**	**13.8**	**35.5**	**33.4**
S/N(dB)Real Time Data	**22.7**	**23.96**	**24.8**	**22.8**	**3.1**	**3.2**	**19.5**	**3.1**	**24.8**	**22.7**
S/N(dB)Non Real Time Data	**18.5**	**19.7**	**20.6**	**18.6**	**-1.1**	**-1**	**15.3**	**-1.1**	**20.6**	**18.5**

Table 31. Received SNR at the signal relay mobile station due to a signal from BS with 120 degrees sectoring of UMTS

Given the S/I from Tables 24 through 27 and the SNR from Tables 28 through 31, the carrier to interference ratio (C/I) on the interceptor link can be calculated from equation 18 for the UE and the BS respectively, and the results of these calculations for the UTRAN are provided in Tables 32 through 35.

$$\left(\frac{C}{N}\right)_{IL} = \frac{1}{\left(\frac{S}{I}\right)_{CCI}^{-1} + SNIR^{-1}} \tag{19}$$

User Equipment (UE) with 120 degrees sectoring															
Frequency (MHz)	1980			1910			1785			1755			849		
$\left(\frac{C}{N}\right)_{IL}$ (dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**5.9**	**5.9**	**5.7**	**5.9**	**5.9**	**5.7**	**5.9**	**5.9**	**5.7**	**5.9**	**5.9**	**5.7**	**5.9**	**5.9**	**5.7**
32	**5.6**	**5.6**	**5.4**	**5.6**	**5.6**	**5.4**	**5.6**	**5.6**	**5.4**	**5.6**	**5.6**	**5.4**	**5.6**	**5.6**	**5.4**
64	**5.4**	**5.4**	**5.2**	**5.4**	**5.4**	**5.2**	**5.4**	**5.4**	**5.2**	**5.4**	**5.4**	**5.2**	**5.4**	**5.4**	**5.2**
128	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**
256	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**

Table 32. Carrier –to-noise ratio of the UE with 120 degrees sectoring at the interception link

User Equipment (UE)															
Frequency (MHz)	840			2570			915			1784.9			1770		
$\left(\frac{C}{N}\right)_{IL}$ (dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**5.9**	**5.9**	**5.7**	**5.9**	**5.9**	**5.7**	**5.9**	**5.9**	**5.7**	**5.9**	**5.9**	**5.7**	**5.9**	**5.9**	**5.7**
32	**5.6**	**5.6**	**5.4**	**5.6**	**5.6**	**5.4**	**5.6**	**5.6**	**5.4**	**5.6**	**5.6**	**5.4**	**5.6**	**5.6**	**5.4**
64	**5.4**	**5.4**	**5.2**	**5.4**	**5.4**	**5.2**	**5.4**	**5.4**	**5.2**	**5.4**	**5.4**	**5.2**	**5.4**	**5.4**	**5.2**
128	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**
256	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**

Table 33. Carrier –to-noise ratio of the UE at the interception link

Base Station (BS)																
Frequency (MHz)		2170			1990			1880			2155			894		
$\left(\frac{C}{N}\right)_{IL}$ (dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**5.3**	**5.3**	**5.7**	**5.3**	**5.3**	**5.7**	**5.3**	**5.3**	**5.7**	**5.3**	**5.3**	**5.7**	**5.2**	**1.1**	**-1.8**
	32	**5.1**	**5.2**	**5.5**	**5.1**	**5.2**	**5.5**	**5.1**	**5.2**	**5.5**	**5.1**	**5.2**	**5.5**	**5.2**	**1.1**	**-1.9**
	64	**5.1**	**5.2**	**5.3**	**5.1**	**5.2**	**5.4**	**5.1**	**5.2**	**5.4**	**5.1**	**5.2**	**5.3**	**5.1**	**1**	**-1.9**
	128	**5**	**5.2**	**5.3**	**5**	**5.2**	**5.4**	**5**	**5.2**	**5.4**	**5**	**5.2**	**5.3**	**5**	**1**	**-1.9**
	256	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.4**	**5**	**5.1**	**5.4**	**5**	**5.1**	**5.3**	**5**	**1**	**-1.9**
Large City	16	**5.3**	**5.2**	**5.3**	**5.3**	**5.2**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.2**	**5.3**	**5.2**	**1**	**-1.9**
	32	**5.1**	**5.2**	**5.3**	**5.1**	**5.2**	**5.4**	**5.1**	**5.3**	**5.4**	**5.1**	**5.2**	**5.3**	**5.2**	**1.1**	**-2**
	64	**5.1**	**5.1**	**5.2**	**5.1**	**5.1**	**5.3**	**5.1**	**5.1**	**5.3**	**5.1**	**5.1**	**5.2**	**5.1**	**1**	**-2**
	128	**5**	**5.1**	**5.2**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.2**	**5**	**1**	**-2**
	256	**5**	**5.1**	**5.2**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.2**	**5**	**1**	**-2**

Table 34. Carrier –to-noise ratio of the BS at the interception link

Base Station (BS)																
Frequency (MHz)		885			2690			960			1880			2170		
$\left(\frac{C}{N}\right)_{IL}$ (dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**5.2**	**1.2**	**-1.7**	**5.3**	**5.3**	**5.6**	**5.2**	**1.1**	**-1.8**	**5.3**	**5.3**	**5.7**	**5.3**	**5.3**	**5.7**
	32	**5.2**	**1.2**	**-1.8**	**5.1**	**5.2**	**5.3**	**5.2**	**1.1**	**-1.9**	**5.1**	**5.3**	**5.5**	**5.1**	**5.3**	**5.5**
	64	**5.1**	**1.1**	**-1.8**	**5.1**	**5.1**	**5.2**	**5.1**	**1**	**-1.9**	**5.1**	**5.2**	**5.4**	**5.1**	**5.2**	**5.3**
	128	**5**	**1**	**-1.8**	**5**	**5**	**5**	**5**	**1**	**-2**	**5**	**5.2**	**5.4**	**5**	**5.2**	**5.3**
	256	**5**	**1**	**-1.8**	**5**	**6**	**5**	**5**	**5.9**	**-2**	**5**	**6**	**5.4**	**5**	**6**	**5.3**
Large City	16	**5.2**	**1**	**-1.8**	**5.3**	**5.1**	**5.3**	**5.2**	**1**	**-1.9**	**5.3**	**5.2**	**5.7**	**5.3**	**5.2**	**5..7**
	32	**5.2**	**1.1**	**-1.9**	**5.1**	**5.1**	**5.1**	**5.2**	**1.1**	**-2**	**5.1**	**5..2**	**5.4**	**5.1**	**5.2**	**5.3**
	64	**5.1**	**1**	**-1.9**	**5.1**	**5**	**5**	**5.1**	**1**	**-2**	**5.1**	**5.1**	**5.3**	**5.1**	**5.1**	**5.2**
	128	**5**	**1**	**-1.9**	**5**	**5**	**5**	**5**	**1**	**-2**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.2**
	256	**5**	**1**	**-1.9**	**5**	**5.1**	**5**	**5**	**1**	**-2**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.2**

Table 35. Carrier –to-noise ratio of the BS at the interception link

The next step is to calculate the *C/N* for the satellite link. It is assumed that the signal relay mobile station has an average transmission power of 100 mW and transmitter gain of 4 dBi. In order to retransmit the intercepted UTRAN signal over the satellite link, the relay mobile station operates at a transmitting frequency of 3000 MHz in order for the receiver to distinguish the intercepted UTRAN signal from other signals. The C/N on the satellite link for the voice channel is

$$\left(\frac{C}{N}\right)_{SL} = EIRP(dBW) - 20\log\left(\frac{4\pi f_r d_r}{c}\right) + \left[\frac{G_r}{T}\right]_{dB/K} - \left[k\right]_{dBW/K-Hz} - \left(B\right)_{dB-Hz} \quad (20)$$

$$= -10 - 20\log\left(\frac{4\pi\times(3\times10^{9})\times(3900\times10^{3})}{3\times10^{8}}\right) + 27 - (-228.6) - 40.86$$

$$= -10+41.93$$

$$= 31.93 \text{ dB}$$

Table 36 shows the $(C/N)_{SL}$ for the UE and the BS for both the voice channel and the data terminal.

$(C/N)_{SL}$ (dB)	Voice Channel	Real Time Data	Non Real Time Data
User Equipment (UE)	**31.93**	**24.2**	**20**
Base Station (BS)	**54.9**	**44.2**	**40**

Table 36. Carrier –to-noise ratio at the satellite link

The total C/N for the channel model is defined in Ref [11] by the following equation:

$$\left(\frac{C}{N}\right) = \frac{1}{\left(\frac{C}{N}\right)_{IL}^{-1} + \left(\frac{C}{N}\right)_{SL}^{-1}} \quad (21)$$

The results of these calculations for the UE and the BS are provided in Tables 37 through 40.

User Equipment (UE)															
Frequency (MHz)	1980			1910			1785			1755			849		
$\left(\frac{C}{N}\right)$(dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**5.9**	**5.8**	**5.7**	**5.9**	**5.8**	**5.7**	**5.9**	**5.8**	**5.7**	**5.9**	**5.8**	**5.7**	**5.9**	**5.8**	**5.7**
32	**5.6**	**5.5**	**5.4**	**5.6**	**5.5**	**5.4**	**5.6**	**5.5**	**5.4**	**5.6**	**5.5**	**5.4**	**5.6**	**5.5**	**5.4**
64	**5.4**	**5.3**	**5.2**	**5.4**	**5.3**	**5.2**	**5.4**	**5.3**	**5.2**	**5.4**	**5.3**	**5.2**	**5.4**	**5.3**	**5.2**
128	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**
256	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**

Table 37. Total Carrier-to-noise ratio of the UE

User Equipment (UE)															
Frequency (MHz)	840			2570			915			1784.9			1770		
$\left(\frac{C}{N}\right)$(dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**5.9**	**5.8**	**5.7**	**5.9**	**5.8**	**5.7**	**5.9**	**5.8**	**5.7**	**5.9**	**5.8**	**5.7**	**5.9**	**5.8**	**5.7**
32	**5.6**	**5.5**	**5.4**	**5.6**	**5.5**	**5.4**	**5.6**	**5.5**	**5.4**	**5.6**	**5.5**	**5.4**	**5.6**	**5.5**	**5.4**
64	**5.4**	**5.3**	**5.2**	**5.4**	**5.3**	**5.2**	**5.4**	**5.3**	**5.2**	**5.4**	**5.3**	**5.2**	**5.4**	**5.3**	**5.2**
128	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**
256	**5.3**	**5.2**	**5.1**	**5.3**	**5.2**	**5.1**	**5.3**	**5.2**	**5.1**	**5.3**	**5.2**	**5.1**	**5.3**	**5.2**	**5.1**

Table 38. Total Carrier-to-noise ratio of the UE

Base Station (BS)																
Frequency (MHz)		2170			1990			1880			2155			894		
$\left(\frac{C}{N}\right)$(dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**5.3**	**5.3**	**5.7**	**5.3**	**5.3**	**5.7**	**5.3**	**5.3**	**5.7**	**5.3**	**5.3**	**5.7**	**5.2**	**1.1**	**-1.8**
	32	**5.1**	**5.3**	**5.4**	**5.1**	**5.3**	**5.5**	**5.1**	**5.3**	**5.5**	**5.1**	**5.3**	**5.5**	**5.2**	**1.1**	**-1.9**
	64	**5.1**	**5.1**	**5.3**	**5.1**	**5.2**	**5.4**	**5.1**	**5.2**	**5.4**	**5.1**	**5.2**	**5.3**	**5.2**	**1**	**-1.9**
	128	**5**	**5.1**	**5.3**	**5**	**5.2**	**5.4**	**5**	**5.2**	**5.4**	**5**	**5.2**	**5.3**	**5**	**1**	**-1.9**
	256	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.4**	**5**	**5.1**	**5.4**	**5**	**5.1**	**5.3**	**5**	**1**	**-1.9**
Large City	16	**5.3**	**5.2**	**5.6**	**5.3**	**5.2**	**5.6**	**5.3**	**5.3**	**5.7**	**5.3**	**5.2**	**5.6**	**5.2**	**1**	**-1.9**
	32	**5.1**	**5.2**	**5.3**	**5.1**	**5.2**	**5.4**	**5.1**	**5.3**	**5.4**	**5.1**	**5.2**	**5.3**	**5.2**	**1**	**-2**
	64	**5.1**	**5.1**	**5.2**	**5.1**	**5.1**	**5.3**	**5.1**	**5.1**	**5.3**	**5.1**	**5.1**	**5.2**	**5.1**	**1**	**-2**
	128	**5**	**5.1**	**5.2**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.2**	**5**	**1**	**-2**
	256	**5**	**5.1**	**5.2**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.2**	**5**	**1**	**-2**

Table 39. Total Carrier-to-noise ratio of the BS

Base Station (BS)																
Frequency (MHz)		885			2690			960			1880			2170		
$\left(\frac{C}{N}\right)$(dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**5.2**	**1.2**	**-1.7**	**5.3**	**5.2**	**5.6**	**5.2**	**1.1**	**-1.8**	**5.3**	**5.3**	**5.7**	**5.3**	**5.3**	**5.7**
	32	**5.2**	**1.2**	**-1.8**	**5.1**	**5.2**	**5.3**	**5.2**	**1.1**	**-1.9**	**5.1**	**5.3**	**5.5**	**5.1**	**5.3**	**5.4**
	64	**5.2**	**1.1**	**-1.8**	**5.1**	**5.1**	**5.2**	**5.2**	**1**	**-1.9**	**5.1**	**5.2**	**5.4**	**5.1**	**5.1**	**5.3**
	128	**5**	**1.1**	**-1.8**	**5**	**5.1**	**5.2**	**5**	**1**	**-1.9**	**5**	**5.2**	**5.4**	**5**	**5.1**	**5.3**
	256	**5**	**1.1**	**-1.8**	**5**	**5.1**	**5.2**	**5**	**1**	**-1.9**	**5**	**5.1**	**5.4**	**5**	**5.1**	**5.3**
Large City	16	**5.2**	**1.1**	**-1.8**	**5.3**	**5.1**	**5.4**	**5.2**	**1.1**	**-1.9**	**5.3**	**5.3**	**5.7**	**5.3**	**5.2**	**5.6**
	32	**5.2**	**1.1**	**-1.9**	**5.1**	**5.1**	**5.1**	**5.2**	**1.1**	**-2**	**5.1**	**5.3**	**5.4**	**5.1**	**5.2**	**5.3**
	64	**5.1**	**1**	**-1.9**	**5.1**	**5**	**5**	**5.1**	**1**	**-2**	**5.1**	**5.1**	**5.3**	**5.1**	**5.1**	**5.2**
	128	**5**	**1**	**-1.9**	**5**	**5**	**5**	**5**	**1**	**-2**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.2**
	256	**5**	**1**	**-1.9**	**5**	**5**	**5**	**5**	**1**	**-2**	**5**	**5.1**	**5.3**	**5**	**5.1**	**5.2**

Table 40. Total Carrier-to-noise ratio of the BS

If the UTRAN works with 60 degrees sectoring then the signal-to-interference ratio will be doubled [9] and the performance of the system will be increased. However, if the UTRAN works with omnidirectional antennas then the signal-to-interference ratio will be decreased by a factor of three [9]. In the Appendix Tables show the results for a 60 degree antenna and an omnidirectional antenna working similarly as above. From these Tables and the Tables above, the C/N is greater than 5 dB in most of the cases. Based on previous studies, if the C/N is greater than 5 dB then interception of the signal is a strong possibility. From the analysis of this chapter there is one constraint--that the signal relay mobile station must be within 1 km of the intended UE and BS to have an opportunity to intercept the transmission.

IV. CONCLUSIONS

A. SUMMARY

This thesis presents an independent evaluation of the performance of the Wideband Code Division Multiple Access (WCDMA) for the Universal Mobile Telecommunication System (UMTS) to determine the feasibility of exploiting this technology. In conducting the analysis of the WCDMA several communication models were examined to determine the possibility of intercepting this signal. This chapter summarizes the main conclusions drawn from this research and provides suggestions for future work.

The main advantage of the WCDMA compared to other multiple access technologies like FDMA and TDMA, which divide the total bandwidth to frequency sub-bands and time slots respectively, is that all users share the entire available bandwidth to transmit and receive information. In order to support very high bit rates (up to 2 Mbps), the use of variable spreading factor is supported, which in turn supports the concept of obtaining bandwidth on demand. The user data rate is kept constant during the 10 ms time frame even though the data capacity among users may change from frame to frame. WCDMA employs coherent detection on uplink and downlink based on the use of pilot symbols. Interference generated by users in the network is the main limitation for determining the network capacity [2].

This analysis of the WCDMA started with an in depth-discussion of the physical layer. This is important because the physical layer structures relate directly to the achievable performance issues when observing a single link between a user terminal and a base station. The physical layer has a major impact on the equipment complexity with respect to the required baseband processing power in the user and the base station equipment.

Furthermore, this analysis used various communication models to provide invaluable information on the susceptibility of the WCDMA technology. These communication models proved that the greatest challenge in intercepting the WCDMA signal is the number of multi-access users. As the number of users increases the system becomes more susceptible to interception. As the spreading factor increases the number of multi-access users increases. Although these models consider ideal conditions, they still provide an excellent example of what it is expected of the WCDMA in the real world environment.

From the analysis of the WCDMA it can be shown that based on the assumptions made in this thesis that it is possible to exploit this system. The analysis of this system has provided the reader with the fundamental tools to conduct further research on this system. The WCDMA is a relatively new standard, and based on its performance and popularity in foreign countries will continue to grow over the next decades.

B. AREAS FOR FURTHER STUDY

For further analysis, the author recommends analysis of the next generation of the WCDMA the High-speed Downlink Packet Access and the High –Speed Uplink Packet Access. These enhancements promise a 50-100% higher cell throughput, which means that it can support up to 5 Mbps per sector per carrier. This new generation introduces technologies designed to minimize partnered interference.

Another recommendation is that the calculations and the simulations be re-evaluated on the information obtained from the next generation of the WCDMA. The results of the analysis of this system in this document are based on ideal conditions with intelligent assumptions. The author recommends that the calculations should be reworked based on real world observations rather than theoretical data.

APPENDIX

User Equipment (UE) Omni															
Frequency (MHz)	1980			1910			1785			1755			849		
Transmitter Gain	0			0			0			0			0		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
EIRP (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
Path Loss (dB)	**170.2**	**170.2**	**170.2**	**169.9**	**169.9**	**169.9**	**169.3**	**169.3**	**169.3**	**169.1**	**169.1**	**169.1**	**162.8**	**162.8**	**162.8**
$\frac{C}{N_o}$ (dB)	**76.4**	**79.4**	**79.4**	**76.1**	**79.7**	**79.7**	**77.3**	**80.3**	**80.3**	**77.5**	**80.5**	**80.5**	**83.7**	**86.8**	**86.8**
$\frac{E_b}{N_o}$ (dB)	**35.5**	**27.8**	**23.6**	**35.9**	**28.1**	**23.9**	**36.4**	**28.7**	**24.5**	**36.6**	**28.9**	**24.7**	**42.9**	**35.2**	**31**

Table 41. Link analysis of UE Omni using the free space propagation model

User Equipment (UE) Omni															
Frequency (MHz)	840			2570			915			1784.9			1770		
Transmitter Gain	0			0			0			0			0		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
EIRP (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
Path Loss (dB)	**162.7**	**162.7**	**162.7**	**172.5**	**172.5**	**172.5**	**163.5**	**163.5**	**163.5**	**169.3**	**169.3**	**169.3**	**169.2**	**169.2**	**169.2**
$\frac{C}{N_o}$ (dB)	**83.6**	**86.9**	**86.9**	**74.1**	**77.1**	**77.1**	**83.1**	**86.1**	**86.1**	**77.3**	**80.3**	**80.3**	**77.4**	**80.4**	**80.4**
$\frac{E_b}{N_o}$ (dB)	**43**	**35.3**	**31.1**	**33.3**	**25.6**	**21.3**	**42.2**	**34.5**	**30.3**	**36.4**	**28.7**	**24.5**	**36.5**	**28.8**	**24.6**

Table 42. Link analysis of BS Omni using the free space propagation model

Base Station (BS) Omni															
Frequency (MHz)	2170			1990			1880			2155			894		
Transmitter Gain	0			0			0			0			0		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**
EIRP (dBW)	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**
Path Loss (dB)	**171**	**171**	**171**	**170.2**	**170.2**	**170.2**	**169.7**	**169.7**	**169.7**	**170.9**	**170.9**	**170.9**	**163.3**	**163.3**	**163.3**
$\frac{C}{N_o}$ (dB)	**94.6**	**100.6**	**100.6**	**95.4**	**101.4**	**101.4**	**95.9**	**101.9**	**101.9**	**94.7**	**100.6**	**100.6**	**102.3**	**108.3**	**108.3**
$\frac{E_b}{N_o}$ (dB)	**53.7**	**49**	**44.8**	**54.5**	**49.8**	**45.6**	**55**	**50.3**	**46.1**	**53.8**	**49.1**	**44.9**	**61.5**	**56.7**	**52.5**

Table 43. Link analysis of BS Omni using the free space propagation model

Base Station (BS) Omni															
Frequency (MHz)	885			2690			960			1880			2170		
Transmitter Gain	0			0			0			0			0		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**
EIRP (dBW)	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**
Path Loss (dB)	**163.2**	**163.2**	**163.2**	**172.9**	**172.9**	**172.9**	**163.9**	**163.9**	**163.9**	**169.7**	**169.7**	**169.7**	**171**	**171**	**171**
$\frac{C}{N_o}$ (dB)	**102.4**	**108.4**	**108.4**	**92.7**	**98.7**	**98.7**	**101.7**	**107.7**	**107.7**	**95.9**	**101.9**	**101.9**	**94.6**	**100.6**	**100.6**
$\frac{E_b}{N_o}$ (dB)	**61.5**	**56.8**	**52.6**	**51.9**	**47.2**	**42.9**	**60.8**	**56.1**	**51.9**	**55**	**50.3**	**46.1**	**53.7**	**49**	**44.8**

Table 44. Link analysis of UE 60 degrees sectoring using the free space propagation model

User Equipment (UE) 60 degrees sectoring															
Frequency (MHz)	1980			1910			1785			1755			849		
Transmitter Gain	0			0			0			0			0		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
EIRP (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
Path Loss (dB)	**170.2**	**170.2**	**170.2**	**169.9**	**169.9**	**169.9**	**169.3**	**169.3**	**169.3**	**169.1**	**169.1**	**169.1**	**162.8**	**162.8**	**162.8**
$\frac{C}{N_o}$ (dB)	**76.4**	**79.4**	**79.4**	**76.7**	**79.7**	**79.7**	**77.3**	**80.3**	**80.3**	**77.5**	**80.5**	**80.5**	**83.7**	**86.8**	**86.8**
$\frac{E_b}{N_o}$ (dB)	**35.5**	**27.8**	**23.6**	**35.9**	**28.1**	**23.9**	**36.4**	**28.7**	**24.5**	**36.6**	**28.9**	**24.7**	**42.9**	**35.2**	**31**

Table 45. Link analysis of UE 60 degrees sectoring using the free space propagation model

User Equipment (UE) 60 degrees sectoring															
Frequency (MHz)	840			2570			915			1784.9			1770		
Transmitter Gain	0			0			0			0			0		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
EIRP (dBW)	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**	**-9**	**-6**	**-6**
Path Loss (dB)	**162.7**	**162.7**	**162.7**	**172.5**	**172.5**	**172.5**	**163.5**	**163.5**	**163.5**	**169.3**	**169.3**	**169.3**	**169.2**	**169.2**	**169.2**
$\frac{C}{N_o}$ (dB)	**83.6**	**86.9**	**86.9**	**74.1**	**77.1**	**77.1**	**83.1**	**86.1**	**86.1**	**77.3**	**80.3**	**80.3**	**77.4**	**80.4**	**80.4**
$\frac{E_b}{N_o}$ (dB)	**43**	**35.3**	**31.1**	**33.3**	**25.6**	**21.3**	**42.2**	**34.5**	**30.3**	**36.4**	**28.7**	**24.5**	**36.5**	**28.8**	**24.6**

Table 46. Link analysis of BS 60 degrees sectoring using the free space propagation model

Base Station (BS) 60 degrees sectoring															
Frequency (MHz)	2170			1990			1880			2155			894		
Transmitter Gain	10			10			10			10			10		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**
EIRP (dBW)	**20**	**26**	**26**	**20**	**26**	**26**	**20**	**26**	**26**	**20**	**26**	**26**	**20**	**26**	**26**
Path Loss (dB)	**171**	**171**	**171**	**170.2**	**170.2**	**170.2**	**169.7**	**169.7**	**169.7**	**170.9**	**170.9**	**170.9**	**163.3**	**163.3**	**163.3**
$\frac{C}{N_o}$ (dB)	**104.6**	**110.6**	**110.6**	**105.4**	**111.4**	**11.4**	**105.9**	**111.9**	**111.9**	**104.7**	**110.7**	**110.7**	**112.3**	**118.3**	**118.3**
$\frac{E_b}{N_o}$ (dB)	**63.7**	**59**	**54.8**	**64.5**	**59.8**	**55.6**	**65**	**60.3**	**56.1**	**63.8**	**59.1**	**54.9**	**71.5**	**66.7**	**62.5**

Table 47. Link analysis of BS 60 degrees sectoring using the free space propagation model

Base Station (BS) 60 degrees sectoring															
Frequency (MHz)	885			2690			960			1880			2170		
Transmitter Gain	10			10			10			10			10		
	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Maximum Transmitter Power (dBW)	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**	**10**	**16**	**16**
EIRP (dBW)	**20**	**26**	**26**	**20**	**26**	**26**	**20**	**26**	**26**	**20**	**26**	**26**	**20**	**26**	**26**
Path Loss (dB)	**163.2**	**163.2**	**163.2**	**172.9**	**172.9**	**172.9**	**163.9**	**163.9**	**163.9**	**169.7**	**169.7**	**169.7**	**171**	**171**	**171**
$\frac{C}{N_o}$ (dB)	**112.4**	**118.4**	**118.4**	**102.7**	**108.7**	**108.7**	**111.7**	**117.7**	**117.7**	**105.9**	**111.9**	**111.9**	**104.6**	**110.6**	**110.6**
$\frac{E_b}{N_o}$ (dB)	**71.5**	**66.8**	**62.6**	**61.9**	**57.2**	**52.9**	**70.8**	**66.1**	**61.9**	**65**	**60.3**	**56.1**	**63.7**	**59**	**54.8**

User Equipment (UE) Omni											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.5	1770
Spreading Factor	Number of users	Signal –to-interference ratio (S/I) (dB)									
16	2	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**
32	4	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**	**7.1**
64	9	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**
128	17	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**
256	35	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**

Table 48. The Signal –to-Interference ratio for the UE Omni of the UMTS

Base Station (BS) Omni											
Frequency (MHz)		2170	1990	1880	2155	894	885	2690	960	1880	2170
Spreading Factor	Number of users	Signal –to-interference ratio (S/I) (dB)									
16	3	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**
32	5	**6.1**	**6.1**	**6.1**	**6.1**	**6.1**	**6.1**	**6.1**	**6.1**	**6.1**	**6.1**
64	11	**5.7**	**5.7**	**5.7**	**5.7**	**5.7**	**5.7**	**5.7**	**5.7**	**5.7**	**5.7**
128	23	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**
256	46	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**

Table 49. The Signal –to-Interference ratio for the BS Omni Voice Channel of the UMTS

Base Station (BS) Omni											
Frequency (MHz)		2170	1990	1880	2155	894	885	2690	960	1880	2170
Spreading Factor	Number of users	Signal –to-interference ratio (S/I) (dB)									
16	1	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**
32	2	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**	**10.1**
64	6	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**
128	12	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**
256	20	**9.1**	**9.1**	**9.1**	**9.1**	**9.1**	**9.1**	**9.1**	**9.1**	**9.1**	**9.1**

Table 50. The Signal-to-Interference ratio for the BS Omni Real and Non Real Time Channel of the UMTS

User Equipment (UE) Omni											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.5	1770
Spreading Factor	Number of users	Signal –to-noise plus interference ratio (SNIR) (dB)									
16	2	**13.8**	**13.8**	**13.8**	**13.8**	**13.8**	**13.8**	**13.8**	**13.8**	**13.8**	**13.8**
32	4	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**
64	9	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**
128	17	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**	**10.8**
256	35	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**

Table 51. The Signal-to-Noise plus Interference ratio for the UE Omni Voice channel of the UMTS

User Equipment (UE) Omni											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.5	1770
Spreading Factor	Number of users	Signal –to-noise plus interference ratio (SNIR) (dB)									
16	2	**13.6**	**13.6**	**13.7**	**13.7**	**13.8**	**13.8**	**13.5**	**13.8**	**13.7**	**13.7**
32	4	**11.9**	**11.9**	**11.9**	**12**	**12**	**12**	**11.9**	**12**	**11.9**	**12**
64	9	**10.7**	**10.7**	**10.7**	**10.7**	**10.8**	**10.8**	**10.6**	**10.8**	**10.7**	**10.7**
128	17	**10.7**	**10.7**	**10.7**	**10.7**	**10.8**	**10.8**	**10.6**	**10.8**	**10.7**	**10.7**
256	35	**10.4**	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**	**10.4**	**10.5**	**10.5**	**10.5**

Table 52. The Signal-to-Noise plus Interference ratio for the UE Omni Real Time channel of the UMTS

User Equipment (UE) Omni											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.5	1770
Spreading Factor	Number of users	Signal –to-noise plus interference ratio (SNIR) (dB)									
16	2	**13.4**	**13.4**	**13.4**	**13.5**	**13.7**	**13.7**	**13.1**	**13.7**	**13.4**	**13.5**
32	4	**11.7**	**11.8**	**11.8**	**11.8**	**12**	**12**	**11.6**	**12**	**11.8**	**11.8**
64	9	**10.6**	**10.6**	**10.6**	**10.6**	**10.8**	**10.8**	**10.4**	**10.7**	**10.6**	**10.6**
128	17	**10.6**	**10.6**	**10.6**	**10.6**	**10.8**	**10.8**	**10.4**	**10.7**	**10.6**	**10.6**
256	35	**10.3**	**10.3**	**10.4**	**10.4**	**10.5**	**10.5**	**10.2**	**10.5**	**10.4**	**10.4**

Table 53. The Signal-to-Noise plus Interference ratio for the UE Omni Non Real Time channel of the UMTS

Base Station (BS) Omni										
Frequency (MHz)	2170	1990	1880	2155	894	885	2690	960	1880	2170
Medium City										
$a(h_{re})$	0.94	0.93	0.92	0.94	0.78	0.78	0.98	0.8	0.92	0.94
$L_{50}(urban)$	138.1	136.8	135.97	137.96	161	161	141.2	162	135.96	138.1
S/N (dB) Voice channel	**18.7**	**19.9**	**20.8**	**18.8**	**-4**	**-3.9**	**15.6**	**-4**	**20.8**	**18.7**
S/N(dB) Real Time Data	**8**	**9.2**	**10.1**	**8.1**	**-14.8**	**-14.7**	**4.8**	**-14.8**	**10.1**	**8**
S/N(dB) Non Real Time Data	**3.7**	**5**	**5.8**	**3.9**	**-19**	**-18.9**	**0.63**	**-19**	**5.8**	**3.7**
Large City										
$a(h_{re})$	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	065
$L_{50}(urban)$	141.3	140.1	139.2	141.2	160.92	160.8	144.5	161.7	139.2	141.3
S/N(dB)Voice channel	**15.4**	**16.7**	**17.5**	**15.5**	**-4.2**	**-4.1**	**12.2**	**-4.2**	**17.5**	**15.4**
S/N(dB)Real Time Data	**4.7**	**6**	**6.8**	**4.8**	**-14.9**	**-14.8**	**1.5**	**-14.9**	**6.8**	**4.7**
S/N(dB)Non Real Time Data	**0.45**	**1.7**	**2.6**	**0.6**	**-19.1**	**-19**	**-2.7**	**-19.1**	**2.6**	**0.45**

Table 54. Received SNR at the signal relay mobile station due to a signal from an Omni BS of UMTS

User Equipment (UE) 60 degrees sectoring											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.5	1770
Spreading Factor	Number of users	Signal –to-noise plus interference ratio (SNIR) (dB)									
16	5	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**
32	10	**7.3**	**7.3**	**7.3**	**7.3**	**7.3**	**7.3**	**7.3**	**7.3**	**7.3**	**7.3**
64	21	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**
128	42	**6.7**	**6.7**	**6.7**	**6.7**	**6.7**	**6.7**	**6.7**	**6.7**	**6.7**	**6.7**
256	84	**6.6**	**6.6**	**6.6**	**6.6**	**6.7**	**6.7**	**6.6**	**6.7**	**6.6**	**6.6**

Table 55. The Signal-to-Noise plus Interference ratio for the UE 60 degrees sectoring Voice channel of the UMTS

User Equipment (UE) 60 degrees sectoring											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.5	1770
Spreading Factor	Number of users	Signal –to-noise plus interference ratio (SNIR) (dB)									
16	5	**7.7**	**7.7**	**7.7**	**7.7**	**7.8**	**7.8**	**7.7**	**7.8**	**7.7**	**7.7**
32	10	**7.2**	**7.2**	**7.2**	**7.2**	**7.3**	**7.3**	**7.2**	**7.3**	**7.2**	**7.2**
64	21	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**
128	42	**6.7**	**6.7**	**6.7**	**6.7**	**6.7**	**6.7**	**6.6**	**6.7**	**6.7**	**6.7**
256	84	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**

Table 56. The Signal-to-Noise plus Interference ratio for the UE 60 degrees sectoring Real Time channel of the UMTS

User Equipment (UE) 60 degrees sectoring											
Frequency (MHz)		1980	1910	1785	1755	849	840	2570	915	1784.5	1770
Spreading Factor	Number of users	Signal –to-noise plus interference ratio (SNIR) (dB)									
16	5	**7.7**	**7.7**	**7.7**	**7.7**	**7.7**	**7.7**	**7.6**	**7.7**	**7.7**	**7.7**
32	10	**7.2**	**7.2**	**7.2**	**7.2**	**7.3**	**7.3**	**7.2**	**7.1**	**7.2**	**7.2**
64	21	**6.7**	**6.7**	**6.7**	**6.7**	**6.8**	**6.8**	**6.7**	**6.8**	**6.7**	**6.7**
128	42	**6.6**	**6.6**	**6.6**	**6.6**	**6.7**	**6.7**	**6.6**	**6.7**	**6.6**	**6.6**
256	84	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.6**	**6.5**	**6.6**	**6.6**	**6.6**

Table 57. The Signal-to-Noise plus Interference ratio for the UE 60 degrees sectoring Non Real Time channel of the UMTS

Base Station (BS) 60 degrees sectoring										
Frequency (MHz)	2170	1990	1880	2155	894	885	2690	960	1880	2170
Medium City										
$a(h_{re})$	0.94	0.93	0.92	0.94	0.78	0.78	0.98	0.8	0.92	0.94
$L_{50}(urban)$	138.1	136.8	135.97	137.96	161	161	141.2	162	135.96	138.1
S/N (dB) Voice channel	**28.7**	**29.9**	**30.8**	**28.8**	**6**	**6**	**25.6**	**6**	**30.8**	**28.7**
S/N(dB) Real Time Data	**18**	**19.2**	**20.1**	**18.1**	**-4.8**	**-4.7**	**14.8**	**-4.8**	**20.1**	**18**
S/N(dB) Non Real Time Data	**13.7**	**15**	**15.8**	**13.9**	**-9**	**-8.9**	**10.63**	**-9**	**15.8**	**13.7**
Large City										
$a(h_{re})$	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	065
$L_{50}(urban)$	141.3	140.1	139.2	141.2	160.92	160.8	144.5	161.7	139.2	141.3
S/N(dB)Voice channel	**25.4**	**26.7**	**27.5**	**25.5**	**5.8**	**5.9**	**22.2**	**5.8**	**27.5**	**25.4**
S/N(dB)Real Time Data	**14.7**	**16**	**16.8**	**14.8**	**-4.9**	**-4.8**	**11.5**	**-4.9**	**16.8**	**14.7**
S/N(dB)Non Real Time Data	**10.5**	**11.7**	**12.6**	**10.6**	**-9.1**	**-9**	**7.2**	**-9.1**	**12.6**	**10.5**

Table 58. Received SNR at the signal relay mobile station due to a signal from an 60 degrees sectoring BS of UMTS

User Equipment (UE) Omni															
Frequency (MHz)	1980			1910			1785			1755			849		
$\left(\frac{C}{N}\right)_{IL}$ (dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**
32	**5.9**	**5.8**	**5.8**	**5.9**	**5.8**	**5.8**	**5.9**	**5.8**	**5.8**	**5.9**	**5.8**	**5.8**	**5.9**	**5.8**	**5.8**
64	**5.2**	**5.1**	**5.1**	**5.2**	**5.1**	**5.1**	**5.2**	**5.1**	**5.1**	**5.2**	**5.1**	**5.1**	**5.2**	**5.1**	**5.1**
128	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**
256	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**

Table 59. Carrier -to-noise ratio of the UE Omni at the interception link

User Equipment (UE) Omni															
Frequency (MHz)	840			2570			915			1784.9			1770		
$\left(\frac{C}{N}\right)_{IL}$ (dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**	**6.2**
32	**5.9**	**5.8**	**5.8**	**5.9**	**5.8**	**5.8**	**5.9**	**5.8**	**5.8**	**5.9**	**5.8**	**5.8**	**5.9**	**5.8**	**5.8**
64	**5.2**	**5.1**	**5.1**	**5.2**	**5.1**	**5.1**	**5.2**	**5.1**	**5.1**	**5.2**	**5.1**	**5.1**	**5.2**	**5.1**	**5.1**
128	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**
256	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**

Table 60. Carrier -to-noise ratio of the UE Omni at the interception link

Base Station (BS) Omni																
Frequency (MHz)		2170			1990			1880			2155			894		
$\left(\frac{C}{N}\right)_{IL}$ (dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**5.1**	**5.9**	**2.8**	**5.2**	**6.6**	**3.8**	**5.2**	**7.1**	**4.4**	**5.1**	**5.9**	**2.9**	**-4.5**	**-14.8**	**-19**
	32	**5.9**	**5.9**	**3.2**	**5.9**	**6.6**	**4.4**	**6**	**7.1**	**5.1**	**5.8**	**5.9**	**3.3**	**-4.4**	**-14.8**	**-19**
	64	**5.5**	**5.1**	**2.4**	**5.5**	**5.7**	**3.3**	**5.6**	**6.1**	**3.9**	**5.5**	**5.2**	**2.5**	**-4.5**	**-14.8**	**-19**
	128	**5.3**	**5.1**	**2.4**	**5.3**	**5.7**	**3.3**	**5.4**	**6.1**	**3.9**	**5.3**	**5.2**	**2.5**	**-4.5**	**-14.8**	**-19**
	256	**5.3**	**5.5**	**2.6**	**5.3**	**6.2**	**3.6**	**5.4**	**6.5**	**4.2**	**5.3**	**5.5**	**2.7**	**-4.5**	**-14.8**	**-19**
Large City	16	**4.9**	**3.6**	**0**	**5**	**4.5**	**1.1**	**5.1**	**5.1**	**1.9**	**4.9**	**3.7**	**0.1**	**-4.6**	**-14.9**	**-19.1**
	32	**5.6**	**3.6**	**0.2**	**5.7**	**4.5**	**1.4**	**5.8**	**5.1**	**2.2**	**5.6**	**3.7**	**0.3**	**-4.6**	**-14.9**	**-19.1**
	64	**5.2**	**3.1**	**-0.2**	**5.4**	**4**	**0.9**	**5.4**	**4.5**	**1.5**	**5.3**	**3.3**	**-0.1**	**-4.6**	**-14.9**	**-19.1**
	128	**5.1**	**3.1**	**-0.2**	**5.2**	**4**	**0.9**	**5.2**	**4.5**	**1.5**	**5.1**	**3.2**	**-0.1**	**-4.6**	**-14.9**	**-19.1**
	256	**5.1**	**3.3**	**-0.1**	**5.2**	**4.2**	**1**	**5.2**	**4.8**	**1.7**	**5.1**	**3.4**	**0**	**-4.6**	**-14.9**	**-19.1**

Table 61. Carrier -to-noise ratio of the BS Omni at the interception link

Base Station (BS) Omni																
Frequency (MHz)		885			2690			960			1880			2170		
$\left(\frac{C}{N}\right)_{IL}$ (dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**-4.4**	**-14.7**	**-18.9**	**4.9**	**3.7**	**0.2**	**-4.5**	**-14.8**	**-19**	**5.2**	**7.1**	**4.4**	**5.1**	**5.3**	**2.8**
	32	**-4.3**	**-14.7**	**-18.9**	**5.6**	**3.7**	**0.4**	**-4.4**	**-14.8**	**-19**	**6**	**7.1**	**5.1**	**5.9**	**5.3**	**3.2**
	64	**-4.4**	**-14.7**	**-18.9**	**5.3**	**3.2**	**-0.1**	**-4.5**	**-14.8**	**-19**	**5.6**	**6.1**	**3.9**	**5.5**	**5.2**	**2.4**
	128	**-4.5**	**-14.7**	**-18.9**	**5.1**	**3.2**	**-0.1**	**-4.5**	**-14.8**	**-19**	**5.4**	**6.1**	**3.9**	**5.3**	**5.2**	**2.4**
	256	**-4.5**	**-14.7**	**-18.9**	**5.1**	**3.5**	**0**	**-4.5**	**-14.8**	**-19**	**5.4**	**6.5**	**4.1**	**5.3**	**6**	**2.6**
Large City	16	**-4.5**	**-14.8**	**-19**	**4.5**	**0.95**	**-2.9**	**-4.6**	**-14.9**	**-19.1**	**5.1**	**5.1**	**1.9**	**4.9**	**5.2**	**0**
	32	**-4.5**	**-14.8**	**-19**	**5.2**	**0.95**	**-2.8**	**-4.6**	**-14.9**	**-19.1**	**5.8**	**5.1**	**2.2**	**5.6**	**5.2**	**0.2**
	64	**-4.6**	**-14.8**	**-19**	**4.8**	**0.7**	**-3**	**-4.6**	**-14.9**	**-19.1**	**5.4**	**4.5**	**1.5**	**5.3**	**5.1**	**-0.2**
	128	**-4.6**	**-14.8**	**-19**	**4.7**	**0.7**	**-3**	**-4.6**	**-14.9**	**-19.1**	**5.2**	**4.5**	**1.5**	**5.1**	**5.1**	**-0.2**
	256	**-4.6**	**-14.8**	**-19**	**4.7**	**0.8**	**3**	**-4.6**	**-14.9**	**-19.1**	**5.2**	**4.8**	**1.7**	**5.1**	**5.1**	**-0.1**

Table 62. Carrier -to-noise ratio of the BS Omni at the interception link

User Equipment (UE) 60 degrees Sectoring															
Frequency (MHz)	1980			1910			1785			1755			849		
$\left(\frac{C}{N}\right)_{IL}$ (dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**
32	**5.7**	**5.7**	**5.6**	**5.7**	**5.7**	**5.6**	**5.7**	**5.7**	**5.6**	**5.7**	**5.7**	**5.6**	**5.7**	**5.7**	**5.6**
64	**5.3**	**5.3**	**5.2**	**5.3**	**5.3**	**5.2**	**5.3**	**5.3**	**5.2**	**5.3**	**5.3**	**5.2**	**5.3**	**5.3**	**5.2**
128	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**
256	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**

Table 63. Carrier -to-noise ratio of the UE 60 degrees sectoring at the interception link

User Equipment (UE) 60 degrees Sectoring															
Frequency (MHz)	840			2570			915			1784.9			1770		
$\left(\frac{C}{N}\right)_{IL}$ (dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**
32	**5.7**	**5.7**	**5.6**	**5.7**	**5.7**	**5.6**	**5.7**	**5.7**	**5.6**	**5.7**	**5.7**	**5.6**	**5.7**	**5.7**	**5.6**
64	**5.3**	**5.3**	**5.2**	**5.3**	**5.3**	**5.2**	**5.3**	**5.3**	**5.2**	**5.3**	**5.3**	**5.2**	**5.3**	**5.3**	**5.2**
128	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**	**5.2**
256	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5.1**

Table 64. Carrier -to-noise ratio of the UE 60 degrees sectoring at the interception link

Base Station (BS) 60 degrees Sectoring																
Frequency (MHz)		2170			1990			1880			2155			894		
$\left(\frac{C}{N}\right)_{IL}$ (dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**5.1**	**5.3**	**6.2**	**5.1**	**5.4**	**6.4**	**5.1**	**5.4**	**6.5**	**5.1**	**5.3**	**6.2**	**2.5**	**-5.2**	**-9.1**
	32	**5.2**	**5.4**	**6.1**	**5.2**	**5.5**	**6.3**	**5.2**	**5.5**	**6.4**	**5.2**	**5.4**	**6.1**	**2.5**	**-5.2**	**-9.1**
	64	**5.2**	**5.4**	**5.9**	**5.2**	**5.5**	**6**	**5.2**	**5.5**	**6.1**	**5.2**	**5.4**	**5.9**	**2.5**	**-5.2**	**-9.1**
	128	**5.2**	**5.4**	**5.9**	**5.2**	**5.5**	**6**	**5.2**	**5.5**	**6.1**	**5.2**	**5.4**	**5.9**	**2.5**	**-5.2**	**-9.1**
	256	**5.2**	**5.4**	**5.9**	**5.2**	**5.5**	**6**	**5.2**	**5.5**	**6.1**	**5.2**	**5.4**	**5.9**	**2.5**	**-5.2**	**-9.1**
Large City	16	**5**	**5.1**	**5.4**	**5**	**5.2**	**5.8**	**5**	**5.2**	**6**	**5**	**5.1**	**5.5**	**2.4**	**-5.3**	**-9.2**
	32	**5.1**	**5.2**	**5.3**	**5.2**	**5.3**	**5.7**	**5.2**	**5.4**	**5.9**	**5.2**	**5.2**	**5.3**	**2.5**	**-5.3**	**-9.2**
	64	**5.1**	**5.2**	**5.1**	**5.2**	**5.3**	**5.5**	**5.2**	**5.4**	**5.6**	**5.2**	**5.2**	**5.2**	**2.5**	**-5.3**	**-9.2**
	128	**5.1**	**5.2**	**5.1**	**5.2**	**5.3**	**5.5**	**5.2**	**5.4**	**5.6**	**5.2**	**5.2**	**5.2**	**2.5**	**-5.3**	**-9.2**
	256	**5.1**	**5.2**	**5.1**	**5.2**	**5.3**	**5.5**	**5.2**	**5.4**	**5.6**	**5.2**	**5.2**	**5.2**	**2.5**	**-5.3**	**-9.2**

Table 65. Carrier -to-noise ratio of the BS 60 degrees sectoring at the interception link

Base Station (BS) 60 degrees Sectoring																
Frequency (MHz)		885			2690			960			1880			2170		
$\left(\frac{C}{N}\right)_{IL}$ (dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**2.5**	**-5.1**	**-9**	**5**	**5.1**	**5.5**	**2.5**	**-5.2**	**-9.1**	**5.1**	**5.4**	**6.5**	**5.1**	**5.3**	**6.2**
	32	**2.6**	**-5**	**-9**	**5.1**	**5.2**	**5.4**	**2.5**	**-5.2**	**-9.1**	**5.2**	**5.5**	**6.4**	**5.2**	**5.4**	**6.1**
	64	**2.6**	**-5**	**-9**	**5.1**	**5.2**	**5.2**	**2.5**	**-5.2**	**-9.1**	**5.2**	**5.5**	**6.1**	**5.2**	**5.4**	**5.9**
	128	**2.5**	**-5**	**-9**	**5.1**	**5.2**	**5.2**	**2.5**	**-5.2**	**-9.1**	**5.2**	**5.5**	**6.1**	**5.2**	**5.4**	**5.9**
	256	**2.5**	**-5**	**-9**	**5.1**	**5.2**	**5.2**	**2.5**	**-5.2**	**-9.1**	**5.2**	**5.5**	**6.1**	**5.2**	**5.4**	**5.9**
Large City	16	**2.5**	**-5.2**	**-9.1**	**5**	**4.6**	**4.2**	**2.4**	**-5.3**	**-9.2**	**5**	**5.2**	**6**	**5**	**5.1**	**5.4**
	32	**2.5**	**-5.2**	**-9.1**	**5.1**	**4.7**	**4.1**	**2.5**	**-5.3**	**-9.2**	**5.2**	**5.4**	**5.9**	**5.1**	**5.2**	**5.3**
	64	**2.5**	**-5.2**	**-9.1**	**5.1**	**4.7**	**3.9**	**2.5**	**-5.3**	**-9.2**	**5.2**	**5.4**	**5.6**	**5.1**	**5.2**	**5.1**
	128	**2.5**	**-5.2**	**-9.1**	**5.1**	**4.7**	**3.9**	**2.5**	**-5.3**	**-9.2**	**5.2**	**5.4**	**5.6**	**5.1**	**5.2**	**5.1**
	256	**2.5**	**-5.2**	**-9.1**	**5.1**	**4.7**	**3.9**	**2.5**	**-5.3**	**-9.2**	**5.2**	**5.4**	**5.6**	**5.1**	**5.2**	**5.1**

Table 66. Carrier -to-noise ratio of the BS 60 degrees sectoring at the interception link

User Equipment (UE) Omni															
Frequency (MHz)	1980			1910			1785			1755			849		
$\left(\frac{C}{N}\right)$(dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**6.2**	**6.1**	**6**	**6.2**	**6.1**	**6**	**6.2**	**6.1**	**6**	**6.2**	**6.1**	**6**	**6.2**	**6.2**	**6**
32	**5.9**	**5.8**	**5.6**	**5.9**	**5.8**	**5.6**	**5.9**	**5.8**	**5.6**	**5.9**	**5.8**	**5.6**	**5.9**	**5.8**	**5.7**
64	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**
128	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.2**
256	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**

Table 67. Total Carrier-to-noise ratio of the UE Omni

User Equipment (UE) Omni															
Frequency (MHz)	840			2570			915			1784.9			1770		
$\left(\frac{C}{N}\right)$(dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**6.2**	**6.1**	**6**	**6.2**	**6.1**	**6**	**6.2**	**6.1**	**6**	**6.2**	**6.1**	**6**	**6.2**	**6.2**	**6**
32	**5.9**	**5.8**	**5.6**	**5.9**	**5.8**	**5.6**	**5.9**	**5.8**	**5.6**	**5.9**	**5.8**	**5.6**	**5.9**	**5.8**	**5.7**
64	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**
128	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.1**	**5.3**	**5.3**	**5.2**
256	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**

Table 68. Total Carrier-to-noise ratio of the UE Omni

Base Station (BS) Omni																
Frequency (MHz)		2170			1990			1880			2155			894		
$\left(\frac{C}{N}\right)$(dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**5.1**	**5.9**	**2.8**	**5.2**	**6.6**	**3.8**	**5.2**	**7.1**	**4.4**	**5.1**	**5.9**	**2.9**	**-4.5**	**-14.8**	**-19**
	32	**5.8**	**5.9**	**3.3**	**5.9**	**6.6**	**4.4**	**6**	**7.1**	**5.1**	**5.9**	**5.9**	**3.3**	**-4.4**	**-14.8**	**-19**
	64	**5.5**	**5.1**	**2.4**	**5.5**	**5.7**	**3.3**	**5.6**	**6.1**	**3.9**	**5.5**	**5.2**	**2.5**	**-4.5**	**-14.8**	**-19**
	128	**5.3**	**5.1**	**2.4**	**5.3**	**5.7**	**3.3**	**5.4**	**6.1**	**3.9**	**5.3**	**5.2**	**2.5**	**-4.5**	**-14.8**	**-19**
	256	**5.3**	**5.5**	**2.6**	**5.3**	**6.2**	**3.6**	**5.4**	**6.5**	**4.2**	**5.3**	**5.5**	**2.7**	**-4.5**	**-14.8**	**-19**
Large City	16	**4.9**	**3.6**	**0**	**5**	**4.5**	**1.1**	**5.1**	**5.1**	**1.9**	**4.9**	**3.7**	**0.1**	**-4.6**	**-14.9**	**-19.1**
	32	**5.6**	**3.6**	**0.2**	**5.7**	**4.5**	**1.4**	**5.8**	**5.1**	**2.2**	**5.6**	**3.7**	**0.3**	**-4.6**	**-14.9**	**-19.1**
	64	**5.2**	**3.1**	**-0.2**	**5.4**	**4**	**0.9**	**5.4**	**4.5**	**1.5**	**5.3**	**3.2**	**-0.1**	**-4.6**	**-14.9**	**-19.1**
	128	**5.1**	**3.1**	**-0.2**	**5.2**	**4**	**0.9**	**5.2**	**4.5**	**1.5**	**5.1**	**3.2**	**-0.1**	**-4.6**	**-14.9**	**-19.1**
	256	**5.1**	**3.3**	**-0.1**	**5.2**	**4.2**	**1**	**5.2**	**4.8**	**1.7**	**5.1**	**3.4**	**0**	**-4.6**	**-14.9**	**-19.1**

Table 69. Total Carrier-to-noise ratio of the BS Omni

Base Station (BS) Omni																
Frequency (MHz)		885			2690			960			1880			2170		
$\left(\frac{C}{N}\right)$(dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**-4.4**	**-14.7**	**-18.9**	**4.9**	**3.7**	**0.2**	**-4.5**	**-14.8**	**-19**	**5.2**	**7.1**	**4.4**	**5.3**	**5.9**	**2.8**
	32	**-4.3**	**-14.7**	**-18.9**	**5.6**	**3.7**	**0.4**	**-4.4**	**-14.8**	**-19**	**6**	**7.1**	**5.1**	**5.1**	**5.9**	**3.3**
	64	**-4.4**	**-14.7**	**-18.9**	**5.3**	**3.2**	**0**	**-4.5**	**-14.8**	**-19**	**5.6**	**6.1**	**3.9**	**5.1**	**5.1**	**2.4**
	128	**-4.4**	**-14.7**	**-18.9**	**5.1**	**3.2**	**0**	**-4.5**	**-14.8**	**-19**	**5.4**	**6.1**	**3.9**	**5**	**5.1**	**2.4**
	256	**-4.4**	**-14.7**	**-18.9**	**5.1**	**3.5**	**0**	**-4.5**	**-14.8**	**-19**	**5.4**	**6.5**	**4.2**	**5**	**5.5**	**2.6**
Large City	16	**-4.5**	**-14.8**	**-19**	**4.5**	**0.95**	**-2.9**	**-4.6**	**-14.9**	**-19.1**	**5.1**	**5.1**	**1.9**	**5.3**	**3.6**	**0**
	32	**-4.5**	**-14.8**	**-19**	**5.2**	**0.95**	**-2.8**	**-4.6**	**-14.9**	**-19.1**	**5.8**	**5.1**	**2.2**	**5.1**	**3.6**	**0.2**
	64	**-4.5**	**-14.8**	**-19**	**4.8**	**0.7**	**-3**	**-4.6**	**-14.9**	**-19.1**	**5.4**	**4.5**	**1.5**	**5.1**	**3.1**	**-0.2**
	128	**-4.5**	**-14.8**	**-19**	**4.7**	**0.7**	**-3**	**-4.6**	**-14.9**	**-19.1**	**5.2**	**4.5**	**1.5**	**5**	**3.1**	**-0.2**
	256	**-4.5**	**-14.8**	**-19**	**4.7**	**0.8**	**-3**	**-4.6**	**-14.9**	**-19.1**	**5.2**	**4.8**	**1.7**	**5**	**3.3**	**-0.1**

Table 70. Total Carrier-to-noise ratio of the BS Omni

User Equipment (UE) 60 degrees Sectoring															
Frequency (MHz)	1980			1910			1785			1755			849		
$\left(\frac{C}{N}\right)$(dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**6**	**6**	**5.8**	**6**	**6**	**5.8**	**6**	**6**	**5.8**	**6**	**6**	**5.8**	**6**	**6**	**5.9**
32	**5.7**	**5.6**	**5.5**	**5.7**	**5.6**	**5.5**	**5.7**	**5.6**	**5.5**	**5.7**	**5.6**	**5.5**	**5.7**	**5.6**	**5.5**
64	**5.3**	**5.2**	**5.1**	**5.3**	**5.2**	**5.1**	**5.3**	**5.2**	**5.1**	**5.3**	**5.2**	**5.1**	**5.3**	**5.3**	**5.2**
128	**5.2**	**5.2**	**5**	**5.2**	**5.2**	**5**	**5.2**	**5.2**	**5**	**5.2**	**5.2**	**5**	**5.2**	**5.2**	**5.1**
256	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**

Table 71. Total Carrier-to-noise ratio of the UE with 60 degrees sectoring

User Equipment (UE) 60 degrees Sectoring															
Frequency (MHz)	840			2570			915			1784.9			1770		
$\left(\frac{C}{N}\right)$(dB)	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
Spreading Factor															
16	**6**	**6**	**5.9**	**6**	**6**	**5.8**	**6**	**6**	**5.9**	**6**	**6**	**5.8**	**6**	**6**	**5.8**
32	**5.7**	**5.6**	**5.5**	**5.7**	**5.6**	**5.4**	**5.7**	**5.6**	**5.5**	**5.7**	**5.6**	**5.5**	**5.7**	**5.6**	**5.5**
64	**5.3**	**5.3**	**5.2**	**5.3**	**5.2**	**5.1**	**5.3**	**5.3**	**5.2**	**5.3**	**5.2**	**5.1**	**5.3**	**5.2**	**5.1**
128	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5**	**5.2**	**5.2**	**5.1**	**5.2**	**5.2**	**5**	**5.2**	**5.2**	**5**
256	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**	**5.2**	**5.1**	**5**

Table 72. Total Carrier-to-noise ratio of the UE with 60 degrees sectoring

Base Station (BS) 60 degrees Sectoring																
Frequency (MHz)		2170			1990			1880			2155			894		
$\left(\frac{C}{N}\right)$(dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**5.1**	**5.3**	**6.1**	**5.1**	**5.4**	**6.3**	**5.1**	**5.4**	**6.4**	**5.1**	**5.3**	**6.1**	**2.5**	**-5.2**	**-9.1**
	32	**5.2**	**5.4**	**6**	**5.2**	**5.5**	**6.2**	**5.2**	**5.5**	**6.3**	**5.2**	**5.4**	**6**	**2.5**	**-5.1**	**-9.1**
	64	**5.2**	**5.4**	**5.8**	**5.2**	**5.5**	**5.9**	**5.2**	**5.5**	**6**	**5.2**	**5.4**	**5.8**	**2.5**	**-5.1**	**-9.1**
	128	**5.2**	**5.4**	**5.8**	**5.2**	**5.5**	**5.9**	**5.2**	**5.5**	**6**	**5.2**	**5.4**	**5.8**	**2.5**	**-5.1**	**-9.1**
	256	**5.2**	**5.4**	**5.8**	**5.2**	**5.5**	**5.9**	**5.2**	**5.5**	**6**	**5.2**	**5.4**	**5.8**	**2.5**	**-5.1**	**-9.1**
Large City	16	**5**	**5.1**	**5.3**	**5**	**5.2**	**5.7**	**5**	**5.2**	**5.9**	**5**	**5.1**	**5.4**	**2.4**	**-5.3**	**-9.2**
	32	**5.1**	**5.2**	**5.2**	**5.2**	**5.3**	**5.6**	**5.2**	**5.4**	**5.7**	**5.2**	**5.2**	**5.2**	**2.5**	**-5.3**	**-9.2**
	64	**5.1**	**5.2**	**5**	**5.2**	**5.3**	**5.4**	**5.2**	**5.4**	**5.5**	**5.2**	**5.2**	**5.1**	**2.5**	**-5.3**	**-9.2**
	128	**5.1**	**5.2**	**5**	**5.2**	**5.3**	**5.4**	**5.2**	**5.4**	**5.5**	**5.2**	**5.2**	**5.1**	**2.5**	**-5.3**	**-9.2**
	256	**5.1**	**5.2**	**5**	**5.2**	**5.3**	**5.4**	**5.2**	**5.4**	**5.5**	**5.2**	**5.2**	**5.1**	**2.5**	**-5.3**	**-9.2**

Table 73. Total Carrier-to-noise ratio of the BS with 60 degrees sectoring

Base Station (BS) 60 degrees Sectoring																
Frequency (MHz)		885			2690			960			1880			2170		
$\left(\frac{C}{N}\right)$(dB)		Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data	Voice Channel	Real Time Data	Non Real Time Data
	Spreading Factor															
Medium City	16	**2.5**	**-5.1**	**-9**	**5**	**5.1**	**5.4**	**2.5**	**-5.2**	**-9.1**	**5.1**	**5.4**	**6.4**	**5.1**	**5.3**	**6.1**
	32	**2.6**	**-5**	**-9**	**5.1**	**5.2**	**5.3**	**2.6**	**-5.1**	**-9.1**	**5.2**	**5.5**	**6.3**	**5.2**	**5.4**	**6**
	64	**2.6**	**-5**	**-9**	**5.1**	**5.2**	**5.1**	**2.6**	**-5.1**	**-9.1**	**5.2**	**5.5**	**6**	**5.2**	**5.4**	**5.8**
	128	**2.6**	**-5**	**-9**	**5.1**	**5.2**	**5.1**	**2.6**	**-5.1**	**-9.1**	**5.2**	**5.5**	**6**	**5.2**	**5.4**	**5.8**
	256	**2.6**	**-5**	**-9**	**5.1**	**5.2**	**5.1**	**2.6**	**-5.1**	**-9.1**	**5.2**	**5.5**	**6**	**5.2**	**5.4**	**5.8**
Large City	16	**2.5**	**-5.2**	**-9.1**	**5**	**4.6**	**4.1**	**2.5**	**-5.3**	**-9.2**	**5**	**5.2**	**5.9**	**5**	**5.1**	**5.3**
	32	**2.5**	**-5.2**	**-9.1**	**5.1**	**4.7**	**4**	**2.5**	**-5.3**	**-9.2**	**5.2**	**5.4**	**5.7**	**5.1**	**5.2**	**5.2**
	64	**2.5**	**-5.2**	**-9.1**	**5.1**	**4.7**	**3.9**	**2.5**	**-5.3**	**-9.2**	**5.2**	**5.4**	**5.5**	**5.1**	**5.2**	**5**
	128	**2.5**	**-5.2**	**-9.1**	**5.1**	**4.7**	**3.9**	**2.5**	**-5.3**	**-9.2**	**5.2**	**5.4**	**5.5**	**5.1**	**5.2**	**5**
	256	**2.5**	**-5.2**	**-9.1**	**5.1**	**4.7**	**3.9**	**2.5**	**-5.3**	**-9.2**	**5.2**	**5.4**	**5.5**	**5.1**	**5.2**	**5**

Table 74. Total Carrier-to-noise ratio of the BS with 60 degrees sectoring

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

[1] A. Richardson, *WCDMA Design Handbook*, Cambridge University Press, Cambridge, England, 2005.

[2] H. Holma, A. Toscala, *WCDMA for UMTS: radio Access for Third Generation Mobile Communication*, John Wiley & Sons, LTD, 2004.

[3] F. Halsall, *Data Communications, Computer Networks and Open Systems*, Addison-Wesley, 1996.

[4] TS 25.211, 3GPP Technical Specifications, Physical channels and mapping of transport channels on to physical channels (FDD),V7.1.0 Release 7,ETSI, 2007

[5] TFCI Transport Format Combination Indicator. Retrieved April, 2007, from http://www.mpirical.com/companion/UMTS/TFCI_Transport_Format_Combination_Indicator.htm

[6] TS 25.104, 3GPP Technical Specifications, Base Station (BS) radio transmission and reception (FDD),V7.6.0 Release 7, ETSI, 2007..

[7] TS 25.104, 3GPP Technical Specifications, User equipment radio transmission and reception (FDD), V7.7.0 Release 7, ETSI, 2007.

[8] T. Rappaport, "*Wireless Communications:Principles and Practice*", Prentice Hall, Upper Saddler River, NJ, 2002.

[9] Tri Ha, EC 4510 class notes, 2007.

[10] A.U. Quddus, R. Tafazolli, B.G. Evans " *Interference suppression in UTRA FDD Downlink Handover Regions*", 3G and Beyond,2005 6th IEE International Conference on 7-9 November 2005, pp. 1-5.

[11] B. Sklar, *Digital Communications: Fundamental and Applications*, Prentice Hall, Upper Saddle River, NJ, 2001.

[12] W. Stallings, *Data and Computer Communications*, 7th Edition, Prentice Hall, Upper Saddle River, New Jersey, 2004.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California