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*Degree Programme in Information Technology*

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**Implementation Aspects of UMTS 900 MHz/2100 MHz  
for High Altitude Platforms**

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**BERNARDO PUENTE, VÍCTOR : UMTS 900 MHz/2100 MHz järjestelmän toteuttamisesta korkealla lentäviä aluksia käyttäen**

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Korkealla lentävät alukset (High Altitude Platforms, HAPs) tarjoavat vaihtoehdon perinteisille maanpäällisille solukkorakenteisille matkapuhelinverkoille. Tavoitteena on pystyä tarjoamaan toimiva ratkaisu radiopääsyverkon toteuttamiselle tämän kaltaisille uusille verkoille. HAP yhdistää hyvät puolet sekä maanpäällisistä että satelliittiperustaisista järjestelmistä. HAP-ratkaisuja onkin laajalti ehdotettu tarjoamaan esimerkiksi kolmannen sukupolven matkaviestinjärjestelmien palveluja. Euroopassa kolmannen sukupolven matkaviestinjärjestelmäksi on valittu UMTS, jonka saatavuus onkin levinnyt viime vuosien aikana merkittävästi. Tästä huolimatta on olemassa alueita, joissa UMTS-palvelua ei ole saatavilla. Erityisesti harvaan asutuilla alueilla, maaseudulla, operaattorit eivät ole löytäneet ratkaisua, jolla UMTS-palvelua voitaisiin tarjota kustannustehokkaasti. Ratkaisuehdotuksena tähän on matalammalla 900 MHz taajuudella toimiva UMTS-järjestelmä, joka tarjoaa paremman peiton. UMTS900-järjestelmä yhdistettynä HAP-toteutukseen tarjoaa mahdollisuuden tuottaa kustannustehokasta, laajan alueen, UMTS-peittoa myös harvaan asutuilla alueilla.

Tässä työssä simuloitiin UMTS:n radiopääsyverkon osana toimivaa HAP-toteutusta sekä 900 MHz taajuudella että alkuperäisellä 2100 MHz taajuudella. Työn tavoitteena oli löytää käytetyn kantoaaltotaajuuden vaikutus peittoalueen kokoon yksittäisen HAP:n tapauksessa käyttäen erilaisia toteutusstrategioita. Myös antennin keilanleveyden vaikutusta UMTS:n suorituskyykyyn tutkittiin. Tulokset osoittavat, että kantoaaltotaajuuden pudotus aiheuttaa selvää parannusta verkon peittoon, kun käytetään sopivaa soluetäisyyttä. Tulokset osoittavat myös eron UMTS:n suorituskyykyssä 900 MHz ja 2100 MHz kantoaaltotaajuuksia käytettäessä.

## ABSTRACT

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High Altitude Platforms (HAPs) represent an alternative to terrestrial mobile telecommunications. The aim of HAPs is to offer a feasible solution for the radio access layer of this kind of networks. The strong point of HAPs resides in the fact that they bring together the best features of terrestrial and satellite systems. HAPs have been widely proposed for deploying telecommunication services such as third generation mobile networks. In Europe, third generation of mobile communications system is using UMTS. It has being widely deployed in the last years but still there are certain areas where 3G coverage is not available. Especially in rural areas with low population density, where the operators did not find a cost efficient way to deploy UMTS services. As a result, UMTS in 900 MHz band emerges as a possible way to improve UMTS coverage for these areas, and combining with a HAP-based deployment, a cost efficient way for a widely deployment in sparsely populated and remote areas for 3G services.

The work shown in this thesis is a comparison of network simulations obtained from the use of HAPs in the radio access network of UMTS using 900 MHz band and 2100 MHz band. The study was aimed to find the impact of carrier frequency on coverage for a single HAP scenario using different deployment strategies. An antenna study has also been done in order to see the impact of antenna beamwidth on UMTS system. The results obtained reveal that the decrease in the carrier frequency caused a clear increase in the coverage, when correct distance between cells was selected. Consequently the results obtained show the variation of the network performance with the separation between cells using both carrier frequencies, 2100 MHz and 900 MHz.

## PREFACE

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## LIST OF ABBREVIATIONS

1G	1st generation
2G	2nd generation
3G	3rd generation
4G	4th generation
API	Application Program Interfaces
ATM	Asynchronous Transfer Mode
B-FWA	Broadband Fixed Wireless Access Services
CAC	Call Admission Control
CDMA	Code Division Multiple Access
CN	Core Network
CS	Circuit Switched
DL	DownLink
EC	European Commission
ECC	Electronic Communications Committee
EIR	Equip Identify Register
ESA	European Space Agency
ETRI	Electronics and Telecommunications Research Institute
FDD	Frequency Division Multiplex
GGSN	Gateway GPRS Support Node
GMSC	Gateway Mobile Switching Center
GPRS	Global Packet Radio System
GPS	Global Positioning System
GSM	Global System for Mobile Telecommunication
GSM900	GSM with a frequency carrier of 900 MHz
HALO	High Altitude Long Operation
HAPCOS	High Altitude Platforms for Communications and Other Services
HLR	Home Location register
IMT-2000	International Mobile Telecommunications-2000
ISDN	Integrated Services Digital Network
ITU	International Telecommunication Union
JAXA	Japan Aerospace Exploration Agency
KARi	Korean Aerospace Research Institute
LOS	Line-of-sight
LTE	Long Term Evolution
MAN	Metropolitan Area Networks
MSC	Mobile Switching Center
NASA	National Aeronautics and Space Administration

NICT	National Institute of Information and Communications Technology
NPSW	Network Planning Strategies for Wideband CDMA
NLOS	Non-line-of-sight
Node B	base station in UMTS
OSA	Open Services Access
PLMN	Public Land Mobile Network
PS	Packet Switched
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAN	Radio Access Network
R&D	Research and Development
RNC	Radio Network Controller
RNS	Radio Network Sub-system
RRC	Radio Resource Control
RRM	Radio Resource Management
SGSN	Serving GPRS Support Node
SHARP	Stationary High Altitude Relay Platform
SIR	Signal-to-Interference Ratio
SLL	Side Lobe Level
SPP	Sub Platform Point
TDD	Time Division Multiplex
TETRA	Terrestrial Trunked Radio
UE	User Equipment
UL	UpLink
UMTS	Universal Mobile Telecommunications System
UMTS900	UMTS with a carrier frequency of 900 MHz
UMTS2100	UMTS with a carrier frequency of 2100 MHz
UTRAN	RAN, UMTS Terrestrial RAN
VHE	Virtual Home Environment
VLR	Visitor Location Register
WCDMA	Wideband Code Division Multiple Access

# 1. INTRODUCTION

Due to the present climate of growth on the demand for communication service, wireless infrastructure providers are under continuous pressure to exploit the limited radio spectrum as efficiently as possible. With this aim, wireless solutions are becoming increasingly due to be the best choice to deploy the networks that would supply this kind of broadband for small-medium enterprises and also for domestic users. However, delivering high capacity services by using wireless technologies represents a challenge due to the radio spectrum is a limited resource which is becoming saturated at the present. Consequently, to provide bandwidth to a large number of users, several strategies have to be adopted with the aim of frequency reuse.

At the moment, UMTS networks have been deployed in the frequency band 1920-1980 MHz / 2110-2170 MHz all over the world. However, there are still areas where there are difficulties to provide UMTS services with low cost. These areas usually are rural zones where due to the low number of possible customers the providers are not providing UMTS. In this point is when HAPs emerge as a possible solutions, because their capability for providing communications services to large areas. With the same aim, several studies have demonstrated that reducing the carrier frequency of the UTMS system, the coverage area increases noticeably. All these studies are focused on terrestrial deployment, and it is from this fact where the aim of this thesis comes up. Then, the main goal of the thesis is to combine both HAPs and UMTS with a lower carrier frequency of 900 MHz in order to study how the coverage area improves, trying to solve in the best possible way the problem of providing UMTS services for sparsely populated and remote areas.

Aerial platform represents a potential solution to the wireless delivery. Nowadays, High Altitude Platforms represents a new alternative to the traditional satellite and terrestrial broadband services and have gained interest thanks to some of their characteristics, making HAPs one of the most potential options in network deployment for the future broadband services. HAPs are now being actively developed in a number of programs world-wide, and the surge of recent activity reflects both the lucrative demand for wireless services and advances in platform technology, such as in materials, solar cells and energy storage. [1] [2]

The studies of the thesis are carried out by simulations with a static radio network simulator modified for HAPs (with Monte Carlo approach). Different scenarios are

used in order to study how the carrier frequency and the antenna beamwidth affect the UMTS system performance. The frequency study is based on the well-known benefits of the change to UMTS 900 MHz in terrestrial deployment in comparison with a UMTS working in 2100 MHz. With the aim of study how the frequency is affecting the system, an antenna beamwidth study has also been done in order to compare how each parameter affects the UMTS system.

The thesis is organized as follows: Chapter 1 introduces the topic and High Altitude Platforms is introduced in Chapter 2. In Chapter 3, basics of UMTS cellular networks are considered, and in Chapter 4, several aspects about the simulation environment are explained. Simulation results are presented in Chapter 5. Finally, the thesis is concluded in Chapter 6.

## 2. INTRODUCTION TO HIGH ALTITUDE PLATFORMS

In this chapter a basic understanding about HAPs will be provided. First, different properties of HAPs will be explained, concerning the applications and advantages of HAPs technology and finally a study of the current research status around the world will be included.

### 2.1 Definition

High Altitude Platforms (HAPs) are quasi-stationary vehicles operating in the stratosphere, at altitudes of typically 17-22 km (around 75,000 ft) above the ground. At this altitude they can maintain a quasi-stationary position, and support enough payloads for the delivery of communication services, remote sensing, and navigation system support. The communication services include broadband, cellular 3G, emergency communications in disaster scenarios, as well as broadcast services. The main advantage of HAPs is that they can provide the best features of both terrestrial masts and satellite services. Particularly, HAPs will enable rapid deployment and highly efficient use of the radio spectrum. Additionally, HAPs is superbly located for surveillance, traffic monitoring and localization services. There are two types of vehicles capable of stratospheric flight: unmanned aircraft and unmanned airships. However, manned aircraft, flying in circles, could also represents a HAP. [3]

### 2.2 Topologies

Due to the long list of network topologies that HAPs can offer, the focus of this section will be on the role of HAPs in beyond third generation (3G) networks. There are three different topologies how HAPs can be deployed. The proposed architectures can be categorized based on how HAPs are deployed.

#### 2.2.1 Terrestrial-HAP-Satellite System

The system architecture proposed in this section is shown in Figure 2.1. This is a mixed infrastructure comprising of HAPs and terrestrial-and satellite systems. The best point of using all together comes from that integrated network infrastructure makes up for the weaknesses of each other. It means that first, the capability of

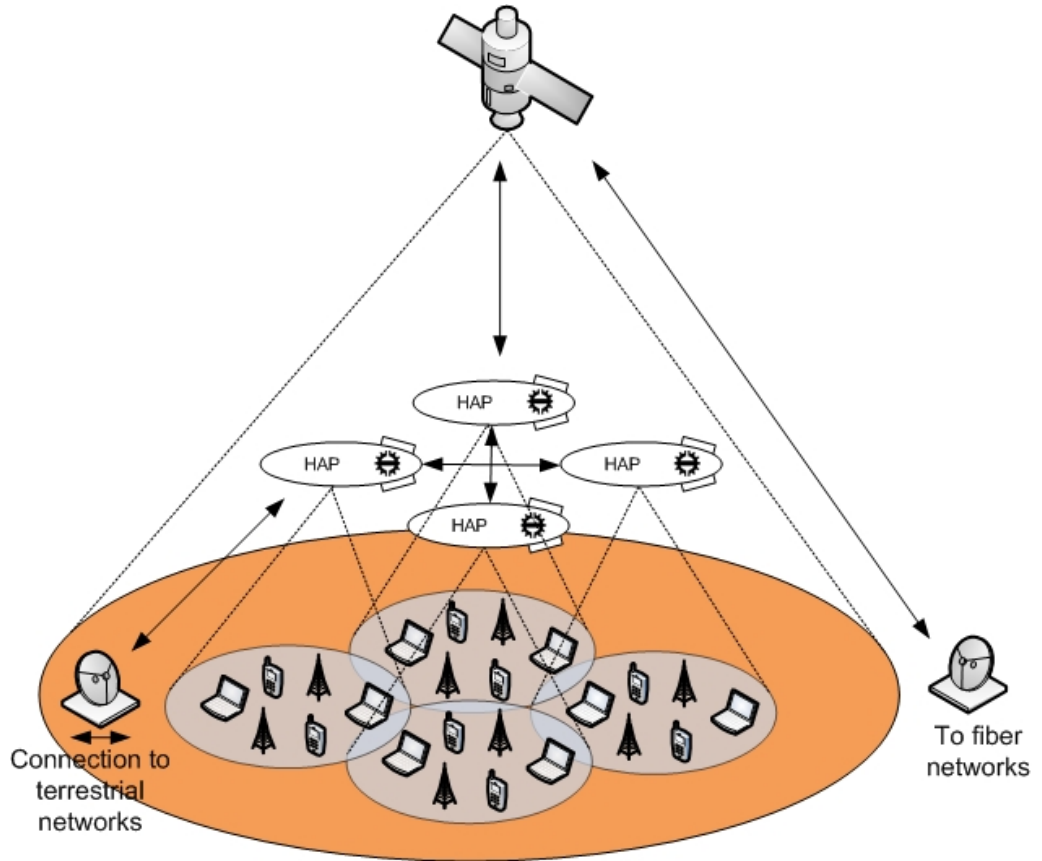


Figure 2.1: An integrated terrestrial-HAP-satellite system.

the satellites of broadcasting and multicasting are used to transmit data from fiber networks to the HAP network, located below the satellite. Secondly, the goal of the HAPs is to be used in order to improve the satellite performance over the earth. Thus, HAPs could be seen as an intermediate point between satellites and the final user. Thereby, HAPs usage mitigates multipath effects, typical of terrestrial cellular systems, and decrease geostationary satellite propagation delays. [4]

On the other hand, HAP can be seen in this hierarchical scenario as a terrestrial system extension. The terrestrial layer is connected to the satellite layer only by the HAP thereby achieving two significant advantages: firstly the satellite does not have to interact with a single terrestrial terminal user and secondly, terminals can be made without great financial and design efforts because they do not have the requirement of interacting directly with the satellite layer. [4]

### 2.2.2 Terrestrial-HAP System

The main advantage of using HAPs integrated within a terrestrial UMTS (Universal Mobile Telecommunications System) is the possibility of covering areas with particular characteristics: sparsely populated areas, sea regions, mountain regions which could be covered only with microcells, which in turn are not economically conve-

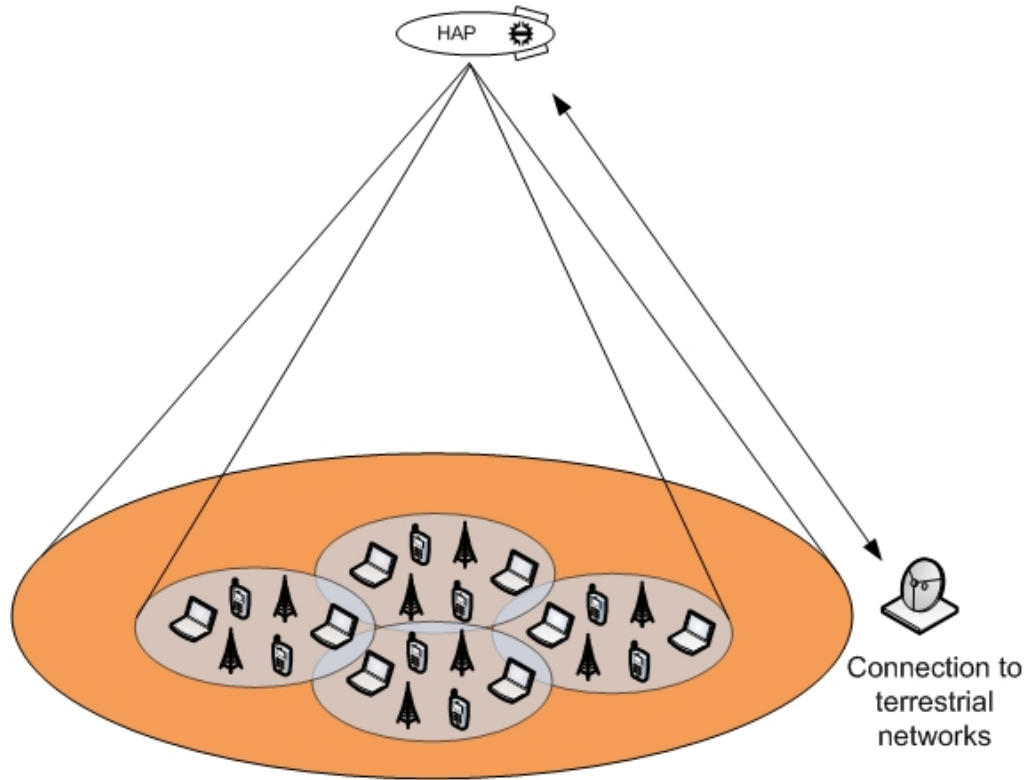


Figure 2.2: An integrated terrestrial-HAP system.

nient due to the low expected traffic. In addition, HAPs could be used in disaster scenarios in order to re-establish communication as quickly as possible.

In this architectural scenario (Figure 2.2) a HAP is considered to project several macrocells and served high-mobility users characterized by low bit rates. Terrestrial base stations are also employed in order to provide access to users with high bit rates. A feasibility study for the integration of a HAP station within a terrestrial UMTS network was presented in [5].

### 2.2.3 Standalone HAP System

HAPs can be deployed as a standalone HAP system as well. It means that usually HAPs are considered as a system to integrate in terrestrial or satellite networks, but it is easy to figure out the potential of standalone HAP systems as presented in [6].

This topology shows some advantages. It can be deployed in areas where terrestrial deployment would be complex and therefore high cost for the operators, such as rural or remote areas where using HAPs would be more feasible and effective as far as cost and deployment are concerned.

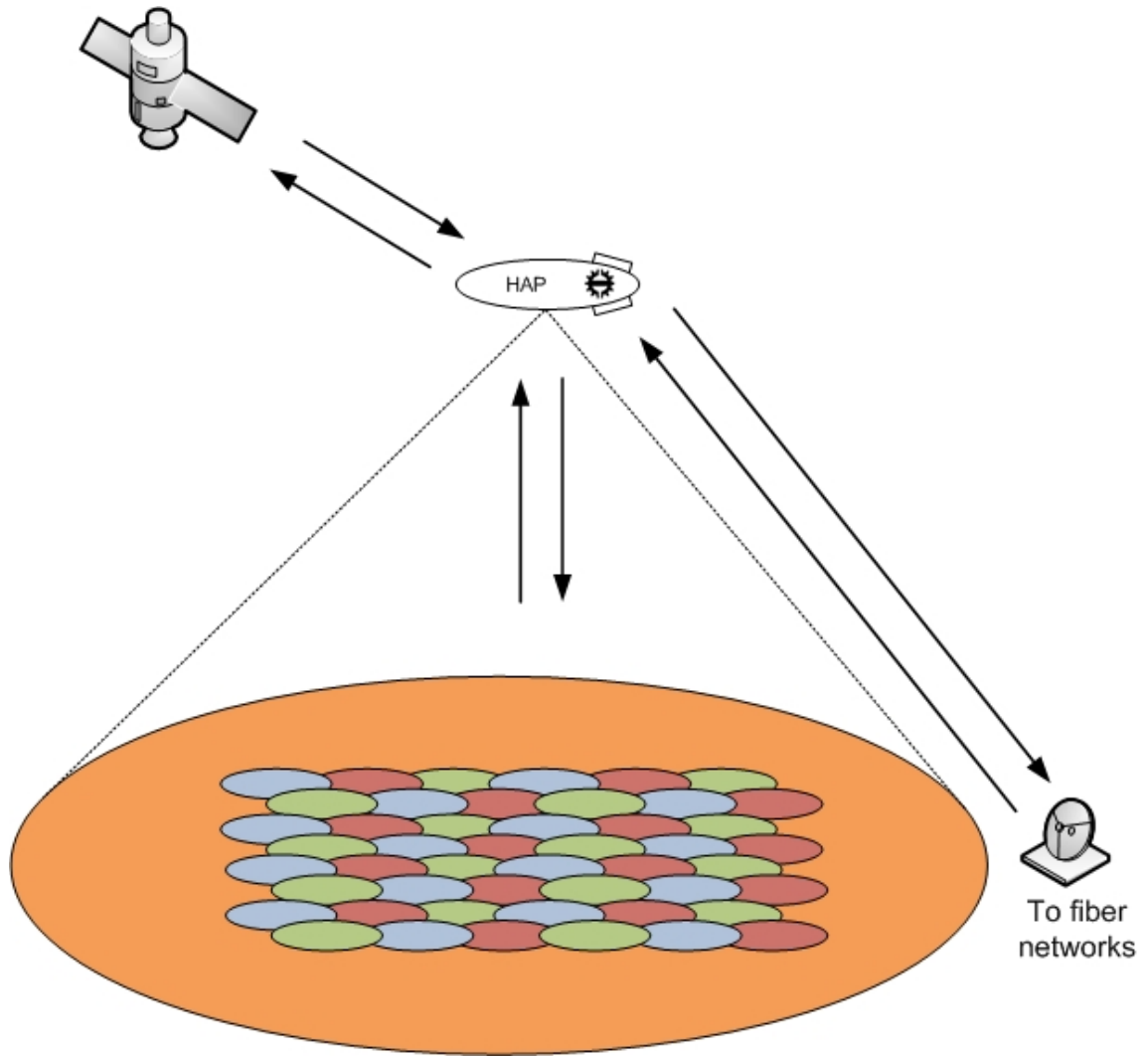


Figure 2.3: A standalone HAP system.

## 2.3 Applications and Services

HAPs are able to offer a wide range of services when considering the topologies that have been mentioned before. The aim of this section is to provide an overview of the main applications and services HAPs are able to supply, whether it is by itself as a standalone HAP system or integrated in a terrestrial or satellite networks. There are many feasibility studies dealing with the subject of providing communications services and applications and because of that next subsections would try to go into wideband services in depth.

### 2.3.1 2G/3G/4G

Nowadays, the provision of 3G and 4G (third and fourth generation) mobile services seems to be the main application of HAPs. High Altitude Platforms offer many advantages when compared to terrestrial base stations, such as a large area of cov-

erage and low shadowing for high elevation angles. Other exceptional benefits are quite direct: propagation paths without obstacles and elimination of the expensive resources spent in ground station installation, maintenance and wire installations. Then, HAPs could be used as an alternative to a terrestrial component for delivering GSM (Global System for Mobile Telecommunication), UMTS and LTE (Long Term Evolution) or could be a complementary element to terrestrial networks. Also it has to be mentioned the huge advantage that the use of HAPs in extensive and sparsely populated areas. On one hand it facilitates deployment of communications networks in developing countries and helping to fill the digital gap. And on the other hand it would enable a faster deployment of new technologies such as LTE. Following with the idea of 3G base stations, HAPs could be incorporated into already deployed terrestrial networks, in urban areas, where higher capacity is needed. They can provide smaller cells using antenna arrays, in order to improve the service in populated areas. [21] [8] [7]

### 2.3.2 Broadband Fixed Wireless Access Applications

This service is one of the most important applications for HAPs together with the delivery of 3G/4G mobile networks. B-FWA (Broadband Fixed Wireless Access Services) means broadband data provision, offering to the final user a set of multimedia services, such as high speed Internet, telephony or video-on-demand.

The spectrum allocation, regulated by the ITU-R for HAPs worldwide for the provision of BWA services, is as follows:

- 2.1 GHz IMT-2000.
- 27/28 and 31 GHz.
- 47/48 GHz.

The 2.1 GHz IMT-2000 band has up to 50/60 MHz total bandwidth, to be used as an alternative to terrestrial masts. This part of the spectrum is to be used for user links for 3G mobile services (data, voice and video). For 27/28 and 31 GHz band has 300 MHz in each direction, shared on a non-harmful interference, non-protection basis with fixed satellite and terrestrial services. The typical application for this band is for user links for fixed broadband (data, voice, and video) services in the spectrum allocation. Finally, the 47/48 GHz band also has 300 MHz in each direction, shared on a co-primary basis with fixed satellite. This band is mainly to be used for gateway feeder links for fixed broadband services.

One of the most important studies to provide B-FWA applications is made by the European Helinet programme. This study is based on a HAP providing coverage of 60 km of diameter, adding up to 121 cells of 5 km diameter on the ground. Each cell

is able to provide bit rates up to 60 Mb/s, if a 25 MHz of bandwidth per cell and 16-QAM (Quadrature Amplitude Modulation) or higher order modulation technique is used. The total throughput achieved is over 7 Gb/s. However there should be a number of distributed backhaul base stations, always less than the number of cells served from the HAP. [9] [10] [11]

### 2.3.3 Emergency and Disaster Scenarios

After or during a natural or man-made disaster, the telecommunication networks are required in order to help the operation of the emergency services. Due to these disaster scenarios, the networks can be unavailable in the area because the infrastructure was destroyed or overloaded by excessive demand. In this respect, HAPs emerges as alternative wireless network provider in order to replace or improve the capacity to existing damaged or overloaded wireless networks during the catastrophe. The feasibility of different scenarios have been studied, including GSM, TETRA (Terrestrial Trunked Radio) and UMTS deployment, with the aim of integrating them in the existing networks. Another fact is that terrestrial mobile communications infrastructure can not manage an unexpected traffic increase and can collapse due to the excess load of users trying to establish a phone call. This situation can lead to communications outages, due to the natural or man-provoked disaster, leaving public and emergency services without network connection.

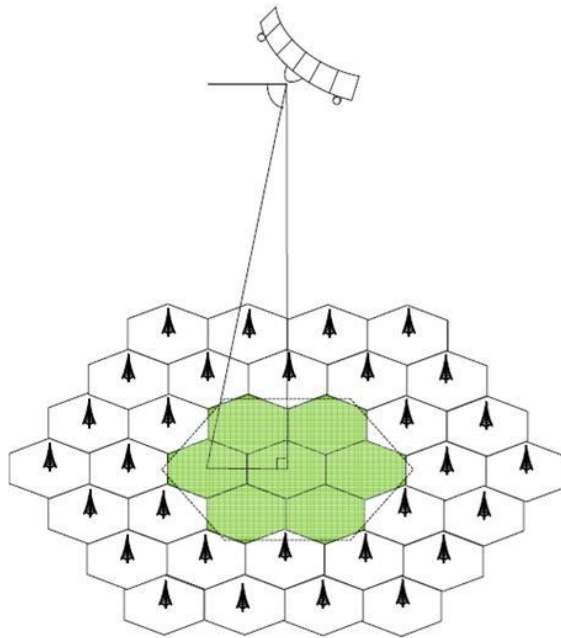


Figure 2.4: An example of cell configuration for HAP assisted disaster scenario. [13]

The consequences of communications outages during disasters can make the performance of emergency services difficult and can have significant economical impact in the area. In order to solve it as soon as possible, a solution has to be found to allow quick restoration of the mobile network over the disaster area and provide the necessary improvement of the capacity demand. HAP makes up a real solution in the propounded scenario, providing in addition a platform that it could be considered invulnerable to most typical natural disaster due to it can be deployed away from the disaster area on demand.

In disaster scenario, HAPs can be quickly deployed carrying telecommunications payloads. From their operational altitude they can offer an improvement of the current capacity of the existing network or help to fill the coverage holes due to the damaged terrestrial infrastructure. Obviously, different kind of services can be provided from HAPs depending on the telecommunications payload on board.

By way of setting an example, we will assume the scenario represented in the Figure 2.4, where a few nodes have failed due to the disaster happened. An emergency mobile network should be deployed over the area to assist emergency services and serve the public until the restoration of terrestrial infrastructures. As the HAP can fly over the area, there are a few important decisions that need to be adopted by the HAP operators to guarantee unproblematic operation of the service: the service area needs to be fixed, the cell layout needs to be designed, the backhaul needs to be set up and the operational existing systems that could interfere with the HAP network should be identified. Further information about this subject can be found in [12] and [13].

### 2.3.4 Military Communications

The potential of HAPs in a range of military communication scenarios is obvious. The main advantages of them in this frame of operation is rapid deployment in existing military wireless networks as nodes or working as a part of a surrogate satellite network. Furthermore by means of HAPs it is possible to provide communications and due to their close range operation layout limited by the transmit power from the ground terminal makes its transmissions difficult to be intercepted. These two characteristics are extremely valued in military activities. [14]

### 2.3.5 Navigation and Positioning

Some countries have begun conducting feasibility studies and GPS (Global Positioning System) projects for HAPs in navigation and positioning services. However, the precise positioning of the airships is one of the most important technical challenge for this aim. Nevertheless, if the GPS (Global Positioning System) transmitters are

mounted on the airships (Figure 2.5) there would be stable augmentations of the accuracy, availability, and integrity of GPS-based positioning systems. [15]

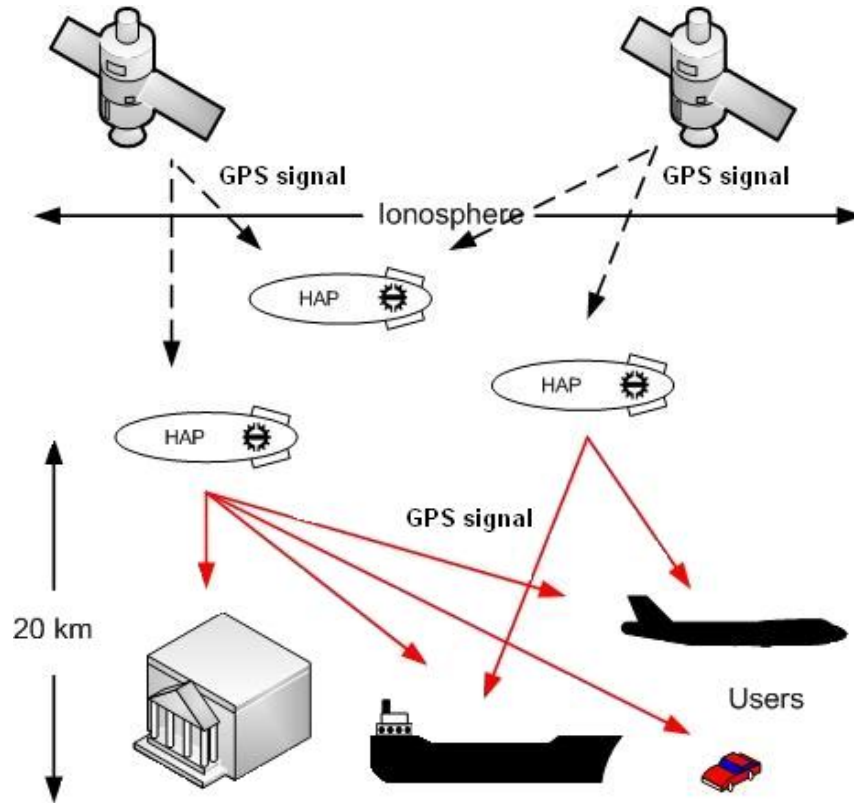


Figure 2.5: Navigation/Positioning service using GPS transmitters on HAPs.

### 2.3.6 Other Telecommunication Services

In addition to the services and applications named, a wide range of telecommunications services can be found. They include environmental surveillance, traffic monitoring (terrestrial, maritime, etc.) or for example to introduce services of rural telephony, broadcasting and data services in the developing countries helping to fill the digital gap.

## 2.4 Advantages and Challenges

HAPs offer a wide range of advantages compared to terrestrial and satellite communication systems deployed. A few of them are going to be shown in the next subsections.

### 2.4.1 Operating Altitude

The operational altitude of HAPs is one of the major advantages. Usually HAPs are operating between 17 and 22 km. This range of height was chosen because belong

to the stratosphere and represents the layer with lowest turbulence levels and mild winds in the atmosphere. Anyway, this values of wind speed as a function of height can vary depending on the latitude, climatological conditions, and others that can cause a different behavior of wind speed that the shown in the Figure 2.6. [1]

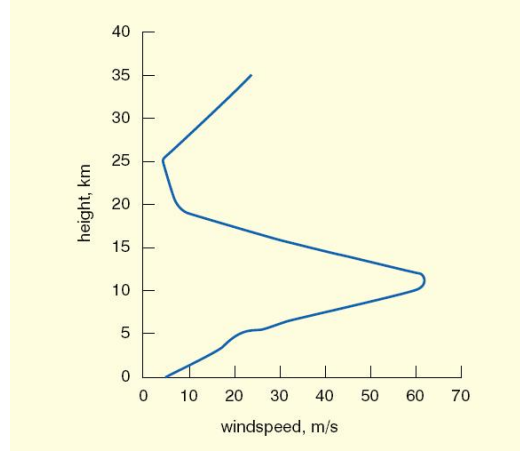


Figure 2.6: Altitude as a function of wind speed. [14]

## 2.4.2 Propagation

In the propagation mechanism for the case of HAP systems, it is necessary to take into account the conditions defined by the scenario. This subsection shows a compact overview of radio propagation for HAP systems.

### Free Space Loss

The path loss in any communication radio link is defined as the ratio of the transmitted power to the received power between a pair of antennas. When propagation takes place in a free space environment, the path loss is known as free space loss, and is given by

$$L_F = 32.4 + 20 \cdot \log(r_{km}) + 20 \cdot \log(f_{MHz}), \quad (2.1)$$

where  $r$  is the distance and  $f$  is the frequency. For HAPs link, the minimum path loss experienced is given by the free space loss, associated with the distance between the platform and the receiver. Other losses caused by other propagation effects are considered in excess loss, and finally the total loss becomes

$$L \equiv L_F + L_{ex}, \quad (2.2)$$

### Multipath

The multipath environment affecting HAPs systems is due to reflections on buildings, trees, parts of HAPs, etc. Figure 2.7 the most typical HAPs scenario affected by multipath is depicted. A wave front is reflected by a smooth surface, i.e. whose dimensions of roughness are relatively large compared with the wave length. Thus, smooth surfaces tend to be reflectors and roughness tend to cause energy dispersion. [16]

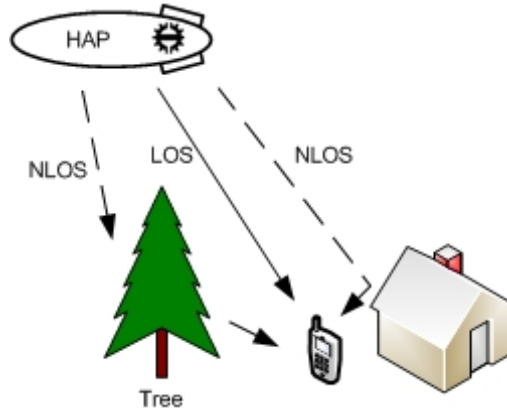


Figure 2.7: HAPs system affected by multipath.

The most important differences between terrestrial and HAP multipath are that the path is longer for stratospheric vehicles than in the terrestrial scenario. Because of that the delay spread increase for HAP multipath.

### Rain Attenuation

The troposphere where HAPs operate consists of a mixture of particles having a wide range of sizes and characteristics, from molecules in the atmospheric gases to raindrops and hail. The main scattering particles concerning HAPs systems are hydrometeors, including raindrops, fog, and clouds. In this case the scattering is only significant to systems operating above around 10 GHz. Therefore, HAPs operating in the 27/31 and 47/49 GHz bands will be affected by this effect. [16]

### Gaseous Absorption

The gaseous molecules located in the atmosphere can absorb energy from radio waves passing through them, and consequently cause attenuation. At higher frequencies the absorption loss has an overall tendency to increase with frequency. In normal atmospheric conditions, only oxygen and water contribute significantly to absorption. The main resonance peaks of oxygen are in 60 and 118.74 GHz, and for water are in 22.3, 183.3 and 323.8 GHz. The impact of the gaseous absorption in

the HAP path has to be only taken into account if the system is working in one of the resonance frequencies of oxygen and/or water. [16]

### Scintillation

The phenomenon of scintillation is the result of the radio wave propagation through a medium with random variations in the refraction index. As it is known, this medium is the troposphere and the variations in the refraction index are mainly because air turbulence in this atmosphere layer. This effect contributes generating constructive and destructive signal echoes at the receiver.

Scintillation is greater in warm, humid climates and is greatest during summer days. In order to reduce this effect, it is advisable to use an antenna with wide aperture. Another approach is to use spatial diversity, where the signals from two antennas are used in order to reduce the overall loss. [16]

### 2.4.3 Incremental and Rapid Deployment

One of the main problems that can happen with an existing communication network system is a change in the traffic demand and service characteristics and therefore requiring more coverage and capacity. For a HAPs based system it only requires a few changes in the antenna configuration or deploying another HAPs at the most. In comparison, for terrestrial/satellite based system an expensive additional deployment has to be designed and implemented (and launching in satellite case). Then, taking into account the easy payload upgrading and rapid deployment, HAPs represent a enormous advantage that speeds up upgrades in the existing communications network system. [1]

### 2.4.4 Topology Planning

Topology planning has a great importance to any wireless infrastructure provider, since efficient cell planning can reduce network cost and increase network capacity. A HAPs cellular system has differences with a terrestrial system. Frequency reuse planning is still applicable but it is important to understand that there are differences in the interference propagation. In the case of HAPs, interference is made by the antennas serving cells on the same channel. Optimum antenna beams will illuminate each corresponding cell without overlapping and uniform power, but in practice, realizable spot beams fall short of this deal.

Some of the issues include in the cell planning for integrated systems take into account bandwidth allocation, QoS (Quality of Service) requirements, cell sectorisation and tessellating, flexibility and reliability, and as well as frequency allocation to the cells of different networks. [17]

### 2.4.5 Call Admission Control

CAC (Call Admission Control) is of utmost importance, since it controls the number of users and thus is strongly related to the user's QoS. It is vital in the decision of whether a call is accepted or rejected based on the quality of service of the rest of users. And because of that, well-established CAC algorithms have been subject of study mainly for standalone systems.

Intelligent CAC schemes should be able to decide according to several criteria such as QoS requirements of the application, the traffic load of each candidate serving network, the user mobility, the energy available at the user terminal, and pricing. [17]

### 2.4.6 Handover Issues

For heterogeneous systems, two types of handovers can be identified: inter-system handovers (vertical) and intra-system handovers (horizontal). The handovers initiate, when the SIR (Signal-to-Interference Ratio) level falls below fixed threshold, often set by system operators. Several studies have addressed the issue of intrasystem handover, especially for terrestrial CDMA (Code Division Multiple Access) cellular systems. In the terrestrial cellular network case, the user is connected to the base station with the minimum radio path loss, which may not be the nearest one. On the other hand, in a HAP system a user is connected to the base station that serves the cell in which the user is located and how it was mentioned in 2.4.4 each HAP can serve several cells. Summarizing, in terrestrial case the users have to change the base station (different location) and for HAP-based deployment the users only need to change the cell (same location). Thus, the need of soft handover can be reduced (as known, is the technique whereby mobile users in transition between one cell and its neighbor transmit to and receive from two or more base stations simultaneously) in CDMA HAP-based cellular systems. [17]

## 2.5 Current Status of HAP Research

In this section, the most important projects and activities of HAPs around the world are briefly discussed.

### 2.5.1 North American HAPS Projects

The unmanned aircraft systems used for civil telecommunications started to be developed by organizations in North America. Different projects from this area are discussed here.

### **SHARP**

SHARP (Stationary High Altitude Relay Platform) was the first civil high altitude platform station program in the world, developed by the Communications Research Center in Canada. In 1982 a research program was finally approved by the Department of Communications. The project was based on an airplane called Wingspan. This program lead to a several patents in Canada and in the USA for the SHARP basic architecture and coverage radius. [18]

### **Sky Station**

This was a North American project consisting of a solar-powered aerostatic high-altitude platform system planned by Sky Station International. A single platform could provide broadband wireless access of 2 Mb/s uplink and 10 Mb/s downlink across three cellular coverage zones. In this initiative is still not designed the inter-platform links in order to provide better coverage and quality of service. Further information can be found in [19] [20].

### **HALO-Proteus**

HALO (High Altitude Long Operation) was the name for the network based on the piloted Proteus airplane (Figure 2.8), developed by Angel Technology Corporation in the USA. The aim of this project was to provide broadband communications. [21] [22]

### **Pathfinder, Pathfinder Plus, HELIOS, SkyTower**

All this projects above-named have been managed by AeroVironment Co., from the USA. And they are named in logical technologic versions. The aim of this enterprise is to commercialize NASA technology. Further information about these designs can be found in [23] [24].

## **2.5.2 European Projects and Activities on HAPS**

In Europe, mainly two organizations have done research activities on HAPs, the ESA (European Space Agency) and the EC (European Commission).

### **HALE**

HALE is an ESA project started in December of 1998. This one was the first in which ESA was involved with HAPs. In these studies, communications services and navigation, such as UMTS, MAN (Metropolitan Area Networks), remote monitoring



Figure 2.8: Proteus in flight. [21]

and passenger information systems, were already identified as immediately commercial application. The airship was designed to carry a 600 kg payload with a relay station, surveillance radar and weather radar or sensor package. [25]

## STRATOS

This was the last project related to HAPS occurred in 2005 by ESA. Two configurations for stratospheric platforms were considered: an aerostatic configuration and a aerodynamic configuration. Both would be electrically driven and solar-powered. A feasibility study of HAPs can be found in [26] [27].

## HeliNet

HeliNet was a global project carried out by a transnational and multi-sectorial partnership of research departments at universities and companies. The aims of this project can be summarized in two points. The first of them was the design and construction of an unmanned solar-powered aircraft, called Heliplat. The second was the development of demonstrators for four pilot applications: broadband communications, environmental monitoring, remote sensing and traffic monitoring. The HeliNet project started in 1999 and was concluded in February 2003. [28]

## CAPANINA

CAPANINA was a specific research project within the 6th Framework Programme of the European Union Commission. The general aim of this project was to figure out the aspects of a new stratospheric infrastructure based on radio-controlled airships, trying to design an overall system or/and network capable of delivering broadband wireless communications to all, even to users who may be marginalized by geography, distance from infrastructure and on moving vehicles at speeds up to 300 km/h. Bit rates of 120 Mb/s were proposed. The Figure 2.9 shows a proposed scenario for the project. [29] [30]

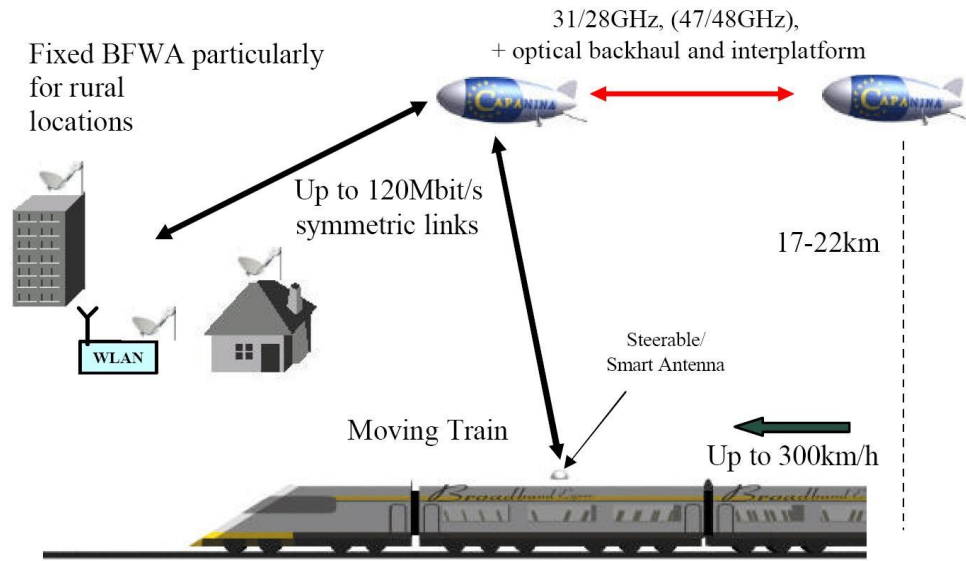


Figure 2.9: Top-level scenario communications from HAPs to fixed and high-speed mobile users for CAPANINA. [29]

## COST 297 - HAPCOS

The COST (297) - HAPCOS (High Altitude Platforms for Communications and Other Services) commenced formal operation in 2005. The main objective of COST 297 is: to increase knowledge and understanding of the use of HAPs for delivery of communications and other services, by exploring, researching and developing new methods, analyses, techniques and strategies for developers, service providers, system integrators and regulators. [3]

### 2.5.3 Asia-Pacific Projects and Activities on HAPS

#### Japanese Activities

In Japan, the main research activities in this field have been undertaken by two organizations related to stratospheric technology, JAXA (Japan Aerospace Exploration Agency) and NICT (National Institute of Information and Communications Technology). NICT has been investigating HAPs systems as future communications infrastructure for the last few years, as part of national R&D projects for stratospheric platforms such as Skynet or similar, and under other circumstances as part of international research teams.

In 2002, a common program between Aero Vironment (USA) NICT, NASA, Toshiba and NEC conducted a series of experiments on digital TV broadcasting and 3G cellular systems using unmanned solar-powered aircraft Pathfinder Plus. It was the world's first experiment on IMT-2000 (International Mobile Telecommunications-2000) using radio-relay transponders onboard a HAPs at an altitude of 20 km. [31]

#### Korean Activities

Activities related with stratospheric airships started in Korea in December 2000 by ETRI (Electronics and Telecommunications Research Institute) and KARI (Korean Aerospace Research Institute). The aim is to develop an unmanned stratospheric airship and ground systems for basic operation and control of the airship. Further information can be found in [23] [32].

### 3. UMTS

In this chapter some theoretical background about the most important features of UMTS and the integration of HAPs in UMTS networks are shown.

#### 3.1 General Issues

The main idea of providing wireless communication services comes from the possibility of employing HAPs as valid alternative to the traditional terrestrial or satellite networks. Mainly, as it was either referred before, providing telephony services and access to broadband digital networks (Internet, ISDN).

The special characteristics of HAPs operational layer allow cellular telephone services the possibility of covering areas with particular features. These ones are rural areas with low population density areas, sea regions, mountain regions, which could be covered only with microcells in traditional networks and therefore its not economically feasible due to the low expected traffic.

The aim to employ stratospheric platforms in cellular communications can be seen as an extension and integration with the GSM or UMTS standards, at a very low cost with respect to satellite solutions. It has to be taken into account that another important advantage of HAP is that the platform can be periodically land and take off from the ground in order to upgrade the payload. The compatibility with future generation mobile networks can be assumed because this can be achieved by simple substituting the platform payload. It is works because the estimate costs of HAPs are very low in comparison to satellite based solutions.

The role that HAPs can play for cellular telephony services is possible to conceive it in two ways. The first one employs HAPs as a backup base station covering a wide rural area, partially served by a network of terrestrial base stations. In this scenario the role of HAPs is to provide coverage to users in critical places which can not be covered by the terrestrial network. Then, the user density per square kilometer that HAP base station has to cover in this condition is relatively low.

In the second possible situation, HAP is supposed to provide full-service coverage to a wide rural area, where no other terrestrial base stations are deployed. In this scenario, the HAP has to be able to manage a traffic capacity comparable with that of a terrestrial network covering the same area with more base stations. Because of the higher density of users, the required technological complexity of the HAP base

station will be greater, in terms of both antenna technology and traffic management. Nowadays, the short-term development of UMTS is focused on urban densely populated areas, by using, for example, new frequencies such as 900 MHz in order to improve the features. In this terms, HAP can also represent a feasible way to provide UMTS services to highly density populated urban zones. [33] [34] [35]

### 3.2 UMTS Services

The ITU (International Telecommunication Union) started the process of defining the standard for third generation systems, referred as IMT-2000. In this UMTS specifications does not include too much information about service specification in order to increase competitiveness between UMTS providers and the introduction of new services providers without the necessity of a network infrastructure. Then, the way that it is defined on the side of the competence, gives to the market the great chance of becoming easily a service builder.

One of the important elements defined in this specifications is the API (Application Program Interfaces) where is defined, for example, an interface called OSA (Open Services Access), conceived to provide a standardized open access to applications developers for UMTS.

Another important concept that should be mentioned is the VHE (Virtual Home Environment). It is a personal service environment portability across network boundaries and between terminals. Personal service environment means that users are consistently presented with the same personalized features user interface customization and services in whatever network or terminal and wherever the user may be located. [36]

UMTS network service has four different QoS classes depending on the traffic type:

- Conversational class: voice, video telephony and video gaming.
- Streaming class: multimedia, video on demand or web cast.
- Interactive class: web browsing, network gaming and database access.
- Background class: email, SMS and downloading.

### 3.3 UMTS Network Architecture

Firstly, UMTS system utilizes the same architecture that has been used by previous generation systems as second generation systems and even by the first generation. UMTS system consists of a group of logical network elements where each one has a defined functionality. The elements can be grouped by functionalities or based on the

subnetwork they belong to. Attending functionality features the network elements can be grouped into the Radio Access Network (RAN, UMTS Terrestrial RAN = UTRAN) that handles all radio-related functionality, and the CN (Core Network), which is the management network, the responsible for switching and routing calls and data connections to external networks. The other group to complete the UMTS system is the UE (User Equipment) which interfaces with the user and the radio interface. The high-level system architecture is shown in the Figure 3.1.

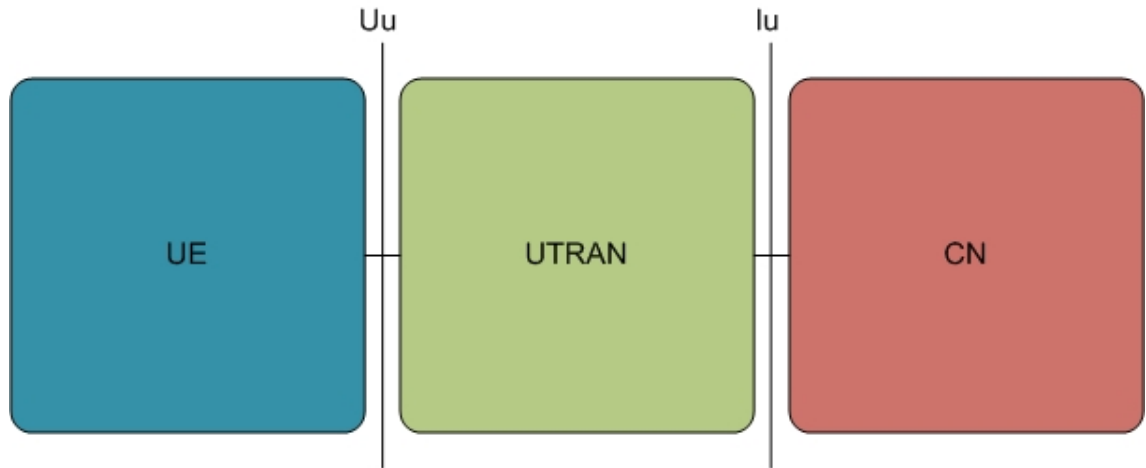


Figure 3.1: UMTS high-level system architecture.

Taking a look in the specifications and standardisation [37] [38], UE and UTRAN consist of completely new protocols, the design of which is based on the needs of WCDMA (Wideband Code Division Multiple Access) radio technology. On the other hand the definition of CN is adopted from GSM, giving to this system, with new radio technology, a global base of well-known CN technology.

In the same way, the network nodes can also be divided into physical functions and logical functions. Figure 3.2 depicts the subnetworks described above and the service layer, which is connected to the CN through API interfaces, making new services and applications deployment possible. The Figure 3.1 also shown two more interfaces, the Iu interface between UTRAN and CN, and Uu interface between UE and UTRAN. [39]

### 3.3.1 Core Network

UMTS Core Network can be divide into two domains: CS (Circuit Switched, like the existing telephony service) and PS (Packet Switched, like the Internet network). This division comes from the different requirements for data, depending on whether it is based on circuit switched voice connection (CS) or packet switched data connection (PS). The CS domain has the following elements: first we have the MSC (Mobile Switching Center) and the VLR (Visitor Location Register) which is the switch

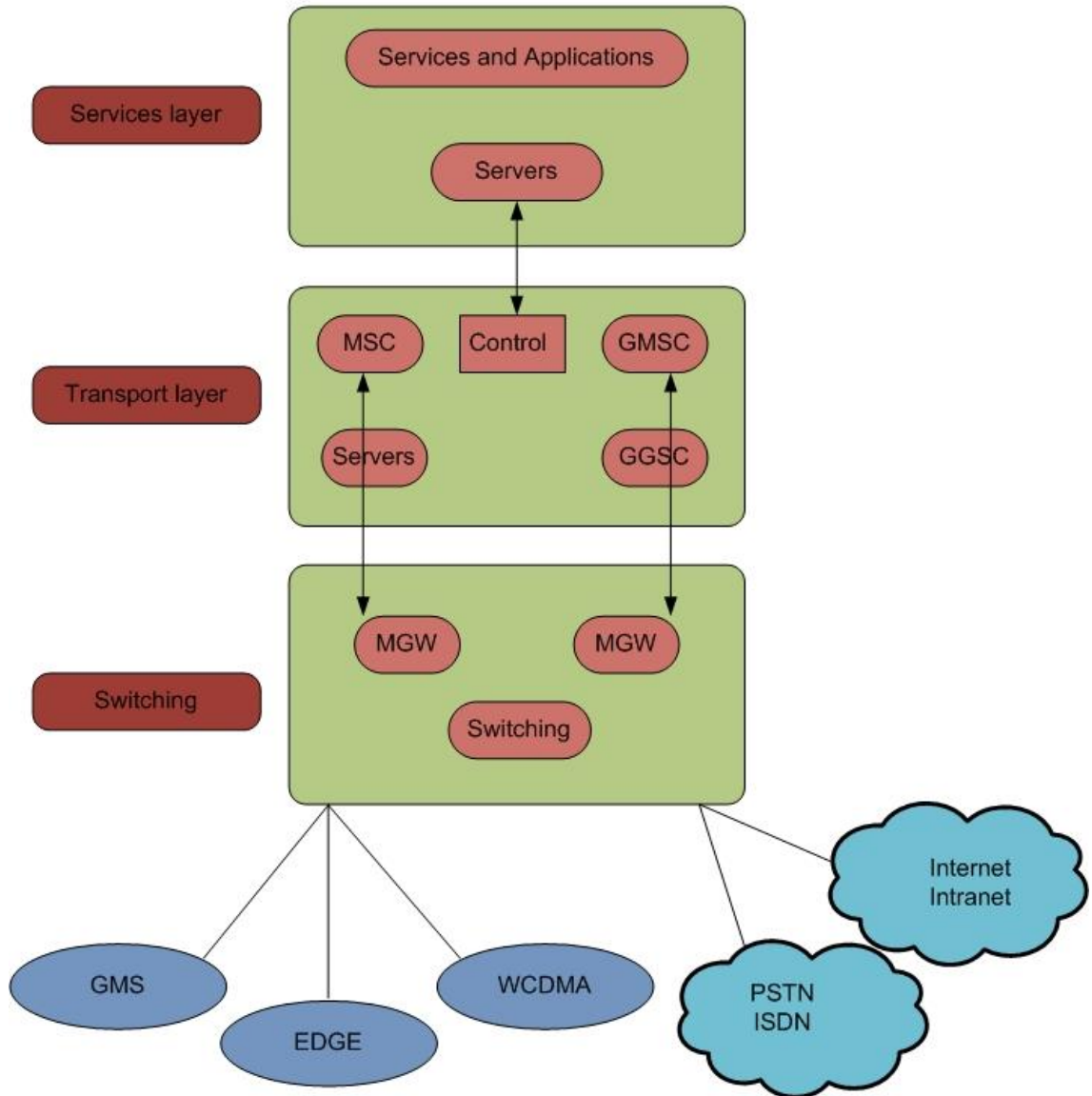


Figure 3.2: Core Network.

(MSC) and database (VLR) that serves UE in its current location for Switched Circuit services (CS). The MSC function is used to switch the CS transactions, and the VLR function holds a copy of the visiting user's service profile, as well as more precise information on the UE's location within the serving system. The part of the network that is accessed via the MSC/VLR is often referred to as the CS domain. Secondly, GMSC (Gateway Mobile Switching Center) is the switch at the point where UMTS PLMN (Public Land Mobile Network) is connected to external

CS networks. All incoming or outgoing CS connections go through GMSC.

The PS domain has the following elements: first element is the SGSN (Serving GPRS Support Node) functionality is similar to MSC/VLR but is typically used for Packet Switched (PS) services. The part of the network that is accessed via the SGSN is often referred to as the PS domain. Other element is the GGSN (Gateway GPRS Support Node). the main functionality is to switch at the point where UMTS PLMN is connected to external PS networks. All incoming and outgoing PS connections go through GGSN.

In addition to the two domains, the network needs various register for proper operation: HLR (Home Location Register), the database located in the user's home system that stores the master copy of the user's service profile. The service profile consist of, for example, information on allowed services, forbidden roaming areas, and supplementary service information such as status of a call forwarding and the call forwarding number. It is created when a new users subscribes to the system. The last element is the EIR (Equip Identify Register). Contains the information related to the terminal equipment and can be used to, e.g., prevent a specific terminal from accessing the network.

### 3.3.2 UMTS Radio Access Network

UTRAN architecture is shown in Figure 3.3:

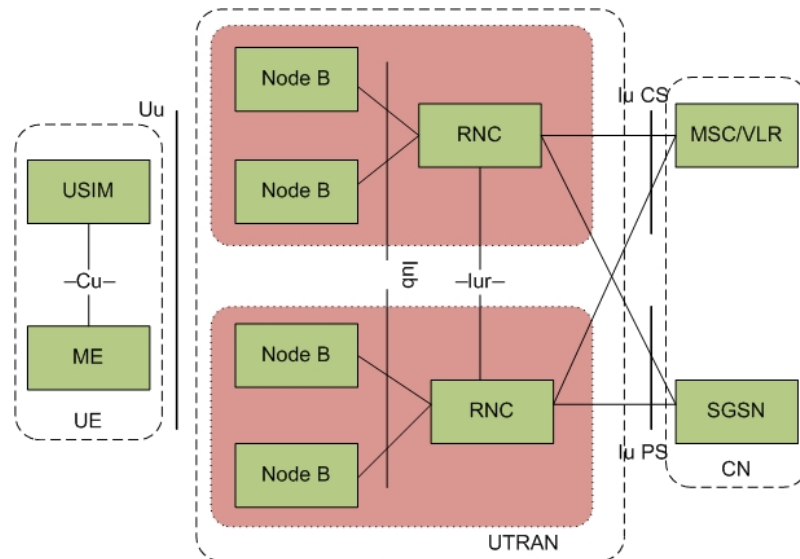


Figure 3.3: UTRAN architecture.

UTRAN is based on one or more RNS (Radio Network Sub-system). An each RNS is a subnetwork within UTRAN and consists of one RNC (Radio Network Controller) and one or more Node Bs. RNCs may be connected to each other via an Iur interface. RNCs and node Bs are connected with an Iub interface. Table 3.1

Concept	Definition
Cu interface:	This is the electrical interface between the USIM smartcard and the Mobile equipment (ME).
Uu interface:	This is the WCDMA radio interface through which the UE accesses the fixed part of the system, and is therefore probably the most important open interface in UMTS.
Iu interface:	This connects UTRAN to CN. This interface gives to the operators the possibility of acquiring UTRAN and CN from different manufacturers.
Iur interface:	This open interface allows soft handover between RNCs from different manufacturers, and therefore complements the open Iu interface.
Iub interface:	This connects a Node B and a RNC. UMTS is the first commercial mobile telephony system where the Controller-Base Station interface is standardised as a fully open interface.

Table 3.1: Open interface definitions.

the main definitions of the different open interfaces are listed.

Before entering deeply in UTRAN elements, we present the main characteristics of UTRAN architecture and the main requirements for the design of the UTRAN: the support of UTRA and all the related functionality. In particular, the major impact on the design of UTRAN has been the requirement to support soft handover and the WCDMA-specific RRM (Radio Resource Management) algorithms. Additionally, the maximization of the commonalities in the handling of packet-switched and circuit-switched data. Also the maximization of the commonalities with GSM, when possible. The use of the ATM transport as the main transport mechanism in UTRAN and the use of the IP-based transport as the alternative transport mechanism in UTRAN.

The radio technology utilized for the radio access in UMTS is WCDMA, which is not compatible with GSM. Thus in order to use UMTS, a new network deployment was made. For UTRAN there are two WCDMA categories, FDD (Frequency Division Duplex) and TDD (Time Division Duplex). FDD assigns two carrier frequencies, one for UL and the other one for DL. These frequencies represent a radio channel or a pair. In TDD, UL and DL use the same frequency. The transmissions is structured in time frames, distributed between UL (UpLink) and DL (DownLink) in dynamic way. [39]

Another remarkable characteristics that has to be mentioned about UTRAN are in the next Table 3.2:

Concept	Definition
Chip rate:	Chip rate has to be elevated to obtain high spreading factors and high capacity, which is limited by the bandwidth of the radio channels. The chip radio rate used for UTRA is 3.840 Mchips/s.
Frequency reuse:	The same frequency is used in all cells and consequently no frequency planning is needed.
Flexibility:	Set of orthogonal codes is used to obtain a variable spreading factor (OVSF). Thus, it is possible to serve users with different bit rate needs and quality of service, as well as, multimedia for certain users.
Coherent detection:	A common pilot channel is used for coherent detection in Node B as well as as in mobile terminals.
Power control:	Performed 1500 times per second.
Macrodiversity:	Processed using Rake receiver structures in base stations and mobile terminals.

Table 3.2: UTRAN characteristics.

### The Radio Network Controller

It is the network element which control the radio resources of UTRAN, interfaces the CN and also terminates the Radio Resource Control (RRC) protocol that defines the messages and procedures between the mobile and the UTRAN.

The RNC is managing handovers that imply signaling with the UE, selection (UL) and division (DL) functions to support macrodiversity associated with Soft Handover between different Node B (base station in UMTS). [39]

### The Node B (Base Station)

The main function of the Node B is to perform the air interface processing, coding and interleaving, rate adaptation, spreading, etc. It also performs some basic RRM operations such as the inner loop power control. [39]

## 3.4 UMTS 900 MHz

UMTS networks have been widely deployed in the frequency band 1920-1980 MHz / 2110-2170 MHz, however, there are still sparsely populated and remote areas where there are difficulties to provide IMT-2000/UMTS services in a cost-efficient way. Several studies based on UMTS terrestrial deployment show that using 900 MHz the provision of the expected IMT-2000/UMTS services to users can be facilitated in those areas. The main interest for European mobile operators to deploy in the 900 MHz band is the larger coverage compared in the 2000 MHz band. UMTS900 offers considerably more cost effective solution for providing UMTS services in rural

area with low population density.

### 3.4.1 UMTS 900 MHz vs. 2100 MHz

The most significant benefits come from the fact that, compared to 2 GHz band, radio wave propagation path loss in 900 MHz frequency band is much smaller. For offering the same service (data rates) and same coverage, the required number of base station sites in 900 MHz band is reduced by 60 % compared to that at 2 GHz. In addition, the use of the 900 MHz band can significantly improve indoor coverage in urban areas. Improved indoor coverage is important because more and more mobile voice and data are used in the indoor environment. This is particularly interesting when considering the increasing use of the mobile phones as a replacement or a complement to fixed phone usage. [40]

### 3.4.2 Technical Solutions for Network Implementation

In Europe, the paired 900 MHz band 880-915 MHz / 925-960 MHz was harmonized for GSM900 (GSM with a frequency carrier of 900 MHz), and it is currently heavily in use. Related to the UMTS on GSM frequency bands, ECC (Electronic Communications Committee) has prepared three sharing and compatibility study reports:

- The compatibility between UMTS and GSM operating in 900 MHz and 1800 MHz bands.
- The compatibility between UMTS 900/1800 and adjacent band systems.
- Border coordination when both GSM and UMTS are deployed in the same frequency band.

Based on the national decisions, mobile operators can decide in what time frame to deploy UMTS in GSM 900 MHz band in line with their business plans. A practical solution is that part of GSM 900 MHz is refarmed to be used by UMTS and part of the band remains in the GSM use as there is a need for a GSM service. For example, one of the most considered options for deploying UMTS900 within existing GSM900 band, the frequency plan is called "sandwich" frequency arrangement as shown in the Figure 3.4. [40]

## 3.5 Role of HAP in UMTS Network

Taking into account the advantages that HAPs represent anyway, its clear the interest to apply them for testing new technologies in radio communications networks and in order to improve the network performance and costs.

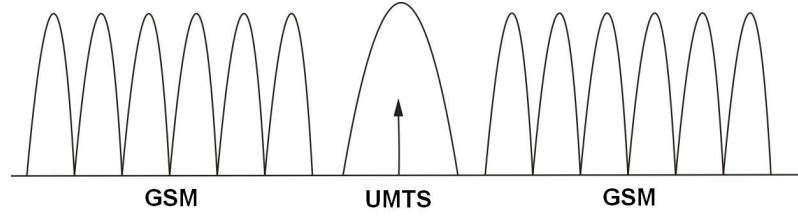


Figure 3.4: "Sandwich" frequency arrangement for deploying UMTS900 and GSM900.

The design of HAP intended to provide the stratospheric segment of UMTS must consider the limitations imposed by the platform technology. Firstly, the weight and volume of the equipment to be installed onboard is limited, and it should be taken into account when assigning network functions to a platform. Also the platform has to be loaded with the electronic equipment in order to provide remote control and telemetry. This weight limitation require the use of satellite equipment, which is much lighter than terrestrial equipment. Another limitation is the energy consumption. The electric power needed for the operation of all the equipment is supplied usually by the solar panels during the daylight and by using batteries at night and during periods of peak power consumption. Also the platform location varies with time. There are two possibilities referring to a HAP position. The first one tries to maintain a quasi-static position and the other one flies along a pre-defined course, presumably circular. Finally the availability of the onboard equipment is limited by the availability of the platform itself, which is affected by weather conditions (e.g. rain attenuation, wind) and other circumstances (e.g. position, altitude). [5] [41]

Due to these characteristics, HAPs can preferably be deployed in the access network domain rather than the core network domain of a telecommunications network due to their limited availability. Therefore, a possible outage would affect only a relatively small area, affecting less users, instead of disabling a vital core network that would affect bigger number of users.

Taking into consideration all the limitations mentioned the most feasible scenarios seems to be two: the first one made up of a single-HAP scenario, where only one platform may be applied as Node B. It is depicted in the Figure 3.5, only one aerial platform is needed and it is able to extend the coverage of the radio access network.

The second scenario includes an inter-platform scenario, where the HAP is supposed to carry both RNC and NodeB equipments. Although it could be limited by maximum payload weight.

Integrating HAPs into this networks represents a UTRAN modification and it assumes some special features. The BS is located in the HAP payload, carrying a set of electronic equipments that act as an aerial NodeB. Figure 3.6 depicts arials platforms carrying a combined RNC and NodeB payload.

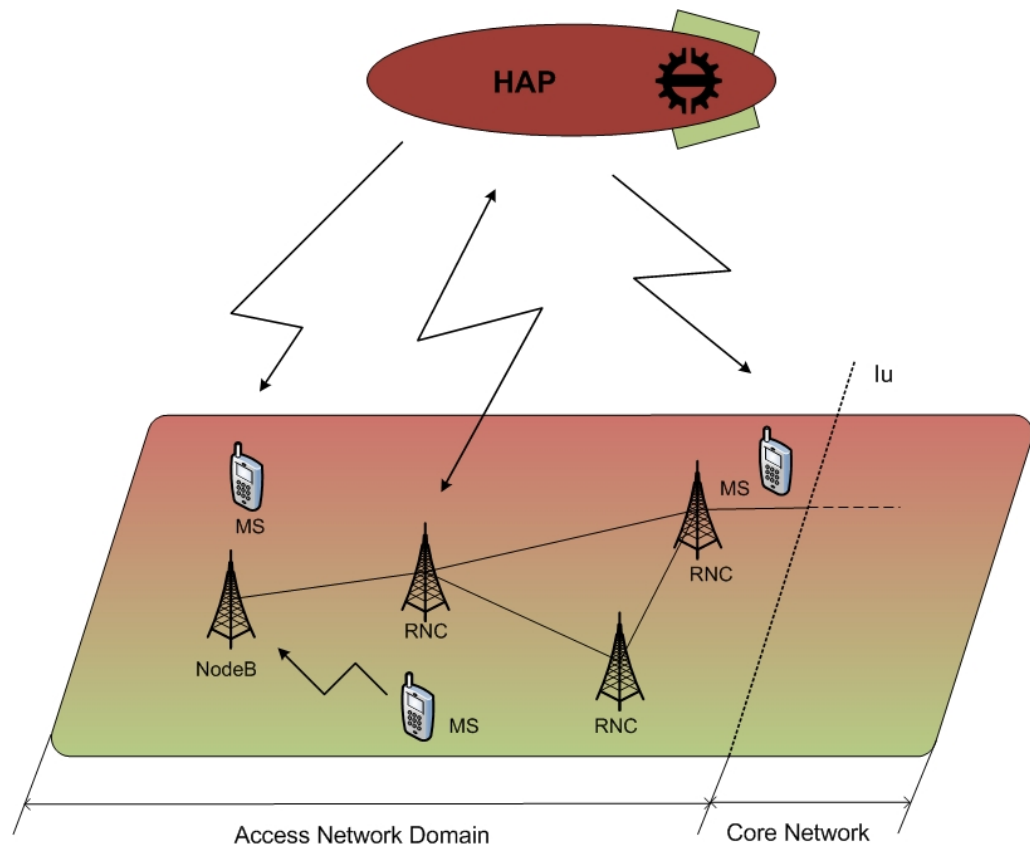


Figure 3.5: Role of HAP in UTRAN.

Focusing on the last scenario, it has to be mentioned that in fact, the RNC could be in another HAP or in a terrestrial node, depending on the role of each element in the network. [5] [41]

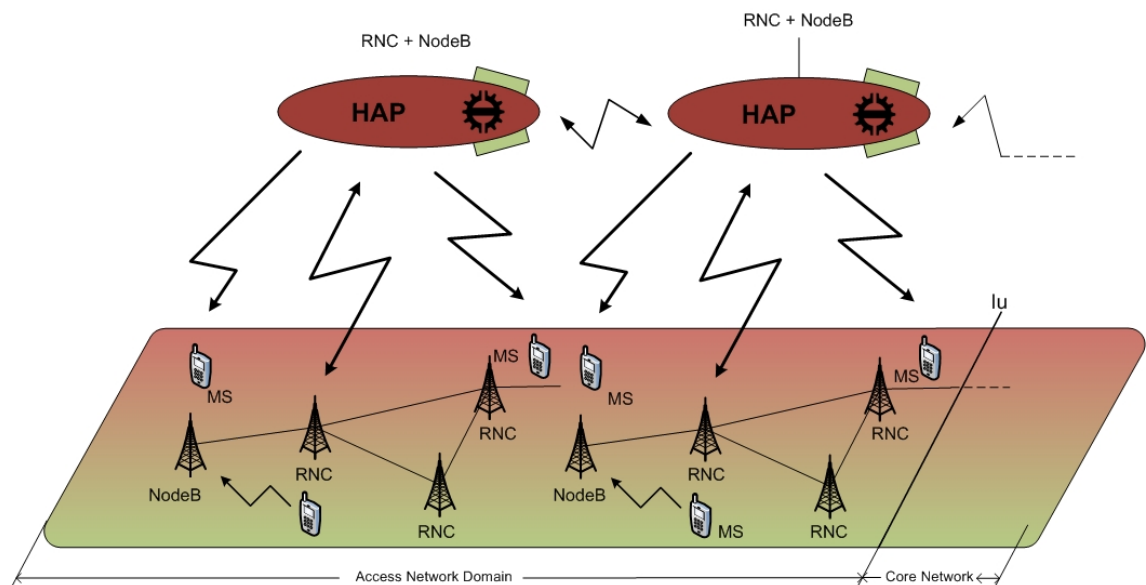


Figure 3.6: HAPs used as RNC and Node B.

### 3.6 Antenna Models

The main element in air to earth interface is the antenna. Depending on the antenna characteristics, there are several parameters such as coverage, footprint or interference that affects directly on QoS and network performance. In order to compensate for the HAPs altitude, the antenna beamwidth must be of a few degrees. Figure 3.7 depicts this fact.

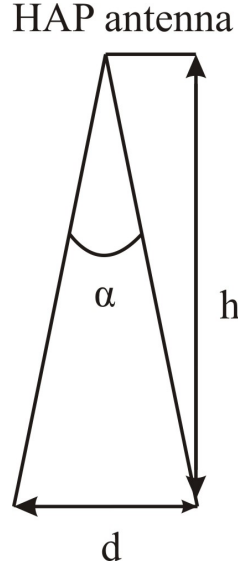


Figure 3.7: HAP antenna beamwidth ( $d \ll h$ ).

Basically, HAPs payload consists of a set of antennas, and RNC or/and NodeB equipments (could be other equipments such as telemetric equipments in order to allow control remote), pointing to a different places on the earth surface, plotting a cell layout for providing UMTS. Following the ITU recommendations, which explains possible HAP antennas for providing IMT-2000. The antenna characteristics of HAPs as a base station to provide IMT-2000 service shall comply with the following:

$$G(\Psi) = \begin{cases} G_m - 3(\Psi/\Psi_b)^2 & dBi \quad for \ 0 \leq \Psi \leq \Psi_1 \\ G_m + L_N & dBi \quad for \ \Psi_1 \leq \Psi \leq \Psi_2 \\ X - 60 \log(\Psi) & dBi \quad for \ \Psi_2 \leq \Psi \leq \Psi_3 \\ L_F & dBi \quad for \ \Psi_3 \leq \Psi \leq 90^\circ \end{cases} \quad (3.1)$$

The 3 dB beamwidth is estimated by:

$$\Psi_b = \sqrt{\frac{7442}{10^{0.1G_m}}}$$

where  $G_m$  is the peak aperture gain [dBi].

Variable	Definition
$G(\Psi)$	Gain at the angle $\Psi$ from the main beam direction [dBi].
$G_m$	Maximum gain in the main lobe [dBi].
$\Psi_b$	One-half the 3 dB beam width in the plane of interest (3 dB below $G_m$ ) [degrees].
$L_N$	Near-inside-lobe level [dB] relative to the peak gain required by the system design, and has a maximum value of -25 dB.
$L_F$	$L_F = G_m - 73$ , far side-lobe level [dBi].
$\Psi_1$	$\Psi_1 = \sqrt{-L_N/3}$ [degrees].
$\Psi_2$	$\Psi_2 = 3.745\Psi_b$ [degrees].
$X$	$X = G_m + L_N + 60 \log(\Psi_2)$
$\Psi_3$	$\Psi_3 = 10^{\frac{X-L_F}{60}}$
$2\Psi_b$	The 3 dB beamwidth.

Table 3.3: Antenna pattern parameters.

### 3.7 Propagation Model

Firstly, it is important to emphasize the important different behavior in the same propagation model operating at low frequency bands in relation to the ones operating in upper bands. One important motivator for this work is the better behavior in lower frequencies of propagation models.

It is easy to notice that there are important difference in the communication propagation model between terrestrial and HAP deployment. For the HAPs case, we should consider environmental conditions defined by scenario. As it was mentioned in subsection 2.5.2, the main environmental mechanism and effects affecting HAPs propagation are free space Loss, multipath, rain attenuation and gaseous absorption. The two last effects are not relevant for the used frequency range (IMT-2000). Thus, there are only these free space loss and multipath effect that we should take into account in UMTS. The free space loss is defined as following:

$$L_F = \left( \frac{4\pi r}{\lambda} \right)^2 \quad (3.2)$$

where  $r$  is the distance between the antennas and  $\lambda$  is the wavelength. Expressing the space loss in decibels:

$$L_F(dB) = 32.4 + 20 \cdot \log(r_{km}) + 20 \cdot \log(f_{MHz}) \quad (3.3)$$

On the other hand it is multipath, that somehow we should consider in the model. As it is known in a multipath environment we consider the slow fading and fast fading. Fading is deviation of the attenuation that the carrier signal experiences over certain propagation media, in our case multipath environment. The fading may vary with time, position and frequency and is often modeled as a random process.

The terms slow and fast fading refer to the rate at which the magnitude and phase change imposed by the channel on the signal changes. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver. The amplitude change caused by shadowing is often modeled using a log-normal distribution with a standard deviation according to the log-distance path loss model. Fast fading occurs when the coherence time of the channel is small relative to the delay constraint of the channel. In this regime, the amplitude and phase change imposed by the channel varies considerably over the period of use. Usually, the fast fading is considered as a constant parameter in order to model the propagation. And the slow fading is modeled through an enhanced empirical model to high elevation angle, and it is as follows:

$$M = A \cdot \ln(p) + B [dB] \quad (3.4)$$

and the coefficients:

$$A = 0.002 \cdot \phi^2 - 0.15 \cdot \phi - 0.7 - 0.2 \cdot f \quad (3.5)$$

$$B = 27.2 + 1.5 \cdot f - 0.33 \cdot \phi \quad (3.6)$$

where  $M$  corresponds to the required link margin for a specified link outage probability,  $P$  (%) in the range 1-20 and  $\phi$  is the elevation angle in degrees. [42] [43]

## 3.8 Radio Network Planning

### 3.8.1 Planning Process

UMTS radio interface is based on WCDMA technology. Before launching a mobile communication network, careful planning must be done to ensure correct and optimized operation of such a network. Planning process of 2G systems has usually been divided into three sections: network dimensioning, detailed planning, and network optimization. The planning process for 3G networks follows the same basic rule with some exceptions. Figure 3.8 shows a high layer definition of the planning process for UMTS. The configuration of the radio access network as well as of the core network must be planned together.

### 3.8.2 Cell Network Architecture with Hexagonal Layout

As it was mentioned in Section 3.7, the HAP is expected to carry a set of antennas and other electronic equipments as payload. This set of antennas represents a

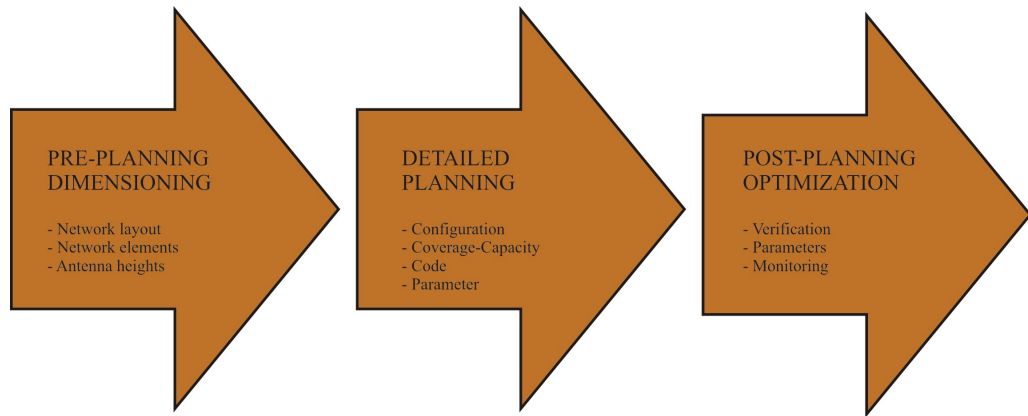


Figure 3.8: WCDMA planning process. [44]

hexagonally covered area over the earth, composed of cells. The hexagonal layout is the most effectively method, without overlapping and filling in the areas without leaving uncovered areas. In order to provide this kind of hexagonal coverage, each one of the antennas carried by the HAP corresponds to a cell, and altogether these cells conform the hexagonal area, Figure 3.9.

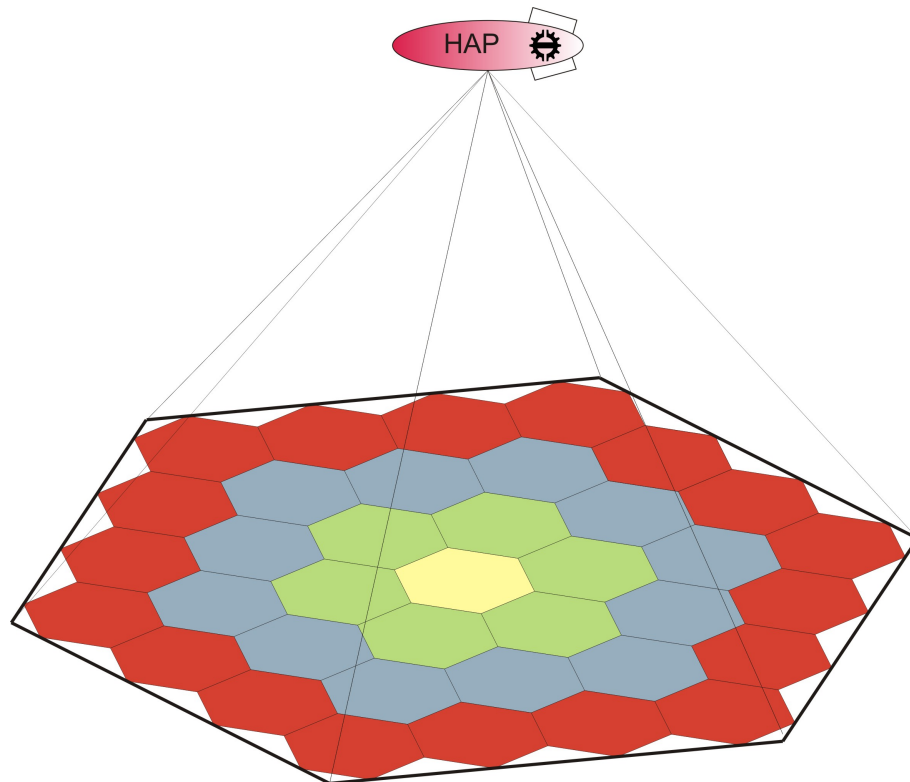


Figure 3.9: Cell arrangement.

### 3.8.3 Interference and Capacity Analysis for HAPs

The interference calculation represents a basic work in cellular planning. It consists of the estimation of the carrier to interference ratio,  $\frac{C}{I}$ . Where C is the carrier power and I is the overall interference value. In order to estimate the interference level, we suppose that all the interfering signals are uncorrelated, and the signals follow different paths. The interfering signals are summed incoherently and the overall interference power is the result.

Mainly, it is possible to separate two interfering signals that have to be considered: downlink interference, caused by signals from base stations in mobile stations, and uplink interference, caused by signals from mobile stations in base stations.

### 3.8.4 Power Budget

Power budget or link budget is an important part of the radio planning process. The target of the power budgets is to calculate the maximum uplink and downlink path loss for difference service speeds to achieve the balanced communication. Power budgets include information about gains and losses in the communication path of a radio link. Table 3.4 shows an example of unbalanced power budget.

In the power budget showed in Table 3.4, we can see a difference of ten decibels in both directions in maximum allowed path loss when using speech service. In order to balance these difference, the power budget can be balanced, for example, by using low noise amplifiers or direction diversity methods in uplink direction.

### 3.8.5 Performance Indicators

The radio link performance indicators are used in radio network planning and dimensioning. They are defined to give information about the UMTS network performance. Some important indicators for the studies in this document are described shortly to understand the analysis of the results performed in the following chapters.

#### Service Probability

Service probability gives the relation between the number of served users and dropped users in the system. Equation 3.7 define the service probability:

$$SP = \frac{Served\_Users}{All\_Users} \quad (3.7)$$

where *Served\_Users* represents the number of successfully served users in the system and *All\_Users* is the total number of users in the system. Typically target values of service probabilities are close to 1.

Parameter	Speech		Data		Units
	DL	UL	DL	UL	
Bit rate	12.2	12.2	384	64	kbps
Load	50	50	75	30	%
Thermal noise density	-173.93	-173.93	-173.93	-173.93	dBm/Hz
Receiver noise figure	8	4	8	4	dB
Noise power at receiver	-100.13	-104.13	-100.13	-104.13	dBm
Interference margin	3.01	3.01	6.02	1.55	dB
Total noise power at receiver	-97.12	-101.12	-94.11	-102.58	dBm
Processing gain	24.98	24.98	10	17.78	dB
Required $\frac{E_b}{N_o}$	7	5	1.5	2.5	dB
<b>Receiver sensitivity</b>	<b>-115.10</b>	<b>-121.10</b>	<b>-102.61</b>	<b>-117.86</b>	<b>dBm</b>
RX antenna gain	0	18	0	18	dB
Cable loss/body loss	2	5	2	5	dB
Soft handover diversity gain	3	2	3	2	dB
Power control headroom	0	3	0	3	dB
<b>Required signal level</b>	<b>-116.10</b>	<b>-133.10</b>	<b>-103.61</b>	<b>-129.86</b>	<b>dBm</b>
TX power per connection	33	21	37	21	dBm
Cable loss/body loss	5	2	5	2	dB
TX antenna gain	18	0	18	0	dB
Peak EIRP	46	19	50	19	dBm
<b>Maximum allowed path loss</b>	<b>162.10</b>	<b>152.10</b>	<b>153.61</b>	<b>148.86</b>	<b>dBm</b>

Table 3.4: An example of UMTS power budget. [44]

### Interference

The total interference in UMTS network is defined in equation 3.8.

$$I_{tot} = N + I_{own} + I_{oth} \quad (3.8)$$

where  $I_{tot}$  is the total interference level in the receiver,  $N$  represents the noise of the receiver,  $I_{own}$  is the total interference power originating from own cell users and  $I_{oth}$  is the corresponding total other cell interference power. The total interference can be downlink or uplink. Downlink consider the scenario where the mobile user is the receiver and in uplink scenario the BS is the receiver. In order to analyze the results we will use the uplink total interference defined by the equation 3.9.

$$I_{totUL} = N_{UL} + I_{ownUL} + I_{othUL} \quad (3.9)$$

where all the parameters have the same meaning than in 3.8 but referred to uplink case.  $N_{UL}$  is not depending on the numbers of users in the system, and  $I_{ownUL}$  and  $I_{othUL}$  are varying as a function of the number of users in the system. The uplink interference terms are defined in equations 3.10 and 3.11

$$I_{ownUL} = \sum_{i=1}^N P_{RX,i} \quad (3.10)$$

where  $N$  is the number of users in the own cell and  $P_{RX,i}$  is the received power in the BS from each user  $i$ .

$$I_{othUL} = \sum_{j=1}^M P_{RX,j} - I_{ownUL} \quad (3.11)$$

where  $M$  is the total number of users in the network and  $P_{RX,j}$  is the received power in the BS from each user  $j$ .  $I_{ownUL}$  is subtracted in the 3.11 equation because the impact of the interference from own cell is considered in  $I_{ownUL}$ .

### Throughput

The throughput is the average rate of successful message delivery over a communication channel. The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot. When throughput calculation for each cell is done in the simulator, the data because the soft handover overhead is included. Thus, the information provided with the throughput is more or less the same than service probability but including the data that the system needs to manage the handovers.

## 4. SIMULATIONS

The main goal of this thesis is to study how the UMTS system is behaving with a frequency change. As was told before, this UMTS system is installed on HAPs, and the frequency change is from 2100 MHz to 900 MHz. The improvements of this frequency change have been studied on terrestrial deployment and the benefits are well-known. Thus, the point of this study is to define the behavior and benefits of this frequency change when a HAP is used as a base station. Also the effect of the antenna beamwidth is studied in order to see how the UMTS is affected for this parameter in comparison with effect of the frequency change.

Based on the equations of free space propagation model, it is easy to see that reducing the operating frequency of the UMTS system an improvement in the path loss is observed (equation 3.3). Resolving the equation for both frequencies

$$L_{F_{900}} = 32.4 + 20 \cdot \log r_{km} + 20 \cdot \log 900 \quad (4.1)$$

$$L_{F_{2100}} = 32.4 + 20 \cdot \log r_{km} + 20 \cdot \log 2100 \quad (4.2)$$

$$\Delta L = L_{F_{2100}} - L_{F_{900}} = 7dB \quad (4.3)$$

an improvement of 7 dB is achieved in the path loss.

In order to study this the behavior of reduced path loss in UMTS networks, two simple scenarios are studied first and finally a complete UMTS network deployment is more deeply studied. The method of analysis (Figure 4.1) is to run a set of simulations with different cell separations, and in the two first scenarios with different antenna beamwidth, shaping a hexagonal layout for both frequencies. An analysis of the results will give the improvement of the frequency change and the impact of the antenna beamwidth in UMTS system using HAPs as a BS.

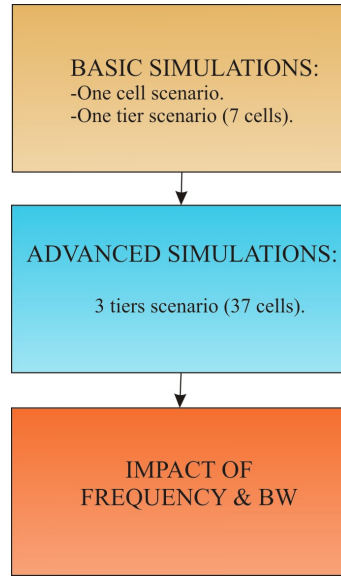


Figure 4.1: Method of study.

## 4.1 HAP Modeling in Radio Network Simulator

### 4.1.1 Static Simulator

The NPSW (Network Planning Strategies for Wideband CDMA) simulator was used to build the scenarios and reach the simulation results. This simulation tool is a static WCDMA simulator built on top of MATLAB. The simulator does not support propagation calculation on a digital map. For that reason, the simulations have been done using a flat earth model. The simulator analyzes the performance of the network in a single static time instance called snapshot. Different parameters of the network can be adjusted by using text files, such as the number of users which are randomly distributed all over the area in question.

The structure of simulator is more or less straight forward following from the general WCDMA coverage and capacity prediction. The simulator is divided in three parts or phases: general initialization, combined uplink and downlink iteration phase, and post-processing phase. In initialization phase, all needed parameter files are read and calculations to be done only once are done. The complexity and duration of this phase depends on the set map resolution, link losses are calculated from all Node BS to all map pixels by using the specified propagation model. In the iteration phase, various performance parameters are calculated iteratively. In the last phase the calculated information can be post-processed to produce various plots and statistics. [45] [47]

### 4.1.2 Modification for HAPs

The simulator was designed for terrestrial networks and not for HAPs. For this reason, a modification to adapt it to HAPs architecture is needed. The modification mainly concerns the estimation of antenna losses given an antenna pattern.

First of all, it has to be mentioned that the base station antenna on a HAP is a linear array of  $N$  elements, positioned uniformly and symmetrically along the vertical axis to the ground. The antenna pattern recommended by ITU in [45] was used in the simulations. The antenna pattern loss given by this antenna mask only depends on the angle  $\theta$ , defined as the antenna boresight or antenna beam direction. It is easy to see the fact that on a surface of a cone, in antenna gain,  $G_{ant} = f(\theta, \phi)$ , all the points have the same antenna gain,  $G_{ant} = f(\theta)$ . Because of that, the antenna mask has a revolution symmetry. Figure 4.1 shows this fact.

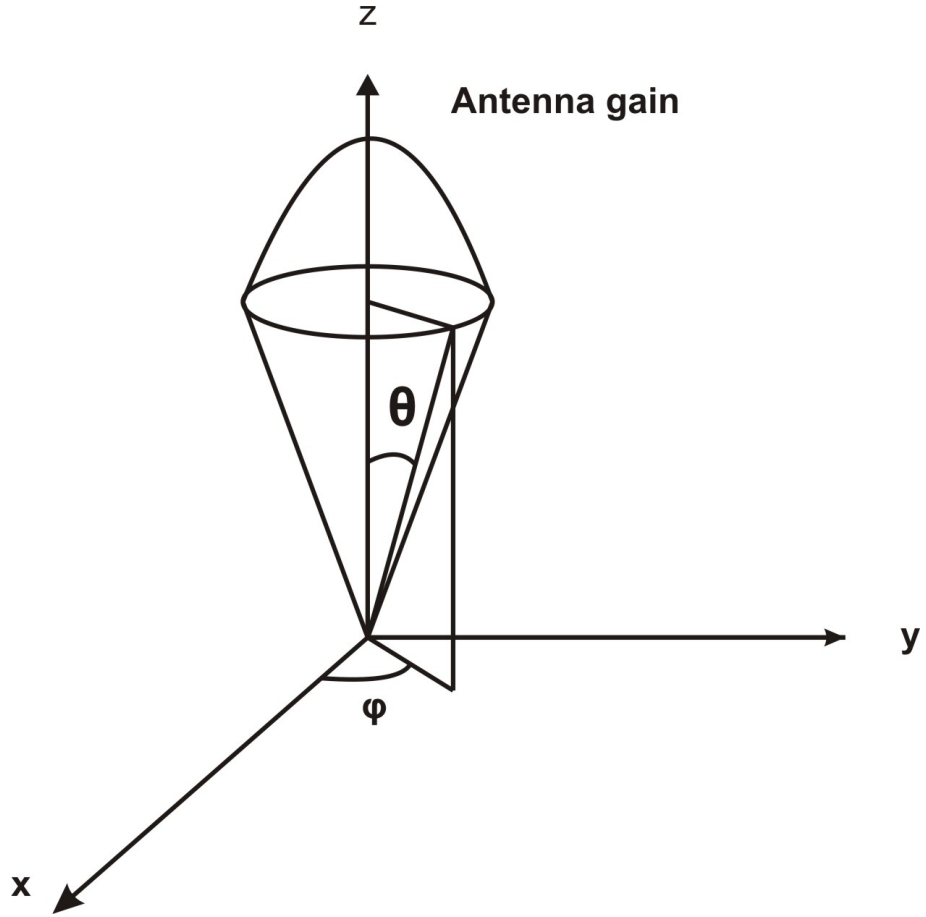


Figure 4.2: Antenna pattern with revolution symmetry.

From Figure 4.2, it becomes clear that only one antenna pattern is needed in order to estimate the antenna gain in a certain direction. Moreover, it is possible to implement a new antenna modeling because of this particularity of the antenna mask used for HAPs with a low computing cost. Next step is to give a slight idea of

the estimation of an antenna gain. Figure 4.3 depicts the scenario under analysis.

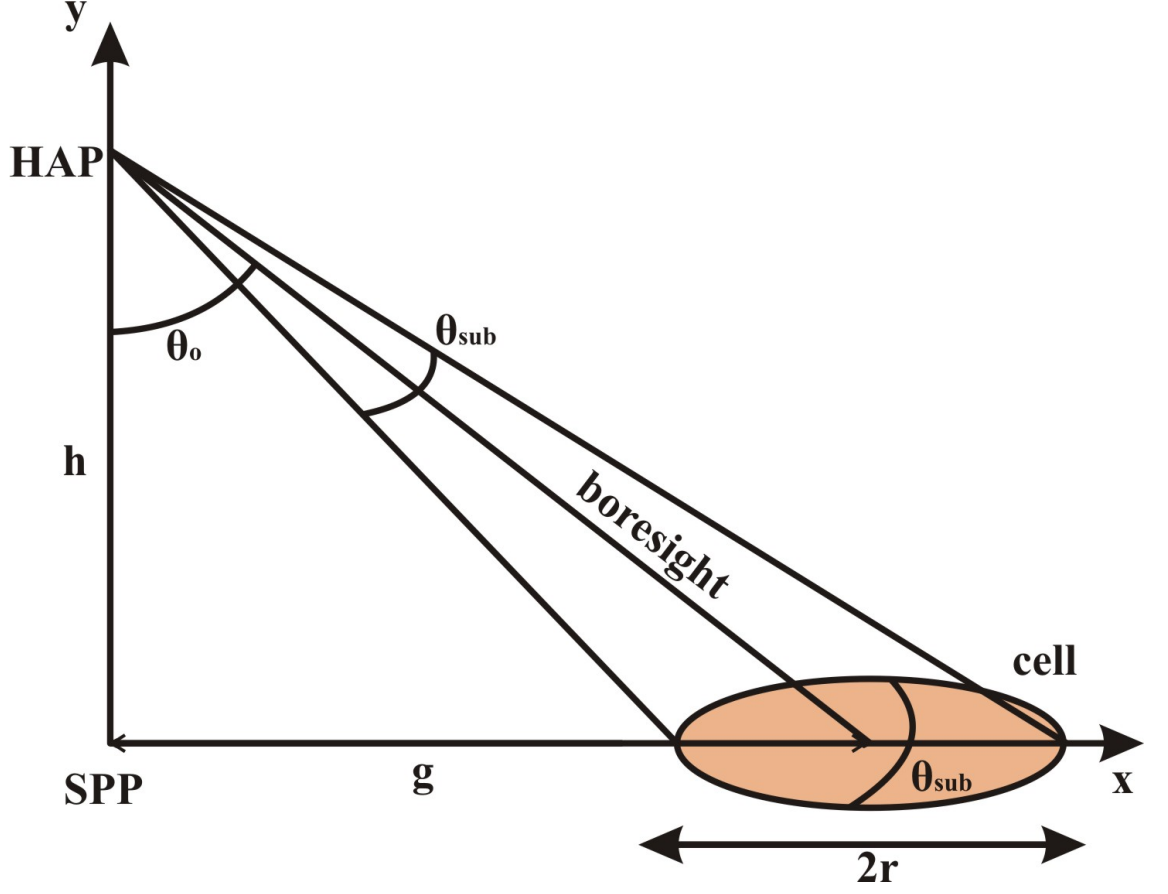


Figure 4.3: Parameters for gain estimation.

From the Figure 4.3,  $h$  is the HAP height and the antenna is pointing to the cell center on the earth surface with a tilting of  $\theta_o$  degrees (boresight angle).  $\theta_{sub}$  is the antenna beamwidth and  $2r$  is the circle that encloses the cell. The cell center is located  $g$  kilometers far from the SPP (Sub Platform Point) and the boresight represents the angle of maximum antenna gain. Remember that we are using a cell network architecture with hexagonal deployment.

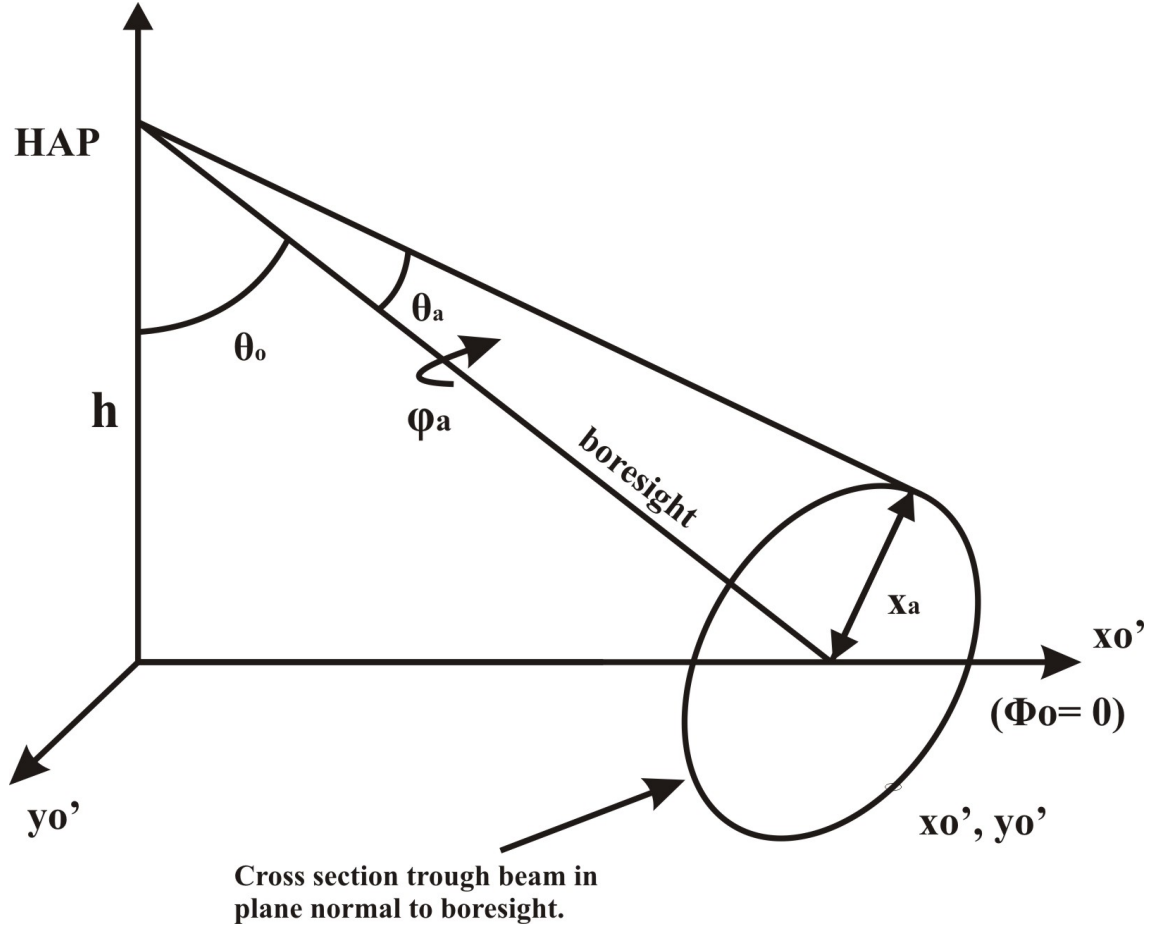
The power at each point on the ground  $\{x, y\}$  is calculated for each antenna beam by deriving the elevation and the azimuth angles  $\theta_a$  and  $\phi_a$  relative to the boresight in polar coordinates.

In the Figure 4.4,  $x_0$  and  $y_0$  are the same points as  $\{x, y\}$ , but are referred to the antenna tilting and direction. According to [46] these points can be expressed:

$$x_0 = \sqrt{x^2 + y^2} \cdot \cos \left( \arctan \frac{y}{x} - \phi_0 \right) \quad (4.4)$$

and

$$y_0 = \sqrt{x^2 + y^2} \cdot \sin \left( \arctan \frac{y}{x} - \phi_0 \right) \quad (4.5)$$

Figure 4.4: Elevations angles for  $x_0$  and  $y_0$  point.

The angle  $\phi_0$  is the antenna tilt and  $\phi_a$  is the angle between the given point and the antenna boresight, expressed as:

$$\theta_a = \arctan \left( \frac{\sqrt{x_a^2 + y_0^2}}{h \cdot \cos(\theta_0) + x_0 \cdot \sin(\theta_0)} \right) \quad (4.6)$$

Figure 4.4 also depicts  $\varphi_a$ , which represents the angle around the boresight and expressed as:

$$\varphi_a = \arctan \left( \frac{y_0}{x_a} \right) \quad (4.7)$$

where  $x_a$  is the displacement  $x_0$  transformed to a plane normal to a centered on antenna boresight:

$$x_a = (x_0 - h \tan(\theta_0)) \cos(\theta_0) \quad (4.8)$$

Then, each point  $\{x, y\}$  is referred to the antenna boresight and direction. By summing all the facts explained before and using a certain antenna pattern, defined

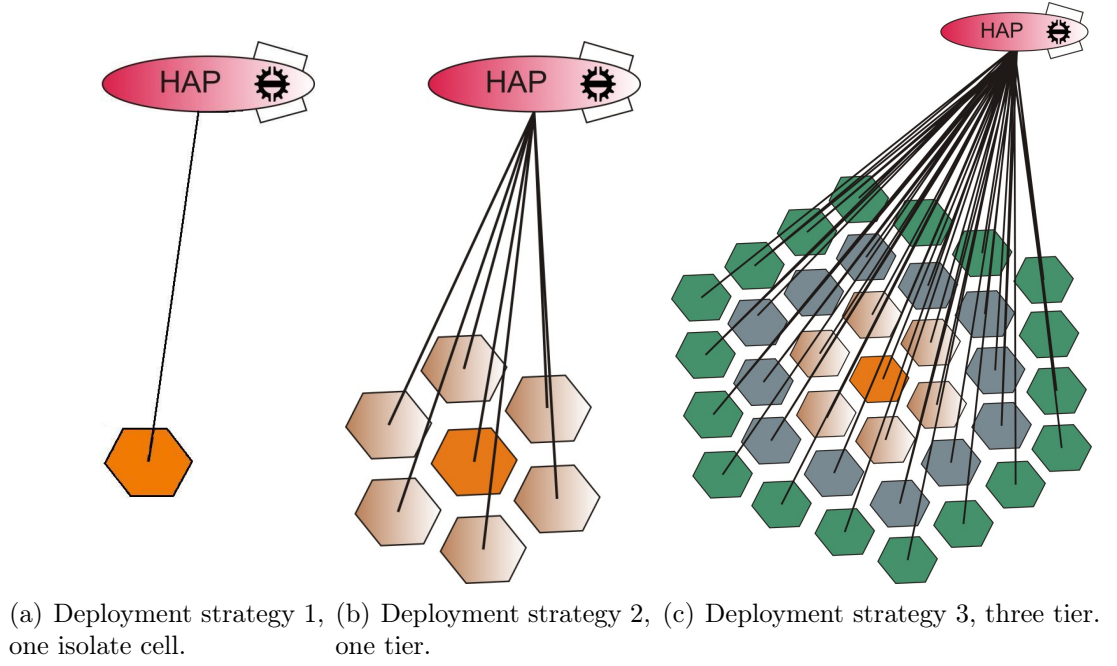


Figure 4.5: Deployment strategies.

according to the ITU mask, the antenna gain is easily estimated by finding the antenna gain for the angle  $\theta_a$ .

## 4.2 Scenario

A single HAP scenario is used in the simulations, which approximates a real situation where a HAP is expected to provide UMTS coverage with a certain QoS and service characteristics. Only the radio interface is considered, so the payload properties are only assumed to satisfy all requirements. Each one of the antennas carried by the HAP has a certain tilting that make a point to somewhere over the earth surface, drawing a cell. Three different deployment strategies with different number of cells are used in the simulations. Figure 4.5 shows the three different deployment strategies.

In order to study the behavior for both frequencies 900 MHz and 2100 MHz, a coverage study is done. The aim of this study is to find the maximum coverage area reachable using different network deployment strategies for both frequencies. Additionally, an antenna beamwidth study is done with the aim of studying how the antenna beamwidth is affecting the system.

### 4.2.1 Simulation Parameters

#### Area of Study

As it was mentioned in Chapter 3, a hexagonal layout is going to be used for HAPs simulations. The area of study will contain a hexagon that represents the area covered by the HAP. In order to find the maximum coverage for both frequencies, different areas are simulated. The area contained in the hexagon will be changing as a function of the distance between cells or tiers. The Figure 4.6 depicts the simulation area and the hexagon, in that case a 1 tier (7 cells) deployment with a certain distance between cells.

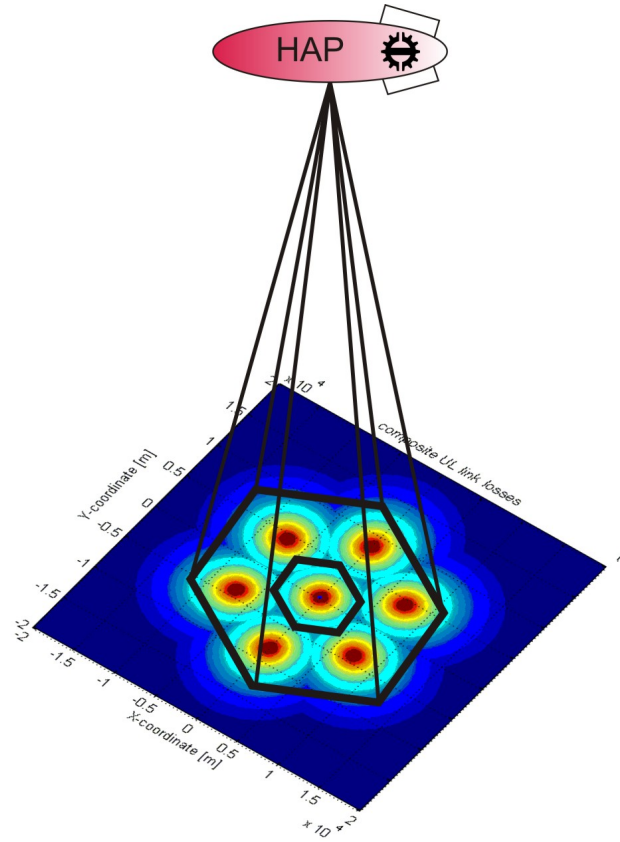


Figure 4.6: Variable simulation area and the hexagonal shape.

#### Network Parameters

Next tables contain all simulation parameters related to HAP, mobile station, propagation model, link performance and other general parameters.

Description	Value	Unit
HAP antenna height	22	km
Base station total maximum transmission power	37	dBm
Base station maximum transmission power per link	30	dBm
Pilot power	27	dBm
Common channel and other channels power	27	dBm
Base station cable losses	1	dB
Base station uplink load limit	0.75	
Base station noise figure	5	dB

Table 4.1: HAP parameters.

Description	Value	Unit
Antenna height	1.5	m
Maximum transmission power	21	dBm
Minimum transmission power	-50	dBm
Antenna gain	1.5	dB
Body loss	1.5	dB
Noise figure	8	dB

Table 4.2: Mobile station parameters.

Description	Value	Unit
SHO window	-3	dB
Traffic bit rate (uplink and downlink)	12.2	kbps
Standard deviation of shadowing	0	dB

Table 4.3: General parameters.

Description	Value	Unit
$E_b/N_0$ uplink	5	dB
$E_b/N_0$ downlink	9.5	dB
Orthogonality factor	0.9	
Voice activity factor uplink	0.67	
Voice activity factor downlink	0.67	

Table 4.4: Link performance parameters.

### 4.2.2 Variables under Study

In order to study the behavior of the UMTS with the frequency change and to analyze how the antenna beamwidth is affecting, it is necessary to study different set of antenna patterns, different cells layouts and different loading scenarios. Summarizing, the variables of study are beamwidth of antenna patterns, traffic scenarios, cell layouts and frequency.

### Antenna Patterns

Two different beamwidths are going to be used in order to study the behavior of the UMTS system. The expression for 2 degrees antenna is based on [48] using the equation 3.1:

$$G(\theta) = \begin{cases} 38.7 - 3 \left( \frac{\theta}{1^\circ} \right)^2 & dBi \quad for \quad 0^\circ \leq \Psi \leq 2.88^\circ \\ 38.7 - 25 & dBi \quad for \quad 2.88^\circ \leq \Psi \leq 3.475^\circ \\ 46.157 - 60 \log(\theta) & dBi \quad for \quad 3.475^\circ \leq \Psi \leq 21.92^\circ \\ -34.2 & dBi \quad for \quad 21.92^\circ \leq \Psi \leq 90^\circ \end{cases} \quad (4.9)$$

The expression for a 5 degrees beamwidth antenna is:

$$G(\theta) = \begin{cases} 30.7 - 3 \left( \frac{\theta}{2.5^\circ} \right)^2 & dBi \quad for \quad 0^\circ \leq \Psi \leq 7.21^\circ \\ 30.7 - 25 & dBi \quad for \quad 7.21^\circ \leq \Psi \leq 8.68^\circ \\ 62 - 60 \log(\theta) & dBi \quad for \quad 8.68^\circ \leq \Psi \leq 54.81^\circ \\ -42.3 & dBi \quad for \quad 54.81^\circ \leq \Psi \leq 90^\circ \end{cases} \quad (4.10)$$

Figure 4.7 shows two figures of the antenna patterns:

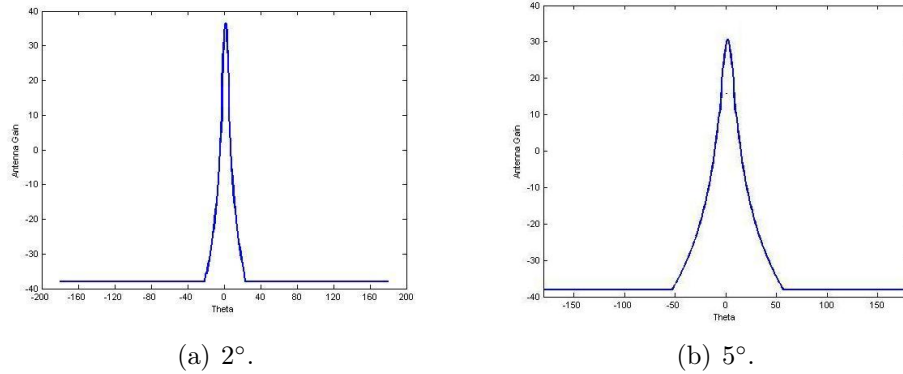


Figure 4.7: Antenna pattern for 2° and 5° antenna beamwidth.

The effect of the antenna beamwidth is directly related to the cell size. Figure 4.8 shows the link losses for a HAP with an altitude of 22 km. It is easy to note the different cell sizes between 2 and 5 degrees antenna beamwidth.

### Traffic Scenarios

The aim of this is to see how the network performance changes as a function of the number of users. This load variation will be used to study the network performance between the maximum coverage area cases for both frequencies. To be more precise,

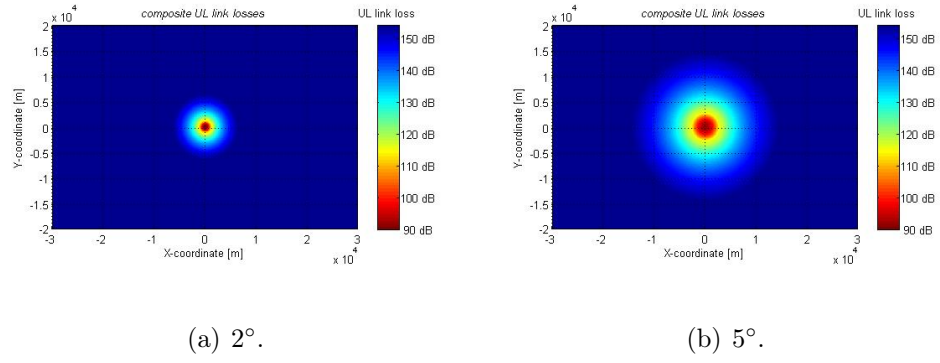


Figure 4.8: Path losses for 2° and 5° beamwidth antenna pattern.

in advanced simulations. In the rest of the simulation scenarios the number of users will keep very low in order not to overload the system. It will lead to appreciate the coverage performance clearly.

In order to obtain the sensible results from the simulations, the users need to be located inside the hexagon that represents the area covered by the HAP. The simulator was modified in order to locate users in the correct area, Figure 4.9.

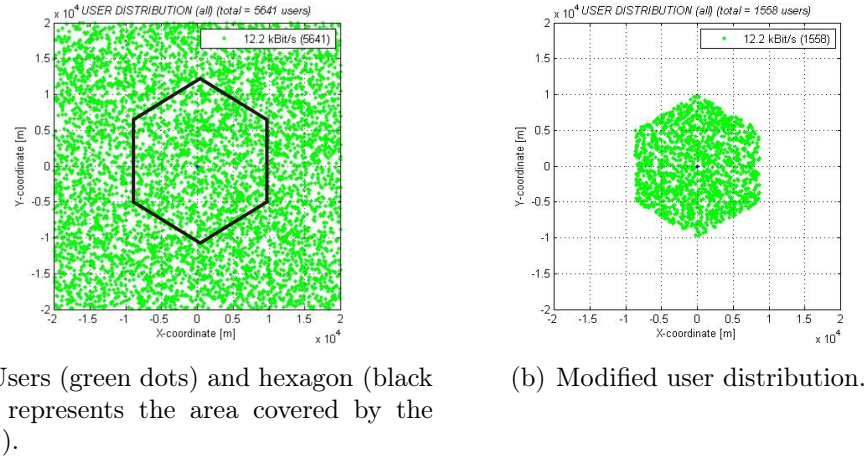


Figure 4.9: One tier and 3 tiers scenario modification.

It is needed to be mentioned that in order to estimate the hexagonal coverage area a 2km more from the last tier is always considered in the simulations. Note that the hexagon where the users are located, has to be modified for each different distance between cells. In the case of one isolate cell the same reasoning was used but with different modification, see Figure 4.10.

Figure 4.10 is from the one isolate cell scenario and the coverage area draw a circle. Because of that the simulator was modified to allocate the users only in the shape where the HAP is providing coverage.

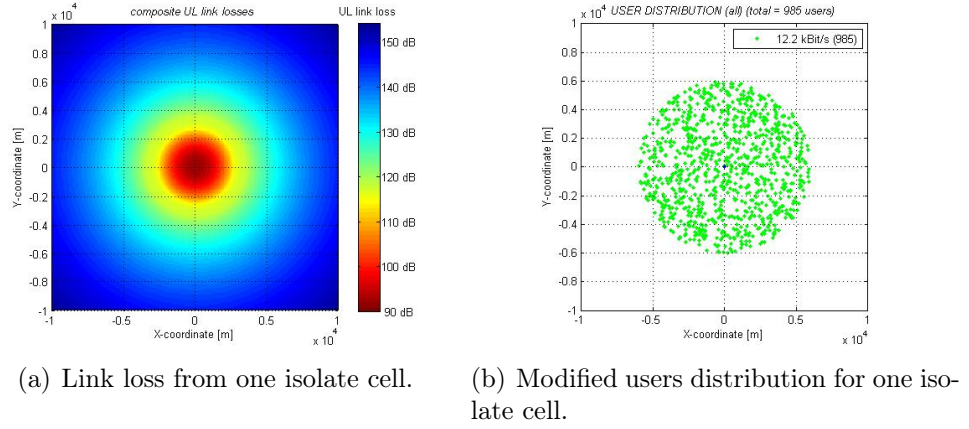


Figure 4.10: One cell scenario modification.

### Cell Layouts

The cells are arranged composing tiers around a single cell located in the center of the structure. For the simulations, three different scenarios for tiers are used. Also a several separation between cells will be used in order to find the optimum distance for each scenario and both frequencies.

The reference cell is always located under the HAP and in the center of the area under study. Figure 4.11 depicts the case of one tier structure and  $d$  represents the distance between cells and tiers. The three different cell scenarios or layouts that are going to be used are depicted in Figure 4.12. It shows the path losses for all the scenarios to be simulated, giving an idea of the configurations used.

### Frequency

The aim is to show the improvements in the UMTS behavior with the frequency change from 2100 MHz to 900 MHz. Figure 4.13 depicts the scenarios for basic simulations (1 isolate cell and one tier scenario) using 2100 MHz and 900 MHz, that we will use as a base to advance simulations (3 tier scenario). Figure 4.13 is showing the path losses for basic scenarios and for both frequencies using a  $2^\circ$  antenna beamwidth.

#### 4.2.3 Simulation Structure

After the variables under study are well-defined, it is time to build the simulation structure, which consists of the correct combination of these variables and the structure of the group of simulations to be done. The simulations are divided in basic and advanced simulations. Table 4.5 shows the simulation structure, depicting the combination of variables under study selected for each scenario.

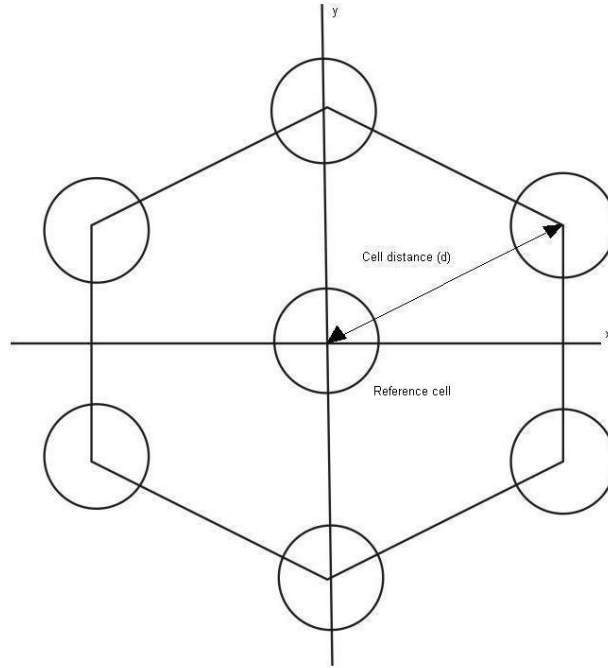


Figure 4.11: One tier structure.

### Basic Simulations

Basic simulations will use two different cell layouts, one isolate cell and one tier scenario. For each cell deployment two different antenna patterns will be simulated (  $2^\circ$  and  $5^\circ$  antenna beamwidth). Each one of these cases also will be simulated with 900 MHz and 2100 MHz. As a result, we have eight different cases of study. In order to study all these cases, the distance between cells is varied using low number of users in the system to be able to get the maximum coverage area for each case.

### Advanced Simulations

Advanced simulations are based on the results of basics simulations. Advanced simulations will use an antenna pattern of  $2^\circ$  for 2100 MHz and 900 MHz frequencies. Advanced simulations are divided in coverage and capacity simulations. In coverage simulations, as in basic simulations, several distance between cells are used in order to find the maximum area coverage for each frequency. In capacity simulations, the maximum coverage case for each frequency are simulated using different number of users. Each simulation consists of the adequate number rounds for Montecarlo simulations, and the final results are the average of these rounds.

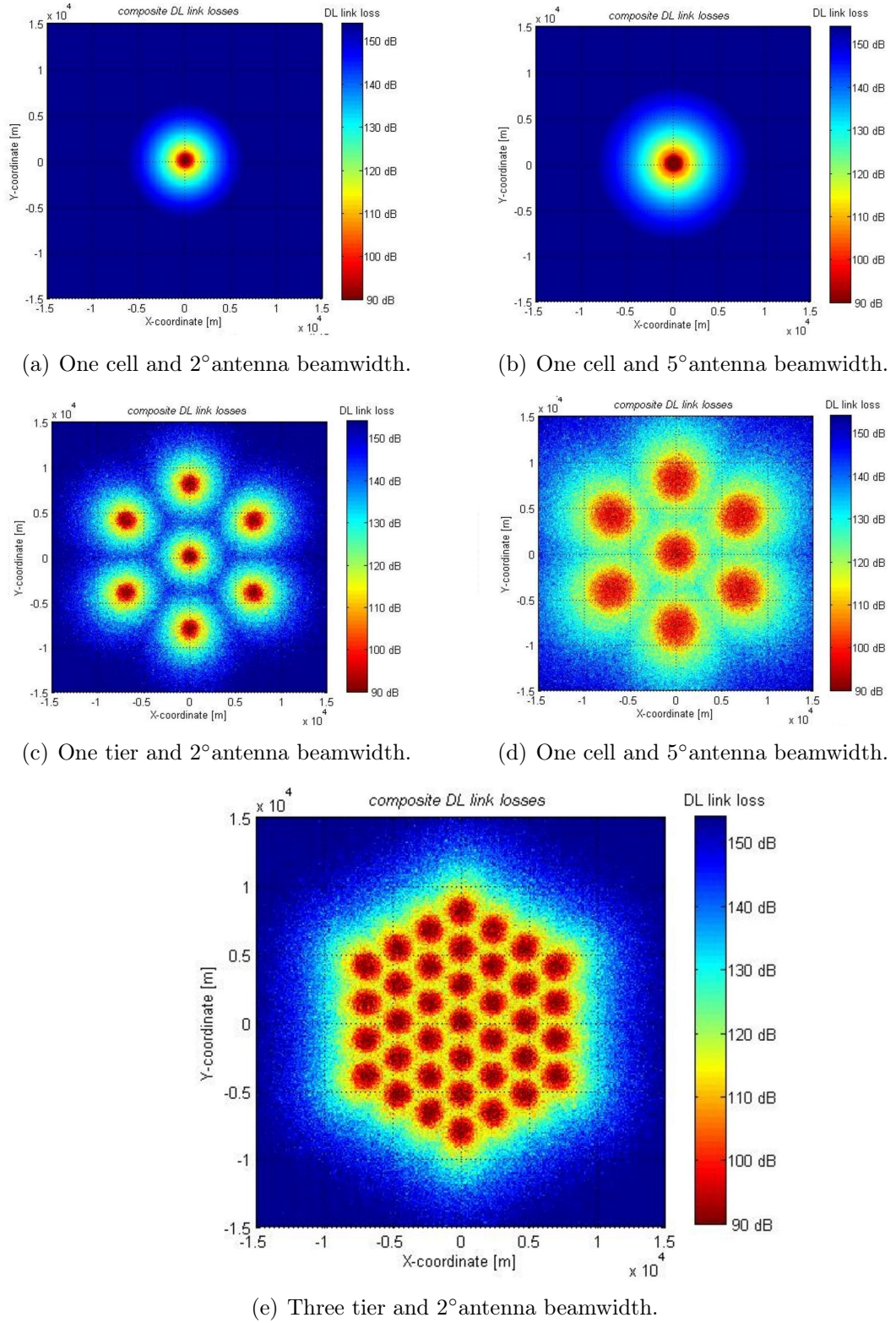


Figure 4.12: Impact of different carrier frequency on path loss in basic simulations.

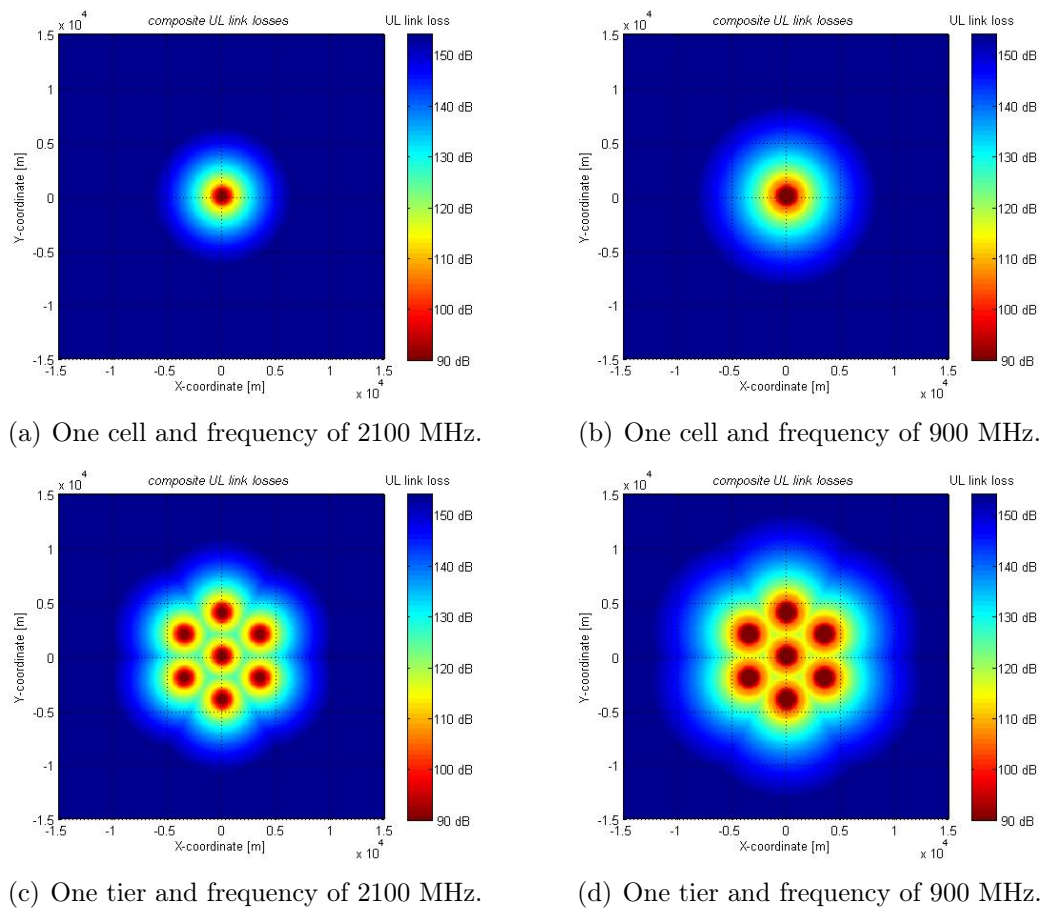


Figure 4.13: Simulation scenarios for basic simulations.

BASIC SIMULATIONS		
Scenario	Parameter	Value
<b>1 cell</b>	Number of cells	1
	Number of users	100
	Traffic area size	Variable
	Antenna beamwidth	2° and 5°
	Frequency [MHz]	900 and 2100
<b>1 tier</b>	Number of cells	7
	Number of users	500
	Traffic area size	Variable, follows network border
	Antenna beamwidth	2° and 5°
	Frequency [MHz]	900 and 2100
ADVANCED SIMULATIONS		
Scenario	Parameter	Value
<b>3 tiers</b>	Number of cells	37
<b>Coverage</b>	Number of users	3000
	Traffic area size	Variable, follows network border
	Antenna beamwidth	2°
	Frequency [MHz]	900 and 2100
<b>3 tiers</b>	Number of cells	37
<b>Capacity</b>	Number of users	Variable (2000...8000)
	Traffic area size	Fixed for each frequency
	Antenna beamwidth	2°
	Frequency [MHz]	900 and 2100

Table 4.5: Simulations structure.

### 4.3 Error Analysis

It is clear that a simulator environment always introduces some errors to the simulations results due to the limitations of the simulator. One of them is the impact that the terrain has in the radio propagation channel measurement (such as cities or rural areas). The simulator does not support propagation calculation based on a digital map. It means that the simulator can not take into account the multipath due to buildings or other obstacles that the signal can find on the path to the receiver. Because of that, the simulations have done using a flat earth model.

Other errors come from the ideality of certain parameters assumed when configuring the simulator scenarios. One of errors comes from the ITU model considered for the antenna (Chapter 4) which considers a SLL (Side Lobe Level) of -73 dB when now real antennas can only reach values of SLL between -30 dB and -40 dB.

## 5. RESULTS

In this chapter all results obtained from the simulations will be shown. As it was mentioned in Chapter 4, simulations are divided in basic simulations and advanced simulations.

### 5.1 Basic simulations

In this section, results from basic configurations will be shown. The results will be divided in one isolate cell and one tier scenario. The results will be shown for each frequency and antenna pattern. Finally, the results will be shown altogether in order to compare the performance.

#### 5.1.1 One Cell

The simulations of one cell were included in order to base the simulations with more cells and hexagonal shape. The one cell scenario is made up of one isolate cell directly under the HAP. The number of users used in these simulations had to be low enough in order to not overload the system. In this way, the system only will drop users because coverage reasons and not because capacity problems. Figures 5.1 and 5.2 show the service probability for each antenna pattern, for different distances between cells.

According to Figure 5.1 for 2° antenna pattern, the best performance in terms of service probability is with a frequency of 900 MHz. The same behavior for 5° beamwidth antenna pattern is perceived, Figure 5.2.

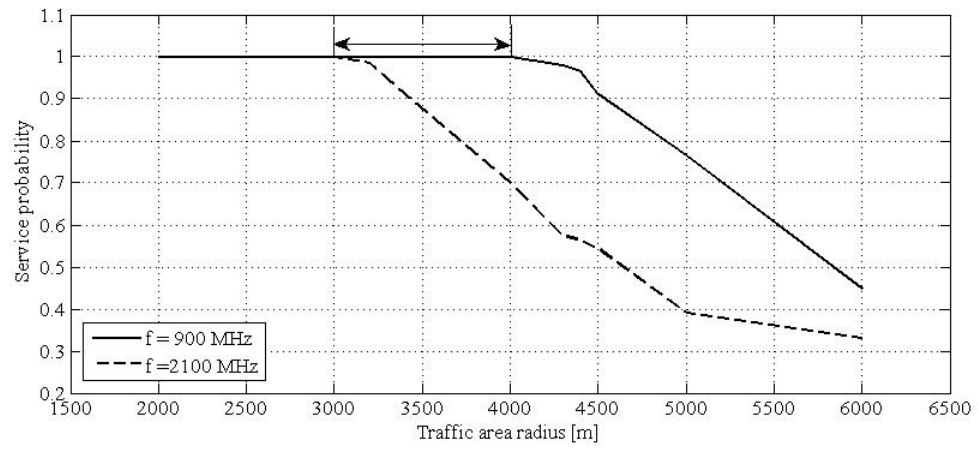


Figure 5.1: Service probability for 2° beamwidth antenna pattern.

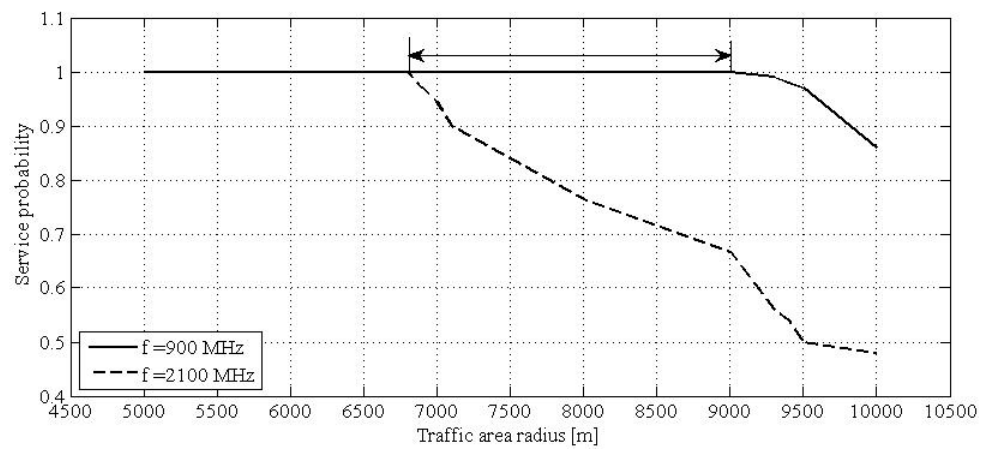


Figure 5.2: Service probability for 5° beamwidth antenna pattern.

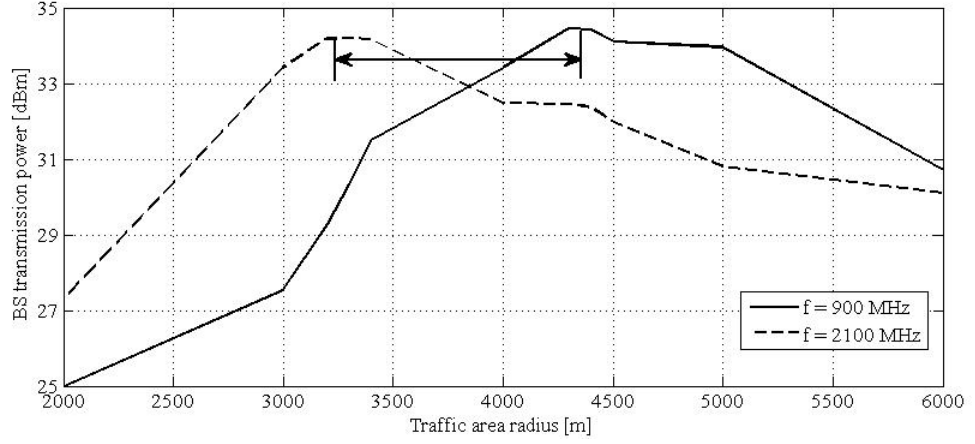


Figure 5.3: Base Station transmission power for 2° beamwidth antenna pattern.

For 2° and 5° beamwidth some similarities are easy to see. In the 2° graph, Figure 5.1, the explanation to the behavior, where the service probability starts to decrease, is that the overall coverage is not enough to cover all the area in which users are located. Because of this there is a concrete radius value, for both frequencies, in which the cell reaches maximum values of path losses (around 130-150 dB) and consequently poor signal levels are reached. The configuration with 900 MHz gives better behavior than 2100 MHz because the system can cover bigger areas. Thus, the coverage area increases. The same behavior is shown in Figure 5.2 but the critical distance has shifted. This is because the overall coverage given by 5° antenna beamwidth is bigger than in 2° antenna.

Figures 5.3 and 5.4, show the total average BS transmission power. The behavior is logical taking into account the service probability graphs shown in Figure 5.1 and 5.2. In each graph, the peak of power is reached almost at the same value of user radius where the average service probability starts to decrease. A possible explanation is that the users start to be dropped because they are located outside the coverage area of the cell and lower BS transmission power is needed to serve the remaining users. For 900 MHz case, clearly lower power values are needed in order to cover equal areas than for 2100 MHz and with the same service probability. The behavior of BS Tx power in different antenna beamwidth is the same but the critical distance is shifted where the Figures 5.3 and 5.4 start to decrease. It is also needed to be mentioned that in both cases (Figures 5.3 and 5.4) the total Tx power remains below maximum (see Table 4.1) 37 dBm which is the value for downlink coverage limited. The average of the uplink load value for all simulated cases is around 0.70, almost in the limit for UL load (see Table 4.1). Because of that we can confirm that the system is not capacity limited.

From Figures 5.1 and 5.2 we can note that the antenna beamwidth has bigger

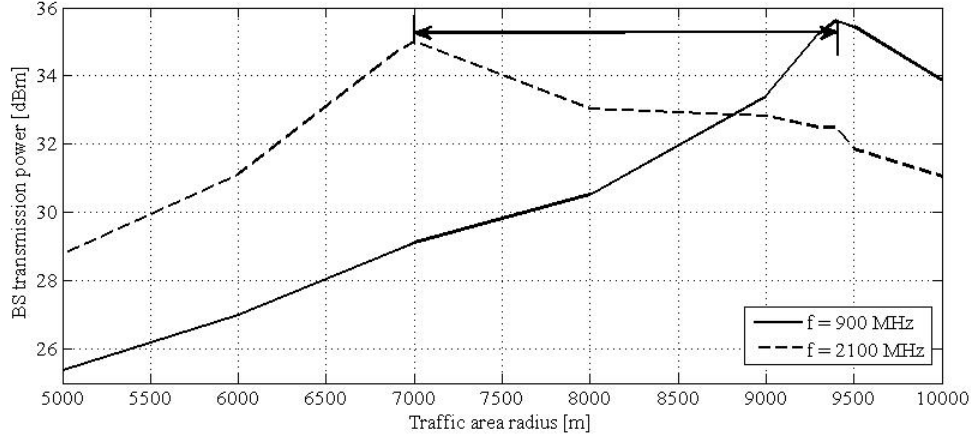


Figure 5.4: Base Station transmission power for 5° beamwidth antenna pattern.

impact on the coverage area than the frequency, because clearly larger values of traffic area radius can be reached with bigger antenna beamwidth. However, frequency also has impact on the coverage area. Thus, the results confirm the theoretical explanation told in the introduction of the Chapter 4 that decreasing the frequency the coverage area increase.

The most remarkable values from these simulations are that changing the frequency from 2100 MHz to 900 MHz the coverage area of one isolate cell increase 77.8 % for 2° antenna beamwidth and 80.4 % for 5°. For 900 MHz the maximum radius area for 2° antenna beamwidth is 4000 m and for 2100 MHz is 3000 m. For 5° antenna beamwidth is 6700 m and 9000 m of users radius area. The impact of the beamwidth is that the area coverage increase to almost 500 % changing from 2° to 5° antenna beamwidth.

### 5.1.2 One Tier

As it was mentioned in Chapter 4, the one tier scenario is made up of 7 cells. One just under the HAP and 6 around this one, drawing a hexagonal shape. The number of users used in these simulations had to be, as in the one cell scenario, enough low in order not to overload the system. Because of that the system only will drop users for coverage reasons. After a few trials changing the number of users in the system, load with 500 users the system is selected. The main differences between this and the one cell scenario is the fact that with seven cells another parameters have to be taken into account. For example the UL interference due to other surrounding cells. Firstly, the average service probability is analyzed and then other UMTS parameters will be studied.

Figures 5.5 and 5.6 show the service probability for each antenna beamwidth as a function of distance between cells. For 2° antenna beamwidth, the best performance

is with a frequency of 900 MHz, as in  $5^\circ$  antenna beamwidth, which is the same improvement as in one cell case. The service probability starts to decrease because there are users that can not be served because, they are outside of the coverage area (too high values of path losses, around 130-150 dB) in which starts to appear coverage holes between cells. As it was mentioned in Chapter 4, now the traffic area follows the network border. Like in one isolate cell scenario, the configuration with frequency of 900 MHz gives better performance than with 2100 MHz frequency because system provides better coverage.

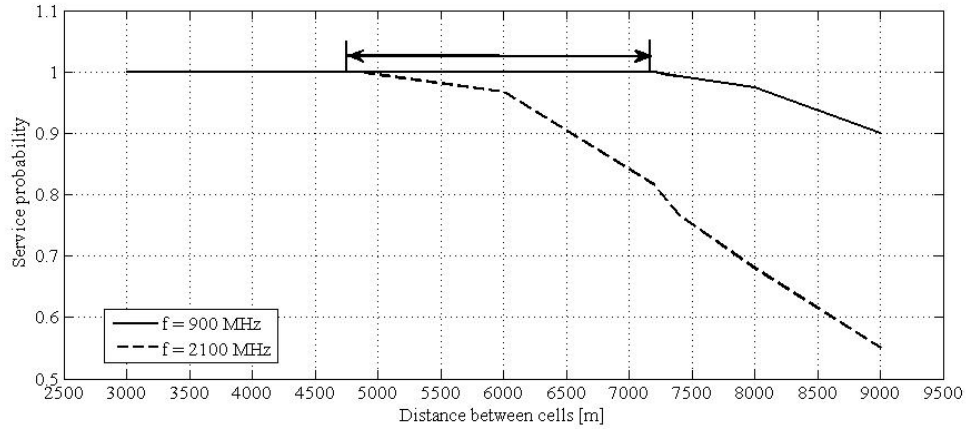


Figure 5.5: Service probability for  $2^\circ$  beamwidth antenna pattern.

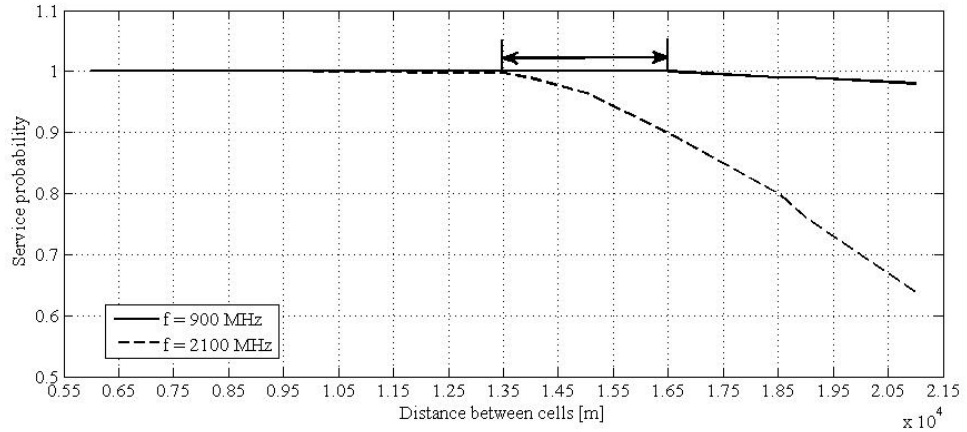


Figure 5.6: Service probability for  $5^\circ$  beamwidth antenna pattern.

Figures 5.7 and 5.8 show the average of the BS transmission power. Firstly, it has to be mentioned that the BS transmission power stays below the maximum level (37 dBm, see Table 4.1) and the UL load (around 0.70 in average for the simulations) is also below the maximum level (0.75, see Table 4.1). Because of that, we can confirm that the system is not capacity limited as in the one cell case.

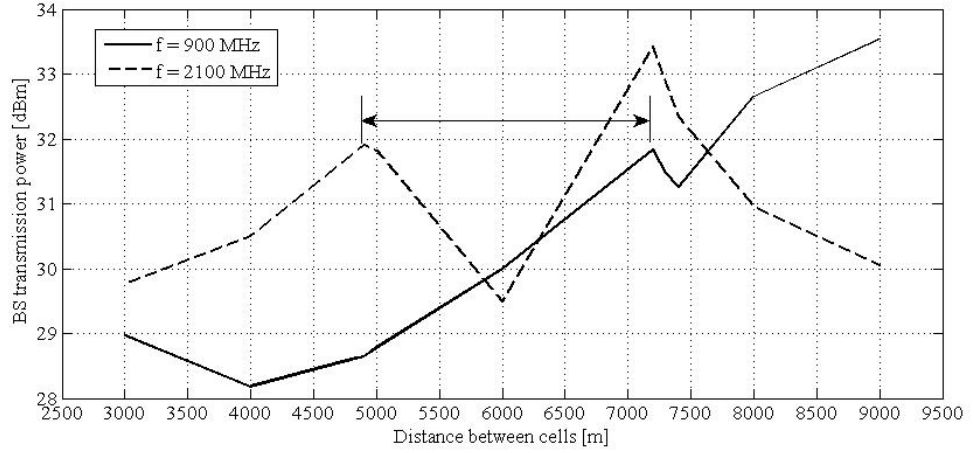


Figure 5.7: Base station transmission power for 2° beamwidth antenna pattern.

The behavior of the Figure 5.7 is logical keeping in mind the graph of service probability shown before in Figure 5.5. In Figure 5.7, there are two peaks visible. The first one can be explained studying at the same time the graph of the service probability, Figure 5.5. Firstly, the power is increasing for values of cell distance between 3000 m and 4800 m because the path loss is increasing due to the cells are becoming further away from the HAP. Thus, the system achieves an optimum point for a cell distance of 4800 m because is reaching the value where the system starts to drop users (the service probability starts to decrease, see Figure 5.5) and the BS Tx power reach a maximum (see Figure 5.7). For a distance between cells more than 4800 m (in Figure 5.7) the BS Tx power decreases because holes of coverage starts to appear between the central cell and the tier, so less users are served.

A possible explanation for the second peak (Figure 5.7) can be as following: power is increased for values of cell distance between 6000 m and 7000 m because the distance from the HAP to the tier starts to have more impact than the holes of coverage between the cell and the tier. It means that the power still can increase (because below the maximum of 37 dBm) in order to serve users that are located in the first tier. With a cell distance larger than 7200 m (Figure 5.7) the holes of coverage start to appear between the cells of the tiers, and because of that the BS Tx power decreases. The explanation of the second peak is based on the results got from the simulations but a deeper analysis of this phenomenon would be required in order to confirm it, going away from the main target of the thesis.

The Figure 5.8 has the same behavior than in the first power peak of Figure 5.7 with a frequency of 2100 MHz. Due to hardware limitations was not possible to simulate for larger values of the distance between cells in the case of 5° antenna beamwidth.

In one tier scenario, the most important values when changing the frequency

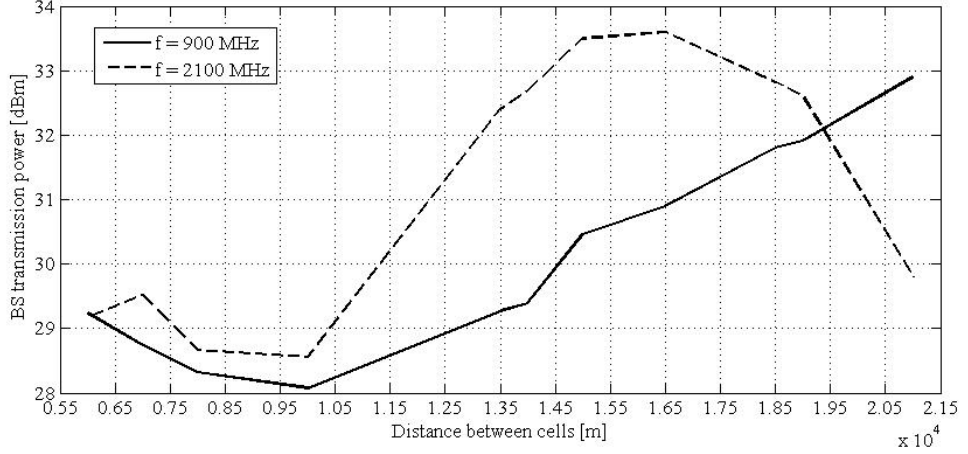


Figure 5.8: Base station transmission power for 5° beamwidth antenna pattern.

from 2100 MHz to 900 MHz are that the coverage area increase 83 % for 2° antenna beamwidth and 80 % for 5° antenna beamwidth. For 900 MHz the maximum distance between cells for 2° beamwidth is 7200 m and for 2100 MHz is 4800 m. For 5° antenna beamwidth, 12500 m and 17500 m. The impact of the beamwidth is that the coverage area increase to 450 % changing from 2° to 5° for 900 MHz and 454 % for 2100 MHz.

Making the average of the most remarkable values between one cell and one tier coverage, we can say that the frequency change from 2100 MHz to 900 MHz increases the coverage area 80.3 %. The antenna beamwidth increases the coverage area by 475 % in average changing from 2° to 5° antenna.

## 5.2 Advanced Simulations

In this section the results from an advanced scenario will be shown, dividing the results between coverage and capacity simulations. For both frequencies, 900 MHz and 2100 MHz, results will be shown. Several number of simulations have been done, including from very low to high distance between cells. Because of that, additional results can be analyzed, for example the overlapping between cells.

The scenario for advanced simulations is made up of 37 cells shaping 3 tiers around one central cell (see 4.13). In Figure 3.15 the cell layout is depicted. The number of cells in this simulation is considered as the top that it can be implemented in a HAP.

### 5.2.1 Coverage

Coverage simulations will show how the frequency change, reducing from 2100 MHz to 900 MHz, is improving the coverage area. The number of users was fixed in order to do not overload the the system. The number of users in the coverage simulations

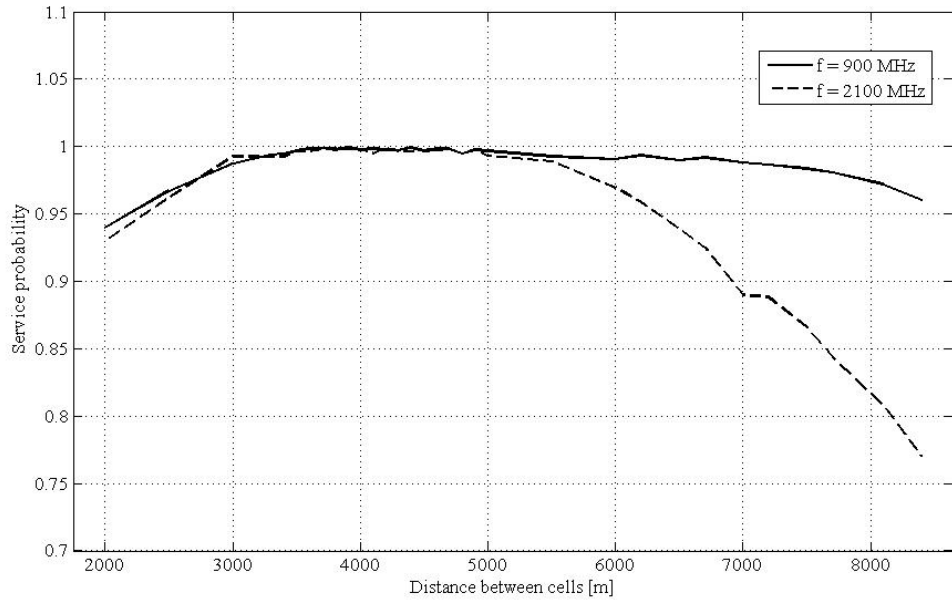


Figure 5.9: Service probability.

is 3000 users. In this way, we can easily note when the system starts to drop users mainly because of coverage reasons. The coverage reasons are considered for the non-served users due to the base station link reaches the power limit or when the mobile station reaches its maximum power. As usual, the service probability is analyzed and then other parameters will be shown in order to confirm the results.

Figure 5.9 depicts the average service probability as function of the distance between cells. Firstly, we can see that considering a cell distance between 2000 m to 3200 m, the service probability increases to almost one. The explanation of this result is based on the overlapping between cells. The overlapping is because the tiers are too close to each other and the cell footprints are overlapped. In this situation the interference level from the other cell, presented in Figure 5.15, in the uplink increases and users starts to be dropped. The service probability increase because the distance between cells is increasing and because of that the tiers are moving away one each other. After that, the service probability keeps around one until 6000 m, when the values f 2100 MHz starts to decrease. This is because the users starts to be located outside the coverage area, starting to appear holes of coverage between the tiers. Figures 5.10, 5.11, 5.12 and 5.13 depict the number of non-served users but divided by the reason they are dropped.

Analyzing the figures from non-served users divided by the reason they are dropped we can see that in figures 5.10 and 5.11 (coverage reasons) the number of dropped users starts to increase before in 2100 MHz than in 900 MHz in both graphs. These results confirm the behavior explained in the Figure 5.9 of the aver-

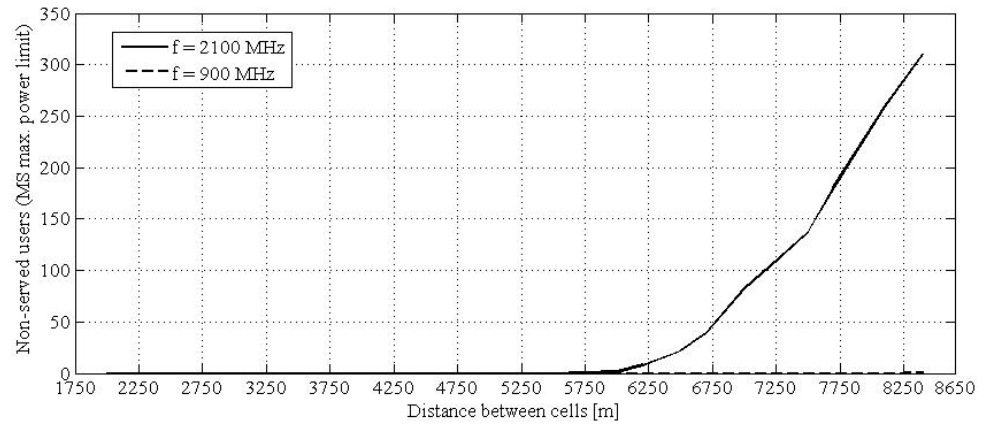


Figure 5.10: Non-served users because MS maximum power limit.

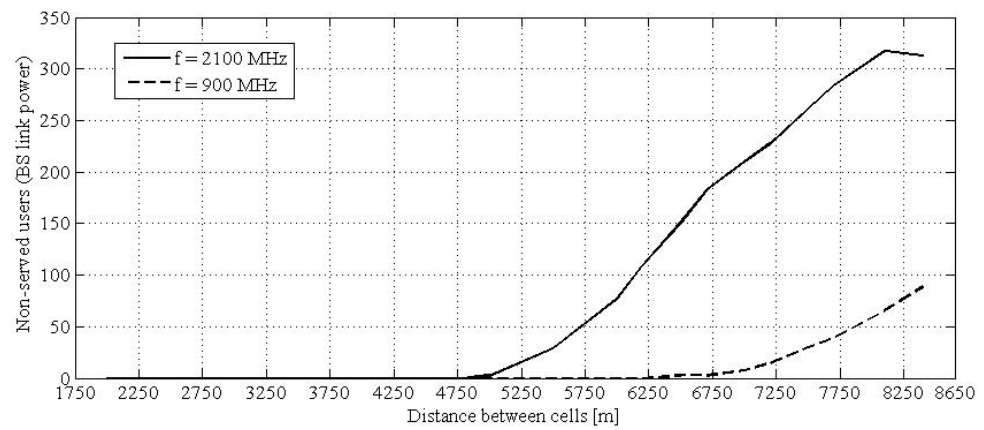


Figure 5.11: Non-served users because BS link power limit.

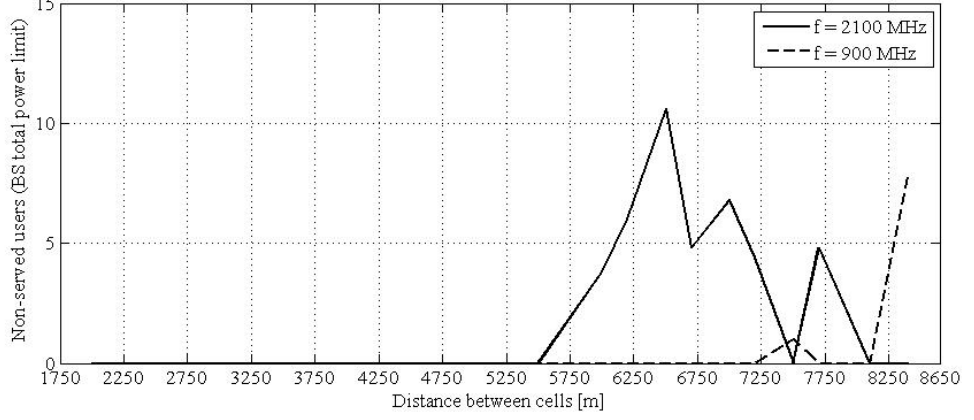


Figure 5.12: Non-served users because BS total power limit.

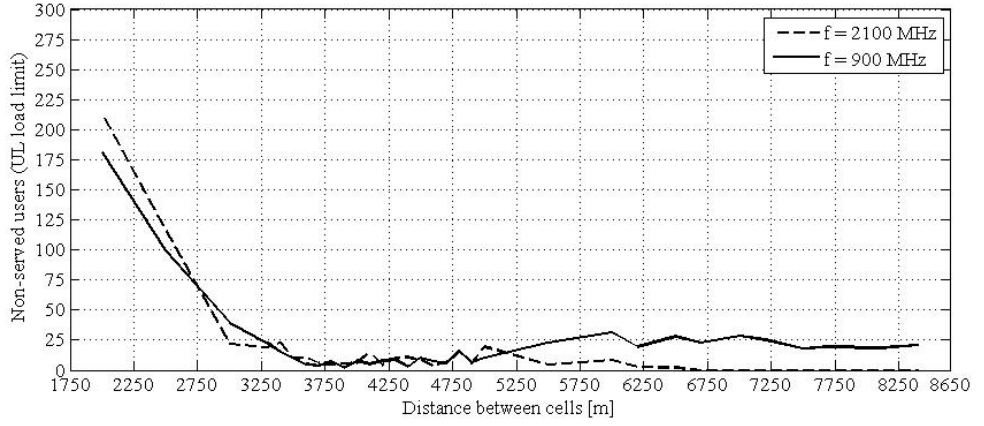


Figure 5.13: Non-served users because uplink load limit.

age service probability. The coverage reasons are two. The non-served users because the first coverage reason are depicted in Figure 5.10 and represents the number of non-served users because the MS reaches the maximum transmission power (see Table 4.2). The non-served users because the second coverage reason are depicted in the Figure 5.11, where the users are dropped because the BS reaches maximum transmission power per link (see Table 4.1).

In Figures 5.12 and 5.13 are depicted the non-served users due to capacity reasons. Capacity reasons are two. The non-served users because the first capacity reason are depicted in the Figure 5.12 and represents the number of non-served users because the BS reaches the total maximum transmission power(see Table 4.1). The non-served users because the second capacity reason are depicted in Figure 5.13 and represents the users dropped because the BS uplink load limit (see Table 4.1). Note that the number of non-served users in 5.12 is very low and is not relevant in the overall number of non-served users because it is not possible to describe any clear tendency. In Figure 5.13 the behavior is changing as a function of the distance

between cells. From 2000 m to 3750 m the values decrease because of the overlapping. In the same way as in Figure 5.9, the cells are moving away and the overlapping between cell footprints is getting lower. After, the values depicted for larger distances between cells keep almost at the same level. Because of that, we can confirm that the behavior for low values of distance between cells (depicted in Figure 5.9) is due to capacity reasons and not for coverage reasons.

Figure 5.14 shows the uplink interference level due to the traffic in the own cell. It tells, how the traffic from the own cell is affecting to a single base station. We can see that for 900 MHz is keeping almost in the same level as a function of the distance between cells. For 2100 MHz, the behavior is affected by the separation between tier. The interference level decreases for larger values of distance between cells due to the number of served users is decreasing.

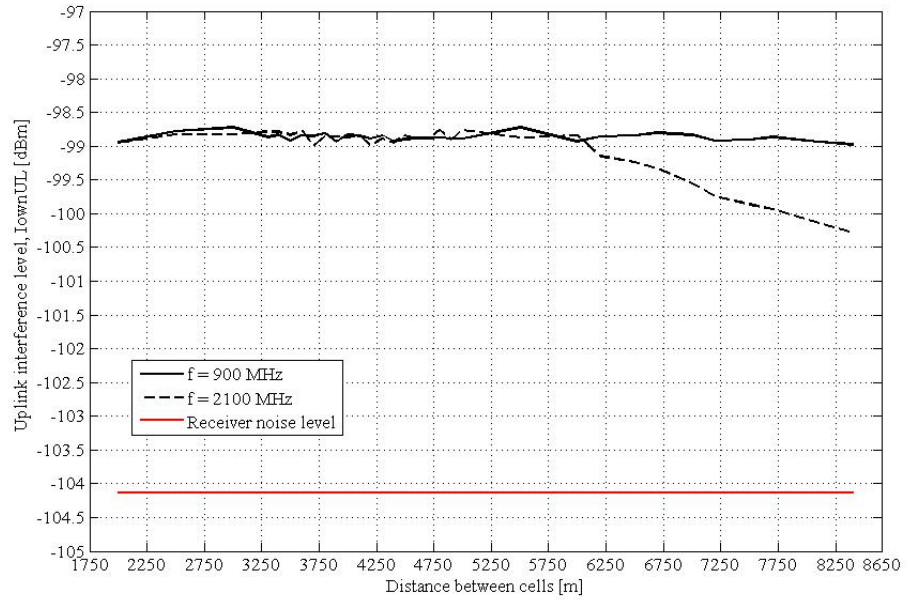


Figure 5.14: Receive Uplink interference level,  $I_{own\ UL}$  [dBm].

In Figure 5.15, the uplink interference level corresponding total other cell interference power. For both frequencies, the graph has a small peak at low cell distances. First, the  $I_{oth}$  increases for values of distance between cells from 2000 to 2500 because the cells are becoming separated. For farther distances than 2500 m the  $I_{oth}$  starts to decrease because the MS considered before as interference from the other cell, are now considered as a interference from the own cell by the simulator. Finally, the value depicted in Figure 5.15 starts to decrease from 6000 m of separation between cells for 2100 MHz. This is a normal behavior in 2100 MHz because the cell footprints are becoming separated and for 900 MHz the behavior is the same but the values are shifted to higher values of distance between cells. It is needed to

be mentioned that in the Figures 5.14 and 5.15 the receiver noise is included in the result and also depicted in the figures (see equation 3.9). We can see that the system is not capacity limited because the level of  $I_{oth}$  and  $I_{own}$  in the uplink (Figures 5.14 and 5.15) do not reach the value of the receiver noise .

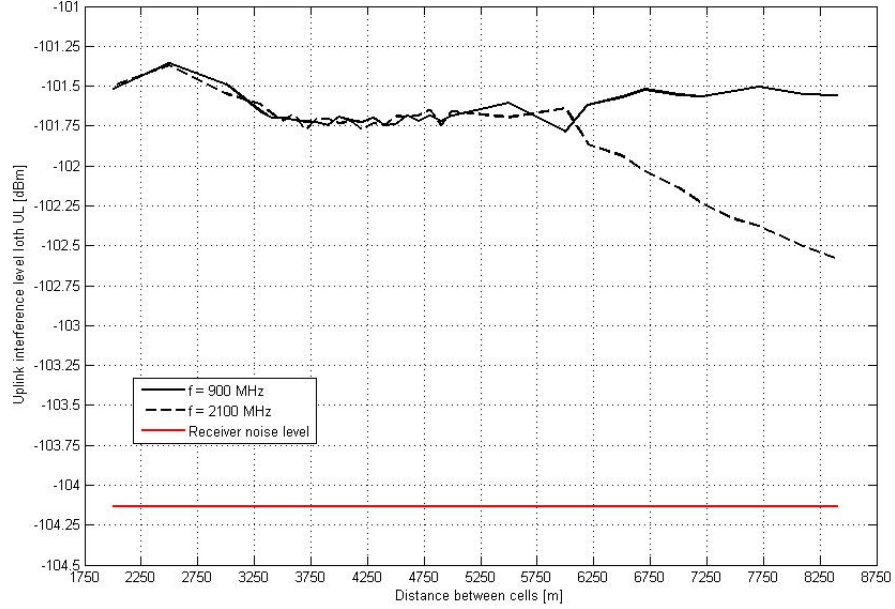


Figure 5.15: Receive Uplink interference level,  $I_{oth}$  UL [dBm].

Figure 5.16 depicts the average cell throughput. This value is the sum of the data rates that are delivered to all the terminals served by one cell. In Figure 5.16 we can see that in the beginning (left side) the throughput increases because the overlapping is decreasing and more users can be served for each cell. In the range 3000 m and 6000 m, throughput remains between 1000 kbps and 975 kbps. Finally for 2100 MHz, the throughput starts to decrease in approximately 6000 m of cell distances. For 900 MHz it also starts to decrease but more slowly. It is easy to see that for a distance between cells of 8500 m the difference between both frequencies is around 175 kbps.

The most significant values from the frequency change from 2100 MHz to 900 MHz are listed following. The average service probability (Figure 5.9) keeps over 95 % for all the different distance between cells. On the other hand for 2100 MHz, the average is under 95 % from 6200 m of distance between cells. Throughput (Figure 5.16) decreases 23.6% from  $d = 5000$  m to  $d = 8400$  m and 1.7 % for 900 MHz. Finally, the coverage area increase in almost 2000 m of radius for 900 MHz. Exactly, the area increases to 75.3 %, keeping the same average service probability.

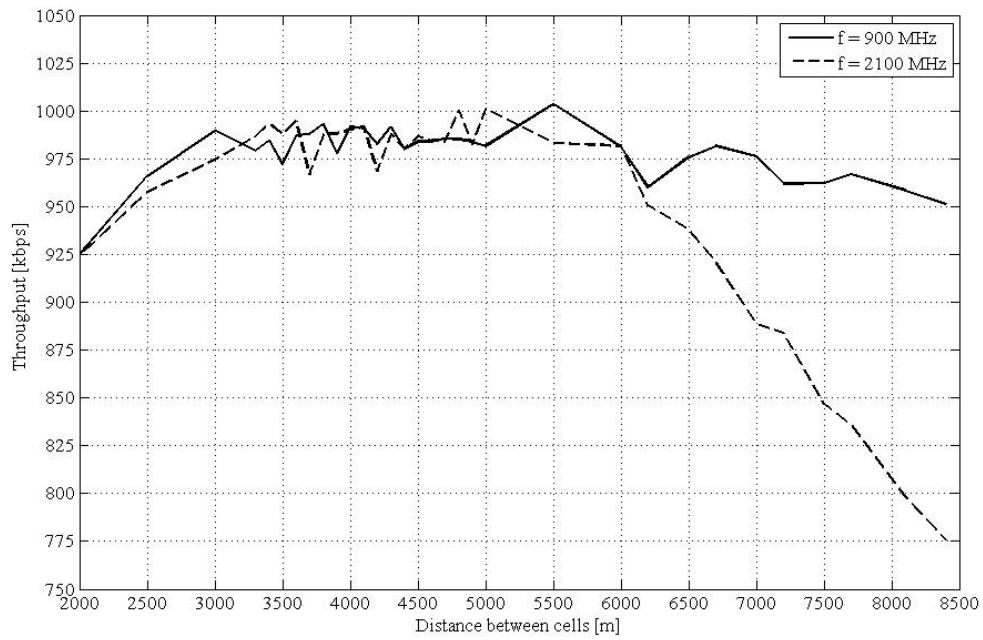


Figure 5.16: Average cell throughput.

### 5.2.2 Capacity

In capacity simulations we will see how the advanced scenario is behaving for both frequencies and larger numbers of users. For each frequency, the case of maximum area of coverage is considered. Exactly, the greatest distance between cells corresponding to a service probability of 95 % was chosen.

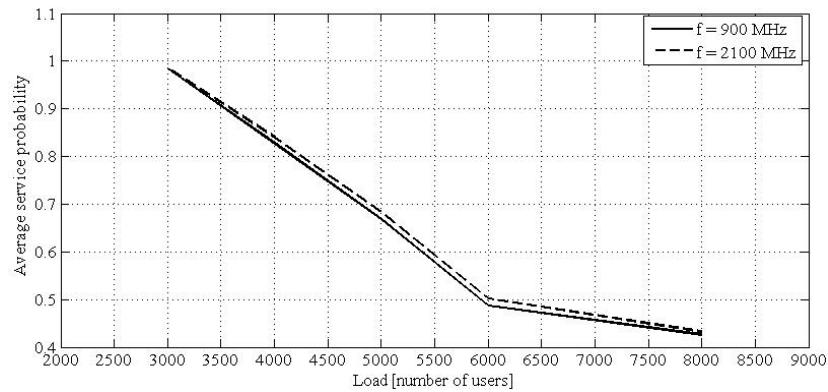


Figure 5.17: Average service probability.

Figures 5.17 and 5.18 depict the service probability and the average cell throughput as a function of different numbers of users in the system. The Figure 5.17 shows that for both frequencies the same performance is achieved. The behavior of the service probability is logical because the system is getting load in excess and the

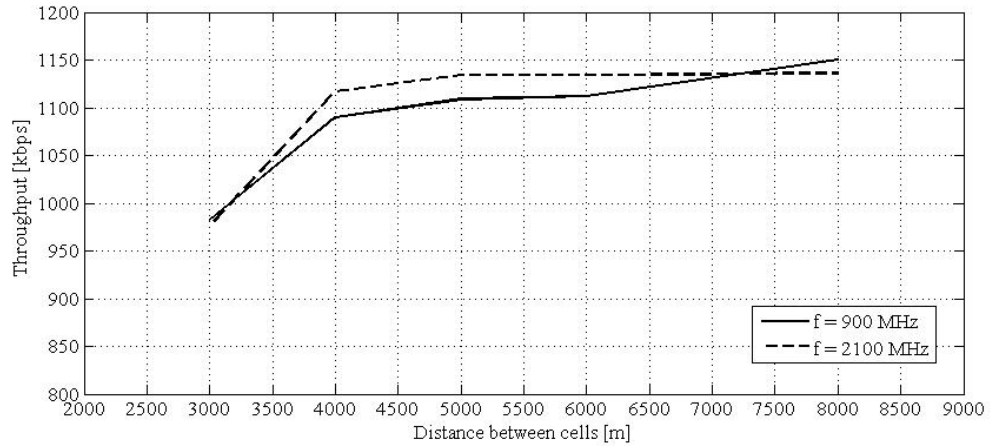


Figure 5.18: Average cell throughput.

system is not able to serve more users (Figure 5.17) and starts to drop. In Figure 5.18 is depicted the average cell throughput. We can see that the throughput level increases as a function of the number of users in the system. The average cell throughput increases because the number of users that each cell is serving also increases. It has to be taken into account that serving one user more represents an increase of 12,2 kbps in the total throughput of the system. Because of that, this behavior is not perceptible in Figure 5.17 of the service probability where the users are increasing in steps of 1000 users and the number of dropped users is increasing clearly more than the served users.

As in Figure 5.17, Figure 5.18 is also not depending on the frequency. Because of that we can be confirmed that the case of 900 MHz, which has a distance between cells of 8100 m, has the same behavior than the case of 2100 MHz with a distance between cells of 6100 m. These values are from the optimum cases from advanced simulations for both frequencies. The optimum cases are the maximum cell distance for a service probability of one (see Figure 5.9).

Table 5.1 shows the most significant values from the simulations. It shows the results from basic and advanced simulations and the average between both simulations.

One cell scenario				
Case	Change		Improvements	
	From	To	$\Delta$ Radius [m]	$\Delta$ Area [%]
2°antenna beamwidth	2100 MHz	900 MHz	1000	78
5°antenna beamwidth	2100 MHz	900 MHz	2300	80
900 MHz	2°ant. BW	5°ant. BW	5000	500
2100 MHz	2°ant. BW	5°ant. BW	3700	498
One tier scenario				
Case	Change		Improvements	
	From	To	$\Delta$ Radius [m]	$\Delta$ Area [%]
2°antenna beamwidth	2100 MHz	900 MHz	2400	83
5°antenna beamwidth	2100 MHz	900 MHz	5000	80
900 MHz	2°ant. BW	5°ant. BW	10300	450
2100 MHz	2°ant. BW	5°ant. BW	7700	454
3 tier scenario				
Case	Change		Improvements	
	From	To	$\Delta$ Radius [m]	$\Delta$ Area [%]
2°antenna beamwidth	2100 MHz	900 MHz	2000	75
Averages				
Case	Change		Improvements	
	From	To	$\Delta$ Radius [m]	$\Delta$ Area [%]
2°antenna beamwidth	2100 MHz	900 MHz	1800	78.8
5°antenna beamwidth	2100 MHz	900 MHz	3100	80
900 MHz	2°ant. BW	5°ant. BW	7650	475
2100 MHz	2°ant. BW	5°ant. BW	5700	476

Table 5.1: The most important values from the results.

## 6. CONCLUSIONS AND DISCUSSIONS

The results from the simulations confirm the improvement that it was expected with the frequency reduction from 2100 MHz to 900 MHz. Firstly, an improvement (Chapter 4) of 7 dB in the path loss with the frequency reduction was shown based on the equations of free space loss. This fact was confirmed first in one cell scenario showing that in this situation, the frequency reduction increases the maximum radius of the traffic area where the service probability keeps in one, from 3000 m to 4000 m for 2° antenna beamwidth and from 6700 m to 9000 m for 5° antenna. Because of that the traffic area due to the frequency reduction increases by 80 %. The next step was to study if the same behavior was happening in hexagonal deployments, where more factors have to be taken into account. The results of one tier scenario showed that the frequency reduction was also improving the coverage area, in this case increasing by 81.5 % in average and the distance between cells from 4800 m to 7200 m for 2° antenna beamwidth and from 12500 m to 17500 m for 5° antenna. And finally a limit case was studied in Advanced simulations.

The results of Advanced simulations showed that finally, with a more realistic UMTS scenario, the implications of the frequency change are: the average service probability increased for higher values of cell distances, giving at 900 MHz values around one while at 2100 MHz goes under 0.7 for equal values of cell distance. Because of that we can conclude that the distance between cells can be spreaded maintaining the same quality of service. Based on the capacity simulations done in Advanced simulations we can confirm that the performance of the UMTS system for 900 MHz and 2100 MHz is more or less the same, using areas more than 78 % larger in 900 MHz than in 2100 MHz.

From the antenna beamwidth study made in basic simulations, an idea of how the frequency is affecting can be made. The antenna beamwidth is maybe the most important parameter in our scenario, and based on the results has an impact of about 475% increasing the coverage area when changing the beamwidth from 2° to 5°. With both results we can conclude that the frequency change introduces a significant improvement increasing the coverage area, and in comparison with the antenna beamwidth we can confirm that the a HAP implementation using the UMTS 900 MHz based system will improve the system performance mainly from the coverage point of view.

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