Economically and Functionally Sound Cellular Mobile Communications System Design Consideration for Minimizing Health Concerns

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ABSTRACT

Some research results published in the literature claim that human's exposure to Electro-Magnetic-Fields (EMF) increases the risk of brain cancer while other research results deny this. Studying all the data available to date, the expert group working for World Health Organization (WHO), in Lyon, France came to a conclusion which classifies Radio-Frequency Electro-Magnetic-Fields (RF-EMF) as possibly carcinogenic to humans and they put RF-EMF in Group 2B. In conjunction with this, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) reconsidered RF exposure limits, which should not be exceeded for human health.

Whereas previous research have often focused on the result of EMF exposure and measures of EMF exposure limits, the work presented here targets methods for decreasing Global System for Mobile Communications (GSM) Base Station (BS) and Mobile Station (MS) related health concerns with reference to the numbers, transmission powers and location of the BSs in the initial design stage. The goal of this thesis is therefore, to develop methods of reducing BS and MS related health concern while maintaining functionality and keeping additional investment expenditure as low as possible for the service providers. The proposed work also provides a review of relationship between EMF exposure due to GSM phones and BSs with cancer risks. The results suggest that, the number of BSs should be increased and the transmit powers and hand-off cut-off levels adjusted such that both BS and MS transmit at minimum possible levels for maintaining a reliable communication link in order to minimize health concerns and improve service quality without compromising the functionality and operational economy. Hence, considering the population, terrain and coverage area and employing the Hata Signal Attenuation Model, a reasonable solution for the Famagusta city is estimated to use 16 Watt BSs and enable full coverage of the targeted geographic area.

Keywords: Electro-Magnetic-Fields, Radio Frequency, Base Station, Mobile Telephone

ÖZ

Bu araştırma, Baz İstasyonlarından (Bİ) ve özelde Cep Telefonları (CT) genelde de Mobil İletişim Cihazlarından (MİC) yayılan Elektromanyetik Alanların (EMA) kanser ile ilişkisinin, yapılan en son çalışmalara atfen incelenmesi ve olası olumsuz etkilerin daha da azaltılması konusunda yapılacak önerilerden oluşturmaktadır. Yapılan birçok ciddi çalışma birbirleri ile çelişmesine rağmen, Dünya Sağlık Örgütü (DSÖ) EMA'nın insan sağlığı açısından "bir ihtimal kanserojendir" ibaresini kullanarak kanser açısından 2B gurubuna dahil etmiştir.

Uluslararası İyonlaştırıcı Olmayan Radyasyondan Koruma Komitesi (ICNIRP), EMA'ların insan sağlığını etkilediği sınırları yayınlanmıştır. Fakat Bİ ve CT'den kaynaklanan EMA'ların bu sınırlarla olan ilişkisi hala tartışılmaktadır. Burada esas olarak Bİ'nın ve CT'larının mümkün olan en düşük güç seviyesinde çalışabilmesi için Bİ'larının yerleşim düzeninin önemi üzerinde durulmuştur. Yerleşim düzeni tasarımı yapılırken halkın sağlıkla ilgili endişeleri ve servis sağlayıcıların ekonomi ve fonksiyon açısından hassasiyetleri de dikkate alınmıştır. Bu doğrultuda, Hata Sinyal Kaybı Modeli'ne göre, Gazimağusa'nın yüz ölçümü ve nüfusu ele alındığı zaman 16 Watt kaynak gücüne sahip Baz İstasyonunun en uygun tasarım olacağı sonucuna varılmıştır.

Anahtar kelimeler: Elektromanyetik Alan, Baz İstasyonlarından, Cep Telefonu

I would like to give my endless thanks to dear my darling Ipek Ruso whom this study could not have been completed without her absolute support.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	Human Head Cross-Section Area, m^2
c	Speed of light, m/s
λ	Wavelength, m
E	Electric Field, v/m
f	Frequency, Hz
h_m	MS Height, m
h_b	BS Height, m
L	Signal Attenuation, dB
M	Magnetic Field, A/m
M	Power Margin Value, dB
P_t	Transmit Power of the BS, Watt
P_i	Ideal BS Transmit Power, Watt
r	Effective Cell Radius, km
S_r	Sensitivity of the MT, dB
S_b	Power Density from BS, W/m^2
S_m	Power Density from MS, W/m^2

BS	Base Station
CIR	Carrier-to-Interference Ratio
CMC	Cellular Mobile Communication
CT	Cep Telefonları
CMCS	Cellular Mobile Communications System
DSÖ	Dünya Sağlık Örgütü
ELF	Extremely Low Frequency
EM	Electromagnetic
EMF	Electro-Magnetic-Fields
EMR	Electro-Magnetic-Radiation
EMU	Eastern Mediterranean University
ETSI	European Telecommunications Standard Institute
GSM	Global System for Mobile Communications
HF	High Frequency
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICNIRP	Uluslararası İyonlaştırıcı Olmayan Radyasyondan Koruma Komitesi

IF	Intermediate Frequency
MS	Mobile Station
MİC	Mobil İletişim Cihazlarından
QoS	Quality of Service
RF	Radio Frequency
RF-EMF	Radio-Frequency Electro-Magnetic-Fields
SIR	Signal to Interference Ratio
UMTS	Universal Mobile Technology System
WHO	World Health Organization

Chapter 1

INTRODUCTION

1.1 Background

As the wireless technologies penetrate our everyday life with an increasing rate, the adverse health effects of the Electro-Magnetic-Radiation (EMR) emerging from MSs and BSs become a more serious concern for the public. Many recent studies have focused on measurement of EMR levels from GSM900 BSs, for certain spectrum ranges under far-field conditions and compare the results with the mostly known guidelines referenced by ICNIRP. The measured results indicated that the EMR levels were below the limit for 900 MHz according to ICNIRP's recommendations [1, 2]. However, in the region of crowded cities where there are intense presence of Radio and TV transmitters, the EMR values were above the limit for within the 100 kHz to 3 GHz set by ICNIRP [3]. Other studies have concentrated on improving the BS coverage [4, 5]. Also a large volume of research was done for clarifying if the Electro-Magnetic-Fields (EMFs) emerging from the wireless communication devices cause or inhibit cancer contradict with each other [6 - 10]. This contradiction caused some people to be reluctant to use high tech Cellular Mobile Communication (CMC) devices due to the health concerns. Thirty one scientists came together at Lyon, France on May 2011 to examine all the data collected on the adverse health effects of EMR emerging from MS and BS. After thorough investigation and lengthy discussions, they concluded that the "EMR emerging from MS and BS is possibly carcinogenic” and they put these radiation in Group 2B, along with talc-based body powder, pickled vegetables and coffee. It has also been underlined by articles referenced by the WHO and ICNIRP that the likelihood of cancer development, induced by MS or BS originated by EM waves, is only existent under exposure to very high energy waves for a long period of time [11]. These concerns can be eliminated by reducing the powers involved in CMC such as the transmitted power of MS and BS, below a level suggested by the WHO and International Agency for Research on Cancer (IARC). On the other hand, in order to design an ideal CMC system, in addition to the health concerns of the MS and BS, the economic issues of the system should also be taken into account. For an economically successful result, the number of BSs should be related to the size of the geographical coverage area and population-density so that, the minimum possible number of BSs should be employed with the minimum possible transmit-power levels.

1.2 Aim of this Thesis

The previous research have often focused on the result of EMF exposure and measured EMF exposure limits. The work presented in this thesis targets methods for decreasing GSM BS and MS related health concerns with reference to the numbers, transmitted powers and location of the BSs in the initial design stage. The goal of this thesis is, therefore, to develop methods of reducing BS and MS related health concerns while maintaining functionality and keeping additional investment expenditure as low as possible for the service providers.

The present work is meant to serve as a resource of the formulation of recommendations for the future of mobile communications. It is intended for an increasing number of concerned researchers and professionals involved in the implementation of regeneration projects in Famagusta, in other parts of Cyprus, and throughout the world.

1.3 Thesis Organization

The study is organized into seven chapters. The first chapter is an introduction to the thesis and a review for the pertinent literature. The second chapter emphasizes the definition of EMF, GSM 900 BS and MS Also EMF generated by the GSM 900, GSM 1800 and 3G Universal Mobile Technology System (UMTS) BSs have been measured on Eastern Mediterranean University (EMU) Campus. The third chapter gives an overview of the CMCS design methodology with reference to the economic, functional and health concerns. The fourth chapter presents the evaluation of the current BS design as a case study and in Chapter 5 the proposed design approach is introduced and the economical, functional and health concerns justified. Budget analysis is done in Chapter 6 for several different scenarios and conclusions and future works are drawn in Chapter 7.

Chapter 2

DEFINITIONS AND MEASUREMENTS

2.1 Introduction

In order to measure the Electro-Magnetic-Radiation (EMR) emerging from BS and design a practical Cellular Mobile Communications System (CMCS), it is very important to understand the meaning of basic terms that are used in this field. Therefore, this chapter's emphasis is on the definition of EMF, GSM 900 BS and MS. Also EMF generated by the GSM 900, GSM 1800 and 3G UMTS BSs have been measured on EMU Campus and the measured values were compared with international reference levels for the exposure analysis. In addition, the measured values emerging from GSM 900 BS were compared with theoretical Electro-Magnetic-Radiation (EMR) emerging from MSs values of Sound CMCS Design Consideration at the end of Chapter 5.

2.2 Electromagnetic Field Pollution Definition

EMR is divided into two main parts: Ionizing (300 GHz +) Radiation and Non- Ionizing (0-300 GHz) Radiation as shown in Figure 2.1. Ionizing Radiation (such as Gamma-rays and X-rays) is radiation composed of particles that singly move enough kinetic energy to emancipate an electron from a molecule or atom, ionizing it [12]. On the other hand, Nonionizing radiation is a term used to describe any kind of EMR that does not move enough energy per quantum to ionize molecules or atoms [13].

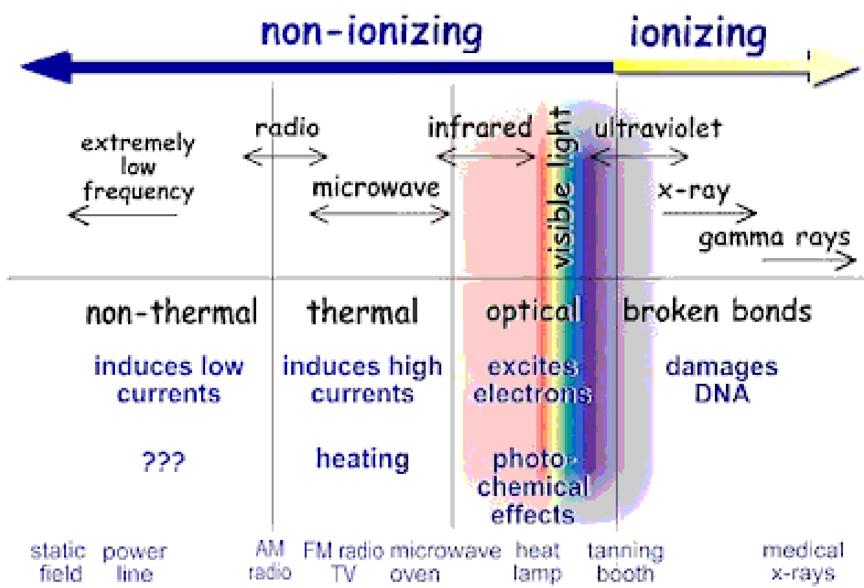

Figure 2.1: Two different types of electromagnetic radiation [13]

Natural sources such as sun light, lightning, some distant stars and Human-made sources which include power socket, radio waves, TV antennas, Radio Stations, Mobile Phone, BSs are the source of EMFs [14].

There are three kinds of EMFs from Human-made sources; Extremely Low Frequency (ELF) Fields (0 - 300 Hz), Intermediate Frequency (IF) Field (300 Hz - 10 MHz) and Radio Frequency (RF) fields (10 MHz - 300 GHz). ELF includes our electricity power supply and all appliances using electricity. IF represents the security systems, anti-theft devices and computer screens. RF includes cellular phone, radar, television, and radio antennas and microwave Owen [14].

EM Pollution or EMF Pollution is a term given to all the human-made EMFs of different frequencies, which fill work places, public spaces and our homes [15].

Everyone is under the constant exposure of EM waves and fields, from the extensive range usage of equipment, microwave ovens, medical equipment, GSM BS, MS, radio and television transmitters and radars.

2.2.1 Electric Field

Electric fields arise from voltage and their strength is measured in volt per meter (V/m). Electric fields are created by differences in voltage: the higher the voltage, the stronger will be the resultant field [14].

Measurements could be carried out in the High-Frequency spectrum for measuring electric fields generated by transmission equipment installations among which radar systems, wireless devices, C2000, UMTS and GSM towers [16].

2.2.2 Magnetic Field

Magnetic fields arise from current flows and their strength is measured in ampere per meter (A/m). Magnetic fields are created when electric current flows: the greater the current, the stronger the magnetic field [14].

Measurements could be carried out in the Low Frequency for magnetic fields around installations through which high currents flow. In most cases the frequency is 50/60Hz, for example in bushbar systems, switchboard cabinets, transformer spaces, overhead lines, and close to high-voltage cables, underground railway lines and trains [16].

2.2.3 Electromagnetic Field

EMF is the combination of both Electric and Magnetic Fields as shown in Figure 2.2.

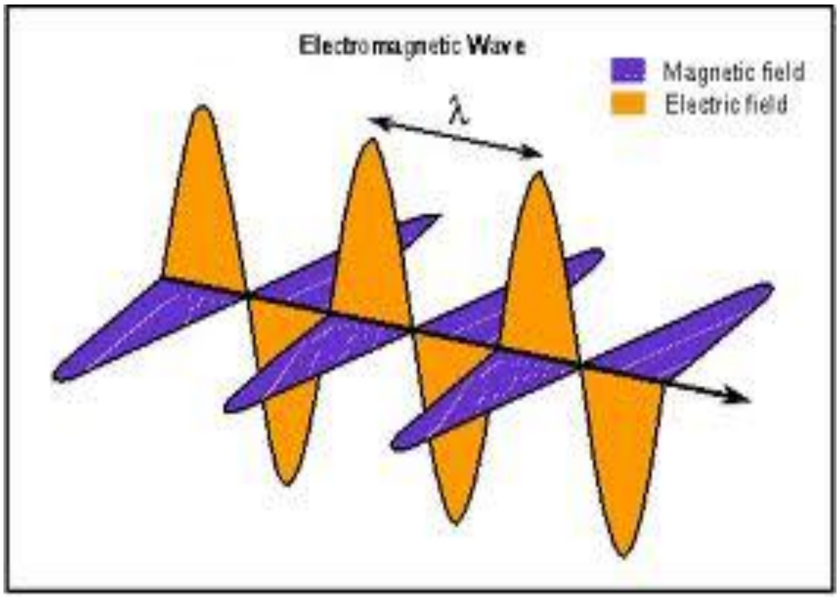

Figure 2.2: Electromagnetic Wave [30]

Sadiku (2001, p.3) states that EMs require the physical interpretation, synthesis, application of magnetic and electric fields and analysis. It may be referred as the study of the interactions between electric charges in motion and at rest [17].

EMFs cause interference with electronics and may affect the health of human beings. It is very important to recognize this at an early stage. This can be done while construction is in progress and at a future construction location, as a result budgets are not exceeded. By means of field-strength measurements one can chart the existing EMFs and radiation emitted by, transformer spaces, UMTS, GSM antennas and to name but a few. Based on these measurements the best location may be determined for rooms where sensitive measurements are to take place, for example in nano laboratories or hospitals [16].

GSM 900 BSs and Mobile telephones produce RF fields with frequencies of 890 MHz to 960 MHz. These fields are used to transmit information over long distances and form the basis of telecommunications.

2.3 Base Station and Mobile Station Definition

2.3.1 GSM 900 Base Station

The frequency band reserved for the GSM900 BSs are divided into two parts: 25 MHz downlink (BS to MS) and 25 MHz uplink (MS to BS). A 20 MHz Guard Band is also reserved between these two bands. The 25 MHz frequency bands are also divided into 125 times 200 kHz speech bands [21].

Cellular communication systems require the use of many BSs located throughout a service area. When a user places a call, his or her handset communicates with a nearby BS, which then relays the call to a central switching office and then to the conventional land line telephone network. As the user moves about, he or she is "handed off" to other BSs [18].

2.3.2 Mobile Station

‘‘A MS comprises all user equipment and software needed for communication with a mobile network’’ [19]. The establishment and planning of new BSs are required, in parallel with the increasing world population. Figure 2.3 shows that Mobile-cellular subscriptions penetrate our everyday life with an increasing rate. Therefore adverse health effects of the Electro-Magnetic-Radiation (EMR) emerging from MS become a more serious concern for the public.

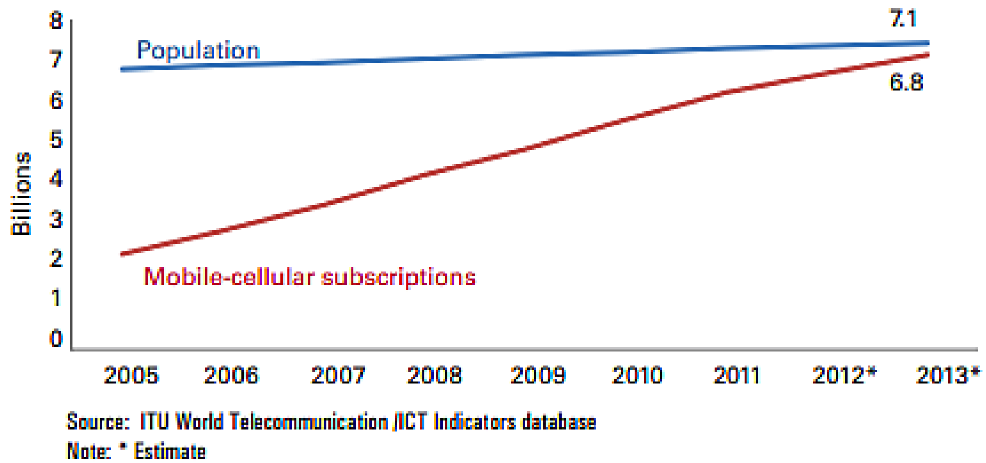

Figure 2.3: Mobile-cellular subscriptions [31]

2.4 EM measurements on EMU Campus

In this study, The Spectran HF-6085 within the 10 MHz to 8 GHz frequency range handheld spectrum analyzer and Omni directional antenna within the 700 MHz to 2.5 GHz frequency rage produced by AARONIA in Germany is chosen as the measurement equipments as shown in Figures 2.4 and 2.5. This type of antennas are standard rod-like antennas. Their main characteristic is that they have omni-directional properties.

Figure 2.4: Spectran HF-6085 handheld spectrum analyzer [33]

Figure 2.5: Radial Isotropic Broadband Antenna OmniLOG 90200 [32]

EMU Campus, which is in the shadow of many BSs, was selected as the work area. EMF generated by the GSM 900, GSM 1800 and 3G UMTS BSs have been measured on this Campus and measurements were made at 5 different points as can be seen in Figure 2.6 and Table 2.1. The exposure limits were obtained using an omni-directional antenna mounted 1.2 m above the ground level.

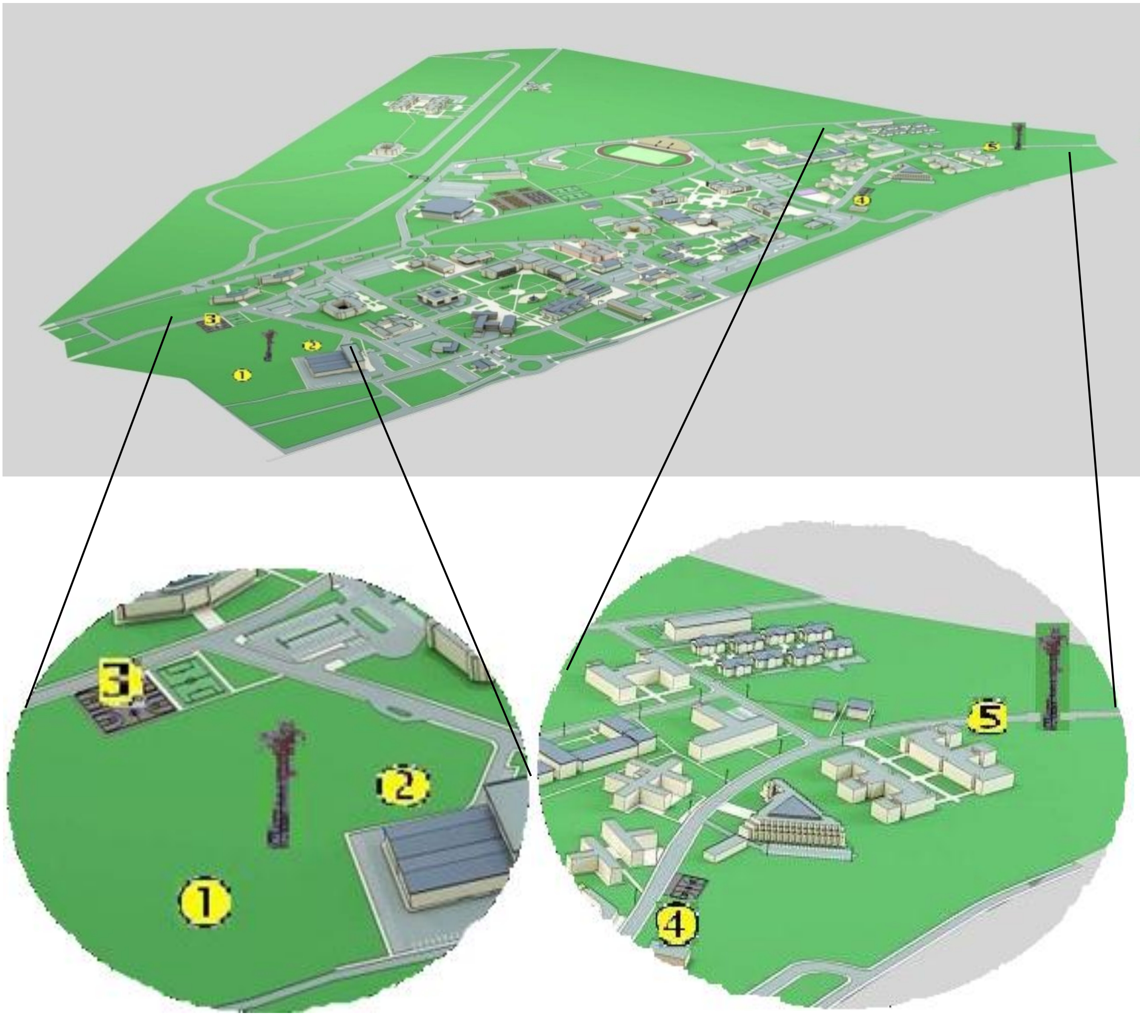

Figure 2.6: Measurement Points on EMU Campus

Table 2.1: Measurement results on EMU Campus.

Frequency Band	**900 MHz**		**1800MHz**		**3G Core**	
	Measurement Time	BS Down-link Tx925 -960 MHz	Measurement Time	BS Down-link Tx1810-1880 MHz	Measurement Time	BS Down link Tx2010-2170 MHz
Measurement Points		E (V/m)		E (V/m)		E (V/m)
①	11:06-11:12	0.125	11:13-11:19	0.042	11:19-11:25	0.059
②	11:50-11:56	0.102	11:57-12:03	0.046	12:03-12:09	0.326
③	12:38-12:44	0.151	12:44-12:50	0.030	12:50-12:56	0.039
④	14:26-14:32	0.141	14:33-12:39	0.014	14:39-14:45	0.475
⑤	14:47-12:53	0.357	14:53-14:59	0.004	15:00-15:06	0.131

The measured values which can be seen in Figure 2.6 and Table 2.1 [28] are compared with the international reference levels for the exposure analysis; it was found that the values were under the limit allowed in the guidelines referenced by ICNIRP which can be seen in Table 2.2.

Table 2.2: The Summary of the ICNIRP exposure guidelines [20]

Frequency Range	E-field Strength(V/m)	H-field Strength(A/m)	B-field (μT)	Power Density S (W/m^2)
Up to 1 Hz	-	3.2×10^4	4×10^4	-
1-8 Hz	10,000	$3.2\times10^4/f^2$	$4x10^4/\sqrt{f}$	-
8-25 Hz	10,000	4,000/f	$5{,}000/\sqrt{f}$	-
0025-0.8 kHz	250/f	4/f	5/f	-
0.8-3 kHz	250/f	5	6.25	-
3-150 kHz	87	5	6.25	-
0.15-1 MHz	87	0.73/f	0.92/f	-
1-10 MHz	$87/\sqrt{f}$	0.73/f	0.92/f	-
10-400 MHz	28	0.073	0.092	2
400-2,000 MHz	$1.375x\sqrt{f}$	$0.037x\sqrt{f}$	$0.0046x\sqrt{f}$	f/200
2-300 GHz	61	0.16	0.20	10

Chapter 3

CELLULAR MOBILE COMMUNICATIONS SYSTEM DESIGN FOR THE CITY OF FAMAGUSTA CONSIDERING ECONOMY, FUNCTIONALITY AND HEALTH CONCERNS

3.1 Introduction

In this chapter, three design scenarios are investigated, specifically determining the maximum number of concurrent mobile phone users that can be served by a BS, the importance of area to be covered and population density on determining the ideal number of BSs and calculating the cell radius. Two different MCCS design approaches with 40 Watt and 2 Watt BS transmit powers for the Famagusta city are be studied. During the system design the Hata Signal Attenuation Model [24] is employed.

The Cellular System Architecture is based on 7 cell/cluster model as shown in Figure 3.1.

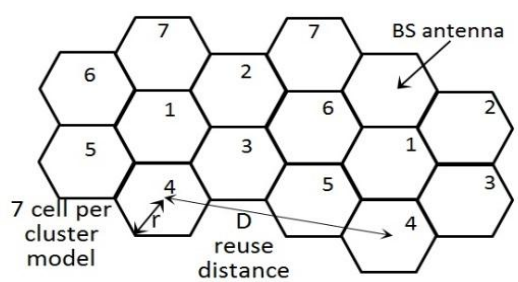

Figure 3.1: The 7 cell/cluster cellular system design model used in this thesis

3.2 Determining the Maximum Number of Concurrent Mobile Phone Users That Can Be Served By a Base Station

As presented in Figure 3.2, the frequency band reserved for the GSM900 BSs is divided into two blocks: 25 MHz uplink (MS to BS) and 25 MHz downlink (BS to MS). A 20 MHz Guard Band is also reserved between these two bands [21]. The 25 MHz frequency bands are also divided into 125 bands with 200 kHz speech bands. In the North of Cyprus, each of the two operators is using half of the allocated 22 MHz band independently. This means that we have 55 full-duplex speech channel/BS, each carrying 8 Time Division Multiple Access channels, adding up to 440 simultaneous conversations. Note that each full-duplex speech channel occupies 25 kHz bandwidth.

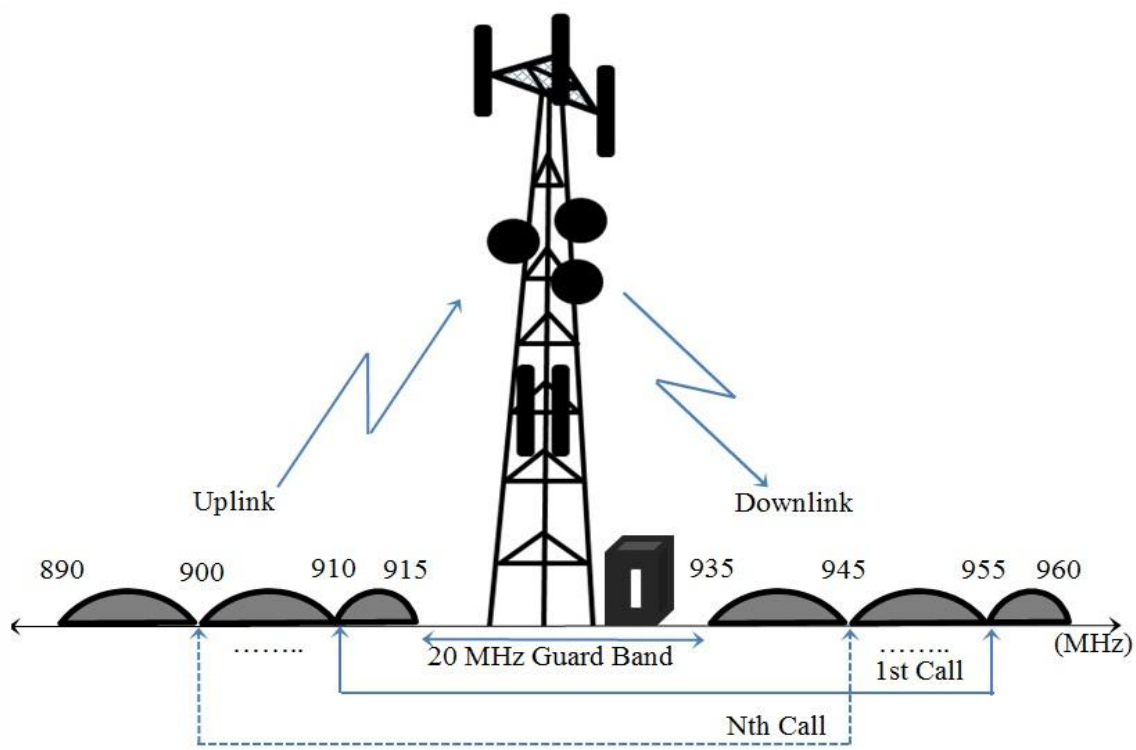

Figure 3.2: GSM 900 Base Station frequency-band representation [21]

3.3 The Importance of Surface Area and Population on the Calculation of the Ideal Number of Base Stations

Nowadays, Mobile Telephones (MTs) are one of the most important gadgets in our everyday life, enabling seamless communication between our connections wherever we are. A Mobile Communication System is said to have 100% Quality of Service (QoS) if it provide the opportunity for 100 percent of the population to use a communication channel and connect with their distant partners simultaneously. At this point, in order to design a practical Cellular Mobile Communications System (CMCS), it is very important to determine what percentage of the population will be given service simultaneously on their MTs. BS system design is also done by considering the coverage area spread and number of people living in the coverage area. Therefore, in an ideal system with 100% QoS, size of the population should also be taken into account in order to determine the number of BSs and their respective transmit powers. At the same time, the less populated or uninhabited areas should also be considered when designing a functionally and economically successful CMCS. Hence, while providing 100% of the population with the opportunity to have simultaneous conversations with their distant partners, adverse health effects should also be considered. Population of Famagusta is 69938 and Surface Area of Famagusta is 997.44 km^2 [22]. Ideally 100% of Famagusta's population can simultaneously engage in full duplex calls through approximately 69938/ 440 = 159 BSs.

3.4 Calculating the Cell Radius for Two Different CMCS Design Approaches with 40 Watt and 2 Watt BS Transmit Powers for the Famagusta City

The effective cell radius for a BS can be calculated using the Hata Signal Attenuation Model, which is referenced by the European Telecommunications Standard Institute (ETSI) [24] and given by:

$$L\ (\text{dB}) = P_t - S_r - M \tag{3.1}$$

where L (dB) is the signal attenuation in dB, P_t is the BS transmit power, S_r is the sensitivity of the MT, and M is the power limit which has values between 1 dB and 3 dB for normal and operational power loss situations.

3.4.1 Maximum Transmit Power (40 Watt)

In order to calculate the effective cell radius for a BS with 40 Watt transmit power, we have: P_t = 40 Watt, S_r = -102 dBm, M = - 0.6 dB. Hence the signal attenuation L (dB) is calculated as 142.6 dB. The topology and geographic details of the Famagusta city resembles an open and crowded city in accordance with the Signal Attenuation Model [24, 25]. Hence, the following equation and description holds:

$$L\ (\text{dB}) = L_u - D \tag{3.2}$$

and

$$L_u\ (\text{dB}) = 69.55 + 26.16 \times \log(f) - 13.82 \times \log(h_b) - a(h_m) + [44.9 - 6.55 \times \log(h_b)] \times \log(r) \tag{3.3}$$

With f = 900 MHz, h_m = 1.5 m ve h_b = 30 m, we have:

$$a(h_m) = 3.2 \times [\log(11.75 \times h_m)]^2 - 4.97 = 3.2\times[\log(11.75 \times 1.5)]^2 - 4.97 = -9.19\times10^{-4}$$

and

$$D = 4.78 \times [\log(f)]^2 - 18.33 \times \log(f) + 40.94 = 4.78 \times [\log(900)]^2 - 18.33 \times \log(900) + 40.94 = 28.06$$

Rearranging (3.3) in order to calculate the effective cell radius, we have:

$$\log(r) = \frac{L\ dB\ \ + D - I}{T} \tag{3.4}$$

where

$$I = 69.55 + 26.16 \times \log(f) - 13.82 \times \log(h_b) - a(h_m) = 69.55 + 26.16 \times \log(900) - 13.82 \times \log(30) + (9.19\times10^{-4})$$

$$= 126.42$$

and

$$T = [44.9 - 6.55 \times \log(h_b)] = 44.9\text{-}6.55 \times \log(30) = 35.22 \tag{3.5}$$

$$\log(r) = \frac{L\ dB\ \ + D - I}{T} = \frac{142.6 + 28.05641809 - 126.4182493}{35.22485578} = 1.255 \tag{3.6}$$

Using the Hata Path Loss Model and the GSM 900 band typical parameters in (3.3) such as, BS height = 30 m and BS transmit power $P_{t\mathrm{BS}}$ = 40 Watt, MS height = 1.5 m and MS transmit power $P_{t\mathrm{MS}}$ = 2 Watt, the effective cell radius can be calculated as 18 km.

As depicted in Figure 3.3, the sensitivities of the MS and BS are –102 dBm and the effective cell radius is calculated to be 18 km when the BS transmit power is 40 Watt. Calculating the area of a hexagon as:

$$2.5981 \times (18)^2 = 841.78 \text{ km}^2 \tag{3.7}$$

While estimating that ideally 100% of Famagusta population can simultaneously engage in full duplex calls through approximately 69938 / 440 = 159 BSs, the solution using 2 BSs each with 40 Watt transmit power will not be sufficient. Besides, considering the geographic area of Famagusta, 159 BSs each 40 Watt will cover 159 × 841.78 km^2 = 133844 km^2. Since the geographic area of Famagusta is 997.44 km^2, a solution covering approximately 134 times larger area will not be economically justifiable and will result in more severe health and economical concerns.

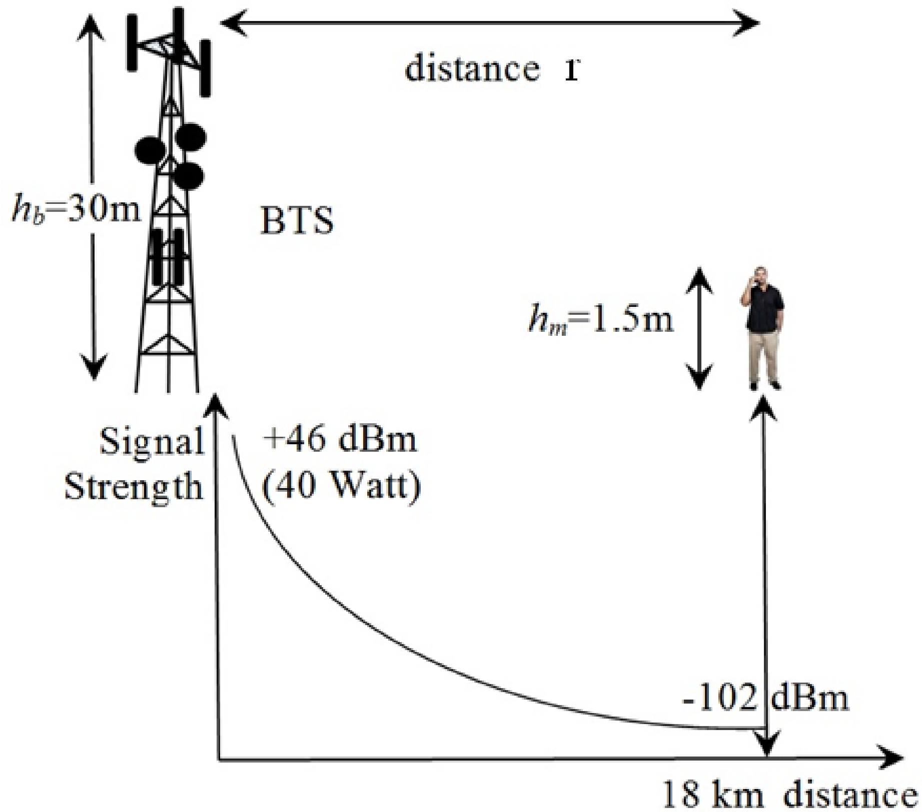

Figure 3.3: Determining the effective cell radius for a 40 Watt BS transmit power

3.4.2 Minimum BS Transmit Power (2 Watt)

As shown in Figure 3.4, the effective cell radius for a BS with 2 Watt transmit power is 1.5 km and the geographic area of a hexagon with Radius 1.5 km is 2.5981× $(1.5)^2$ = 5.85 km^2. Accordingly, there are 997.44 km^2 / 5.85 km^2 = 170 BSs for the Famagusta city with 997.44 km^2. Since 440 people can be talking simultaneously over a BS, 170 BSs serve 74800 people talk simultaneously. But, for 100 percent of Famagusta city be given CMC Service (Grade of Service = 1), 159 BSs are required. This solution is optimal in terms of health concerns because the transmitted power from the BSs is as low as that of the MSs. However, due to the need for additional 170 – 159 = 11 BSs, an economically heavy burden is placed on the operators.

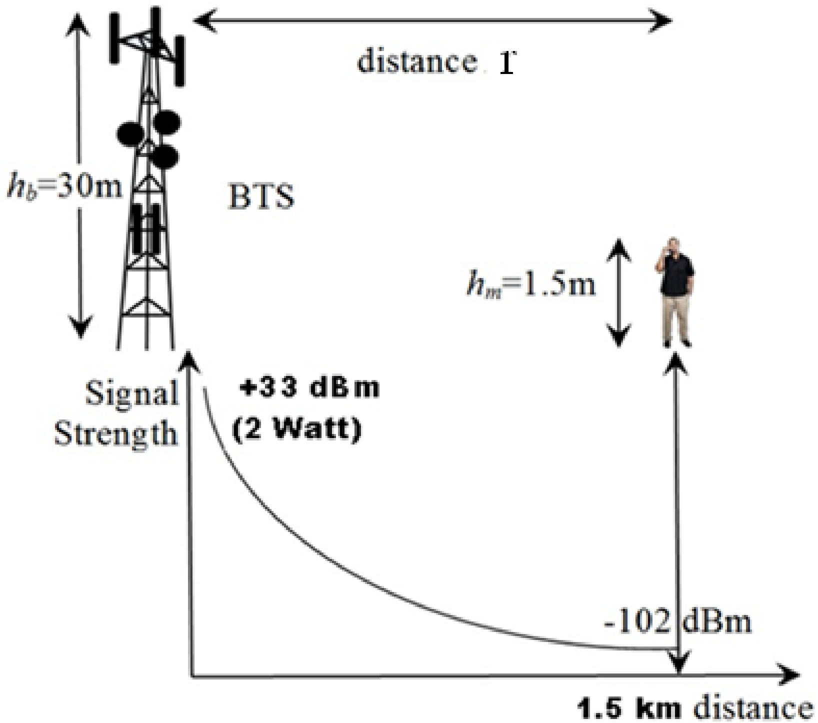

Figure 3.4: Determining the effective cell radius for a 2 Watt BS transmit power.

As can be seen from the above calculations, the CMCS designed using very large or very small BS transmit powers will not result in an economically, functionally and health-wise acceptable solution.

Chapter 4

EVALUATION OF THE CURRENT BS DESIGN FOR THE FAMAGUSTA CITY

4.1 Introduction

Currently 82 BSs cover the Famagusta city [23], providing simultaneous conversation to only 440 × 82 = 36080 people, which is 100 × 36080/69938 = 0.52 or 52% of the population. These BSs have minimum 10 Watt and maximum 40 Watt transmit Powers [23]. As stated above, a BS with a 40 Watt transmit power covers a 841.78 km^2 geographic area. Considering that the geographic area of Famagusta is 997.44 km^2, 2 BSs each with 40 Watt transmit power are sufficient to cover the entire city if the only target performance measure is geographical signal strength distribution.

4.2 Design Methodology

In order to derive a concise formula to find the optimum transmitted power for a BS to cover a specific area, the following assumptions should be made:

f = Frequency = 900 MHz

h_m = MS Height = 1.5 m

h_b = BS Height = 30 m

S_r = the sensitivity of mobile receiver = -102 dBm

M = the power margin value = - 0.6 dBm

$$P_i = (log(r) \times T) - 102.6 - D + I \tag{4.1}$$

This is an optimization problem where the optimum value should be reached at the point when the BS is at the lowest power level [27].

Chapter 5

AN ECONOMICAL, FUNCTIONAL AND HEALTH-AWARE BS SYSTEM DESIGN CONSIDERATION FOR THE FAMAGUSTA CITY

5.1 Introduction

An ideal BS system, while providing service for 100% of the population should also provide a near-uniform power distribution throughout the coverage area. The ideal number in terms of number of people served is shown to be 159. Hence, the ideal BS transmit power (P_i) can be calculated to be

$$P_i = (log(r) \times T) - 102.6 - D + I \qquad (4.1)$$

Calculation of log(r)

Since the geographic area of Famagusta is 997.44 km^2, each BS will have a coverage area of 6.27 km^2 (that is 997.44/159 = 6.27). Hence, the effective cell radius is estimated to be

$$r^2 = 6.27/2.5981 \Rightarrow r = 1.55 \text{ km}^2$$

Eventually, log(r) is calculated as

$$10^{\log(r)} = 1.55 \Rightarrow \log(r) = 0.19$$

5.2 Lower Base Station Transmit Power Scenario

The ideal BS transmit power can be calculated using (4.1) as:

P_i = (0.19 × 35.22485578) - 102.6 - 28.05641809 + 126.4182493 = 2.46 Watt

The ideal BS transmit power for the Famagusta city is 2.46 Watt. The sensitivities of the MS and BS are –102 dBm and the effective cell radius is calculated to be 1.55 km as illustrated in Figure 5.1.

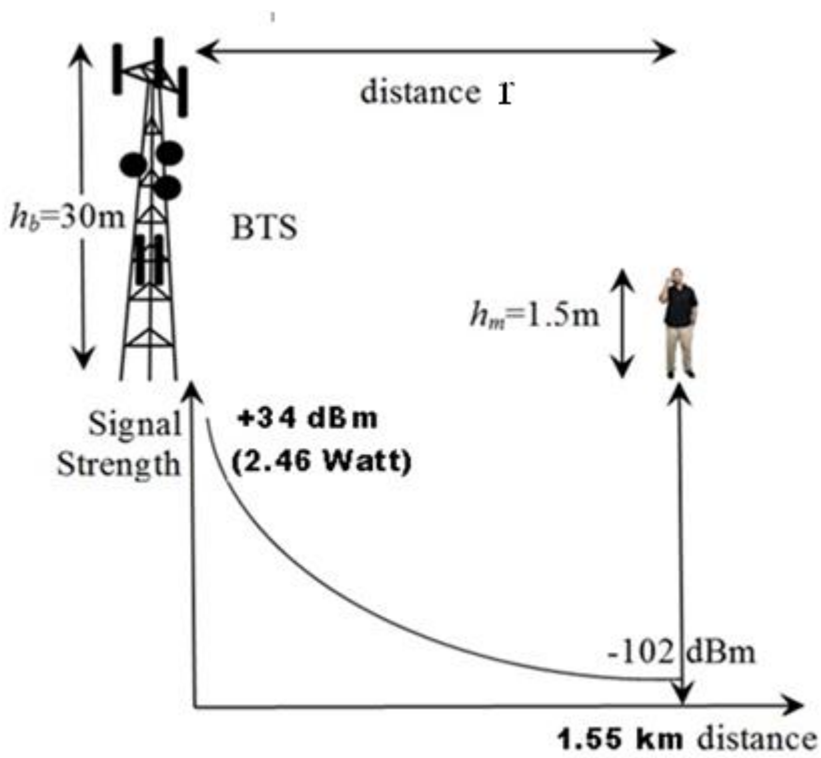

Figure 5.1: Determining the effective cell radius for a 2.46 Watt BS transmit power.

The results obtained show that the minimum BS transmit power for an ideal CMCS design for the Famagusta city is 2.46 Watt. This can also be seen in Figure 5.2 where the effective radiated power versus the received signal level is plotted using Hata Signal Attenuation Model.

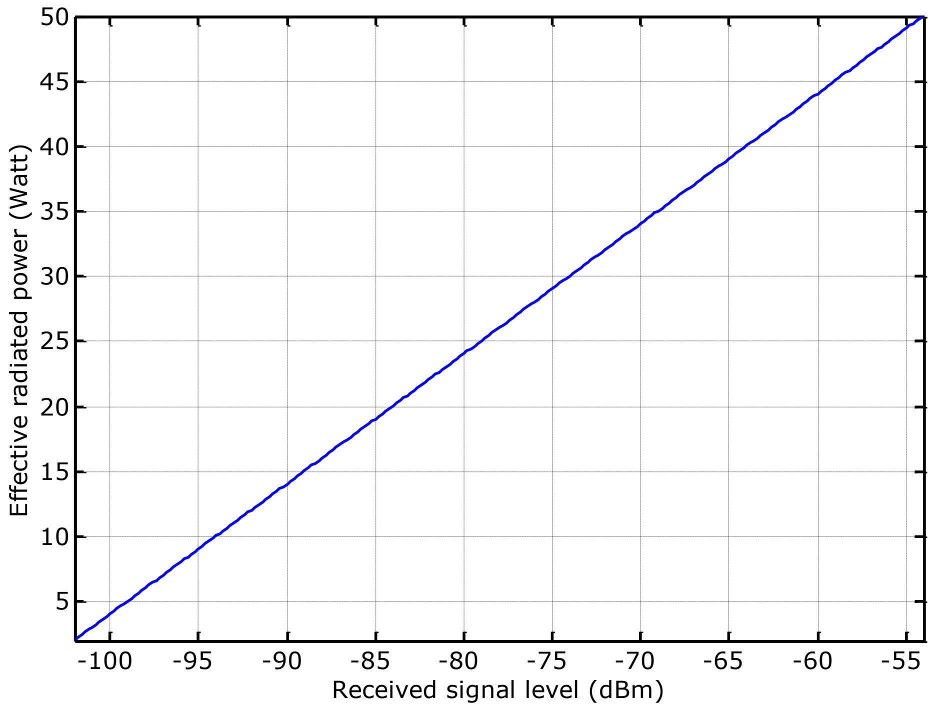

Figure 5.2: The effective radiated power versus received signal strength at distance

r = 1.5 km using Hata Signal Attenuation Model

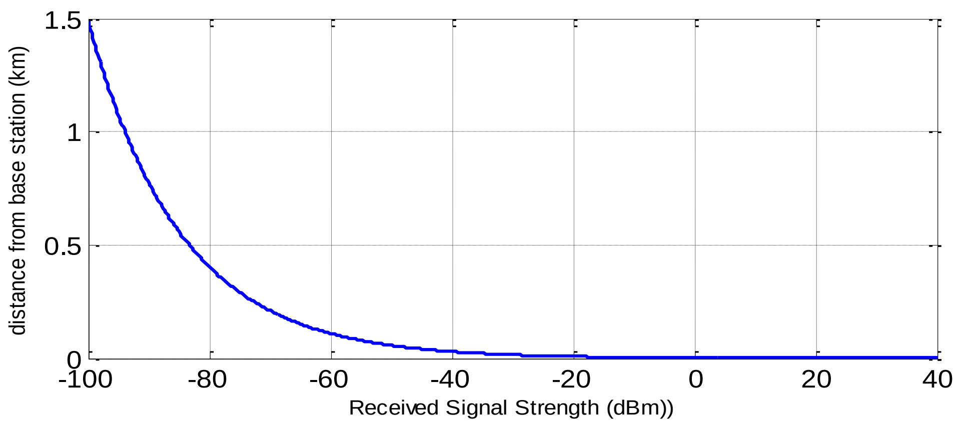

Figure 5.3 (a): Distance from BS versus received signal strength at MS; covering the

entire range from very near to BS to the theoretical cell edge

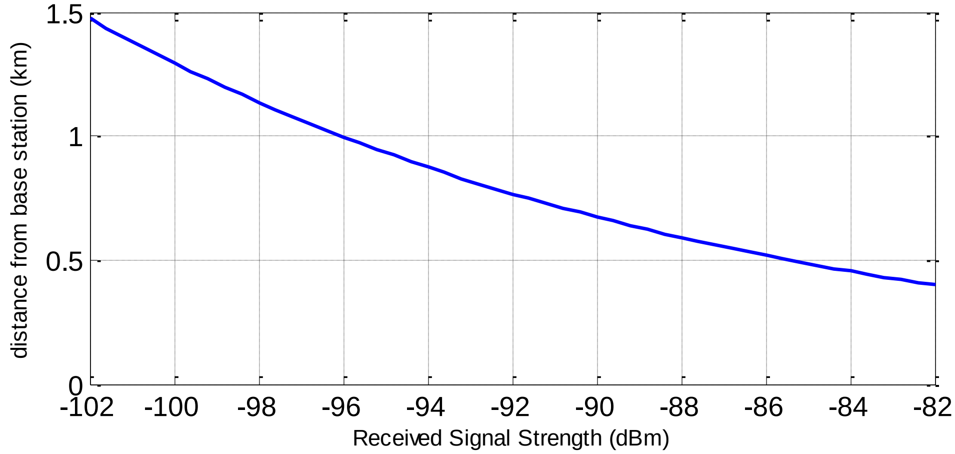

Figure 5.3 (b): Distance from BS versus received signal strength at MS; the coverage scenario where the MS transmit power is less than the maximum value

Figure 5.3 (a) show that the distance from BS versus received signal strength at MS; covering the entire range from very near to BS to the theoretical cell edge and the coverage scenario where the MS transmit power is less than the maximum value shown in Figure 5.3 (b). Using the Hata Signal Attenuation Model, a 2.46 Watt BS will have a coverage area of radius 1.55 km. Similarly a hexagonal coverage area will have $2.5981\times(1.55)^2 = 6.27\ km^2$. This result reveals that the Famagusta city will require 159 BSs. Since a BS provides service for 440 people, 159 BSs will provide service for 69960 people. Considering that 159 BSs are required for 100% Grade of Service, 2.46 Watt BS transmit power is the best solution for population, economic and coverage area reasons. When 2.46 Watt BS transmit power levels are used, all MSs are closer to BSs and for reflector antennas, the power level distribution level is calculated as [25]:

$$S_b = 4P/A \tag{5.1}$$

Measurements have shown that the power level due to a 2.46 Watt BS falls 900 times right below the BS tower and becomes 2.73 mW. The human head cross-section (A) presented in (5.1) is calculated as 0.045 as shown below:

$$A = \pi r^2 = 3{,}14 \times 0.12^2 = 0.045 \text{ m}^2 \qquad (5.2)$$

where r is taken as 12 cm. Substituting for all values in (5.1), S_b is found to be 0.243 W/m^2. This is 18.5 times lower than the limits provided by ICNIRP [20].

5.3 Lower Mobile Station Transmit Power Scenario

When the minimum BS transmit power case is considered, the MSs are receiving signals at -102 dBm and transmitting at its maximum possible power level of 2 Watt at the edges of the cells. Since this is not a desirable situation, a different scenario where the cell radius is reduced and frequency handover will take place to switch to the neighboring cell is employed. The cut-off power level is increased to one lower level (such as -88 dBm) as indicated on the power level detector on the MS screen as shown in Figure 5.4.

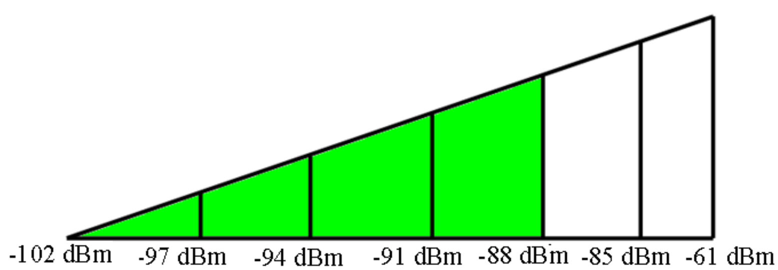

Figure 5.4: The cut-off power level at MS is increased to -88 dBm as indicated by the power level detector on the MS screen [26]

The effective cell radius (R) for BS transmit power can be calculated to be

$$R = 10^{\frac{P_{Txi} + S_r + M + D - I}{T}} \tag{5.3}$$

The Sensitivity of Received signal level for a 2.46 Watt BS transmit power can be calculated using (5.3) as shown in Figure 5.5.

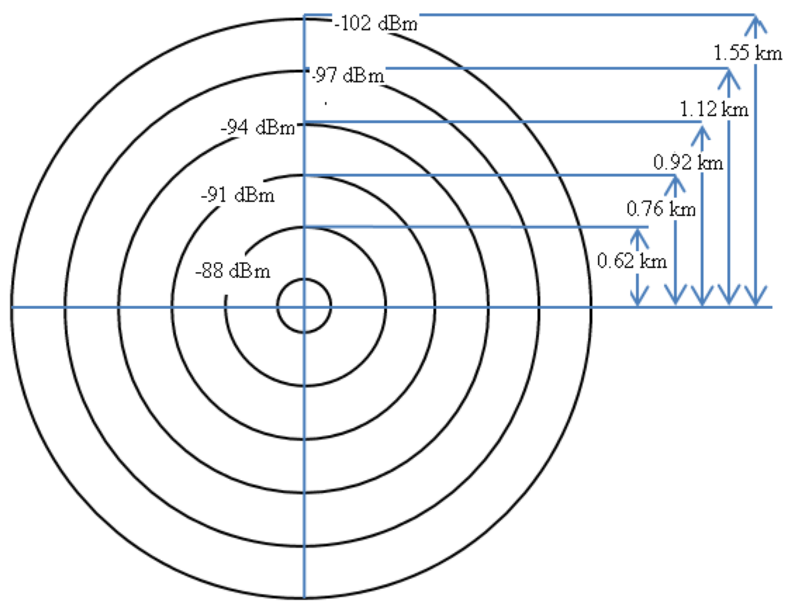

Figure 5.5: Distance from BS versus received signal strength at MS for 2.46 Watt BS transmit power [26]

For a BS transmit power level of 2.46 Watt, when the cut-off level for frequency handover is -88 dBm, the effective cell radius is 0.62 km in order to preserve the 159 BS scenario and maintain the -88 dBm cut-off power level at the cell edges. Hence, the BS transmit power (P_{Txi}) can be calculated to be

$$P_{Txi} = (log(R) \times T) - 88.6 - D + I \quad (5.4)$$

The BS transmit power should be increased to 16 Watt so that the cell radius is increased back to 1.55 km.

The results obtained show that the Lower MS Transmit Powers for an ideal CMCS design for the Famagusta city is -88 dBm. The Sensitivity of Received signal level for a 16 Watt BS transmit power can also be seen in Figure 5.6 (a) and (b), where Distance from BS versus received signal strength is plotted using Hata Signal Attenuation Model. The 7 cell/cluster model still provides 17.3 dB SIR. The Signal-to-Interference Ratio (SIR), also called the Carrier-to-Interference Ratio (CIR), is the quotient between the average received modulated carrier power S or C and the average received co-channel interference power I, for example cross-talk, from other transmitters than the useful signal [29].

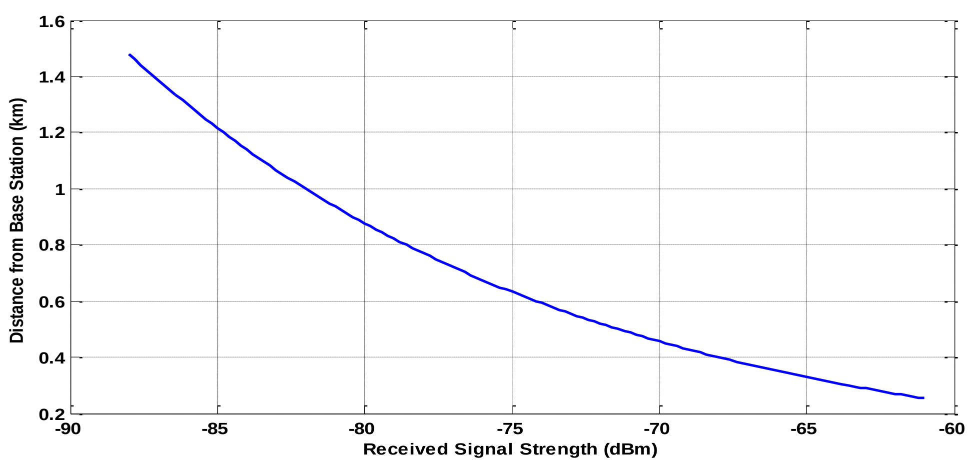

Figure 5.6 (a): Distance from BS versus received signal strength at MS for 16 Watt BS transmit power (from -60 dBm to -90 dBm)

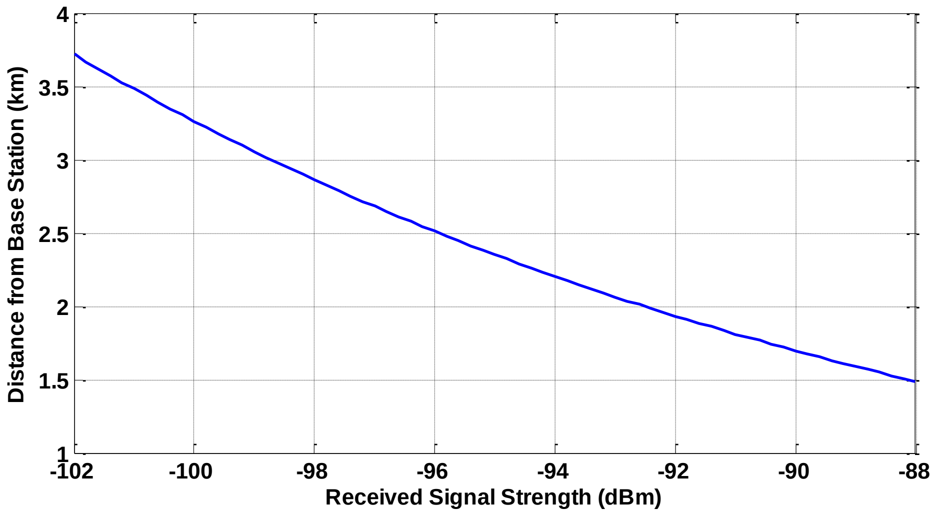

Figure 5.6 (b): Distance from BS versus received signal strength at MS for 16 Watt BS transmit power (from -88 dBm to -102 dBm)

The ideal BS transmit power for the Famagusta city is 16 Watt. The sensitivities of the BS is – 88 dBm and the effective cell radius is calculated to be 1.55 km as illustrated in Figure 5.7.

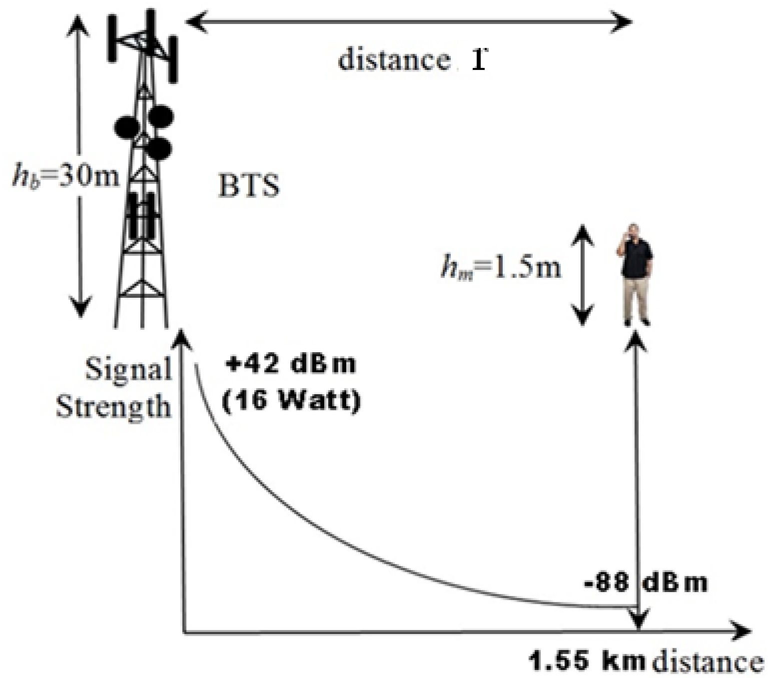

Figure 5.7: Determining the effective cell radius for a 16 Watt BS transmit power.

The BS number shown that 159 for 100% Grade of Service, when 16 Watt BS transmit power levels are used, all MSs are closer to BSs and when the cut-off level for frequency handover is -88 dBm, the transmit power level at MT is 12 dBm (0.0158 Watt) as shown in Table 5.1.

Table 5.1**:** Received signal level for Mobile Telephone [26]

Receiving power level	Transmission power level from MS	Nos. of reception Level indication bars	Communication condition
-61 dBm	-15 dBm	6	Very Good
-64 dBm	-12 dBm	6	Very Good
-67 dBm	-9 dBm	6	Very Good
-70 dBm	-6 dBm	6	Good
-73 dBm	-3 dBm	6	Good
-76 dBm	0 dBm	6	Normal
-79 dBm	3 dBm	6	Normal
-82 dBm	6 dBm	5-6	Normal
-85 dBm	9 dBm	4-5	Bad
-88 dBm	12 dBm	3-4	Bad
-91 dBm	15 dBm	2-3	Very Bad
-94 dBm	18 dBm	1-2	Very Bad
-97 dBm	21 dBm	0-1	Very Bad
-100 dBm	24 dBm	0	Unavailable
-103 dBm	27 dBm	0	Unavailable

The human head cross-section (A) presented in (5.5) is calculated as 0.045 m^2 as shown below:

$$A = \pi r^2 = 3{,}14 \times 0.12^2 = 0.045 \tag{5.2}$$

Therefore, $0.5A^2/\lambda = 0.5 \times 0.045^2/0.33 = 0.0031$ m. If the distance between MT and the human head is lower than 0.0031 m, for reflector antennas, the power level distribution is calculated as [25]:

$$S_m = 4P/A \tag{5.5}$$

Substituting for all values in (5.5), S_m is found to be 1.404 W/m^2. This is 3 times lower than the limits provided by ICNIRP [20].

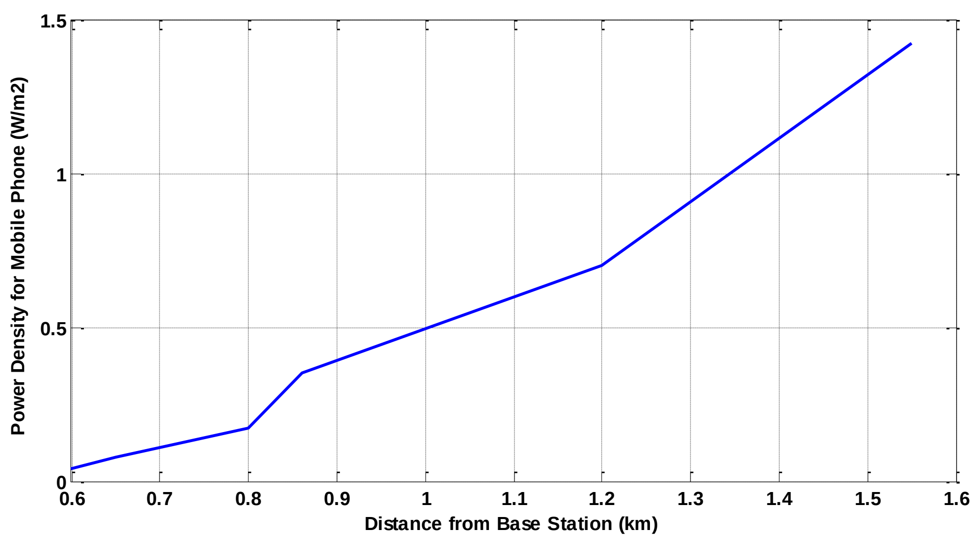

Figure 5.8: Distance from BS versus Power density for Mobile Phone (Sm)

As shown in Figure 5.8, when the MT is placed 0.62 km far away from the BS which has a transmit power of 16 Watt, the Power density for the MT is found to be 0.04 W/m^2. This is 112 times lower than the limits provided by ICNIRP [20].

Table 5.2: Comparison between measured values from 900 MHz and theoretical EMR emerging from Mobile Stations (MS) values

Frequency Band	**Distance**	**Measured Result**	**Our Design Consideration**
	From Base Station to Point	BS Down-link Tx 925-960 MHz	for the Mobile phone
Measurement Points		E (V/m)	E (V/m)
①	0.06 Km	0.125	0.06
②	0.03 Km	0.102	0.02
③	0.9 Km	0.151	9.1
④	0.6Km-0.01Km	0.141	4.09-0.003
⑤	0.11 Km	0.357	0.22

The measured values emerging from 900 MHz which can be seen Table 2.1 were compared with theoretical Electro-Magnetic-Radiation (EMR) emerging from MSs values of Sound CMCS Design Consideration as shown Table 5.2; it was found that the values were under the measured values. This theoretical value comes from Lower Mobile Station Transmit Power Scenario. In this scenario all off the unit values were power density (W/m^2), but since the unit of measured values were Electric field (V/m), the units are changed from Power density to Electric Field using equation 5.6.

$$E_m[\text{V/m}] = \sqrt{Sm\ \frac{\text{W}}{m^2} \times 377[\Omega]} \qquad (5.6)$$

Chapter 6

BUDGET ANALYSIS

6.1 Introduction

When the cut-off level for frequency handover is -88 dBm, the effective cell radius for a BS with 2.46 Watt transmit power is 0.62 km and the geographic area of a hexagon with radius 0.62 km is $2.5981\times(0.62)^2 = 0.999$ km^2. Accordingly, there are 997.44 km^2 / 0.999 km^2 = 998 BSs for the Famagusta city with 997.44 km^2. Since 440 people can be talking simultaneously over a BS, 998 BSs serve 439120 people talk simultaneously. But, for 100 percent of Famagusta city be given CMC Service (Grade of Service = 1), 159 BSs are required. This solution is optimal in terms of health concerns because the transmitted power from the BSs is as low as that of the MSs. However, due to the need for additional 998 - 159 = 839 BSs, an economically heavy burden is placed on the operators.

On the other hand, when the BS transmit power is 16 Watt with the cut-off level for frequency handover is -88 dBm, the cell radius is 1.55 km. Similarly a hexagonal coverage area will have $2.5981\times(1.55)^2 = 6.27$ km^2. This result reveals that the Famagusta city will require 159 BSs. Since a BS provides service for 440 people, 159 BSs will provide service for 69960 people. Considering that 159 BSs are required for

100% Grade of Service, 16 Watt BS transmit power is the best solution for population, economic and coverage area reasons.

Chapter 7

CONCLUSION AND FUTURE WORK

7.1 Conclusion

A lot of materials have been published in the literature about the human health hazards of EM waves emerging from MS and BS. While these materials do not provide solid evidence about the adverse health effects of these EM waves, WHO has published the only conclusive report, claiming that “the EM waves emerging from MS and BS could possibly be carcinogenic” under certain conditions. According to WHO, EM waves could be carcinogenic when a person is subject to high power EM waves for a relatively long period of time. This justifies the importance of the locations where the BSs be erected. Hence, the BSs need to be designed in harmony with the geographic area and population density in order to optimize the system for economy, functionality and health concerns. Hence, considering the population, terrain and coverage area and employing the Hata Signal Attenuation Model, a reasonable solution for the Famagusta city is estimated to use 2.46 Watt BSs and enable full coverage of the targeted geographic area. However, since the MSs and BSs are not desired to transmit at their maximum available power levels, the minimum acceptable received signal level will have a value of -88 dBm, which is higher than the MS sensitivity of -102 dBm to enable reasonable transmitted signal levels from both MSs and BSs.

7.2 Future Work

When considering the ideal BS system design, the population density is also a major issue to be considered. Adjusting the number of BSs and transmit power levels in accordance with the population density will make the design extremely successful. For example, employing low power BSs wherever the population density is high and high power BSs wherever the population density is low improves the systems success rate.

Turning the method used to find the best value for health, economy and functionality into an optimization problem and solving for the optimum value for BS Transmit Power and distances.

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APPENDIX A

Matlab Codes

```
% The required BS Transmit Power will change as a function of the minimum
% signal level acceptable at the receiver. In a design scenario where the
% health concerns are taken into account, the signal level is not expected
% to fall below a certain value where the MS and BS will both require to
% increase their transmit powers to 50% of its rated value (maximum value)
% To conclude the discussion presented above, we need to know what value
% does each level on the received power meter of the MS corresponds to.
POP = 69938;          % Population of Famagusta city
f = 900;              % carrier frequency
h_b = 30;             % height of BS (30m)
h_m = 1.5;            % height of MS (1.5m)
CPBS = 440;           % 440 Channel per BS
SA = 997.44;          % Surface Area of Famagusta in km^2
M = -0.6;             % power margin in dB
```

```
Sr = -90: -0.2 : -102;   % received signal level in dBm, minimum -102 dBm

%sr = 10.^( (Sr/10)-3 );         % convert from dBm to power level

T = 44.9 - 6.55 * log10(h_b);

NBS_i = POP/CPBS;      % ideal #BS = population / Channel per BS

d = sqrt ( (CS/NBS_i)/2.598 );

%m = 10^(M/10);         % convert from dB to value

D = 4.78 * (log10(f))^2 - 18.33 * log10(f) + 40.94;

I = 69.55+26.16*log10(f)-13.82*log10(h_b)-(3.2*(log10(11.75*h_m))^2-4.97);

Pi = T*log10(d)+Sr+M-D+I;

% The required BS Transmit Power will change as a function of the minimum

% signal level acceptable at the receiver. In a design scenario where the

% health concerns are taken into account, the signal level is not expected

% to fall below a certain value where the MS and BS will both require to

% increase their transmit powers to 50% of its rated value (maximum value)

% To conclude the discussion presented above, we need to know what value

% does each level on the received power meter of the MS corresponds to.

POP = 69938;            % Population of Famagusta city
```

```
f = 900;                % carrier frequency

h_b = 30;               % height of BS (30m)

h_m = 1.5;              % height of MS (1.5m)

CPBS = 440;             % 440 Channel per BS

CS = 997.44;            % Surface Area of Famagusta in km^2

M = -0.6;               % power margin in dB

Sr = -88: -0.2 : -102;   % received signal level in dBm, minimum -102 dBm

%sr = 10.^( (Sr/10)-3 );          % convert from dBm to power level

T = 44.9 - 6.55 * log10(h_b);

NBS_i = POP/CPBS;       % ideal #BS = population / Channel per BS

d = sqrt ( (CS/NBS_i)/2.598 );

%m = 10^(M/10);          % convert from dB to value

D = 4.78 * (log10(f))^2 - 18.33 * log10(f) + 40.94;

I = 69.55+26.16 * log10(f)-13.82*log10(h_b)-(3.2*(log10(11.75*h_m))^2-4.97);

PTxi = 14.46

d = 10.^( (PTxi- Sr +M+ D-I)/ T)
```

```
plot(Sr, d);

% The required BS Transmit Power will change as a function of the minimum

% signal level acceptable at the receiver. In a design scenario where the

% health concerns are taken into account, the signal level is not expected

% to fall below a certain value where the MS and BS will both require to

% increase their transmit powers to 50% of its rated value (maximum value)

% To conclude the discussion presented above, we need to know what value

% does each level on the received power meter of the MS corresponds to.

N = 7

POP = 69938;          % Population of Famagusta city

f = 900;              % carrier frequency

h_b = 30;             % height of BS (30m)

h_m = 1.5;            % height of MS (1.5m)

CPBS = 440;           % 440 Channel per BS

CS = 997.44;          % Surface Area of Famagusta in km^2

M = -0.6;             % power margin in dB

Sr = -88;             % received signal level in dBm, minimum -102 dBm
```

```
%sr = 10.^( (Sr/10)-3 );          % convert from dBm to power level

T = 44.9 - 6.55 * log10(h_b);

NBS_i = POP/CPBS;       % ideal #BS = population / Channel per BS

d = sqrt ( (CS/NBS_i)/2.598 );

%m = 10^(M/10);          % convert from dB to value

K = 4.78 * (log10(f))^2 - 18.33 * log10(f) + 40.94;

I = 69.55+26.16*log10(f)-13.82*log10(h_b)-(3.2*(log10(11.75*h_m))^2-4.97);

PTxi = 2.46

R = 10.^( (PTxi- Sr +M+ K-I)/ T);

D = ((3*N).^(1/2))*R

SIR = 10*log10((R.^-4)/((2*(D-R).^-4)+(2*(D+R)^-4)+(2*D.^-4)))
```

APPENDIX B

Antenna Parameters

Freq [GHz]	**Gain [dBi]**	Gain [dBd]	Antenna-Factor
0,7	**-3,0028**	-5,1528	30,13
0,71	**-2,6586**	-4,8086	29,91
0,72	**-2,2474**	-4,3974	29,62
0,73	**-2,2504**	-4,4004	29,74
0,74	**-3,4986**	-5,6486	31,11
0,75	**-7,9715**	-10,1215	35,70
0,76	**-5,1241**	-7,2741	32,97
0,77	**-3,4611**	-5,6111	31,42
0,78	**-2,4237**	-4,5737	30,49
0,79	**-1,1863**	-3,3363	29,36
0,8	**-0,679**	-2,829	28,97
0,81	**-0,6256**	-2,7756	29,02
0,82	**-0,7579**	-2,9079	29,26
0,83	**-1,4349**	-3,5849	30,04
0,84	**-2,8094**	-4,9594	31,52
0,85	**-2,901**	-5,051	31,72
0,86	**-0,6961**	-2,8461	29,61
0,87	**0,1626**	-1,9874	28,85
0,88	**0,1781**	-1,9719	28,94
0,89	**-0,0041**	-2,1541	29,22
0,9	**-0,6132**	-2,7632	29,92
0,91	**-1,165**	-3,315	30,57
0,92	**-1,6218**	-3,7718	31,12
0,93	**-1,5464**	-3,6964	31,14
0,94	**-1,908**	-4,058	31,60
0,95	**-1,9639**	-4,1139	31,74
0,96	**-1,7546**	-3,9046	31,63
0,97	**-1,1905**	-3,3405	31,15
0,98	**-1,2216**	-3,3716	31,27
0,99	**-1,2603**	-3,4103	31,40
1	**-1,8395**	-3,9895	32,07
1,01	**-2,9961**	-5,1461	33,31
1,02	**-4,3443**	-6,4943	34,74
1,03	**-3,8234**	-5,9734	34,31
1,04	**-2,8461**	-4,9961	33,41
1,05	**-1,9953**	-4,1453	32,65
1,06	**-1,663**	-3,813	32,40
1,07	**-1,6119**	-3,7619	32,43
1,08	**-1,8492**	-3,9992	32,74

1,09	**-2,529**	-4,679	33,50
1,1	**-2,6722**	-4,8222	33,73
1,11	**-2,5318**	-4,6818	33,66
1,12	**-2,0654**	-4,2154	33,28
1,13	**-1,7362**	-3,8862	33,02
1,14	**-2,0962**	-4,2462	33,46
1,15	**-2,7883**	-4,9383	34,23
1,16	**-3,2356**	-5,3856	34,75
1,17	**-3,209**	-5,359	34,80
1,18	**-3,0913**	-5,2413	34,75
1,19	**-3,3208**	-5,4708	35,06
1,2	**-3,8559**	-6,0059	35,67
1,21	**-4,0119**	-6,1619	35,89
1,22	**-3,699**	-5,849	35,65
1,23	**-3,8611**	-6,0111	35,89
1,24	**-4,2862**	-6,4362	36,38
1,25	**-4,5963**	-6,7463	36,76
1,26	**-4,9158**	-7,0658	37,15
1,27	**-5,1732**	-7,3232	37,48
1,28	**-5,5858**	-7,7358	37,96
1,29	**-6,0237**	-8,1737	38,46
1,3	**-7,499**	-9,649	40,00
1,31	**-9,3036**	-11,4536	41,88
1,32	**-10,5485**	-12,6985	43,19
1,33	**-11,4314**	-13,5814	44,13
1,34	**-11,8527**	-14,0027	44,62
1,35	**-9,8972**	-12,0472	42,73
1,36	**-9,4233**	-11,5733	42,32
1,37	**-9,0976**	-11,2476	42,06
1,38	**-9,4426**	-11,5926	42,47
1,39	**-10,2165**	-12,3665	43,30
1,4	**-11,5051**	-13,6551	44,65
1,41	**-12,9824**	-15,1324	46,19
1,42	**-14,5672**	-16,7172	47,84
1,43	**-16,7918**	-18,9418	50,12
1,44	**-18,1603**	-20,3103	51,55
1,45	**-16,4145**	-18,5645	49,87
1,46	**-15,5936**	-17,7436	49,11
1,47	**-17,7189**	-19,8689	51,29
1,48	**-19,2673**	-21,4173	52,90
1,49	**-15,1259**	-17,2759	48,82
1,5	**-11,7095**	-13,8595	45,46
1,51	**-9,6416**	-11,7916	43,45
1,52	**-7,6041**	-9,7541	41,47
1,53	**-6,6746**	-8,8246	40,59
1,54	**-5,975**	-8,125	39,95
1,55	**-5,361**	-7,511	39,39
1,56	**-4,6231**	-6,7731	38,71
1,57	**-4,0723**	-6,2223	38,22
1,58	**-3,2146**	-5,3646	37,41

1,59	**-3,1744**	-5,3244	37,43
1,6	**-3,5279**	-5,6779	37,84
1,61	**-4,8942**	-7,0442	39,26
1,62	**-3,9191**	-6,0691	38,34
1,63	**-1,4826**	-3,6326	35,95
1,64	**-1,0032**	-3,1532	35,53
1,65	**-0,7599**	-2,9099	35,34
1,66	**-0,4465**	-2,5965	35,07
1,67	**-0,3315**	-2,4815	35,01
1,68	**-0,3721**	-2,5221	35,10
1,69	**-0,4219**	-2,5719	35,21
1,7	**-0,2003**	-2,3503	35,04
1,71	**0,0299**	-2,1201	34,86
1,72	**-0,0164**	-2,1664	34,95
1,73	**-0,211**	-2,361	35,20
1,74	**-0,2136**	-2,3636	35,25
1,75	**0,0211**	-2,1289	35,07
1,76	**0,2411**	-1,9089	34,90
1,77	**0,5165**	-1,6335	34,67
1,78	**0,825**	-1,325	34,41
1,79	**1,1078**	-1,0422	34,18
1,8	**1,3161**	-0,8339	34,02
1,81	**1,4359**	-0,7141	33,94
1,82	**1,681**	-0,469	33,75
1,83	**1,7612**	-0,3888	33,71
1,84	**1,7458**	-0,4042	33,78
1,85	**1,7817**	-0,3683	33,79
1,86	**1,6659**	-0,4841	33,95
1,87	**1,6705**	-0,4795	33,99
1,88	**1,7251**	-0,4249	33,98
1,89	**1,9571**	-0,1929	33,80
1,9	**2,0564**	-0,0936	33,74
1,91	**2,1247**	-0,0253	33,72
1,92	**2,0518**	-0,0982	33,84
1,93	**1,9391**	-0,2109	34,00
1,94	**1,7596**	-0,3904	34,22
1,95	**1,7787**	-0,3713	34,25
1,96	**1,7798**	-0,3702	34,29
1,97	**1,7749**	-0,3751	34,34
1,98	**1,5905**	-0,5595	34,57
1,99	**1,433**	-0,717	34,77
2	**1,3413**	-0,8087	34,91
2,01	**1,3956**	-0,7544	34,89
2,02	**1,6173**	-0,5327	34,72
2,03	**1,8217**	-0,3283	34,55
2,04	**2,0545**	-0,0955	34,36
2,05	**2,1284**	-0,0216	34,33
2,06	**2,0611**	-0,0889	34,44
2,07	**2,0586**	-0,0914	34,49
2,08	**2,0558**	-0,0942	34,53

2,09	**2,0885**	-0,0615	34,54
2,1	**1,9467**	-0,2033	34,72
2,11	**1,7186**	-0,4314	34,99
2,12	**1,5982**	-0,5518	35,15
2,13	**1,5753**	-0,5747	35,22
2,14	**1,7773**	-0,3727	35,06
2,15	**2,0189**	-0,1311	34,86
2,16	**2,0412**	-0,1088	34,87
2,17	**1,8206**	-0,3294	35,13
2,18	**1,4738**	-0,6762	35,52
2,19	**1,3857**	-0,7643	35,65
2,2	**1,2828**	-0,8672	35,79
2,21	**1,1285**	-1,0215	35,99
2,22	**1,1448**	-1,0052	36,01
2,23	**1,0491**	-1,1009	36,14
2,24	**0,7578**	-1,3922	36,47
2,25	**0,4029**	-1,7471	36,87
2,26	**0,1077**	-2,0423	37,20
2,27	**-0,2814**	-2,4314	37,63
2,28	**-0,5594**	-2,7094	37,94
2,29	**-0,5906**	-2,7406	38,01
2,3	**-0,5998**	-2,7498	38,06
2,31	**-0,7754**	-2,9254	38,27
2,32	**-1,1887**	-3,3387	38,72
2,33	**-1,3531**	-3,5031	38,93
2,34	**-1,8319**	-3,9819	39,44
2,35	**-2,4127**	-4,5627	40,06
2,36	**-2,8543**	-5,0043	40,54
2,37	**-2,9128**	-5,0628	40,63
2,38	**-3,3202**	-5,4702	41,08
2,39	**-3,5104**	-5,6604	41,30
2,4	**-3,7068**	-5,8568	41,54
2,41	**-3,4913**	-5,6413	41,36
2,42	**-3,844**	-5,994	41,75
2,43	**-3,9344**	-6,0844	41,87
2,44	**-4,2363**	-6,3863	42,21
2,45	**-4,5864**	-6,7364	42,60
2,46	**-4,9922**	-7,1422	43,04
2,47	**-4,7514**	-6,9014	42,83
2,48	**-4,57**	-6,72	42,69
2,49	**-5,0323**	-7,1823	43,18
2,5	**-5,8183**	-7,9683	44,00