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WASHINGTON UNIVERSITY IN ST. LOUIS
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A THESIS ON UTILIZING HIGH ALTITUDE PLATFORMS (HAPs) TO PROVIDE
WIRELESS COMMUNICATIONS COVERAGE TO CLOSE COVERAGE GAPS –
CASE STUDY: PROVIDING UMTS SERVICE TO THE NON-RADAR COVERAGE
AREA IN THE GULF OF MEXICO REGION (GOMEX)

by
Amad Y. El-Disi

A thesis presented to the School of Engineering and Applied Science
of Washington University in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

May 2010
Saint Louis, Missouri

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Amad Y. El-Disi

2010

ABSTRACT

A Thesis on Utilizing High Altitude Platforms (HAPs) to Provide Wireless Communication Coverage to Close Coverage Gaps – Case Study: Providing UMTS Service to the Non-Radar Coverage Area in the Gulf of Mexico Region (GOMEX)

by

Amad Y. El-Disi

Master of Science in Computer Science

Washington University in St. Louis, 2010

Research Advisor: Professor Paul Min

The increase in demand for high-capacity wireless services has posed great challenges to telecommunication service providers, especially for delivery of the 'last mile'. Terrestrial networks are limited in some regions and costly, requiring a large number of base-stations to provide good wireless communication services. Satellite based telecommunication services have many capacity and performance limitations in voice and video communication applications. High Altitude Platforms (HAPs) have gained considerable interest in the past few years due to their potential to exploit the best aspects of terrestrial and satellite-based systems, while offering advantageous propagation characteristics. This thesis proposes utilizing High Altitude Platforms (HAPs) to provide affordable, efficient and robust telecommunication coverage for remote and oceanic regions. These platforms can carry multipurpose communications payloads that allow them to function either as a cellular base station or low satellite system. When fully deployed, they are able to provide services and applications ranging

from broadband wireless access, navigation and positioning systems, remote-sensing and weather observation/monitoring systems, future generation mobile telephony, etc. The proposed system, named Gulf Of Mexico High Altitude Platforms Network (GOMEX-HAPs Net), will focus on the Gulf of Mexico because of its vital importance to the US and there is an area of approximately 240 square mile gap where there is no wireless coverage of any kind. GOMEX-HAPs Net will include a set of interconnected unmanned airships flying at high altitudes over 70,000 feet to achieve maximum footprint per HAP, minimize wind effects and ensure that it will be flying above all classes of commercial air planes (under 55,000 ft). Although this system is able to provide a variety of wireless communication service, the thesis will focus on providing 3G coverage to the coverage gap in the gulf. The thesis will begin with an introduction to wireless communication and the challenges in providing the “last mile” coverage in remote regions, followed by a comprehensive discussion about HAPs systems including their categories and advantages, and a comparison of HAPs with both terrestrial and satellite based communication networks. The proposed system architecture will be discussed and the system performance as a 3G backhaul will be explained.

Acknowledgments

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Amad Y. El-Disi

Washington University in St. Louis

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1. Introduction

The wireless communication market continues to experience phenomenal growth rates which accompany an increase in the demand for several types of services, multimedia environment applications, high capacity systems and broader urban coverage. Both scientific and business analysis indicates that this demand is expected to continue to increase due to the greater reliance of the private and public sectors on wireless technologies in enhancing and simplifying its operations and services. This demand has led to the successful and rapid deployment of terrestrial and satellite wireless networks and the development and efficient utilization of spectrum and advanced multiple access techniques. However, as both schemes are not expected to keep up with the needed capacity for future wireless applications and services, the telecommunication industry stakeholders in both commercial and defense sectors started to look into aggressive solutions to resolve this perceived challenge.

The provision of wireless services via High Altitude Platform Stations (HAPS), which operate in the stratosphere at altitudes from 17 to 22 km; provides telecommunication providers an emerging solution that can exploit the best features of both terrestrial and satellite schemes. This thesis will discuss the utilization of high altitude platforms as a backhaul for wireless communication networks.

1.1 Thesis Objective

The need for wireless communication in remote regions, the increase in human offshore operations, the demand for high-capacity wireless services and the added delivery challenges of the “last mile” wireless service created an environment where utilization of HAPS as a backbone for wireless communication is an affordable solution to provide coverage where terrestrial and satellite based backhauls might not be a feasible

solutions. This thesis explores the utilization of High Altitude Platform Stations (HAPS) for wireless communication coverage to the Gulf of Mexico (GOMEX) region.

1.2 GOMEX Overview

This thesis proposes that there is an exigency for providing enhanced communication infrastructure in the Gulf of Mexico (GOMEX) region, and the method by which to do so. The reasons for this pressing need are not only because GOMEX is the ninth largest body of water in the world, but there are at least three other compelling reasons. Firstly, it borders five coastal states in the southern United States which are witnessing a dramatic increase of 40% [17] in population growth, from 44.2 million in 1995 to 61.4 million in 2025. Second, it is integral to regional commerce; it includes two regional ports (Port of Louisiana in New Orleans and Port of Houston), both ports are considered of the ten busiest ports in the world by cargo volume.

The Gulf of Mexico is considered an important source for marine resources such as oil and gas, oysters and shells, and a medium for marine-based activities such as navigation, recreation, and commercial fishing.

1.2.1 Non-Radar Coverage Problem in GOMEX

The non-radar airspace (NRA) of the GOMEX was the inspiration for providing HAPS wireless communication coverage to this region. NRA is the likely reason for poor communication between pilots and air traffic controllers and flight delays. The dark-region in the middle shown in Figure 1.1 indicates the NRA where aircrafts fly outside of the range of air-traffic controlled radars, which can results in many air traffic control quality issues. For one, VHF radio is not available so communication is only available through HF radio. The HF radios have its own disadvantages, namely, a lower voice quality which in turn can cause miscommunication, and a delay in the control loop.

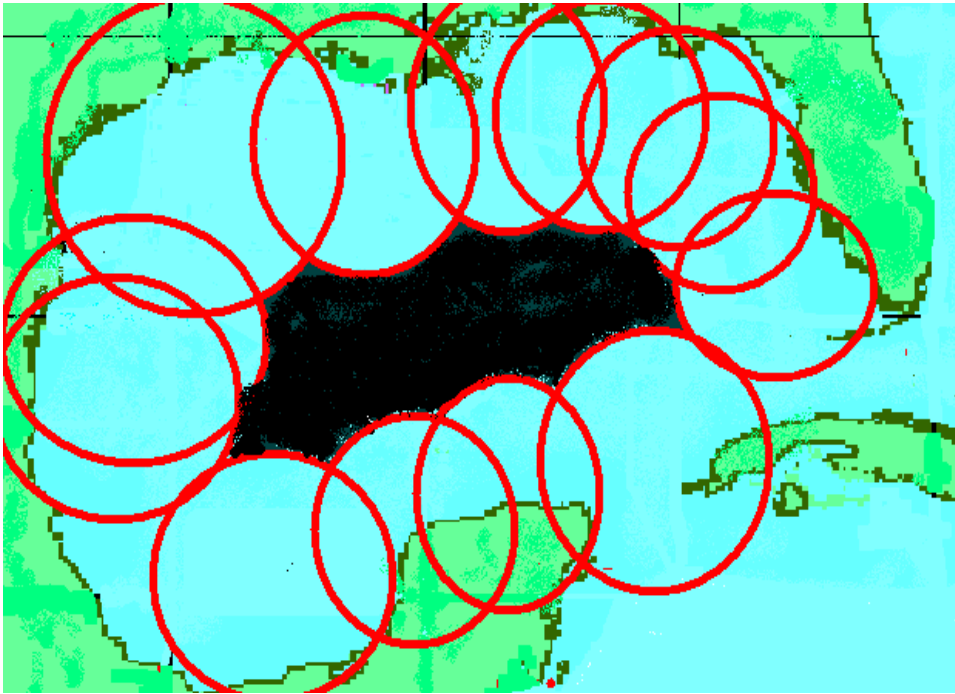


Figure 1.1 GOMEX Non-Radar Area [19]

1.3 Wireless Communication Overview

A communications system essentially consists of three basic components: a transmitter, a receiver, and a communication channel (link-medium). In any given communication system, the bi-directional conversation between points A and B can only occur if both points have the ability to communicate via a wireless channel. Figure 1.2 illustrates the main elements needed to establish a form of communication between two locations.

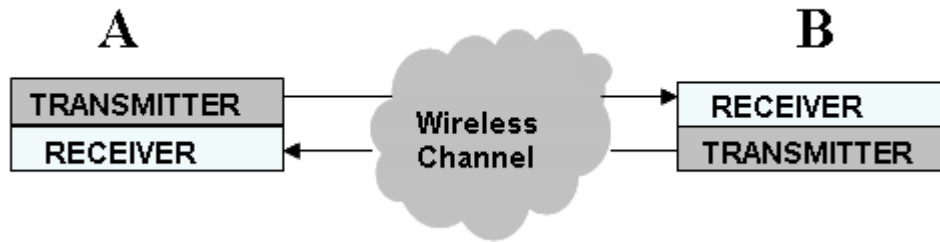


Figure 1.2 Example of Two-Point Wireless Communications Link

The main function of the transmitter is to transmit the message/signal over the communication channel. Quite often the original signal is not suitable for transmission over the communication channel to the receiver; therefore a transducer converts the original signals into a time varying electrical signal called a message signal. The transmitter assures the matching of the message signal to the wireless channel by a process called *modulation*. There are other functions that are performed by the transmitter like the filtering of the information-bearing signal, signal amplification, and signal radiation.

The communication channel is the physical medium that is used to convey information from a transmitter to a receiver. The medium could be a transmission line (telephone and telegraph) air, water or the vacuum of space. The specific mediums may contain various obstructions such as natural terrestrial features like mountainous terrain or bodies of water, manmade features such as buildings, or motor vehicles, or even space features such as planets or space debris, depending on the medium. Regardless of the deployed transmission medium, the transmitted signals usually suffer some level of degradation.

The third element of the wireless communication system is the receiver. The main responsibility of the receiver is to capture the transmitted signal and perform signal processes that are vital in order to change the signal format from a channel transmission signal into the more common form of images, sounds, or data. The sequence of

processes that take place in order to remove the modulation from the received signal to get the original baseband signal is called *demodulation*. Besides the receiver's main role of demodulation, it also performs signal filtering and noise suppression.

The communication system and the signal processing of its components introduce degradation to the transmitted signals. There are many technologies and methods that are aimed to increase the efficiency of the communication system by minimizing signal degradation and maximizing the number of transmitted signals at a rate of one time per channel.

1.3.1 Wireless Networks Categories

Networking technologies has developed rapidly due to the evolution of new generations which yield faster and more efficient services due to the implementations of wireless systems in a vast array of applications. There are many methods that could be applied to categorize wireless communication networks. These include networks that can be distinguished by usage, technology, bandwidth, frequency and range. In this section, we will define the categories of wireless networks based on geographic area coverage of the service. Figure 1.3 depicts the categories of wireless networks.

1 m	Square meter	Personal Area Network (PAN)
10 m	Room	Local Area Network (LAN)
100 m	Building	
1 Km	Campus	
10 Km	City	Metropolitan area network (MAN)
100 Km	Country	Wide area network (WAN)
1000 Km	Continent	
10,000 Km	Planet	The Internet

Figure 1.3 Categories of Wireless Networks

Wireless Personal Area Network (W-PAN)

The wireless personal area network is a computerized network of devices around an individual interconnected through a radio frequency. WPAN also could support the connectivity of its owner to a local internet service provider. Typically, a wireless personal area network with operating frequencies around 2.4 GHz in digital mode, facilitates wireless communications within about 10 meters. In ideal cases, however; it is possible to achieve a range of up to 100 meters. W-PAN's have unique characteristics such as short-range data rates of up to 55Mb/s, peer-to-peer connectivity, a small number of nodes in the network. It is also able to run at ultra low power and at a relatively low cost.

There are several new technologies developed to operate in WPAN. Bluetooth®, standardized on the basis of IEEE 802.15, is one of the most commonly used WPAN specifications for wireless communications among portable digital devices. IEEE 802.15 is the standard for a small size radio chip that can be plugged into individual's devices such as mobile phones, Blackberry solutions, computers, printers etc. Other wireless technology that fits in the WPAN category is ZigBee (802.15.4), IrDA and UWB.

Currently, the WPAN technologies are undergoing rapid development to achieve the objective of facilitating seamless automated operations with different types of functions among an individual's body, home and business devices and service provider systems. In order to accomplish this objective, every device in a WPAN should be able to interact with any other device in the same network. Further research efforts are underway to study the technical feasibility and advantages of ad hoc meshed WPAN topologies.

Wireless Local Area Network (W-LAN)

Local area network (LAN) is defined as the connectivity of two or more computers in network within a limited area. Wireless LANs (WLANs) is to utilize the connectivity between computers in a limited area without using wires and the ability to provide networking capabilities using wireless communication technologies to transfer information between devices in the area. In a typical WLAN environment, devices enable the nodes of the network to communicate wirelessly via access points within 100 meters of the devices. The continued growth of applying WLAN technologies in homes and business is due to its convenience, mobility, productivity, ease of deployment, scalability and affordability.

There are many competing technologies that provide WLAN connectivity, including Home RF, Wi-Fi, HiperLAN and Bluetooth. Standards of WLAN are identified by IEEE 802.11 which uses Ethernet protocol and Carrier Sense Multiple Accesses with Collision Avoidance (CSMA/CA) for path sharing and data encryption. Wi-Fi networks are commonly used in several consumer applications operating in frequencies ranging from 2.4-GHz to 5.8 GHz.

In WLAN technologies, the standards of qualities of service (QoS) are addressed. QoS enables the packets prioritization in order to provide different priorities to different applications, users, or to guarantee a certain level of performance to a data flow. Further

studies are in the process especially in the realm of networking security issues. The next-generation WLAN standard which is known as 802.11n is expected to support data rate applications exceeding 100 Mbps. This feature will be accomplished by applying the wideband radio frequency (RF) channels, Multiple-Input, Multiple-Output (MIMO) radio technology, and advanced and efficient networking protocols.

Wireless Metro Area Network (W-MAN)

A wireless metro area network is a network that serves a geographical area that is larger than a LAN, ranging from networks connected within several blocks of buildings to networks that cover entire cities. In some cases, WMAN could be formed due to the connectivity of several WLANs through a central network operation center (NOC). WMAN might be owned and operated by a single organization or it might be formed by integrating heterogeneous networks owned and operated by different organizations. Metropolitan area networks can span up to 50km by utilizing repeaters, modems and wire/cable.

The air interfaces for WMAN are defined by technologies standards IEEE 802.16, also known as WirelessMAN. WiMax, identified as IEEE 802.16d, operates in the 2-to-11 GHZ frequency range and is one of the newest and most famous of these technologies. WiMax maximum data rates can reach up to 70 Mbps and cover a range of up to 50 kilometers when operated within line of sight and under ideal conditions. Future developments are in progress on the mobility standards of WMAN. Many researches of the telecommunication industry are focused on developing efficient mobile WMAN systems that provide broadband internet and telecommunication services.

Wireless Wide Area Network (W-WAN)

Wireless wide area networks are digital cellular networks that are capable of providing regional, nationwide, or even global mobile communications connectivity that can

include voice, data and video services. The usage of the cellular network gives the WWAN a greater mobility which allows a broader availability of connectivity, faster access to information, and an avoidance of the physical constraints of cables and wires. The most famous WWAN technologies are the Global System for Mobile Communications (GSM) and Code Division Multiple Access (CDMA). The mobile network which is currently the main infrastructure for WWAN is explained in the next section.

1.4 Mobile Networks Evolution

The rapid developments and advancements in the wireless technologies and market demand have contributed to the revolutionary expansions of mobile networks and services. Mobile networks evolution has gone through several stages categorized into “generations” as it is shown in Figure 1.4. A brief overview of each generation will be explained in this section.

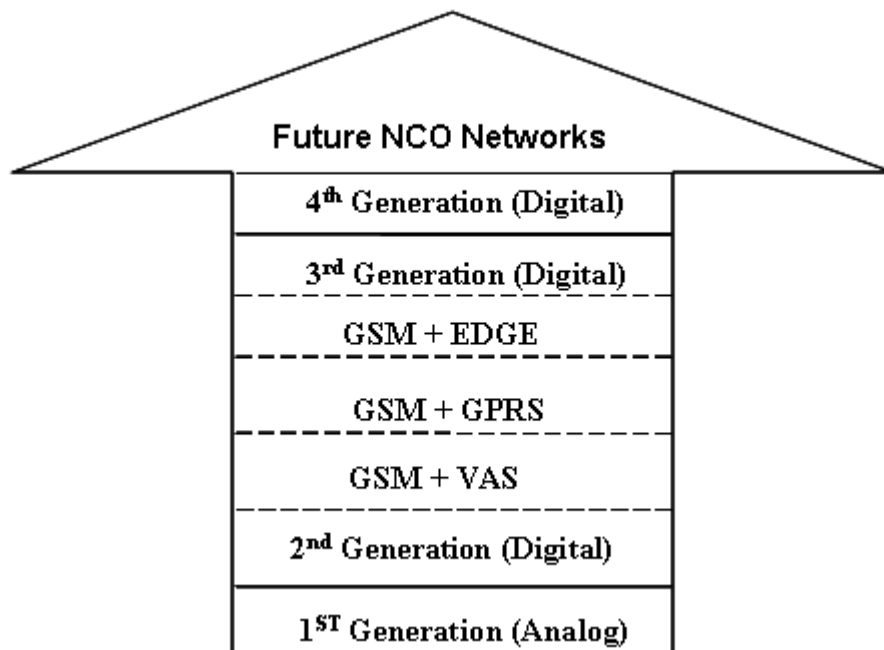


Figure 1.4 Evolution of Mobile Networks

1.4.1 First-Generation System (Analog)

It was basically composed of different types of analog networks of distributed transceivers communicated to provide connectivity to users with the mobile phones. First-Generation mobile systems were basically used for voice communications only. These systems typically allocated two different 25 MHz frequency bands for downlink and uplink messages. The voice signals were transmitted by the method of frequency modulation. In order to maximize the network capacity, re-using the same frequency in different cells and Frequency Division Multiple Access (FDMA) schemes were applied.

1.4.2 Second-Generation System (Digital)

The monumental success of the analog system resulted in rapid growth rates of cellular subscribers, causing an insufficient spectrum to support the quality of service required. This happened during the time of substantial advancement in the digital systems; this led to the next step in the evolution of a variety of digital mobile networks.

Europe developed a system that resulted in 26 telecommunications companies working together. These systems included the Groupe Speciale Mobile (GSM), and were later to be known as the Global System for Mobile communications.

Applying Time Division Multiple Access (TDMA) scheme in 2G allowed up to eight users to share the same channel spaced 200 kHz apart. The basic system used frequencies in the 900 MHz band, but other bands in the 1800 and 1900 MHz (USA) bands were added. New bands in the 850 MHz region were also added.

1.4.3 Third-Generation System (3G)

The third generation of mobile phone standards and technology was first developed in Europe; it was called UMTS (Universal Terrestrial Mobile System). IMT-2000 is the

ITU-T name for 3G system, while cdma2000 is the American 3G variant. Unlike IEEE 802.11 networks, 3G networks are wide area cellular telephone networks which evolved to incorporate high-speed internet access and video telephony. IEEE 802.11 (common home Wi-Fi) networks are short range, high-bandwidth networks primarily developed for data. The UMTS system will be explained in more detail in the next chapter.

1.4.4 Fourth-Generation System (All-IP Network)

The fourth generation (4G) is still in the development process. It involves assuring the interoperability and compatibility of all networks with the Internet Protocol (IP), what is referred to as an All-IP Network. This approach will assure a common platform for all the technologies, allow open system development and upgrade of the mobile networks, and introduce many of the internet based services and applications into the mobile communication business. The all IP open system architecture would transform the cellular communication systems into network-centric operations architecture which would enhance the accessibility of cellular networks into most of the World Wide Web networks.

One of the unique features of 4G is the multicasting. This would allow wide spectrum of services and service providers with 4G capability to provide connectivity to each other and proved an always –on service with higher bit rate and lower cost.

1.5 Satellite Networks Technology

Communication satellites provide an effective platform to relay radio signals between points on the ground. Users who employ these signals enjoy a broad spectrum of telecommunication services on the ground, sea and in the air. Recently, such systems have become practical to a point where a typical household can have its own satellite dish. The satellite services initially was used for aerospace and defense communications,

but later the technology was applied to use by the average consumer in the areas of TV and radio broadcasting, telephony systems, and broadband internet connection link. The basic architecture of satellite communication system is shown in figure 1.5.

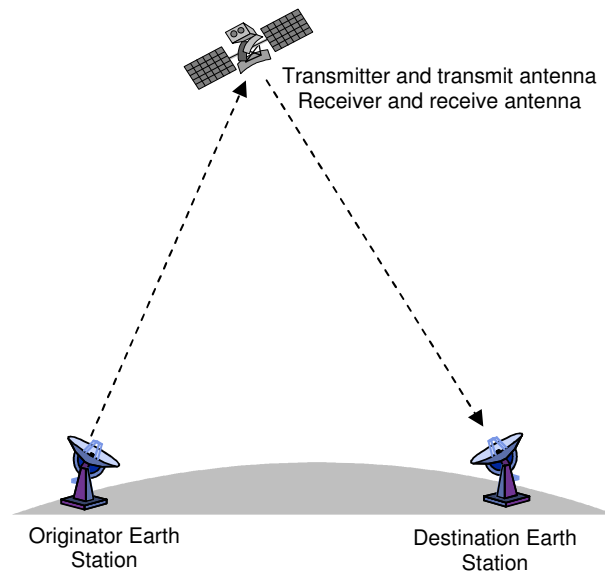


Figure 1.5 Basic architecture of Satellite Communication System

1.5.1 Geostationary Earth Orbit Satellites (GEO)

GEO satellites are placed in orbit above the equator at an altitude of 35786Km. At this altitude the Satellite appears stationary to an observer on earth. As a result antennas that relay to and from GEO satellites do not need any special device to keep track of the satellite's motion and can point to a point on the rotating Earth. The GEO altitude will ensure that it can cover nearly one-third of the Earth's surface with the exception of the Polar Regions and make one complete revolution in a day. GEO satellites are useful in direct TV distribution, positioning systems, broadcast systems, voice and data commercial communications systems and many other civilian and military applications.

1.5.2 Medium Earth Orbit Satellites (MEO)

MEO satellites orbit sometimes is referred as intermediate circular orbit (ICO). MEO is any satellite that orbits the earth within an altitude range of 2000 – 35786 Km above earth. The most common usage of this orbit is in navigation services such as global positioning systems (GPS). MEO satellites could be utilized to provide communication coverage in areas that fall in the blind spot of GEO satellites, such as the Polar region. MEO satellites cover more earth area than low earth orbit satellite but they have a higher latency.

1.5.3 Low Earth Orbit Satellites (LEO)

Low earth orbit satellite is generally defined as any satellite orbiting within the area extending from the Earth's sphere up to an altitude of 2,000 km. Normally the LEO satellites travel at a speed of 27400Km/h within an altitude range of 200 – 2000 Km, thus the time it would take for a LEO to finish a full orbital cycle is typically 90 minutes. A constellation of LEO satellites are equipped with a means of hand-off feature to allow the link to be passed from one satellite to another in order to provide meaningful and seamless communication. Due to the relative proximity of LEO satellites to earth, it would require less energy and it would cost less to launch them and put them into their orbit, also it would require lower power communication transceivers to establish successful link with LEO satellites.

1.6 Last-Mile Coverage

In communication systems, the 'last mile' term refers to the maximum distance of delivering connectivity coverage from a communications service provider to a user's

premises. This connectivity can be wired or wireless, terrestrial or satellite based. The last mile connection is often asymmetric, with more bandwidth available downstream than upstream, since users generally pull down data more than they send out.

The challenges of providing the 'last mile' coverage are considered one of the main obstacles faced by service providers in the delivery of mobile communication services to customer's terminals. In recent years many technologies have been developed to resolve this issue, including: Asymmetric Digital Subscriber Line (ADSL), Fiber optic cables, Broadband Fixed Wireless Access (BFWA), Mobile telephony, Wireless LAN/WAN, and Satellite technology. Due to the limitation or expensive costs of most of these technologies, High Altitude Platforms (HAPs) have been proposed for the provision of communication services from the stratosphere. Currently, the HAPs concept is considered as one of the best alternative technologies for the issue of "last mile" service coverage. HAPs have the potential to deliver communication services over a wide coverage area, regardless of the nature of the terrain or the climate of the region. The next section will discuss some of the different technologies applied to provide 'last mile' connectivity.

2. High Altitude Platforms (HAPs)

2.1 Overview

The High Altitude Platforms (HAPs) system concept envisages the utilization of un-piloted High-Altitude, Long-Endurance (HALE) airborne stations as platforms to relay telecommunication signals for several purposes. The HAPs concept takes advantage of the advancements in microwave power transmission developments associated with the modern Solar Power systems and High Altitude Powered Platform concepts. This newly developed concept seems like a very simple concept but it has an enormous potential.

HAPs will be utilized to provide cellular communication and broadband services applications especially in remote and oceanic regions where it is difficult to have an affordable infrastructure. Serving as a communication backhaul, these platforms are to remain relatively stationary at the upper atmospheres for long periods of time. Although stratospheric platforms are an old idea, only recently, they have become considered as a promising enabling technology. Currently there are several major organizations that are devoted to the development and commercial marketing of HAPS based systems for wireless communications as well as for environmental and security monitoring and remote sensing.

HAPs are designed to fly at altitudes of around 20km (70,000 FT) because the average wind speed in the stratosphere is minimal at altitude of about 20 KM. The relationship between the wind speed at specific altitudes and the actual altitude is described in Figure 2.1. Moreover, at these altitudes, the signal delay will be negligible compared to satellite signal, and propagation delay will be minimized. The average lifespan of each platform is expected to exceed 5 years before landing for refueling, upgrade and maintenance.

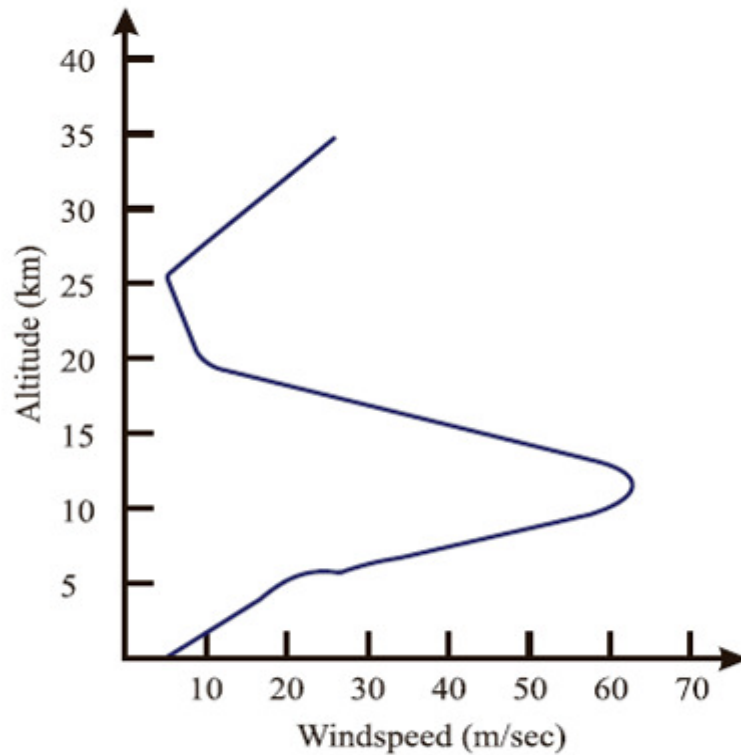


Figure 2.1 Wind Velocity with respect to the Altitude [20]

2.2 Categories of HAPs

There are three distinguishable types of proposed high altitude long endurance (HALE) aerial vehicles. These types are categorized depending on the platforms structure, the way they are operated, managed and maintained. Collectively, the unmanned aircraft and manned aircraft of the three types are referred to as High Altitude Aeronautical Platforms (HAAPs).

2.2.1 Unmanned Airship

These are mainly un-manned, powered airships that can maintain a relatively stationary position at 70,000 feet. They can be well over 100m in length and could carry a payload

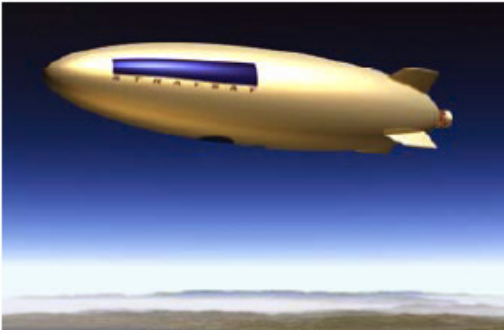
of about 800kg or more. Lifting these ships will be accomplished using the concept of lighter-than-air gases. Differential thrust and electric-powered props control the pitch and roll and keep it in position. Since liquid fuel is heavy, all power must be generated on station. This could be accomplished by using thin-film photovoltaic solar cells and commercially light weight high power fuel cells.

By generating its own power, usage of light weight structure and equipment materials and keeping gas loss to a minimal amount, this type of aerial vehicle could stay up and relatively stationary for a period of 5 years. These features qualify this type of HAPs to be the most effective airship for telecommunication services and applications and the most comparative technology to satellite systems.

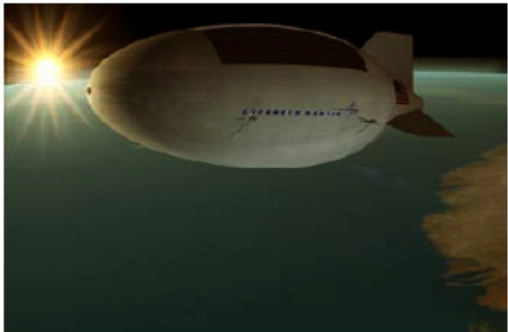
Currently, several countries are developing this type of airship for several types of uses. Figure 2.2 illustrates promising and on-going programs to produce this type of airships.



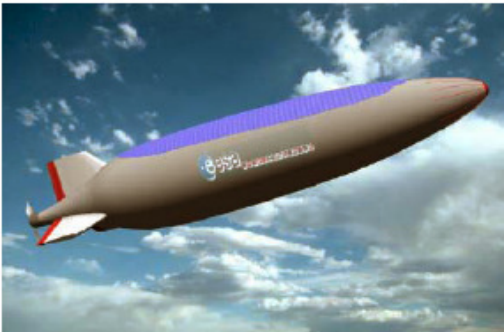
**NAL "SPF" (Stratospheric PlatForm)
(JAPAN)**



ATG "StratSat" (UK)



Lockheed Martin NESS (US)



European Space Agency (ESA)

Figure 2.2 Solar Power Unmanned Airships [11]

2.2.2 Unmanned Aircraft

These types of aerial vehicles are also known as High Altitude Long Endurance platforms (HALE Platforms). They make use of high tech light weight material, long wingspan to fly for long periods and programmable electric motors to continuously fly on a race track pattern. Figure 2.3 illustrate examples of the latest solar power unmanned aircraft prototypes developed by NASA.



Figure 2.3 Solar Power Unmanned Aircraft [11]

Power is derived from solar cells mounted on the wings and stabilizers, which also charge the on-board fuel cells. The span of flight duration for this category of vehicles varies from days to a month. Some theoretical concepts of this type of aircraft propose that there are methods and technologies that could keep them flying to up to six months or more.

This type of aircraft has faster flying speeds and more maneuvering capabilities than unmanned airships. It is also smaller sized and its preparation and operational logistics are less complex than for airships. This type of aircraft could be most useful for surveillance applications and disaster relief communication.

2.2.3 Manned Aircraft

This category of vehicles is basically a piloted airplane that is designed specifically to handle high altitudes. It has an average flight duration of some hours which is mainly due to the fuel constraints and human factors. This type is mainly used for defense and some civilian services like weather monitoring services. Figure 2.4 below shows the different types of aerial vehicles both manned and unmanned.



Angel Technologies HALO (Proteus 9)
Manned aircraft for the delivery of communication services



M-55 stratospheric aircraft (Geoscan Network)
Piloted aircraft for the delivery of wireless services and remote sensing

Figure 2.4 Long Range High Altitude Manned Aircraft [11]

The table below provides a summary and a breakdown of general comparison of the three categories; Airships, Unmanned Aircrafts and HAAPS Piloted aircrafts.

From studying the table shown in Figure 2.5, it is apparent that the best suited type for operating as a cellular communication base station (BS), or operating as a telecommunication relay in the sky function as a LEO satellite would be the unmanned high altitude airships. Their flight duration which is up to 5 years now but with the development of aerial refueling solutions its expected to increase to up to 10 years if, also their ability to carry a heavier communications payload and surveillance sensors and their ability to remain relatively stationary comparing to other types is what qualified it to be most proffered solution for many researchers.

	Airships (unmanned)	Solar-powered unmanned Aircraft	Manned Aircraft
Size	Length 150 ~ 200 m	Wingspan 35 ~ 70 m	Length \approx 30 m
Total weight	\approx 30 ton	\approx 1 ton	\approx 2.5 ton
Power source	Solar cells (+Fuel cells)	Solar cells (+Fuel cells)	Fossil Fuel
Flight Duration	Up to 5 years	Unspecified (\approx 6 mths)	4 – 8 hours
Position Keeping (Radius)	Within 1 km cube	1 – 3 km	\approx 4 km
Mission Payload	1000 ~ 2000 kg	50 ~ 300 kg	Up to 2000 kg
Power for Mission	\approx 10 kW	\approx 3 kW	\approx 40 kW
Example	Japan, Korea, China, ATG, Lockheed Martin, SkyStation etc.	Helios, Pathfinder Plus (AeroVironment), Heliplat (European project)	HALO (Angel Technologies) M-55 (Geoscan Network)

Figure 2.5 General comparison of airships solar powered unmanned and manned aircrafts [11]

2.3 Comparing the Terrestrial, Satellite and Stratospheric Communication Systems

Until sufficient interest has developed in utilizing HAPs as an infrastructure for telecommunication systems, HAPs is not meant to replace, but rather to complement, existing terrestrial and satellite networks. A comparison between the features of HAPs versus terrestrial and satellite networks demonstrates the advantages of integrating HAPs within existing networks. The most important similarities and differences of stratospheric platforms vis-à-vis terrestrial and satellite systems are summarized in

survey conducted by S. Karapantazis and F.-N. Pavlidou [11] and shown in Appendix A.

2.4 HAPs Applications

The multiple superior features of HAPs translate into the attractiveness of utilizing HAPS in various applications. Below is a list of possible HAPs applications:

- HAPs allow broadcast services and wireless communications to be delivered more cost effectively, with easy maintenance requirements.
- Increase in the cellular communications cells capacity and ease of planning the cells, provide more and better coverage and require much less infrastructure and are less affected by natural disasters
- Its network architecture also allows it to be a multicast for both Internet and DVB (Digital Video Broadcast) type services.
- Unlike satellite systems, HAPs have relatively low propagation delays and broadband capability using small sized antennas and terrestrial terminal equipment, and is thus ideal for use in data and Internet traffic throughput, interactive applications, and protocol constraints.
- Data communication, basic voice, and video are typical services that will be offered from aerial platforms. More advanced services include news gathering, videoconferencing, remote sensing, telemedicine, navigation, localization, and emergency message broadcasting.

2.5 HAPs-Based Cellular Communication

Proponents of using HAPs for cellular telephone services advertise several advantages of the system. The primary advantage is their higher return on investment when serving

rural areas where there is lower traffic. Further, the current terrestrial based telecommunication system might not support disaster situations when the infrastructure might suddenly become unavailable.

A single HAP which provides full service coverage of a wide rural area is expected to be more technologically complex (e.g. utilize more advanced antenna technology), and each macrocell served by a platform can be subdivided into a number of sectors, with each sector connected to an aerial base station on the platform. A HAP can also be used as a “backup” base station instead, supplementing the services provided by existing terrestrial base stations, so that pockets of areas which are not covered by the terrestrial network would be included in this integrated system. In such a use, the traffic density in HAPs is expected to be low. Figure 2.6 illustrates a typical HAPs network architecture scenario assuming a variety of possible interconnections.

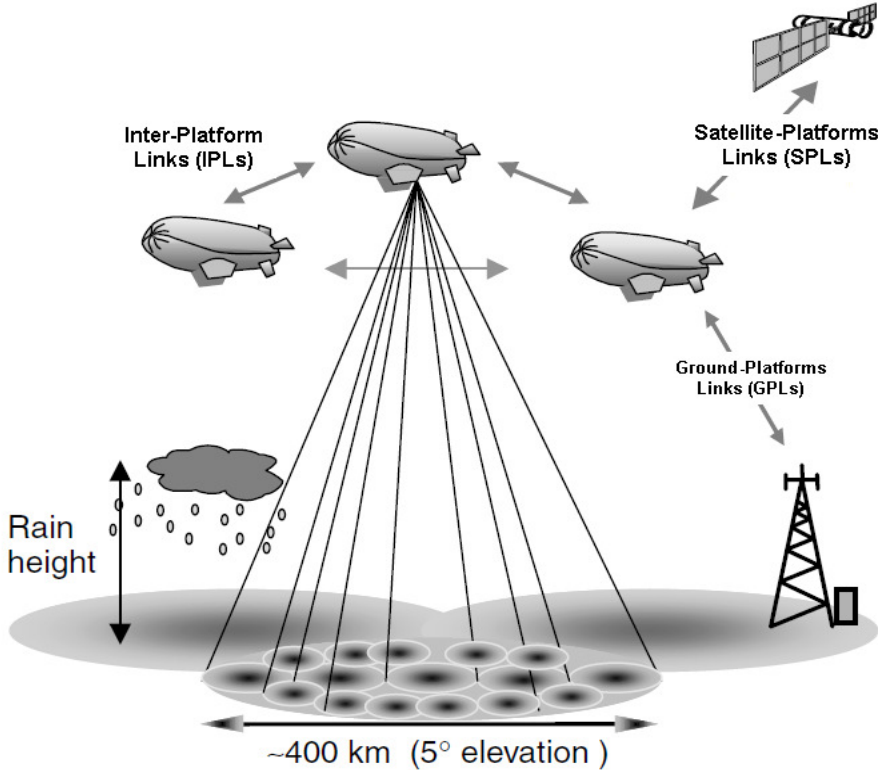


Figure 2.6 Typical HAPs Cellular Network Architecture

2.6 HAPs Links Types

The architecture design phase of the HAPs system takes into consideration the system coverage and the type of services to be offered. System coverage has two design implications: the first is system capacity which is affected by the platform coverage area that is composed of smaller cells to increase the capacity; the second is service area which determines the number and configuration of the HAPs required. The type of services to be offered is impacted by the choice of network topology. HAPs can be standalone operations or they can be interworking operations connected to external networks via gateways. The different types of platform interconnections and the design implications together yield four possible network architecture scenarios, which are defined and explained in the next sections.

2.6.1 Standalone Platform Links

A standalone HAP system is conventionally used to provide basic coverage or additional capacity for short-term events such as sports events (e.g. the Olympics) or disaster relief operations. In such scenarios, onboard switching is most likely required as ground stations may not be readily available for switching on the ground. In the HAPS standalone, the coverage is limited to communication between users within the platform coverage area, or with other networks in the ground connected to the HAP. The typical capacity of a standalone HAP system is 200 Mbit/s for the uplink, shared between the users in a cell, and 2 Mbit/s shared capacity for the downlink. Figure 2.7 illustrate a standalone HAP with sectorized cells covered by its directional antennas.

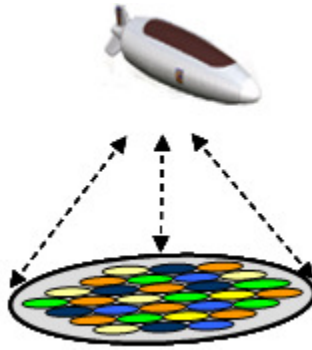


Figure 2.7 Stand-Alone High Altitude Platform Scenario

2.6.2 Network of Platforms Connected via Ground Stations

Multiple HAPs systems are communication systems where different HAPS are interconnected either via ground stations (discussed in this section) or via IPLs (next section). The system coverage provided by ground connections is dependent on the ground segment facilities. Switching can be ground or onboard. The advantage of onboard switching is the improvement of QoS between communicating parties within the same platform coverage area. In ground switching, the advantage is in the reduction in platform payload requirements (such as weight and power consumption limitation). Figure 2.8 shows how a ground station could be used as a relay between two HAPs. In some cases, the ground station could be designated to function solely as HAPs ground station, in other cases, HAPs interconnection could be achieved via existing cellular base station.

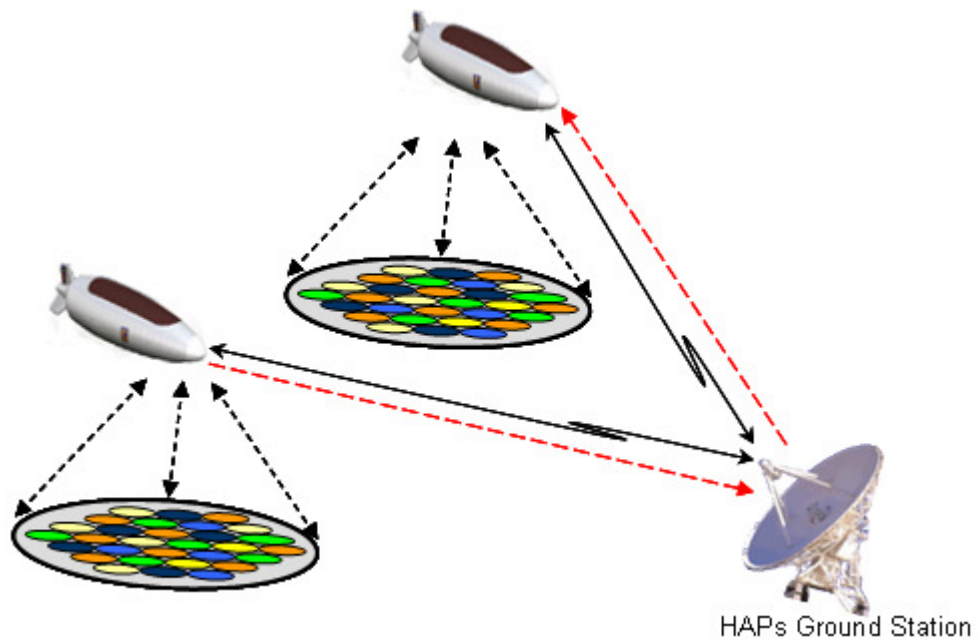


Figure 2.8 Network of Platforms connected via ground station

In standalone operations, capacity is increased by the number of cells within a coverage area. In multiple HAPs systems, capacity can be increased by the number of platforms deployed. Fixed user antennas are employed as their relatively narrow beam-widths enable the progressive reduction in the interference levels of other HAPs positioned away from the boresight of the user antennas.

2.6.3 Network of Platforms Connected via Inter-Platform Links (IPLs)

In the case of multi HAPs network, Inter-Platform Link (IPL) is used to connect between HAPs. Depending upon the technical requirements, the IPL terminals can be either optical or radio frequency. There are advantages to using IPL versus ground station connection. One is the flexibility of system coverage, whereby coverage can be extended with less need for terrestrial infrastructure and up/down link segments. A second is its ability to bridge spans between ground stations while rerouting traffic to less loaded ground stations and gateways. When IPL networks are used, ground stations

could serve as a gateway to other networks or as a backup interconnection between platforms in the event of IPL failure. As shown in figure 2.9, IPL helps the formation of HAPs meshed network.

There are also some drawbacks to using IPL networks. One of them is that it increases the payload burden with its additional weight and power consumption. The other is its requirement for steerable IPL antennas that must meet pointing, acquisition and tracking (PAT) conditions. Since natural weather phenomena such as wind, gusts, and turbulence can affect the motion of the platforms, they will also affect the IPL distance and antenna pointing angle.

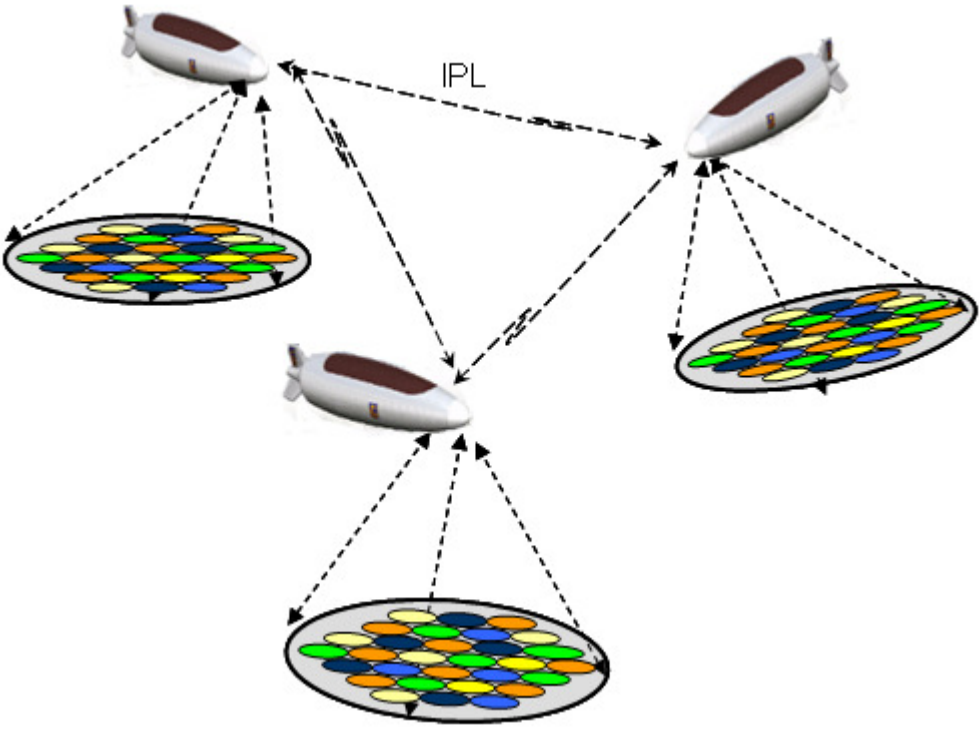


Figure 2.9 Network of platforms connected via interplatform links

IPLs can connect either adjacent platforms with overlapping coverage areas, or remote platforms within the same, or backbone, network.

Since signal attenuation tends to be greater in the higher mm0waveband, therefore the maximum distance set between IPL-connected platforms to minimize the effects of such attenuation, and that distance should not exceed 450-500 km.

2.6.4 Network of Platforms Connected with Satellites (PSLs)

A third type of platform network connection is via satellites using radio frequency terminals. This RF platform to satellite link (PSL) shown in figure 2.10, is used primarily where there is non-existing or inadequate ground infrastructure or when we need to minimize the communication payload in HAPs. PSL has two main functions. One is to integrate the HAP system with non-local terrestrial or satellite networks, the other is as a backup system when the ground station or IPL connection is disabled. There are drawbacks to the use of PSL networks. They use heavier terminals which consume more power, have longer communication paths, and correspondingly greater loss in spreading.

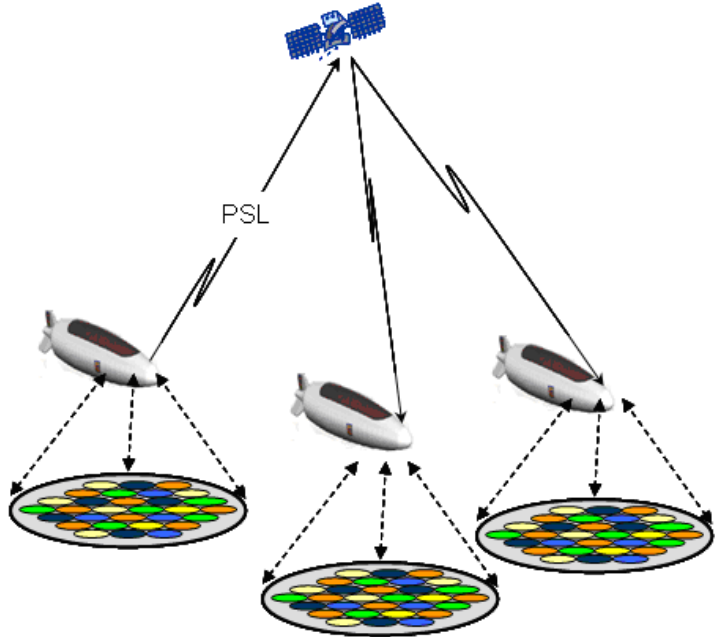


Figure 2.10 Network of High Altitude Platforms connected via Satellite

2.7 UMTS-HAP Networks

The ITU has approved the use of HAPs in the IMT-2000/UMTS spectrum for providing 3G mobile service. As discussed in an earlier section, the HAPs system can provide UMTS as a standalone system, or it can be integrated into a system of ground based towers.

The HAPs UMTS system and ground tower-based UMTS system both utilize the same infrastructure, and have the same functionality and service and operational requirements. Although their delivery platforms are different, to the cellular user, the mobile network operates in the same way for HAPs as it does for traditional ground based stations.

The HAPs system is however superior in several aspects. To begin with, a single HAP can encompass a signal coverage area of 500 km radius. The HAPs system handoff is also advantageous in terms of: (a) softer cell to cell handoff due to all the cell antennas being positioned on the same platform, thereby eradicating the need for time delay correction; and (b) its ability to operate in several chip times, thereby enabling service to fast moving vehicles. HAPs also have a dynamic beam assignment that allows the provision of both service to hot spots, and point-to-point high speed coverage. Last but not least, the improved beam radiation pattern characteristic of the HAPs system results in lesser cell interference and thus corresponding higher spectral efficiency.

3. GOMEX-HAPs Communication Network (GOMEX-HAPs Net)

This chapter proposes that there is an exigency for building a reliable wireless communication backbone in the Gulf of Mexico (GOMEX), and that the HAPS based UMTS-HSDPA network is the most reliable that could provide wireless coverage to close the gap of radar coverage and wireless communication in this region. The GOMEX-HAPS communication system is intended to provide a variety of communication services including: UMTS, Aviation Communication Systems, Broadband Services, and communication services intended to support civilian and defense government services.

3.1 Network Functional Specification

From the system engineering perspective, the functional specifications dictate the expected behavior of the system. Functional specifications document what is needed by the system user as well as the required properties of inputs and outputs.

3.1.1 Network Services

The variety of communication services provided by GOMEX-HAPs Net can be basically divided into two major categories; *low data rate services* for mobile terminals and *high data rate services* for fixed terminals.

The following categories of network services may be included in HAP communication services:

- Broadband Wireless Access
- Cellular Telephony (2G and 3G)

- Multicasting Services
- Broadcasting Services

The allocation of additional uplink channels in HAPs and the low signal time-latency comparing to GEO satellites will allow better reception of interactive video and internet access. GOMEX-HAPs Net will also provide affordable subscription services to the population in the GOMEX region.

From the standpoint of profitability, GOMEX-HAPs Net may initially provide basic cellular telephony services, aviation surveillance services and governmental coast guard communication services. As the market grows for wireless services based HAPs and development of communications systems customized for HAPs, then GOMEX-HAPs services would be expanded to provide other services like broadband communication

3.1.2 System Availability and Efficiency

Network availability is defined as the percentage of time for which services are not affected by network outage (due to shadowing or blocking). In wireless communications systems, environmental considerations (i.e., structure, rain, terrain, etc) have the greatest effect on network availability. Since GOMEX-HAP is going to be operating over oceanic region, the structure and terrain impacts would be minimal.

Another factor that impacts network availability is the *loss margin*. At the frequencies for which HAPS have been allocated, and especially those in the millimeter-wave part of the spectrum (above 27 GHz for HAPS), link budgets do not allow for very much loss margin. Because of the importance of mitigating loss, *gain* is therefore an essential parameter that needs to be accounted for in the link budget, particularly so at low elevation angles, e.g. 15° , where the direct path between the HAPS and the ground station is longer and so the path loss becomes larger than in the case of higher elevation

angles, e.g. 90° . The impact of a lower elevation angle on path loss is illustrated in the example in Figure 3.1.

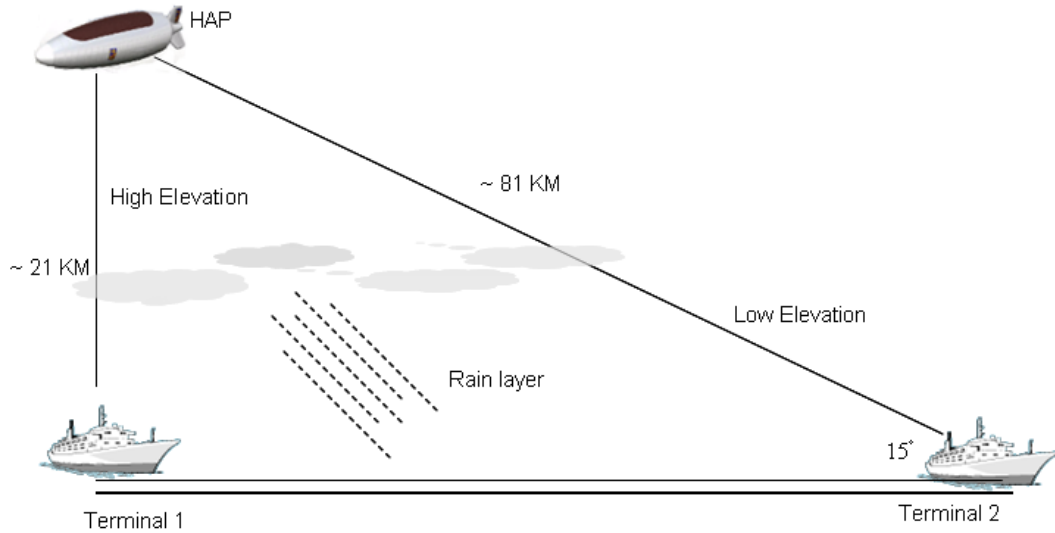


Figure 3.1 Impact of Lower Elevation Angle on Path Loss

Assuming an operating frequency of 28 GHz, a HAPS at 21km above the ground is viewed by a user on the ground from two elevation angles, 90° (Terminal 1) and 15° (Terminal 2). While the direct path between Terminal 1 and the HAPS is 21km and 80km between Terminal 2 and the HAPS is 80km, resulting in two different path losses, 152 dB and 164 dB respectively. The difference of 12 dB represents 16 times more power, and this is high enough that it may not be accommodated for in a tight HAPS link budget.

$$L_{90} = 20 \log \left(\frac{4\pi(21000)(28 \times 10^9)}{3 \times 10^8} \right) = 148 \text{ dB} \quad (3.1)$$

$$L_{15} = 20 \log \left(\frac{4\pi(81000)(28 \times 10^9)}{3 \times 10^8} \right) = 160 \text{ dB} \quad (3.2)$$

Gain is also significant to the ground antenna as it determines the data rates available to the customer on the ground. High-gain antennas are necessary at millimeter-wave frequencies in order to overcome rain fades. Using rain statistics and link budget calculations, and assuming a downlink of 28 GHz, a channel bandwidth of 12.5MHz, and a cell diameter of 6km, the table shown in Figure 3.2 outlines a few scenarios of system availabilities with the link margin required to overcome rain fades [Thornton, 01].

Ground Terminal Type	Data Rate (Mb/S)	Availability
High Portable (100% antenna)	2	99
Fixed (28% antenna)	4	99.9
	10	99
Steered (2% antenna)	12	99.9
	40	99

Figure 3.2 Example of downlink data rates at 28GHz for various types of user. Inspired by [Thornton, 01]

High antenna directivity, which is the intensity with which the antenna radiates in its preferred direction, is needed to minimize co-channel interference and maximize signal-to-noise ratio so as to direct the wanted signal to users within the coverage area. Cellular applications are dependent on the high directivity of antenna beams to illuminate a specified cell coverage region, outside of which will result in interference in contiguous cells and the decrease of *carrier-to-interference ratio* (CIR). The CIR can also be adversely affected by rain scattering and attenuation which as already mentioned are more critical at millimeter-wave frequencies, resulting in suboptimal system performance. It has been proposed that this can be solved by using tighter antenna bandwidths and sidelobes.

The antenna directivity is the ratio of the maximum radiation intensity to the average radiation intensity. The directivity and the power gain are then related by the following equation:

$$G(\theta, \phi) = eD(\theta, \phi) \quad (3.3)$$

where G is the gain of antenna, e is the efficiency, and D is the directivity.

From its definition, the directivity (D) is given by:

$$D = \frac{4\pi U_m}{W} = \frac{4\pi}{\Omega_A} \quad (3.4)$$

where U_m is the maximum radiation intensity [W/rad^2], W is the total power radiated and Ω_A is the beam solid angle [rad^2]

Given the tight requirements imposed by link budgets, all three parameters must be considered when designing the system. For instance, this relationship indicates that high directivity with poor efficiency could still result in loss if power is poorly radiated, and this is the case of some HAPs antennas.

3.1.3 Internetworking Requirements

GOMEX-HAPs users should be able to be connected with existing networks via prevailing routing technologies and protocols to take advantage of existing cellular infrastructure and established network roaming agreements for purpose of subscription management and billing. Internetworking can be in two different ways. When the GOMEX-HAPs network is complementary to current networks, it is termed Loose

interworking; and when it is a sub-component of an existing network, it is termed Tight interworking.

Loose interworking affords more independence and flexibility for the HAPs network; however security, mobility, and QoS standards need to be measured against Internet Engineering Task Force (IETF) benchmarks. Tight interworking allows the GOMEX-HAPs network to connect to the UMTS network via radio access technologies such as UTRAN and GERAN, which obviates the need to address security, mobility and QoS standards, and where GGSN serves as the interface between the UMTS core network and the Internet. The same standards and requirements apply to satellite networks where multi-HAPS platforms communicate via a satellite backhaul channel. Therefore GOMEX-HAPS should support both loose and tight internetwork schemes.

Cell Planning

Cell planning is used to optimize coverage, make better usage of the frequency and enhance signal quality. HAPS, terrestrial and satellite systems share allocated frequency bands so interference analysis is critical to cell planning, which have different considerations for HAPS than for terrestrial systems. HAPS-based systems are affected by co-channel interference which determines the CIR distribution on the ground, but are unaffected by propagation characteristics due to terrain characteristics. To minimize interference, antenna specifications are of paramount importance to ensure optimum antenna beams that will illuminate its corresponding cell with uniform power across the cell and no power falling outside of it. For instance, aperture types have better radiation characteristics. Antenna selection should also consider the production of beams that have very low sidelobes and a steep roll-off in the main lobe, and directivity that is neither too high (resulting in excessive power roll-off at the edge) or too low (resulting in excessive power falling outside of the cell).

Call Admission Control

Call admission control (CAC) schemes are used to control the number of users within the service area. There are many CAC schemes for HAPs that have been published.

According to the scheme presented in [Foo, 02a], the call will be admitted if the downlink transmit power of all mobiles was found so as to satisfy the signal-to-noise (SIR) requirements at available power levels. To calculate the grade of service (GoS) the following algorithm is used:

$$\text{GoS} = P_b + 10P_d \quad (3.5)$$

where P_b is the blocking probability, P_d is the probability of having a drop call.

CAC is necessary to ensure each mobile's QoS requirements, by regulating the volume of traffic or mobiles within a service area so that the **signal-to-interference ratio (SIR)** level is always above a predefined limit. If incoming traffic is received beyond this limit, the interference level will be increased while the SIR will fall below its predetermined threshold, and **handover** is initiated often by system operators.

3.1.4 Handover

Handover is the process of changing the channel associated with the current connection while a call is in progress. This process is initiated when a user is crossing the cell boundary or deteriorations of the signal. Therefore, handover is based on the strength of the received signals, in relation to the threshold or point at which communication quality deteriorates.

Figure 3.3 illustrates how the threshold can affect when handover occurs by comparing its relative value to the signal strengths of two HAPs (HAP1 and HAP₂) at the point

where they are equal. If signal strength were to be lower than T_1 , then handoff will occur at position A. But if the threshold were lower than this point, e.g. T_2 , then handover would be delayed until the current signal crosses T_2 at position B. In the scenario where the threshold is T_3 , the mobile user may now be so far from BS_1 that the quality of the communication link from BS_1 is reduced to the point that the call is dropped and there is also increased interference to co-channel users. This model shows that overlapping cell coverage may be created. Further, since preexisting knowledge of the crossover signal strength between the current and candidate HAP is a prerequisite for determining the threshold, there are other factors which may be used in conjunction with threshold to design the handover operation model. In some cases, the network topology or regulatory issues might hand off users from one channel to another even if the used channel is still able to provide the service.

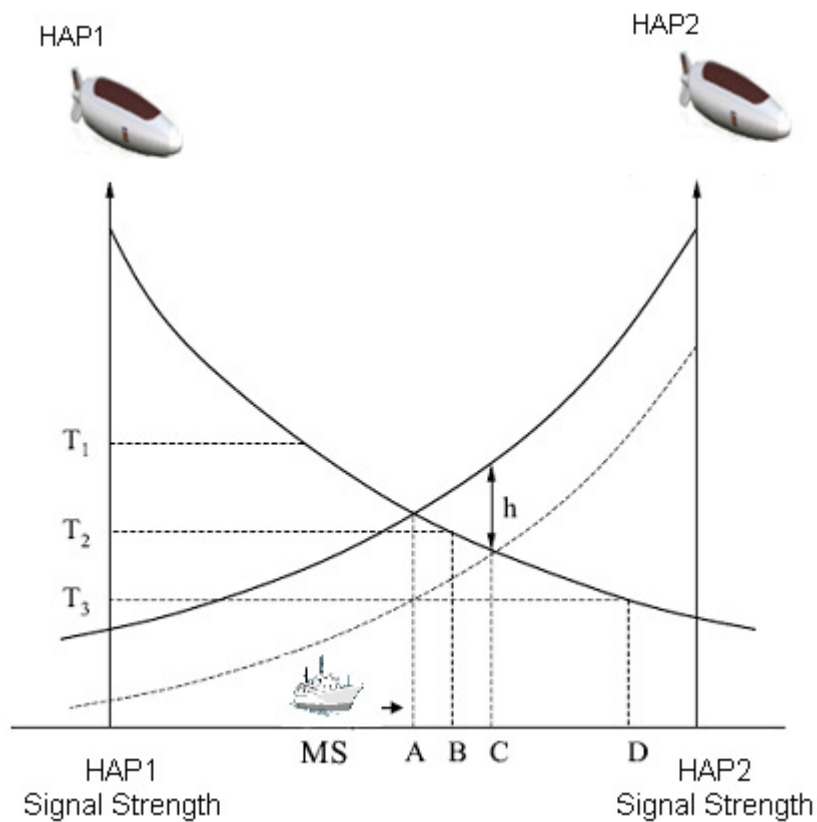


Figure 3.3 Signal strength and hysteresis between two adjacent HAPs for potential handover

3.1.5 Quality of Service (QoS) Requirements

QoS requirements for GOMEX-HAPs should consider both the restrictions and limitations of radio interface, as well as solutions for air interface constraints, and should be based on those specified for ITU Broadband Radio Access Networks. QoS provisioning should only be implemented where there is user subscription, and the user should be charged for the level of QoS provided and subscribed. The GOMEX-HAPs network operator should be able to monitor the QoS provisioning, within any HAP or the entire network should have little impact on that in other networks. There should also be a mechanism in place to prevent unauthorized users from sending inadmissible data through the network.

In order to simplify interworking with the operator's ISP platform, the QoS mechanisms of GOMEX-HAPs networks towards external networks should be aligned with the IP mechanisms. Finally, as part of expandability, the GOMEX-HAPs network should easily integrate the IP Multimedia Subsystem QoS requirements.

3.1.6 GOMEX-HAP Network Management

The Network Control Center (NCC) is the command center managing the communication services provided by the GOMEX-HAPs Net. Using the PSLs, network staff in the NCC will be able to perform all real-time network management tasks including, resource allocation, links security and user authentication, traffic management and data compilation for billing and system health management including system configuration, testing, maintenance and software upgrade. Beside the NCC, GOMEX-HAP operators would be able to perform all non-real-time network management tasks via remote control centre in the ground station.

3.2 System Architecture

GOMEX-HAPs network architecture design can be optimized by placing the most complex components of the system in the ground segment, minimizing payload and power consumption, and maximizing reliability. While the transparent HAP functions primarily as a relay station transmitting information from an uplink to a downlink channel, the HAP functions as an on-board processing system with multiple components such as a multichannel transponder, antenna interfaces, digital signal processing system, and so on.

A typical HAPs communications system consists of stratospheric and ground segments. The stratospheric segment includes mainly the airship, telecommunications payload, and navigation and surveillance equipment. The ground segment consists mainly of ground station hubs which connect the HAPs network with the terrestrial communication networks and its user, and Command and Control centers which track, maintain and control aerial system platforms. In the next section we will discuss each of the segments in more details.

3.2.1 Stratospheric Segment

The stratosphere layer is the second major layer of Earth's atmosphere, just above the troposphere, and below the mesosphere. In GOMEX-HAPS, this stratospheric segment may be divided into three main elements, the telecommunication payload, the airship and the flight control system. The payload represents the motivation for the mission itself, which for a HAPS communication system involves telecommunications equipment and infrastructure. In the next three sections we will discuss in brief the main components of the stratospheric segment. The subsystems which form the stratospheric segment are shown in Figure 3.4.

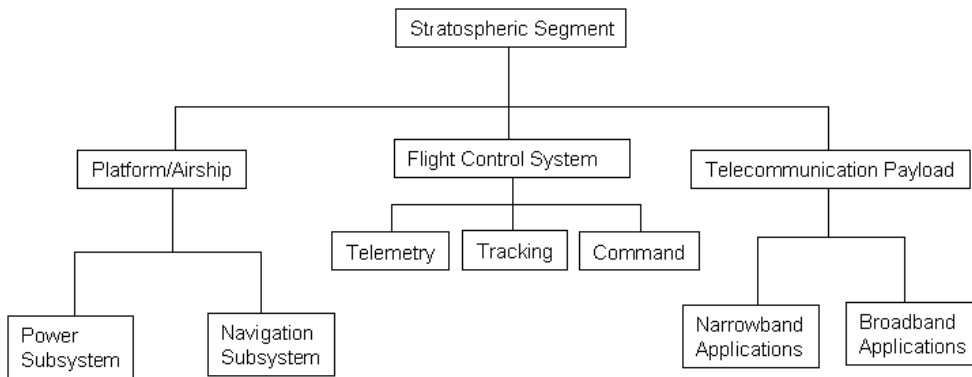


Figure 3.4 The Subsystems of the Stratospheric Segment

Platforms (HAPs)

The GOMEX-HAPs airships consist of lighter-than-air airship (LTA) positioned in the stratosphere balloons called “aerostats” equipped with propulsion systems powered by solar power, flying over 100m long with a payload of about 800kg or more as shown in Figure 3.5. The platform will be kept within an altitude of 20-21 km where air density is approximately one-fourteenth that at sea level. The aim is for this type of aerial vehicle to stay aloft up to 5 years or longer. During operation, the airship is kept relatively stationary using a light weight high tech engine and position sensors with advanced control system to counteract movements due to wind. The engine could also be utilized to move the airship to a new position assigned by the ground controller. The *aerostatic* platforms can carry heavier payloads (about 1000 kg mass) [14], having easy and precise station-keeping for nominal environmental conditions and sufficient surface area for power generation.

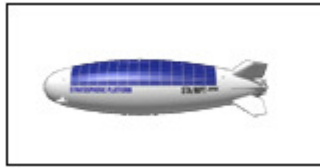


Figure 3.5 Lighter than air high altitude platform

Telecommunication Payload

The platform payload, which cannot exceed 100kg, will consist of phased array and transceiver antennas to provide gateway link with terrestrial stations and subscribers, a switching device, a cluster of digital signal processors that perform receiving, relaying, multiplexing, switching and transmitting functions.

The interface between the platform and the ground station flight control systems is performed by the telemetry, tracking and command (TT and C) subsystems. Additional to the payload that insures its connectivity with the ground, HAPs also include a communication payload that connects it with other HAPs in the network or with a Satellite system. Besides these mentioned main components, there might be other communication payload types in place, depending upon the specific application of the system. Due to the possibility of supporting different types of services, the payload could utilize several multiple-access techniques and it must be adapted to services and the frequency bands regulated by national and international telecommunications authorities to control possible frequency interference with satellite and ground systems.

A typical HAPs transponder architecture that could be applied to the GOMEX-HAPs is illustrated in the block diagram in Figure 3.6. In this case, this transponder has a bandwidth of 500MHz using code division multiple accesses (CDMA). Each antenna beam uses 8 wideband carriers. The bandwidth of each carrier is 1.25 MHz. So, the total bandwidth used by one antenna beam is $8 \times 1.25 = 10$ MHz. Therefore, the total antenna beams produced by the transponder would be $500 / 10 = 50$ beams. Each antenna beam

uses different frequencies to reduce intracellular interference and 2 separate antenna beams also use different frequencies to reduce intercellular interference.

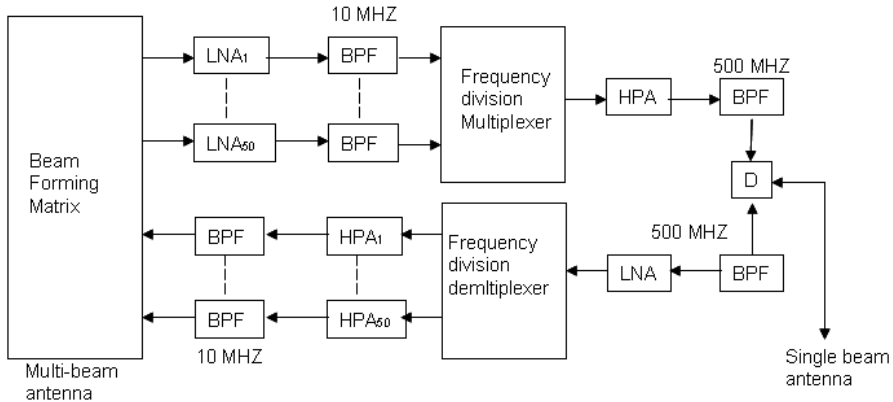


Figure 3.6 A Typical HAPS Transponder Architecture Applied to GOMEX-HAP

The uplink process begins with the reception of the carriers by a platform antenna subsystem. The carriers are then amplified by a low-noise amplifier (LNA), while pass-band filters limit their bandwidth up to 10MHz, and then multiplexed using frequency division multiplexing (FDM). These multiplexed signals are further amplified by a high-power amplifier (HPA) stage, filtered and multiplexed, before being transmitted to the ground station. The downlink process engages a demultiplexer instead of a multiplexer [ITU-F1500, 00], however the steps are the same as in the uplink except in reverse direction

Flight Control and Power System

The majority of the airship surface will be covered with thin-film solar cells to generate all the necessary power for the airship surveillance and navigation equipment, station-keeping systems, telecommunications transceivers and antennas, and fuel cell re-charging systems. The main problem with using solar power systems as a power source is the operations during night time. Using re-chargeable traditional batteries will add to the weight of the airship, therefore, to overcome this problem, the preferred choice will be to use a Regenerative Fuel Cell (RFC) technology to provide a continuous source of

power during both day and night. As shown in figure 3.7, the electrical power subsystem consists of three main elements: the primary and secondary energy sources, and a power/control distribution network.

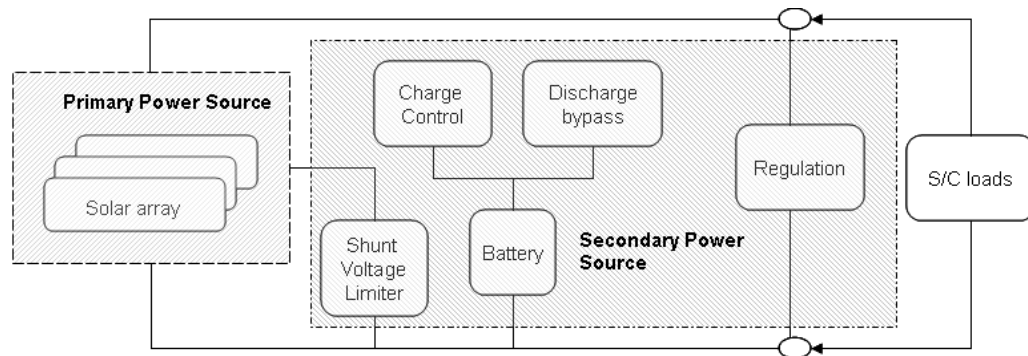


Figure 3.7 The Elements of an Electrical Power Subsystem

3.2.2 Ground Segment

The earth segment of HAPs wireless network architecture consists of ground stations, base station equipment, main switching center, and user terminals, as shown in Figure 3.8.

The earth segment also includes the large number of cells projected by the high gain transmit/receive antennas used onboard the HAPs. The cells are constructed in the same pattern that is created by a traditional cellular system, as shown in Figure 3.8. The size of the HAP footprint in the earth segment and the number of cells in the spot beams are determined by the antenna array which is designed to match the demand for the capacity within any selected coverage area.

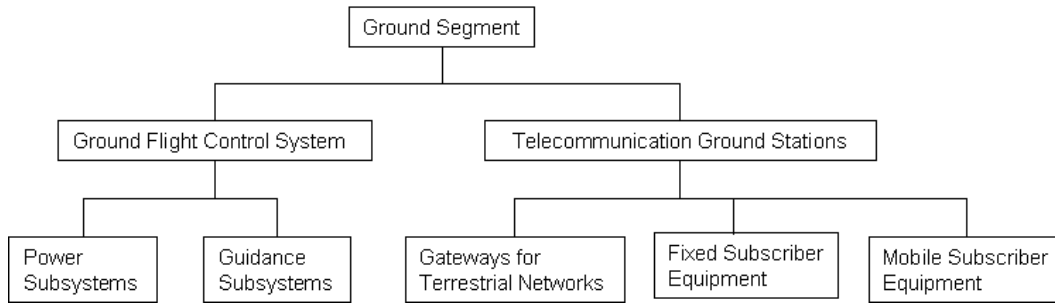


Figure 3.8 Cellular System of a Ground Segment

The power designated to each cell, and the cell’s boundaries, are configured to enhance the system capacity. In order to provide a high level of capacity for high-density zones, more channels should be assigned to the zone, therefore we will have more cells but the size of each cell will be smaller, whereas for less dense zones we will need less channels, therefore each cell size will be larger.

The HAPs ground segment will include a Network Control Center (NCC) to function as the command and control center for the HAPs network. The NCC will control and manage all communications, network switching and management facility for the HAPs data system. It will also serve as the point of connectivity between partnering carriers and their customers. It will route subscriber communication to the proper platform via a ground station, store device location and usage information, and provide monitoring and test functions for overall network management.

3.3 GOMEX-HAP Network Topology

In order to decide how many HAPS are needed to provide the adequate coverage needed, we need to know the area covered by a single HAP. For a given platform altitude h , the diameter of the HAPS footprint can be computed using the formula:

$$d = 2R \left(\cos^{-1} \left(\frac{R}{R+h} \cos \theta \right) - \theta \right) \quad (3.6)$$

where R is the Earth radius (6378 km), θ is the minimum elevation angle and h the altitude.

Equation (3.6) leads to a minimum elevation angle of $\theta = 15$ degrees for a footprint diameter of $d = 152$ km and a minimum elevation angle of $\theta = 0$ degrees for a footprint diameter of $d = 1'033$ km (both at a platform altitude $h = 21$ km).

Applying the above equation give that each HAP would cover an area of $72,000 \text{ km}^2$ at $\theta = 15$ degrees.

The total area of the Gulf of Mexico = 615,000 square mile ≈ 1.6 million km^2

The radar gap of GOMEX = 60,000 square mile $\approx 144,400 \text{ km}^2$

Therefore 3 HAPs would be sufficient to cover the Non-Radar Area (NRA) gap.

In order to connect the 3 HAPs stationed above the gap with the terrestrial UMTS, we would need additional 3 **boarder HAPs** that would be connected with the Core HAPS via IPL. The high level of the network topology is shown in figure 3.9. In order to achieve best utilization of HAPs, it's recommended to station the boarder HAPs over highly populated coastal regions so it could relief the load on the terrestrial UMTS networks.

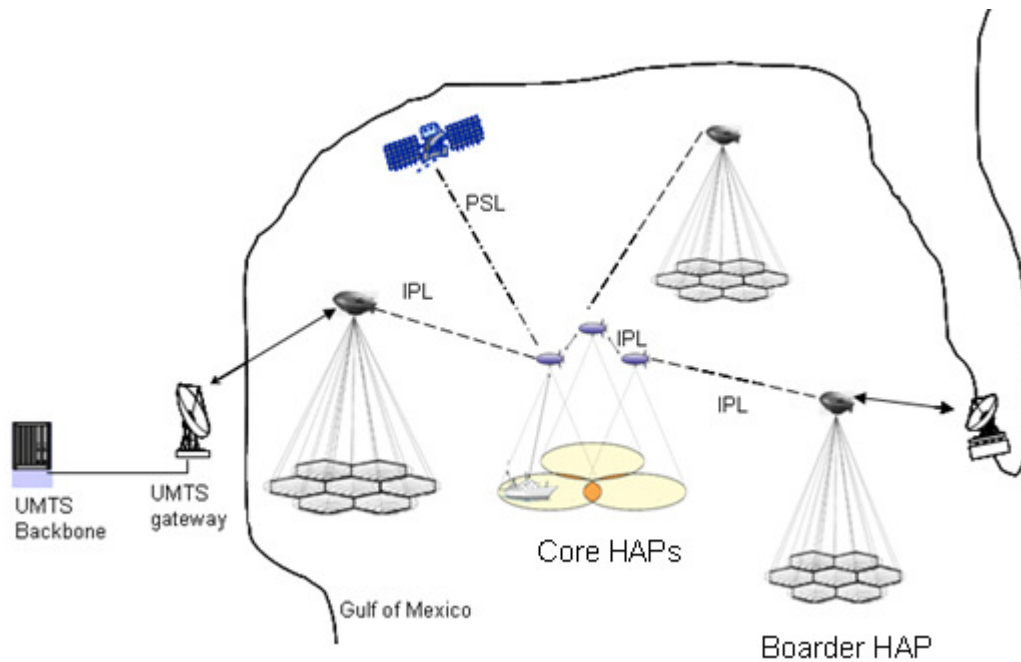


Figure 3.9 GOMEX-HAPs Net Typology

3.4 HAPS Antenna Subsystems

Since GOMEX-HAPs is intended to provide various sorts of communication services such as broadband, cellular 3G, emergency and broadcast to fixed and mobile users, therefore the antennas for both on HAPs and the users antennas are considered key elements which affect system performance.

Like any wireless communication system, the performance factor for HAPs lies in the Antenna system. The GOMEX-HAPs platforms will be operating above oceanic region; therefore it would be costly to bring down the platform for repairs or modification. Therefore, HAPs antenna should have specific requirements to make it more reliable and adaptable to HAPS operational requirements.

3.4.1 HAPS Antennas Recommendations for 2.1 GHz

For IMT-2000, the ITU-R has defined an operating frequency around 2 GHz, which will be exploited particularly in North America. For HAPS applications, newer requirements for 3G (Third Generation) cellular have been established [ITU-145, 05], whereby to maintain co-channel interference levels at a minimum, all HAPS-based ground stations should comply with the following radiation characteristics:

$$G(\psi) = G_m - 3 \left(\frac{\psi}{\psi_b} \right)^2 \quad \text{for } 0^\circ \leq \psi \leq \psi_1 \quad (3.7)$$

$$G(\psi) = G_m + L_N \quad \text{for } \psi_1 \leq \psi \leq \psi_2 \quad (3.8)$$

$$G(\psi) = X - 60 \log(\psi) \quad \text{for } \psi_2 \leq \psi \leq \psi_3 \quad (3.9)$$

$$G(\psi) = L_F \quad \text{for } \psi_3 \leq \psi \leq 90^\circ \quad (3.10)$$

where

$G(\psi)$ = gain at angle ψ from the main lobe principle direction, dBi

G_m = maximum gain at optical axis of the antenna, dBi

ψ_b = half of the 3dB beam width in the plane considered, degrees

L_N = nearest sidelobe level dB, with respect to the required peak gain for the system design, whose maximum value is -25 dB;

and $L_F = G_m - 73$, the furthest sidelobe level, dBi.

$$\psi_1 = \psi_b \sqrt{-\left(\frac{L_N}{3}\right)} \quad (3.11)$$

$$\psi_2 = 3.745\psi_b$$

$$X = G_m + L_N + 60 \log(\psi_2) \quad (3.12)$$

$$\psi_3 = 10^{\frac{X-L_F}{60}} \quad (3.13)$$

The angles ψ_1, ψ_2, ψ_3 , are given in degrees, whereas X is in dB. The 3dB beam width ($2\psi_b$) is computed as:

$$\psi_b = \sqrt{\frac{7442}{10^{0.1G_m}}} \quad (3.14)$$

The above-mentioned recommendation is only applicable for frequencies around 2 GHZ.

3.5 Rain Attenuation

Wave attenuation is positively correlated with the number of raindrops along the path, the size of the drops and the length of the path through the rain, as shown in Figure 3.10. The equation to compute wave attenuation (dB/km) is typically:

$$\gamma = aR^b$$

where a and b depend on frequency and average rain temperature and γ has units dB/km. Figure 3.10 shows values for a and b at various frequencies at 20°C for horizontal polarization [ITU-P838, 92].

Frequency (GHz)	a	b
1	0.0000387	0.912
10	0.0101	1.276
20	0.0751	1.099
30	0.187	1.021
40	0.35	0.939

Figure 3.10 Parameters for Empirical Rain Attenuation Model, extracted from [ITU-P838, 92]

The effects of rain attenuation are negligible at lower frequencies (2.1GHz and below), but significant at higher frequencies (above 20GHz). Fig 3.10 illustrates the attenuation in dB/km due to rain.

3.5.1 GOMEX-HAPs Interconnection

Due to the lack of availability of ground stations within the reach of the footprint of GOMEX-Core HAPs, and the distance between border-HAPs is too long to be connected via ground station, therefore HAPs interlinks will be either IPL or PSL. This would allow for communication between two or more contiguous platforms without the need for ground network elements and with fewer requirements for ground and uplink/downlink segments, while increasing the flexibility of system coverage. In the scenario of an IPL failure, border-HAPs will not be able to connect GOMEX-HAPs with the terrestrial UMTS, in such case, PSL will serve as back up for certain nodes, depending on the priority level of the node and the contractual agreements with the service provider.

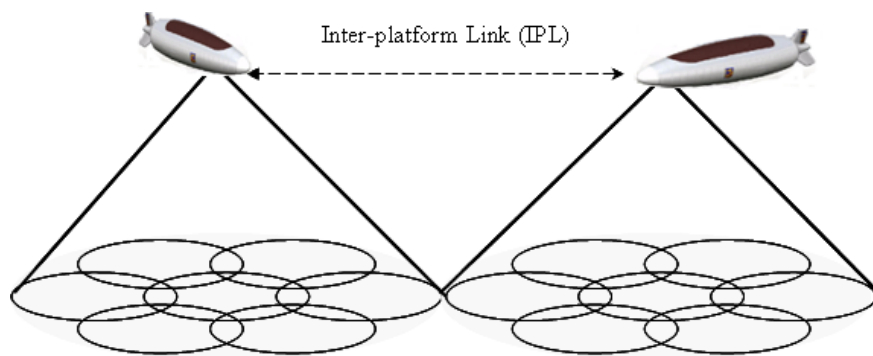


Figure 3.11 HAPS Inter-Platforms Link (IPL)

3.5.2 Integrating GOMEX-HAP with Satellite and Terrestrial Networks

For the GOMEX-HAP to be an efficient communication system it must be able to interconnect with terrestrial and satellite based networks. GOMEX-HAPs, GEO satellite and terrestrial systems can coexist to provide fixed and mobile communication service, as numerous studies have shown.

However a few important factors must be taken into account when designing this interconnected system : the *interference propagation paths* between HAPs ground stations and Fixed Satellite Service (FSS) satellites; *interference levels for frequency sharing* between High-Density Fixed Satellite Service (HD-FSS) downlink and HAPs links; *co-channel interference effects* from HAPs into UMTS terrestrial towers, including the effects of arbitrary services areas, shadowing, and reverse link co-channel interference. Further efforts are also required to establish a methodology for more realistic and applicable coordination contours between terrestrial and HAPs ground stations, and to standardize uniform interference criteria. Figure 3.12 shows the proposed integration of GOMEX-HAP, satellite and UMTS network. The GOMEX-HAPs network would connect with a '**border**' HAP via an optical link, while the latter would be connected with the terrestrial network.

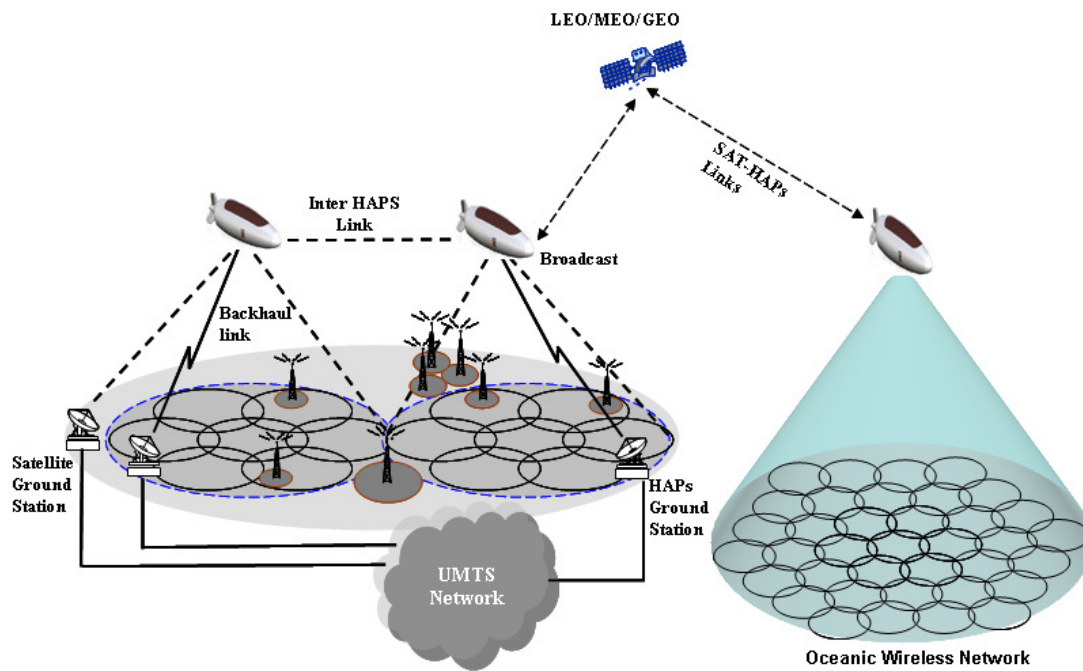


Figure 3.12 Proposed Integration of GOMEX-HAPs, Satellite and UMTS Network

4. System Modeling

In this chapter we will perform the mathematical modeling and analysis on applying the 28/31 GHz since it's the allocated spectrum for the North America region. We will study HAPs geometric footprint, then we will briefly review the basic methods to calculate signal power and link budget. Then we will perform the channel modeling and the last part of this section we will analyze the UMTS system performance in HAPs.

4.1 Geometric Footprint Analysis

In order to perform geometric analysis on HAPs footprint, the major and minor axes and their variations with the utilized antenna beam-widths and beam direction should be determined. The coverage analysis could be defined based on two assumptions; first is to assume that the earth surface is flat and then we perform the analysis based on the curved surface of earth

4.1.1 Flat Surface Analysis

In this analysis we would assume that the ground cells are formed by directing a beam using phased arrays. Referring to Figure 4.1, the HAP is stationed at an altitude about 21 km high, which is very small comparing with the earth's radius, therefore we can approximate the earth as a flat surface as shown in the figure. The footprint of the antenna beam is illustrated with this ellipse which has major and minor axes.

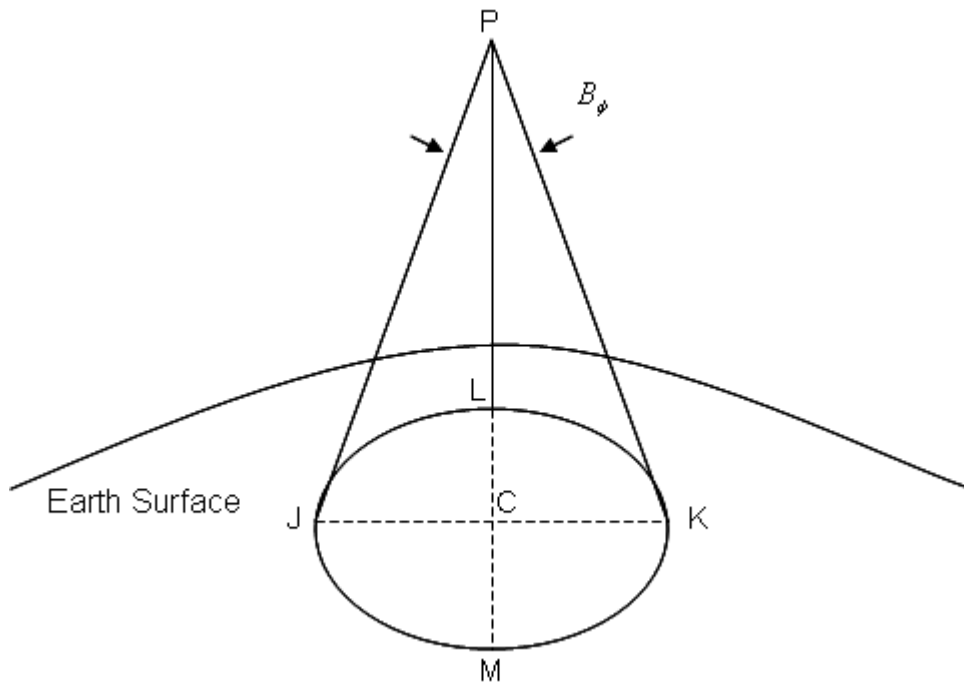


Figure 4.1 HAP Cell Footprint

Let's denote major access JK as y_f and the minor access HK as x_f . Figure 4.2 defines the cell formed by beams B_θ and B_ϕ .

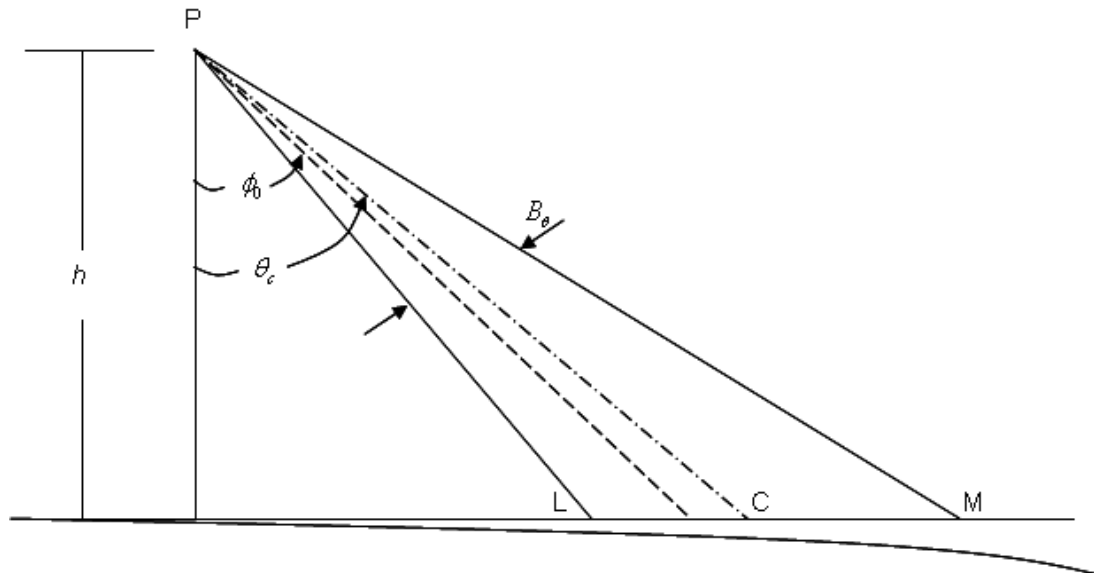


Figure 4.2 Flat Surface

In Figure 4.2, the major access LM is given as:

$$y_F = h \left(\tan \left(\theta_0 + \frac{B_\theta}{2} \right) - \tan \left(\theta_0 - \frac{B_\theta}{2} \right) \right) \quad (4.1)$$

The minor access JK is given by:

$$x_F = 2h \sec(\theta_c) \tan \left(\frac{B_\phi}{2} \right) \quad (4.2)$$

where the center of the cell (C) is located by an angle from the platform given by:

$$\theta_c = \tan^{-1} \left(\tan \left(\theta_0 - \frac{B_\theta}{2} \right) + \frac{y_F}{2h} \right) \quad (4.3)$$

So the shape of the foot print will be defined from the minor and major axis. If we use the flat surface assumption, it's easier to perform calculations but when the coverage area increases the approximation error will increase, we will not be able to use it.

4.1.2 Curved Surface Analysis

Taking into consideration the curvature of the earth surface would complicate the calculations but give more accurate results. The geometry which defines the cell formed by the antenna is shown in Figure 4.3.

In this figure, the major axis is the arc between the two ground central angles ϕ_1 and ϕ_2 is give as [23].

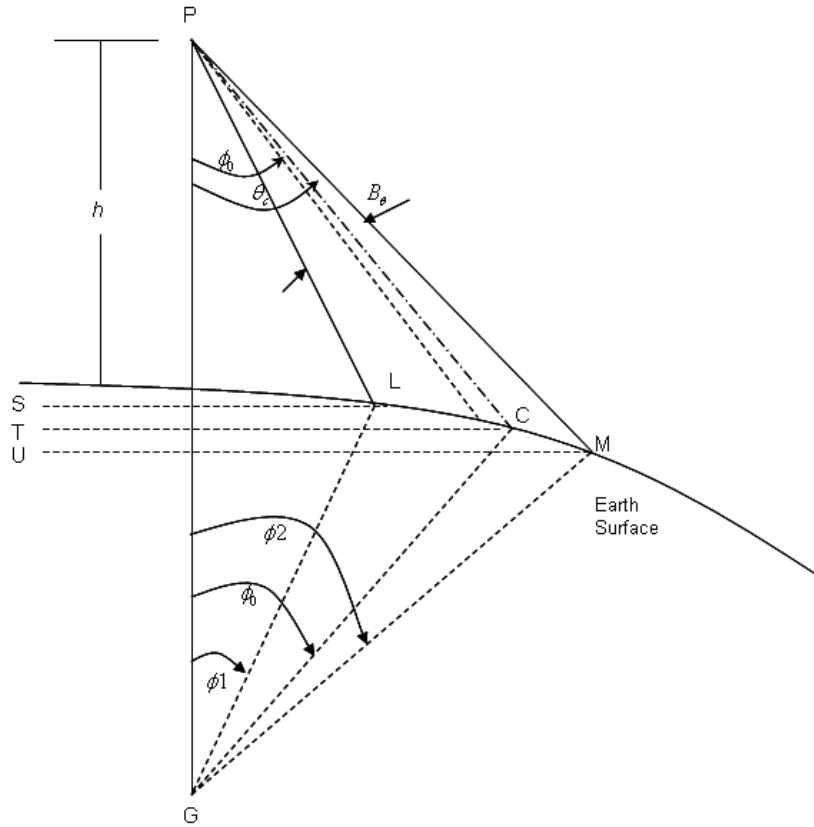


Figure 4.3 Curved Surface

In this figure, the major axis is the arc between the two ground central angles ϕ_1 and ϕ_2 is give as [footprint paper].

$$\phi_1 = \sin^{-1} \left(\left(1 + \frac{h}{R} \right) \sin \left(\theta_0 - \frac{B_\theta}{2} \right) \right) - \theta_0 + \frac{B_\theta}{2} \quad (4.4)$$

where R is the earth radius.

The cell center ground center angle is given by:

$$\phi_0 = \frac{1}{2} (\phi_1 + \phi_2) \quad (4.5)$$

The distance PT is given by:

$$PT = h + R \left(1 - \frac{1}{2} (\cos(\phi_1) + \cos(\phi_2)) \right) \quad (4.6)$$

and the distance TC is given by:

$$TC = \frac{1}{2} R ((\cos(\phi_1) + \cos(\phi_2)) \tan \phi_0) \quad (4.7)$$

The distance between the platform and the cell center PC is given by:

$$PC = \sqrt{PT^2 + TC^2} \quad (4.8)$$

From the above equations the major access y_c can be defined as:

$$y_c = LM = R(\phi_2 - \phi_1) \quad (4.9)$$

or

$$y_c = R \left(\sin^{-1} \left(\left(1 + \frac{h}{R} \right) \sin \left(\theta_0 + \frac{B_\theta}{2} \right) \right) - \sin^{-1} \left(\left(1 + \frac{h}{R} \right) \sin \left(\theta_0 - \frac{B_\theta}{2} \right) \right) - B_\theta \right) \quad (4.10)$$

So the cell center

$$\theta_c = \tan^{-1} \left(\frac{TC}{PT} \right)$$

$$\theta_c = \tan^{-1} \left\{ \frac{\tan(\phi_0)}{2 \left(1 + \frac{h}{R} \right) / (\cos(\phi_1) + \cos(\phi_2)) - 1} \right\} \quad (4.11)$$

Therefore the cell minor access x_c is given by:

$$x_c = JK = 2PC \tan \left(\frac{B_\theta}{2} \right) \quad (4.12)$$

or

$$x_c = 2h \sec(\theta_c) \tan\left(\frac{B_\phi}{2}\right) \quad (4.13)$$

which can be represented as:

$$x_c = 2R \tan\left(\frac{B_\phi}{2}\right) \left(\left(1 + \frac{h}{R} - \frac{1}{2} ((\cos(\phi_1) + \cos(\phi_2))) \right)^2 + \frac{1}{4} ((\cos(\phi_1) + \cos(\phi_2))^2 \tan^2(\phi_0)) \right)^{\frac{1}{2}} \quad (4.14)$$

The relative error in the major access between using the flat model and the curved model is given by:

$$\varepsilon_y = \frac{y_c - y_f}{y_c} * 100\% \quad (4.15)$$

The results of the MatLab simulation are reported in Chapter 5 Section 5.1. Comparing Figures 5.1 and 5.2, we notice that for both the flat surface model and the curved surface model using the directional antenna, there are variations of the cell major access with beam direction at different beam widths, and an increase in the footprint with increasing beam direction and beam width.

Also, we will notice that using the flat surface model simplifies the equations but increases the error rate, whereas the curved surface model equations are more complicated but the error rate is less. The variation in the error rate within axes is also dependent on the distance from the center of the circle and is greater in the outer circle than it is in the inner circle. Therefore we could utilize both models by applying the flat surface model with simple equation in the cell near the center where the error rate is minimal and acceptable, while for the outer cells we could apply the curved surface model.

4.2 GOMEX-HAPs Link Budget

The HAPS communication is based on the line-of-sight principle. This type of links is governed by free space propagation with only limited variation with respect to time.

There are other effects that might cause signal attenuation and cause time variation in the signal sequence. The moist in the air is one of the effects but rain rain attenuation effects are negligible at the range of 2.1GHz. In the next step we will apply the basic communication theories to define the transmitted and received powers and the loss of signal in the process.

4.2.1 Free-Space Propagation and Path Loss Theory

Path loss (or path attenuation) is the loss in signal strength of an electromagnetic wave as it propagates through space. Calculating path loss is basically to find the ratio of the transmitted power to the received power between a pair of antennas, and it is usually expressed in decibels.

The link between a given HAP and earth terminal is specified by the basic microwave radio link equation:

$$P_r = \frac{P_t G_t G_r c^2}{(4\pi)^2 D^2 F^2} \quad (4.16)$$

where

P_r is the received power by the receiver antenna in Watts;

P_t is the transmitted power by the transmitter in Watts;

G_r is the receiver gain;

G_t is the transmitter gain;

c is the speed of light ($3 \times 10^8 \text{ m/s}$)

D is the path length in which the signal travels in meters;

F is the frequency in hertz

In order to simplify the communication equation, we will represent the above equation using the decibel (dB). The formula to represent the dB gain is given as;

$$P_{\text{dB}} = 10 * \log\left(\frac{P_t}{P_r}\right) \quad (4.17)$$

The free space loss between HAP antenna and the receiver antenna L_f is given by:

$$L_f = \left(\frac{4\pi}{\lambda}\right)^2 \quad (4.18)$$

This equation could be presented as:

$$L_f = \left(\frac{4\pi r f}{c}\right)^2$$

where r is the distance between the antennas, c is the speed of light, and f is the operating frequency.

Expressing the free space loss in dB as L

$$L_f = 10 \log\left(\frac{4\pi r f}{c}\right)^2 = 20 \log\left(\frac{4\pi r f}{c}\right) \quad (4.19)$$

Therefore, the Free space loss (dB) = 32.44 + 20 log f (MHz) + 20 log r (km).

In order to estimate HAPs transmitter service area we should calculate the Effective Isotropic Radiated Power (EIRP), which is defined as the amount of power that a theoretical isotropic antenna would emit to produce the peak power density observed in the direction of maximum antenna gain. From the definition, the EIRP is given by:

$$EIRP = \int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} \rho_{\max} r^2 \sin(\theta) d\theta d\phi \quad (4.20)$$

where ρ_{\max} is the maximum time-averaged power density found over the surface of the measurement sphere. Assuming that the maximum power density can be defined using the bore-sight gain of the antenna,

$$\rho_{\max} = \frac{P_t G_t}{4\pi r^2} \quad (4.21)$$

Combine this with the equation for EIRP to get

$$\begin{aligned} EIRP &= \int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} \frac{P_t G_t}{4\pi r^2} r^2 \sin(\theta) d\theta d\phi \\ &= P_t G_t \end{aligned} \quad (4.22)$$

EIRP in db is represented as:

$$EIRP = 10 * \log(P_t G_t)$$

The next step is to find the carrier-to-noise ratio (CNR or C/N). The CNR is the quotient between the average received modulated carrier power C and the average received noise power N after the receiver filters and it is given by:

$$\frac{C}{N} = \frac{P_r}{kT_s B} \quad (4.23)$$

where:

k = Boltzmann's constant (1.38×10^{-23} J/K)

T_s = System noise temperature of receiver (K)

B = Noise bandwidth (Hz)

4.3 Channel Modeling

In this section, we will apply the small-scale fading scheme by Dosis-Fantini to identify the characteristics of the channel connecting HAP and a terrestrial user to derive the channel model in the 2.1-GHz frequency range. Rain attenuation effects will not be taken into account since they are negligible at the selected frequency range. In this analysis, the power delay profile for HAP is obtained and then the coherence bandwidth and the coherence time are evaluated.

In this channel model, illustrated in the figure 4.4 shown below, the HAPs platform or transmitter (TX) is assumed to be at a point in space with coordinates $(0, 0, z_0)$, and the ground receiver (RX) is assumed at a point in space with coordinates $(x_0, 0, 0)$, where x_0 and z_0 are not at the same horizontal plane.

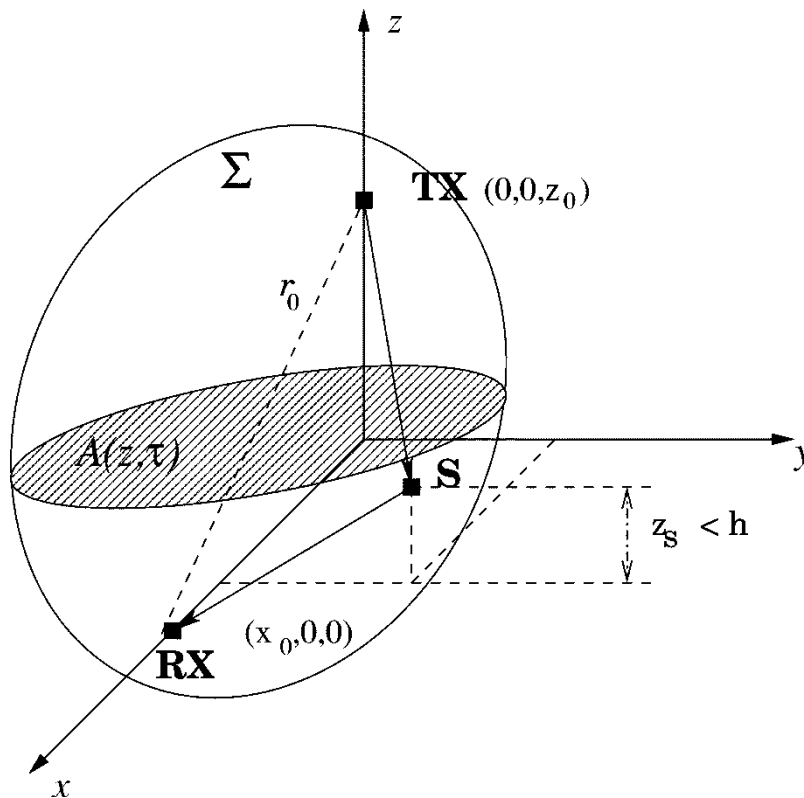


Figure 4.4 Channel Model [2]

Consider the ellipsoid Σ as the boundary containing the scatterers that cause excess delays $< \tau$ e.g. S, with a height $z_s < h$, and assume that S is uniformly distributed in a thin layer close to the ground, since scatterers are typically land structures which are within a certain height h .

Then the length of the direct transmission path r_0 is calculated by:

$$r_0 = \sqrt{x_0^2 + z_0^2} \quad (4.24)$$

and consequently, the propagation delay is obtained as:

$$\tau_0 = \frac{r_0}{c} \quad \text{where } c \text{ is the speed of light} \quad (4.25)$$

A reflected wave that is incident on the receiver with an excess delay τ will have covered a path length given by

$$k(\tau) = r_0 + c\tau \quad (4.26)$$

TX and RX are points which form the foci of the ellipsoid Σ , where the sum of the distance from TX and RX equals $k(\tau)$. Thus, all the scatterers in Σ generate a total path length $< k(\tau)$, and any reflected ray with an excess delay $< \tau$, i.e. with total path length $< k(\tau)$, must be associated with a scatterer S located in the ellipsoid Σ . The area $A(z, \tau)$ is the intersection of the ellipsoid Σ with a horizontal plane at the height z .

The volume $\mathbf{V}(\tau)$ is the space containing the scatterers with an excess delay smaller than τ and it is obtained from the intersection between the ellipsoid Σ and the plane $z = h$ is defined as the set of points (x, y, z) that satisfies the condition:

$$\sqrt{(x-x_0)^2 + y^2 + z^2} + \sqrt{x^2 + y^2 + (z-z_0)^2} < k(\tau) \quad (4.27)$$

where $0 < z < h$

An evaluation of the area $A(z, \tau)$ of the ellipse due to the intersection of the ellipsoid with a horizontal plane of height z and an integration of $A(z, \tau)$ with respect to z from 0 to h yields :

$$v(\tau) = \frac{-\pi\omega(\tau)(r_0 + c\tau)}{4\sqrt{(z_0^2 + \omega(\tau))^3}} \left[\frac{4}{3}h^3 - 2z_0h^2 - \omega(\tau)h \right] \quad (4.28)$$

$$\text{where } \omega(\tau) = c^2\tau^2 + 2r_0c\tau \quad (4.29)$$

The cumulative distribution function (cdf) of the excess delay, $F_{\text{ps}}(\tau)$ is then expressed as the ratio between the volume $\mathbf{V}(\tau)$ and that corresponding to the maximum excess delay of the system, $\mathbf{V}(\tau_m)$. That is:

$$F_{\text{ps}}(\tau) = \frac{V(\tau)}{V(\tau_m)} \quad (4.30)$$

where τ_m is the maximum excess delay beyond which the received power $\mathbf{P}(\tau)$ is very small. There are still no available measurements for τ_m in the HAPs scenario although

values are well known in the terrestrial scenario, so instead estimated values obtained from conventional aircrafts are used to approximate a nominal value for τ_m .

The results of simulation are shown in chapter 5. MATLAB application is utilized to simulate the multipath fading channel, where the paths are arrayed at equidistance from $\tau \approx 0$ to $\tau \approx \tau_m$. First, assume the initial path is in the LOS where the delay $\tau \approx 0$. The other paths through the Nth path are each delayed in time so as to achieve a multipath reception. Second, derive the time-varying effect of the channel by multiplying the delayed input by a unity power fading process $r_i(t)$. Third, simulate the fading process by obtaining a Gaussian distribution of the array which is band-limited with an FIR filter of bandwidth corresponding to the maximum Doppler spread f_m . Fourth, multiply the delayed and fading input with the corresponding gain factor $\sqrt{P_i}$ according to the power delay profile. Finally, obtain the final output by summing the outputs from all the paths with additive white Gaussian noise (AWGN).

The development of the channel model assumes that the height of the scatterers h and the distance of the receiver from the sub-platform point x_0 can be representative of the entire class of the cumulative distribution functions of the excess delay. This is confirmed when the plots of different values of x_0 with h constant are compared with the plots of different values of h with x_0 constant, and all the plots are the same shape.

4.3.1 HAPS Downlink Analysis

In this analysis, we will perform HAPS downlink capacity of a UMTS-HSDPA. Referring to Figure 4.5, we assume a BS_j ($j = 0, \dots, J$) represents a HAP base station (BS) serving the j th cell, as shown in Fig. 4.5. Therefore, for mobile located at (r, θ) in the reference cell served by BS_0 , the carrier-to-noise and interference ratio (CNIR) is given by:

$$CNIR = \frac{G P_{ru}}{P_{intra} + P_{inter} + P_N} \quad (4.31)$$

where

G is the UMTS-HSDPA processing gain (Spreading Factor) = 16

P_{ru} is the received power of the desired signal of the UMTS-HSDPA user under consideration

P_{intra} is the received intracellular Interference

P_{inter} is the received intercellular Interference

P_N is the receiver thermal noise

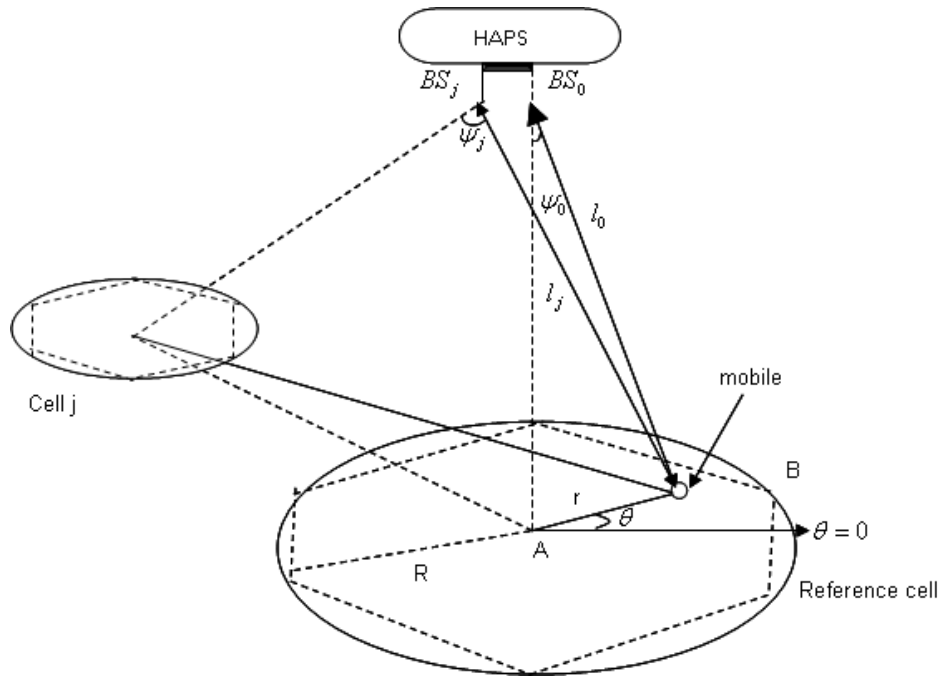


Figure 4.5 Downlink Analysis of a UMTS- HSDPA [21]

Equation (4.20) could be rewritten as [Taha, 21]:

$$CNIR = \frac{G_p \kappa P_u G(\psi_0) l_0^{-s} \zeta_0}{\kappa (P_{T0} - P_u) G(\psi_0) l_0^{-s} \zeta_0 \phi + \kappa \sum_{j=1}^J P_{Tj} G(\psi_j) l_j^{-s} \zeta_j + P_N} \quad (4.32)$$

where

κ is the propagation loss factor

P_u is the power assigned to the UMTS-HSDPA user under consideration

$G(\psi_0)$ is the normalized antenna gain in dB evaluated at the angles under which the mobile is seen from the antenna boresights of \mathbf{BS}_0 .

$G(\psi_j)$ is the normalized antenna gain measured in dB evaluated at the angles under which the mobile is seen from the antenna boresights of \mathbf{BS}_j

l_0 is the distances from the mobile to \mathbf{BS}_0 ,

l_j is the distance from the mobile to \mathbf{BS}_j .

P_{Tj} is the total power transmitted by the cell j

ζ_0 signify the shadowing corresponding to l_0 in dB

ζ_j and ζ_0 signify the shadowing corresponding to l_j in dB

s is the path loss exponent = 2

ϕ is the non-orthogonality factor

J is the number of cells in the HAP constellation that contribute in the intercellular interference

The effective path loss L between the HAP and the UMTS-HSDPA user under consideration is given by :

$$L(\text{dB}) = 20 \log_{10} \left(\frac{4\pi d}{\lambda} \right) + L_{BPL} + L_{shd} - G_{ant-HAP} (\text{dB}) \quad (4.33)$$

where

d is the distance between the HAP and the user in meters.

λ is the wavelength.

L_{BPL} is the additional penetration loss assumed to be 12 dB

L_{shd} is the shadowing margin assumed to be 10 dB in urban zones and 5 dB in rural zones

$G_{ant-HAP}$ is the HAP antenna gain at the boresight given in dB

The factor κ is given by :

$$\kappa = \frac{1}{10^{L(\text{dB})/10}} \quad (4.34)$$

The power P_u assigned to the HSDPA user under consideration is given as:

$$P_u = \frac{P_{HSDPA}}{N_u} \quad (4.35)$$

where

N_u is the number of the HSDPA users per cell and

P_{HSDPA} is the power assigned for the HSDPA user's channels $\approx 20\%$ of the maximum transmitted power by the base station (HSDPA offered on a best effort basis with a minimum reserved power)

Since the transmit antenna beams of all base stations essentially originate from the same point, so $l_j = l_0$ and $\zeta_j = \zeta_0$ (total correlation). Thus, the carrier-to-noise and interference ratio CNIR can be given as [21]:

$$CNIR = \frac{G_p \kappa P_u G(\psi_0) l_0^{-s} \zeta_0}{\kappa (P_{T0} - P_u) G(\psi_0) l_0^{-s} \zeta_0 \phi + \kappa \sum_{j=1}^J P_{Tj} G(\psi_j) l_0^{-s} \zeta_0 + P_N} \quad (4.36)$$

When P_N is very small compared to the interference power, CNIR can be written as:

$$CNIR \approx \frac{G_p \kappa P_u G(\psi_0) l_0^{-s} \zeta_0}{\kappa (P_{T0} - P_u) G(\psi_0) l_0^{-s} \zeta_0 \phi + \kappa \sum_{j=1}^J P_{Tj} G(\psi_j) l_0^{-s} \zeta_0} \quad (4.37)$$

This can be re-written as:

$$CNIR \approx \frac{G_p P_u G(\psi_0)}{(P_{T0} - P_u) G(\psi_0) \phi + \kappa \sum_{j=1}^J P_{Tj} G(\psi_j)} \quad (4.38)$$

The downlink performance is studied with the following assumptions:

- Height of HAP = 20 km
- Cell radius $R = 2$ km
- P_T (full load) = 10 W/cell
- $P_{HSDPA} = 2$ W/cell regardless of cell load
- HAP antenna gain at zero angle of 37 dB with 3 dB beam width of 2.42°
- $P_N = 100$ dBm
- Frequency of operation = 2.14 GHz
- $G_p = 16$
- $J = 60$

Also, we will use the values of required CNIR at dB loss of 1 as shown below:

Modulation Scheme	Code Rate	Required CNIR (dB)
16QAM	7/8	16
16QAM	1/2	11
QPSK	7/8	10
QPSK	1/2	5

Figure 4.6 Required CNIR at 1 dB loss [22]

In chapter 5, the performance of HAPs HSDPA for two directions (0° and 30°) within the cell, simulating different scenarios for users at a given distance from the cell center and at different orientations, has been analyzed and compared. The results show that for users at a random orientation, the CNIR of the two directions (0° and 30°) represents the envelope of the CNIR values for those users. They also show differences in the performances for urban versus rural areas. For urban users, the CNIR effective range is lower; the HSDPA mode can support 16QAM with code rate of 1/2 and QPSK modulation schemes when cells are not fully loaded, but only QPSK with code rate of 1/2 if fully loaded.

5. MAT-LAB Results

5.1 Footprint Results

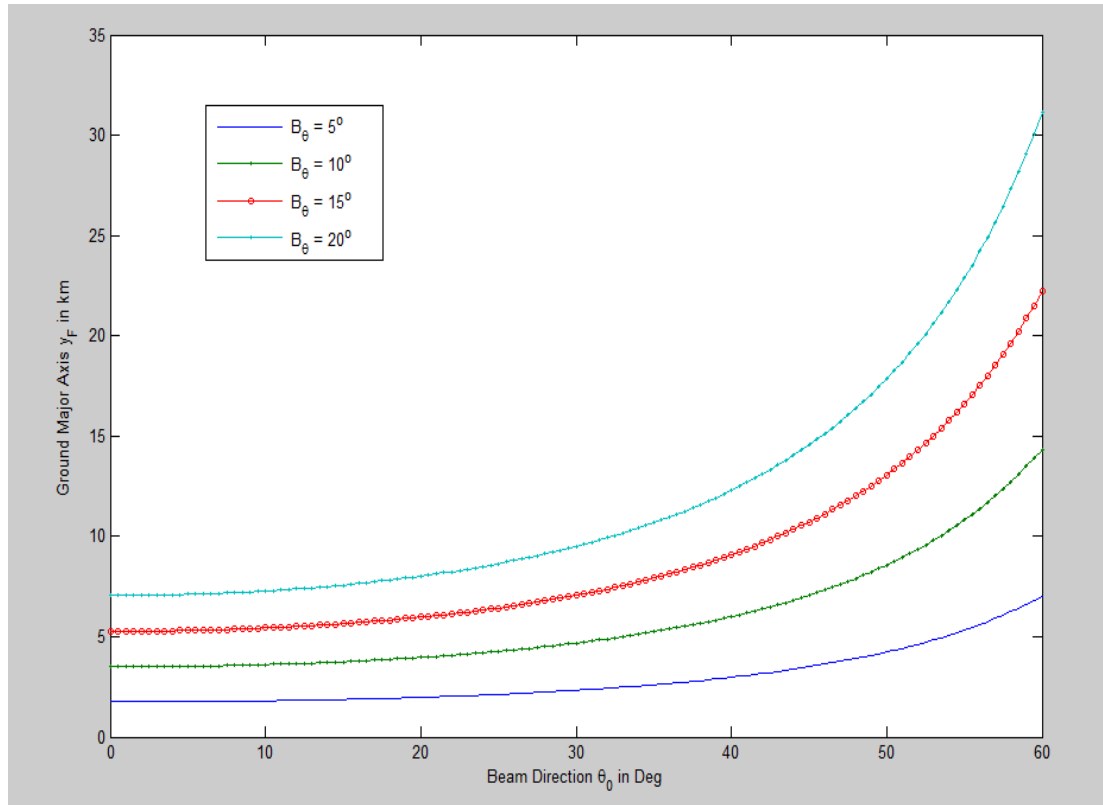


Figure 5.1 Variations of the cell major axes (y) with the beam direction θ_0 at different beamwidths B_θ for flat surface (y_F) coverage models using directional antennas.

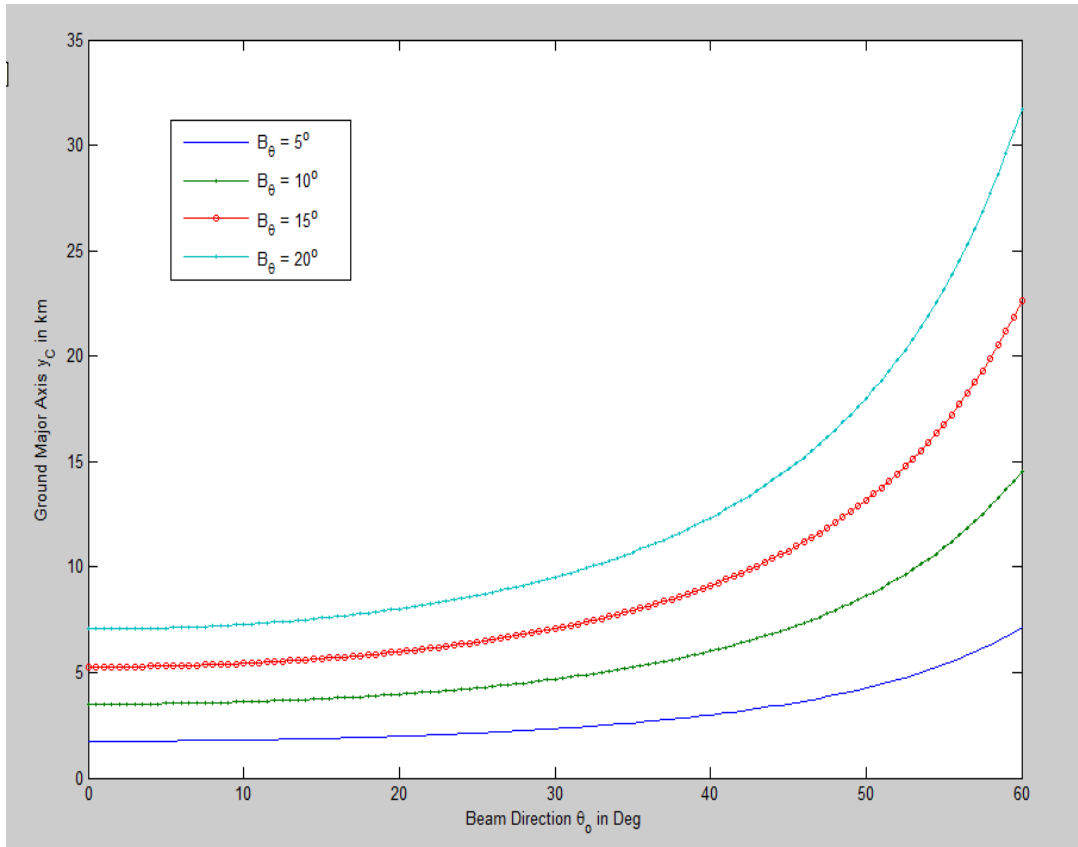


Figure 5.2 Variations of the cell major axes (y) with the beam direction θ_0 at different beamwidths B_θ for curved surface (y_C) coverage models using directional antennas.

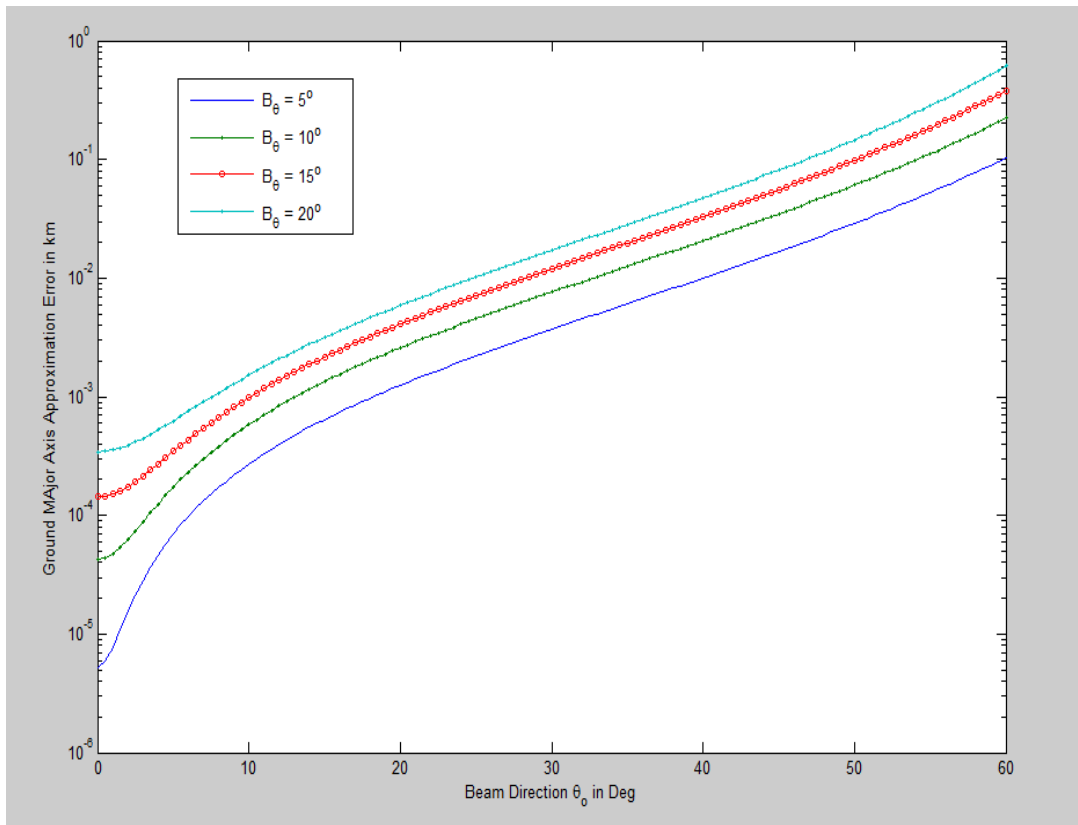


Figure 5.3 Absolute error variation between major access flat surface model and curved surface model with beam direction at different beamwidths.

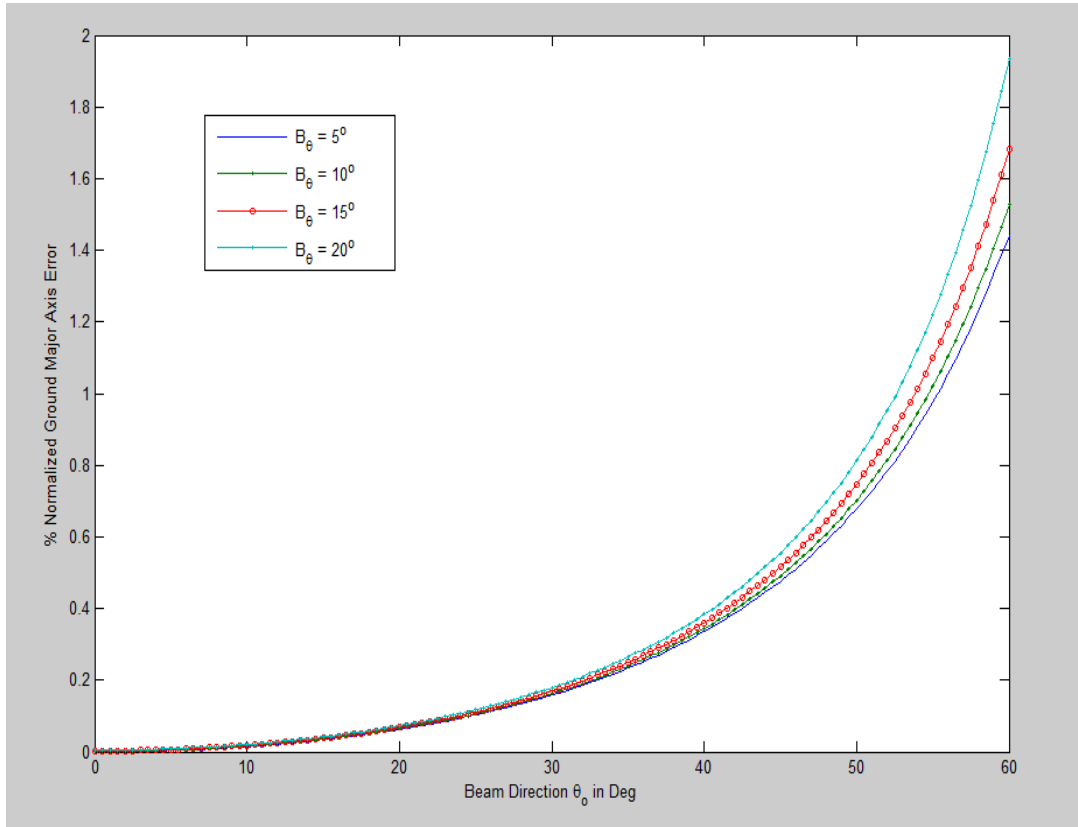


Figure 5.4 Relative error variation between major access flat surface model and curved surface model with beam direction at different beamwidths.

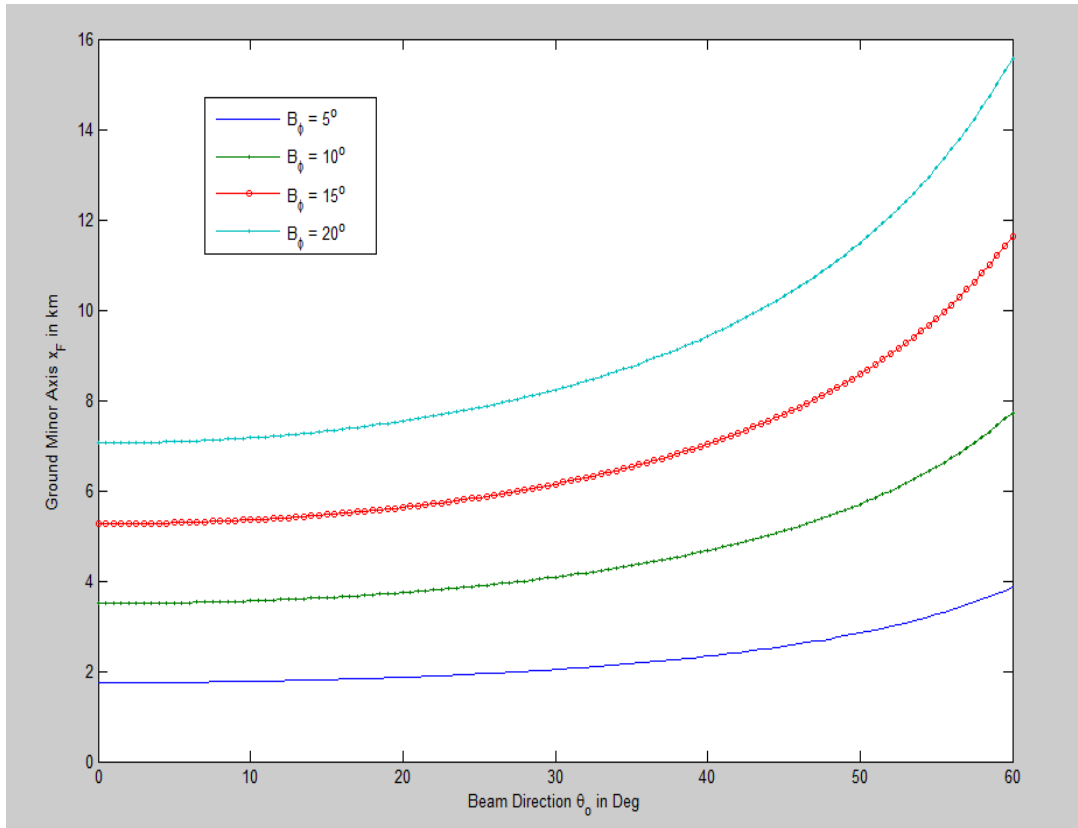


Figure 5.5 Variations of the cell minor axes (x) with the beam direction θ_0 at different beamwidths B_θ for flat surface (x_F) coverage models using directional antennas.

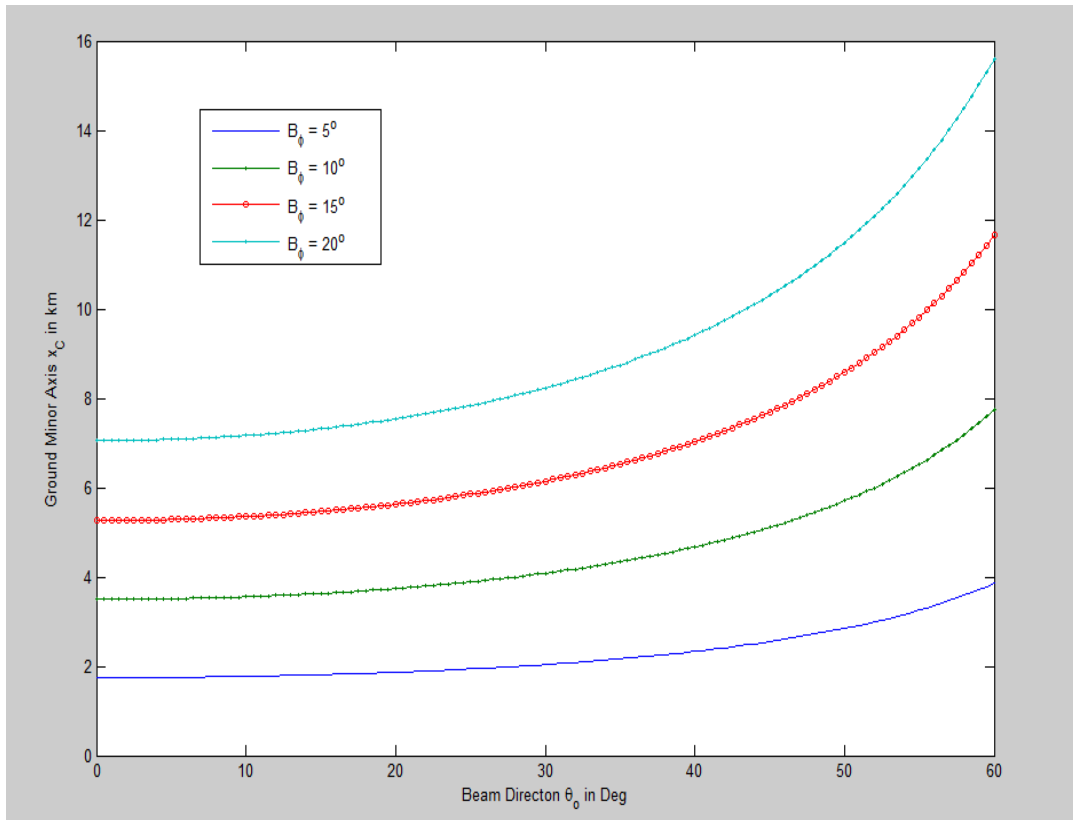


Figure 5.6 Variations of the cell minor axes (x) with the beam direction θ_0 at different beamwidths B_θ for curved surface (x_C) coverage models using directional antennas.

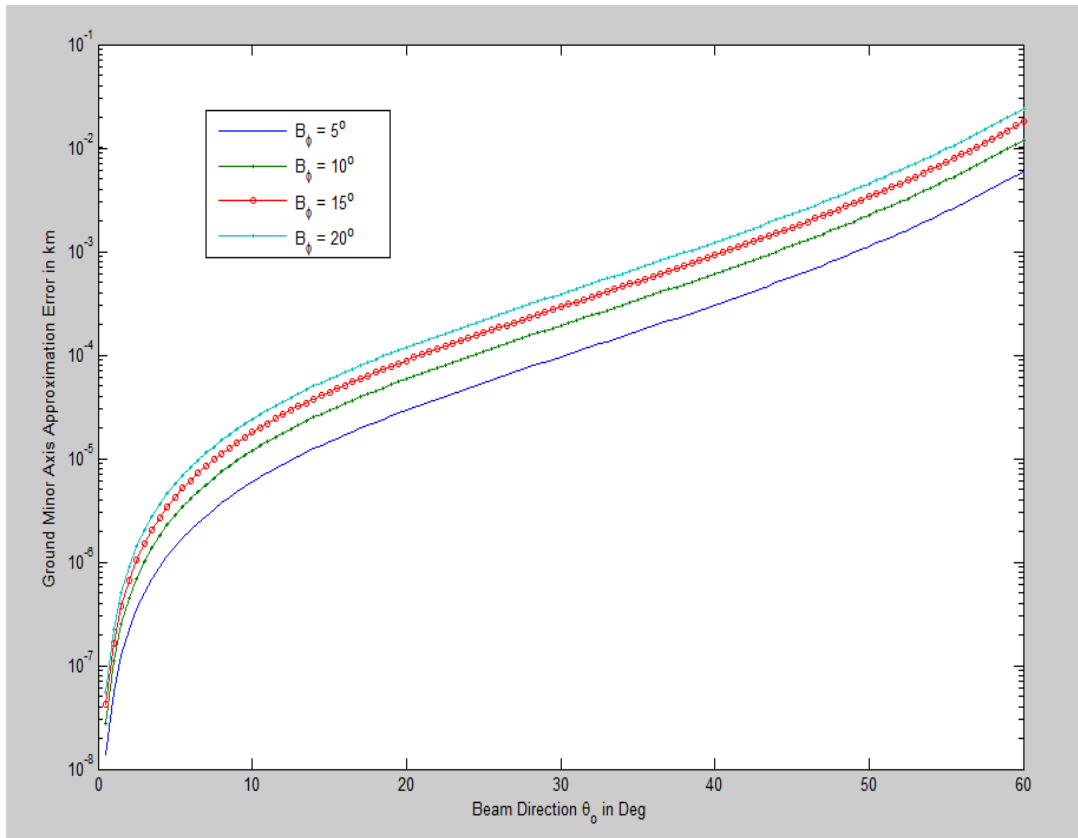


Figure 5.7 Absolute error variation between minor access flat surface model and curved surface model with beam direction at different beamwidths.

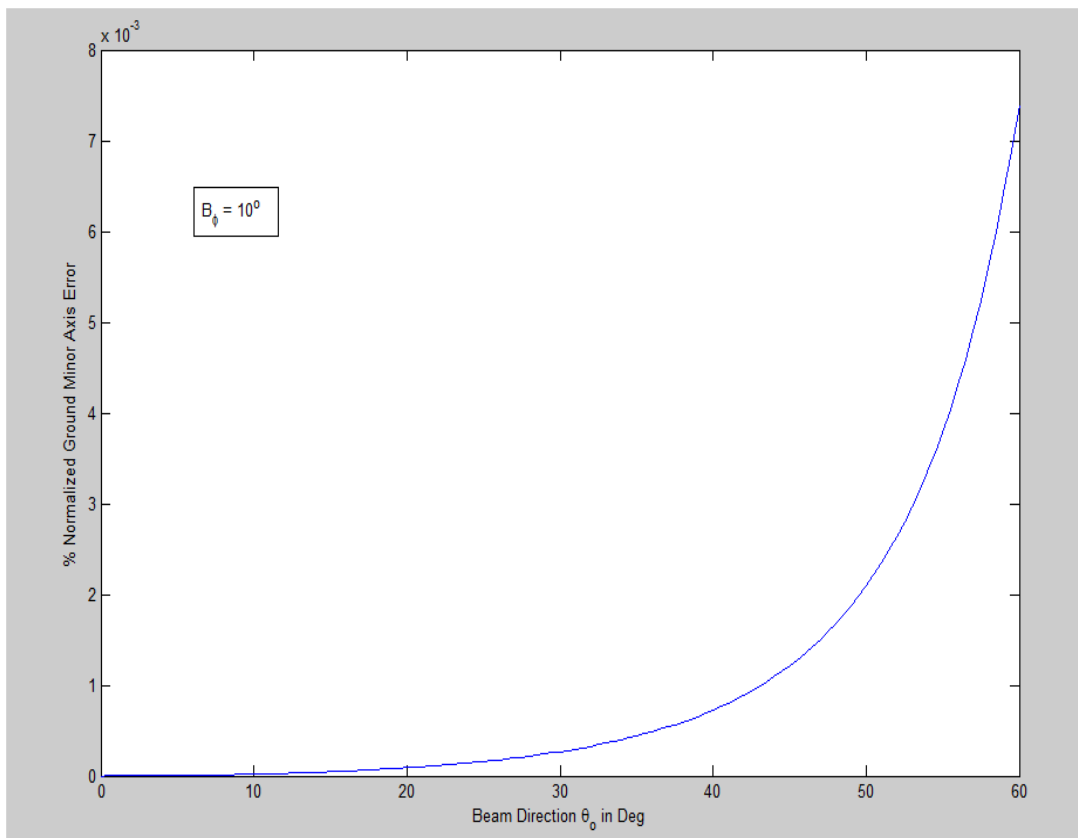


Figure 5.8 Relative error variation between major access flat surface model and curved surface model with beam direction at different beamwidths

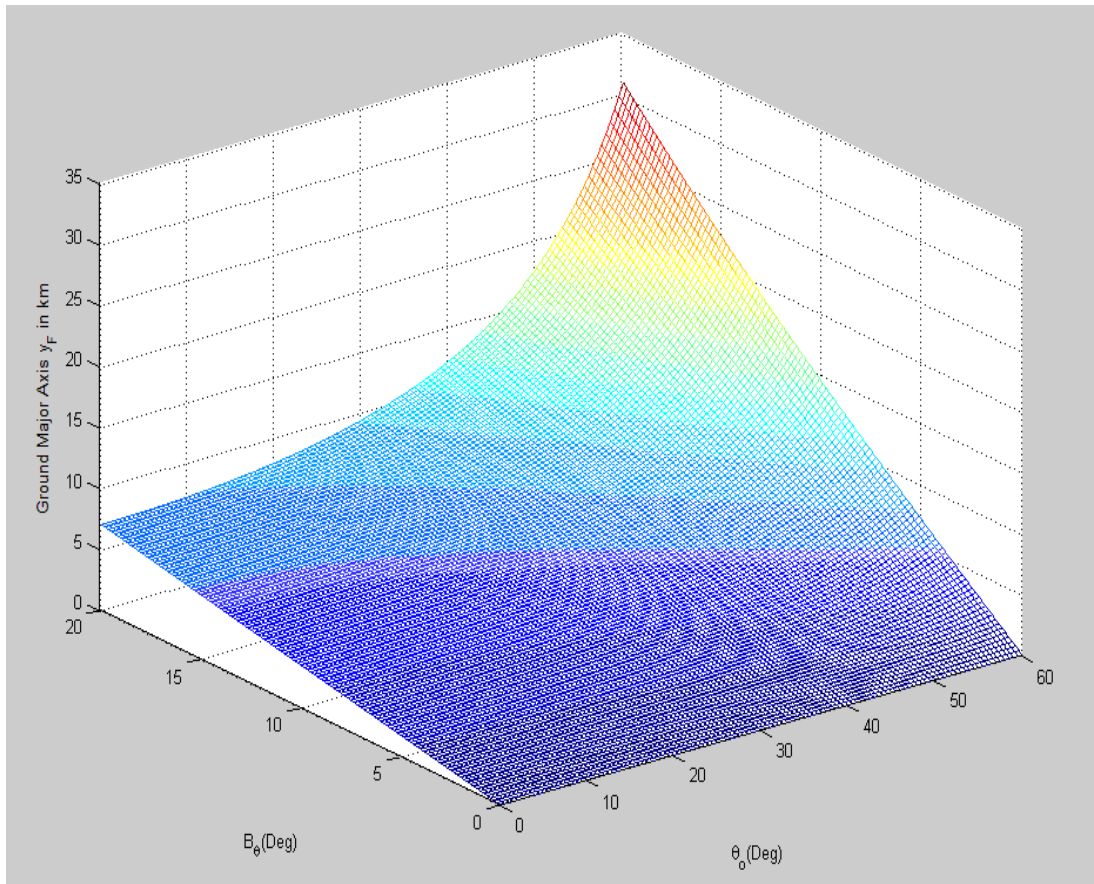


Figure 5.9 3-D illustration of flat surface major access variation with beam direction at different beamwidths

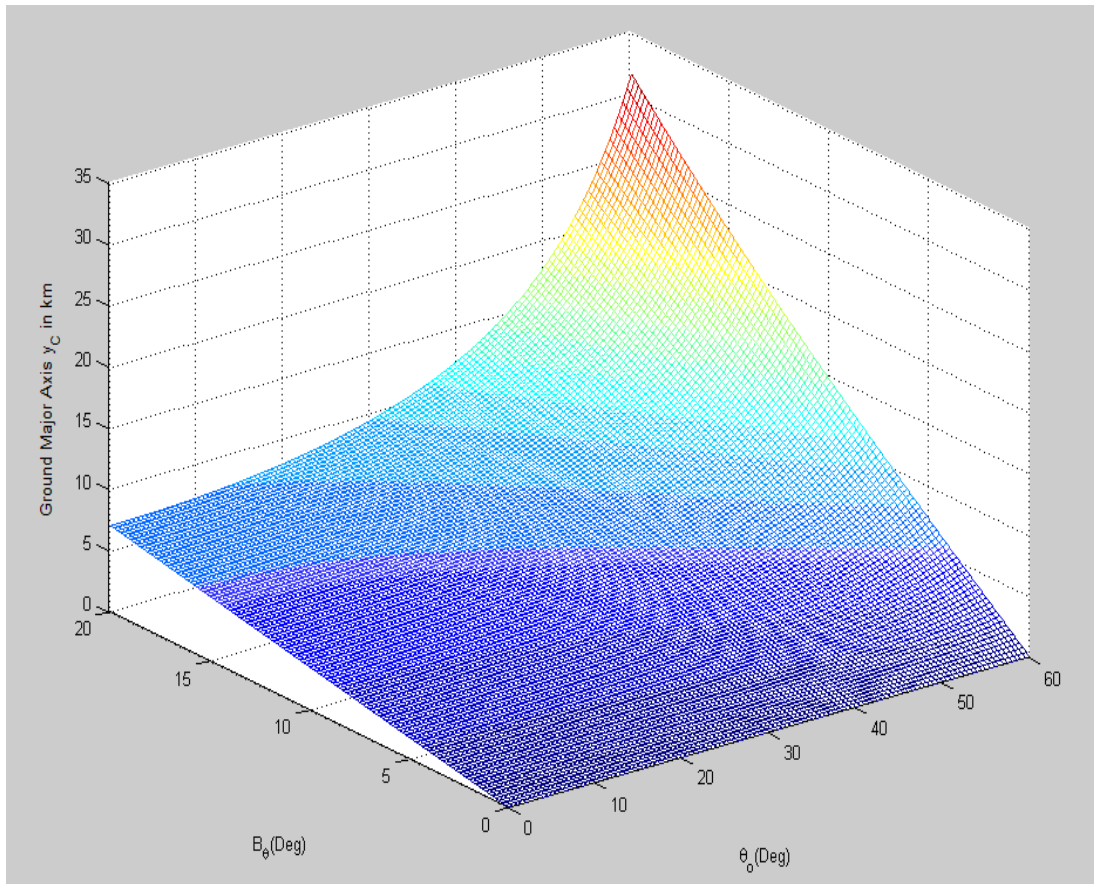


Figure 5.10 3-D illustration of curved surface major access variation with beam direction at different beamwidths

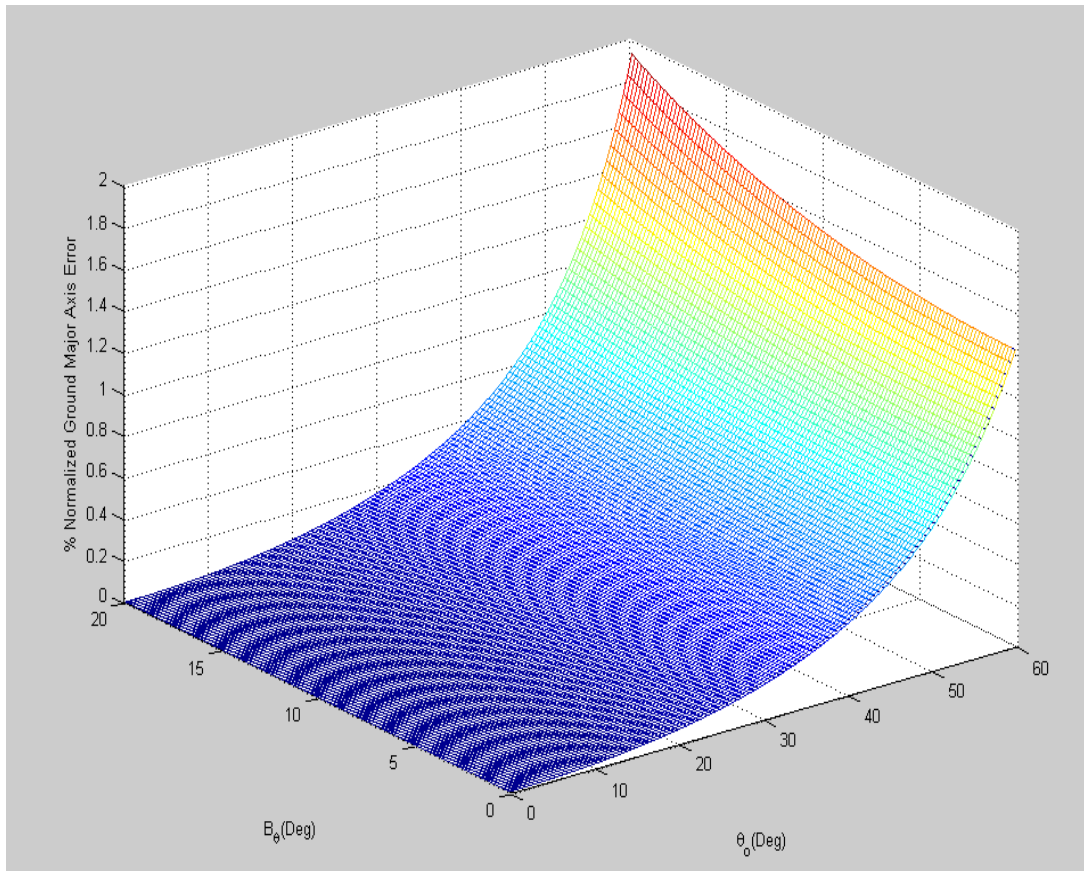


Figure 5.11 Major access absolute error variations represented in 3-D

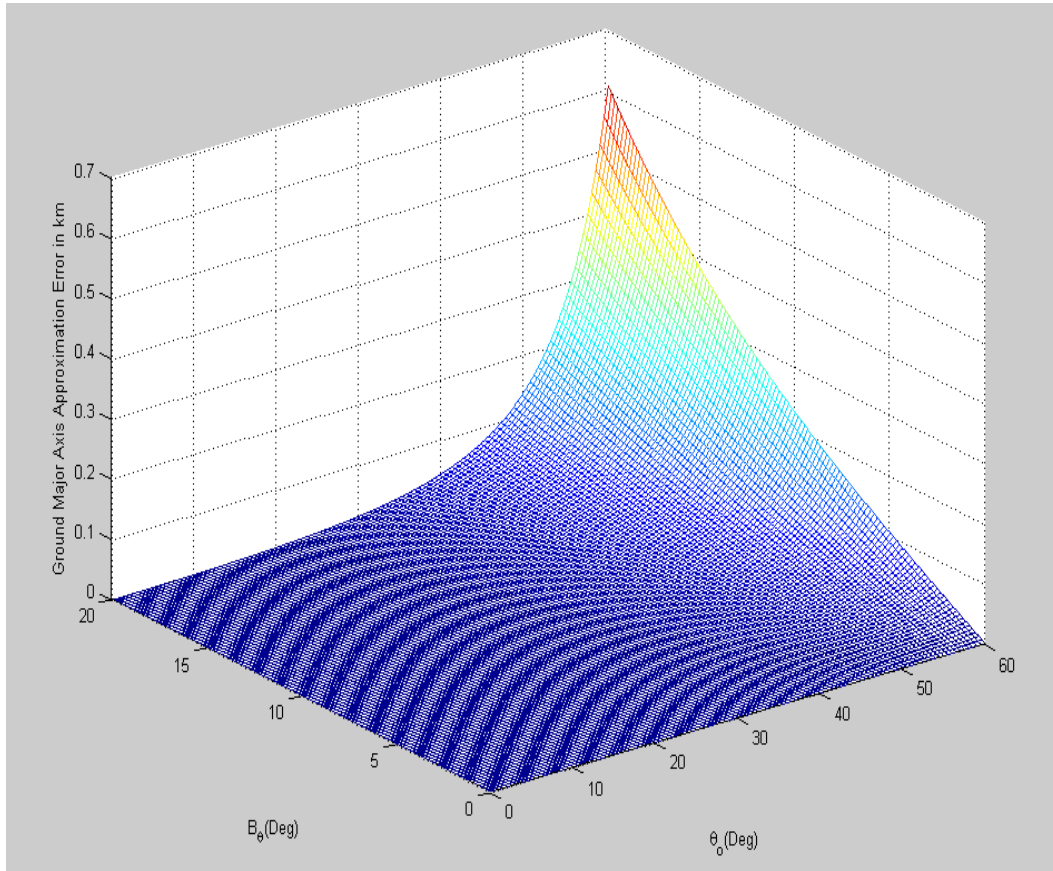


Figure 5.12 Major access relative error variations represented in 3-D

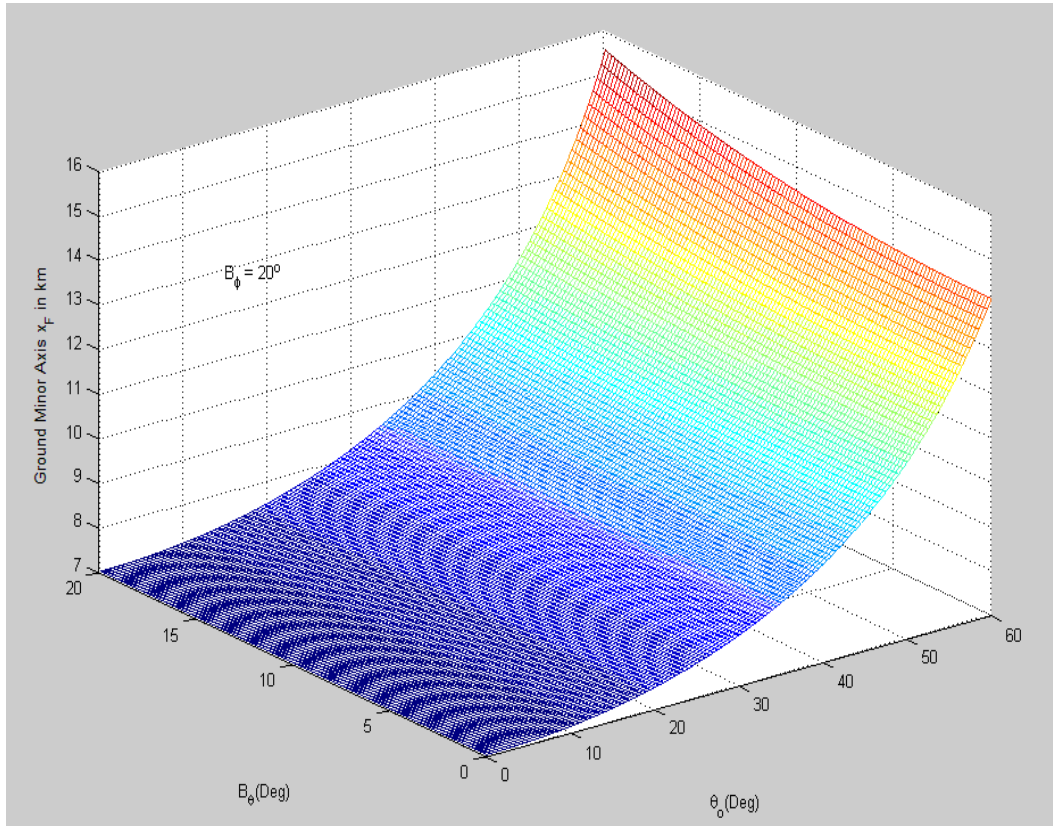


Figure 5.13 3-D illustration of flat surface minor access variation with beam direction at different beamwidths

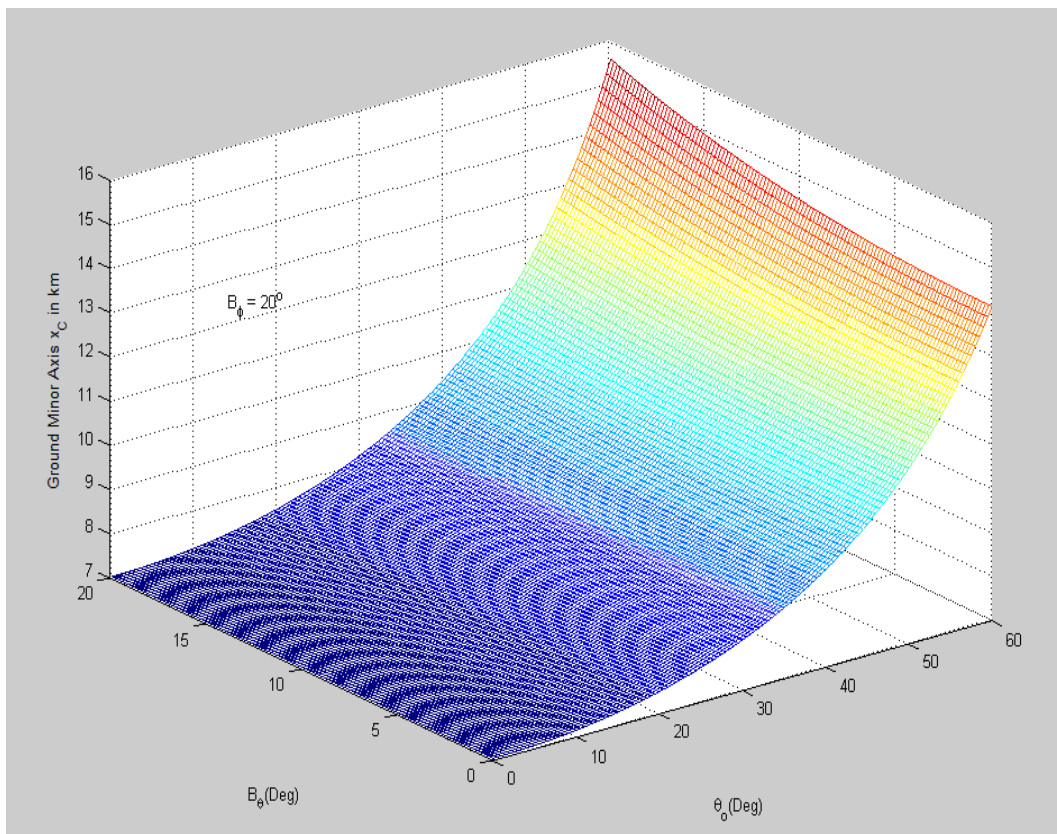


Figure 5.14 3-D illustration of curved surface minor access variation with beam direction at different beamwidths

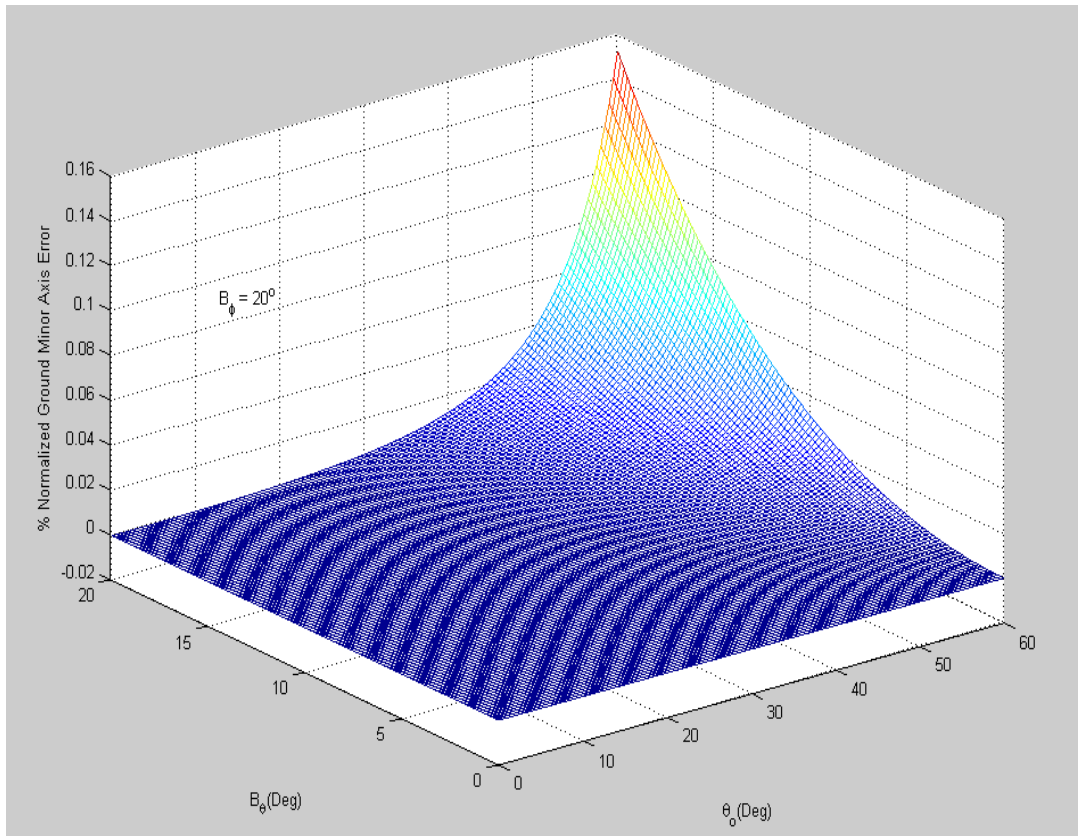


Figure 5.15 Minor access absolute error variations represented in 3-D

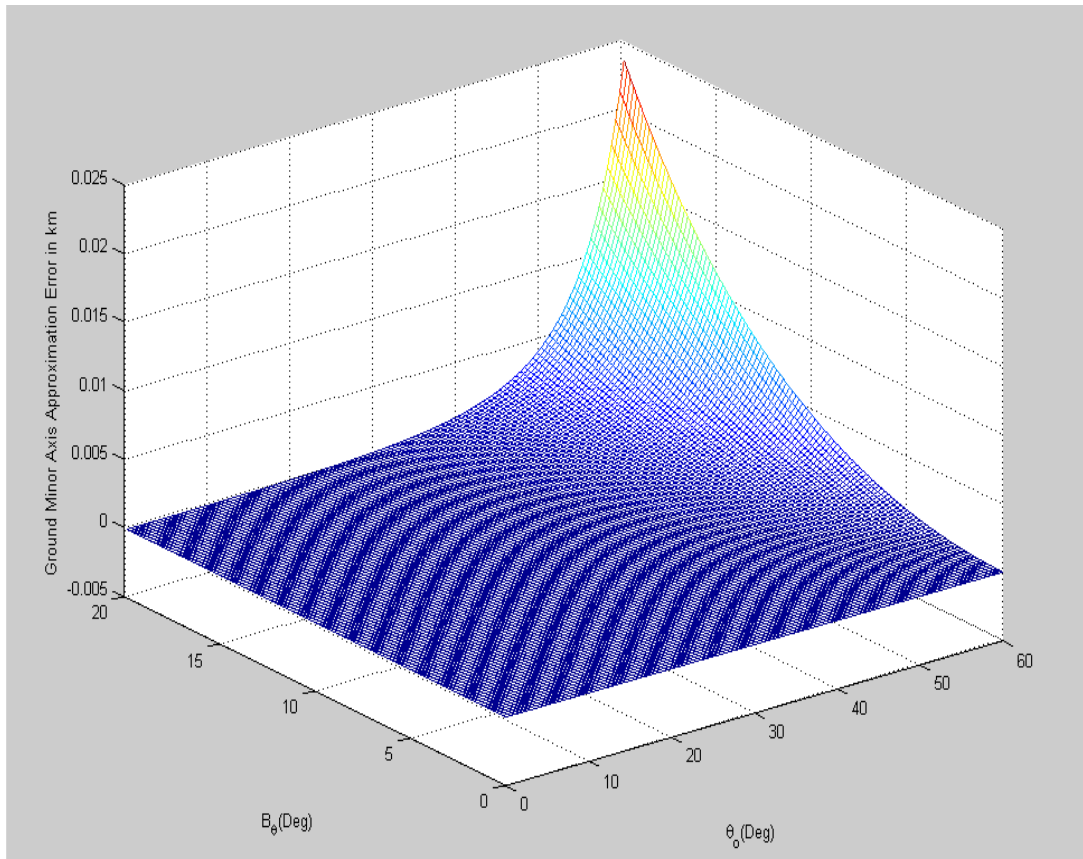


Figure 5.16 Minor access relative error variations represented in 3-D

5.2 Channel Modeling Results

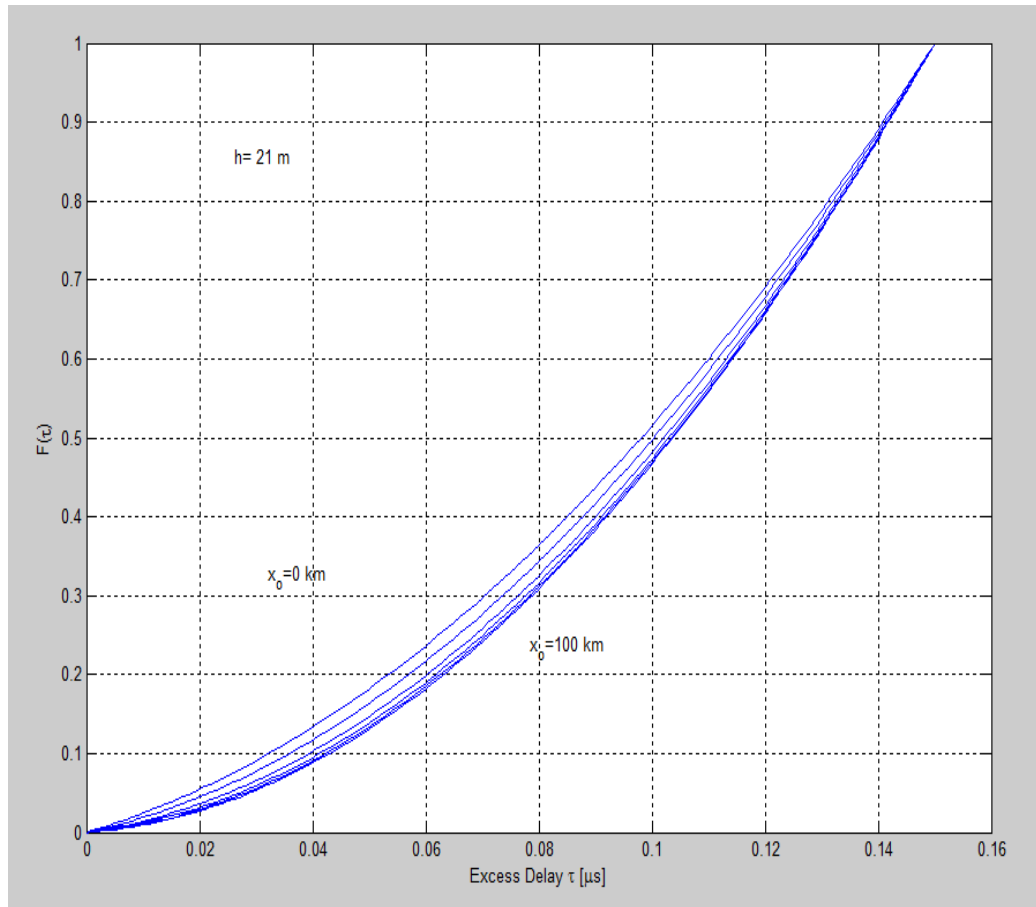


Figure 5.17 Excess delay cumulative distribution with $\tau_m = 0.15\mu s$, $h=21$ m, $z_0 = 20$ km, and x varying from 0 to 100 Km with step 20 Km.

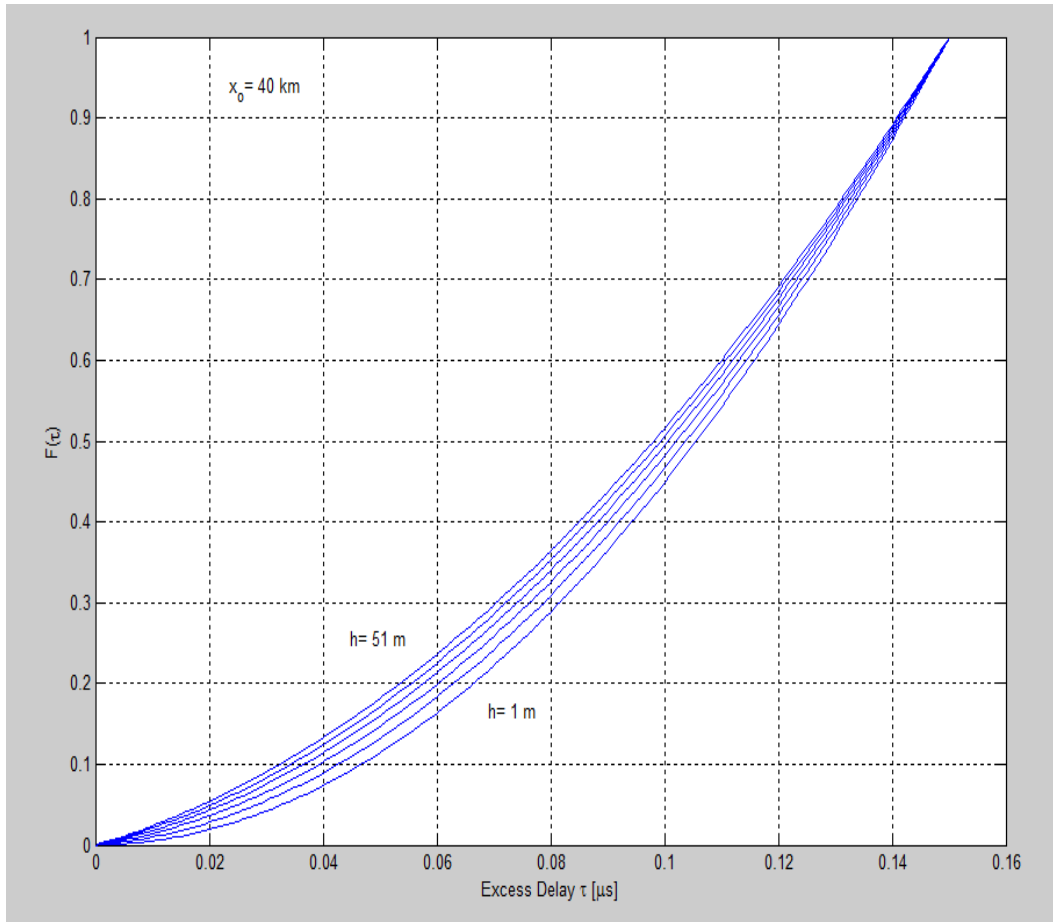


Figure 5.18 Excess delay cumulative distribution with $\tau_m = 0.15\mu s$, $x_0 = 40\text{km}$, $z_0 = 17\text{km}$, and varying from 1m to 51 with step 10m.

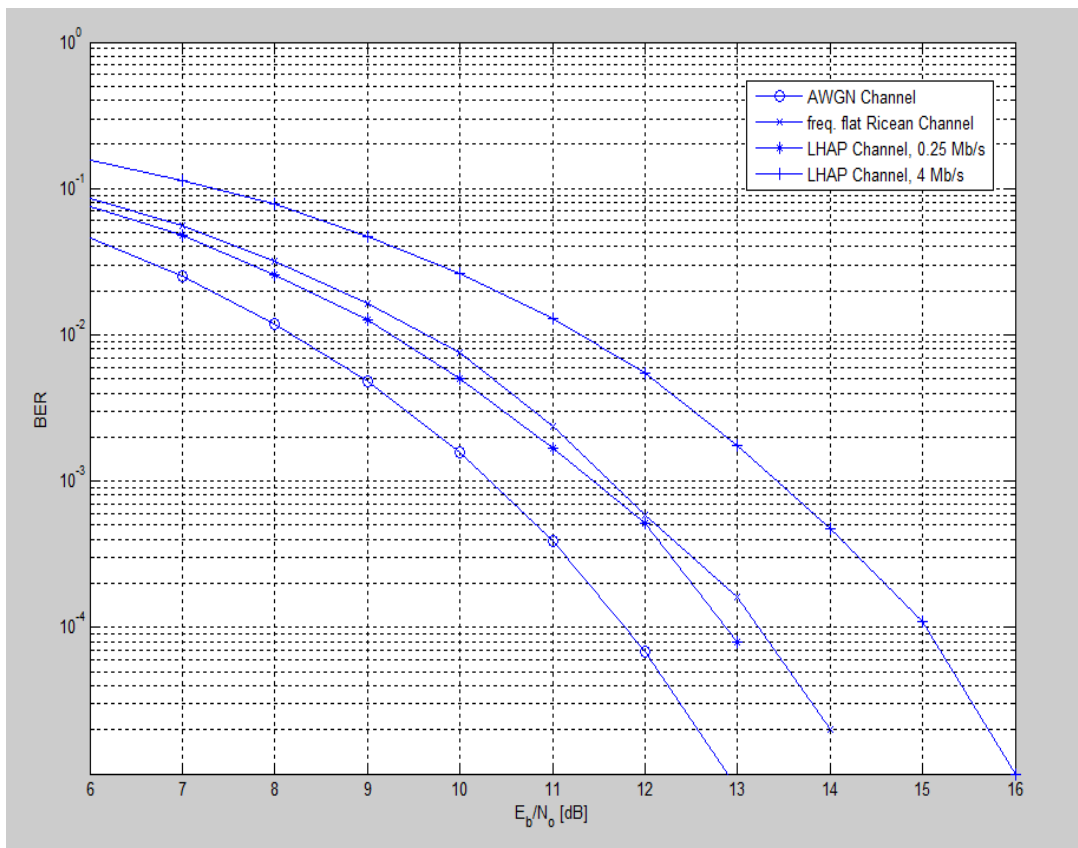


Figure 5.19 BER for a 4-DPSK transmission scheme obtained over AWGN, frequency-flat Ricean and stratospheric channel with a C/M ratio of 18 dB, at a bit rate of 0.25, 1, 4 Mb/s.

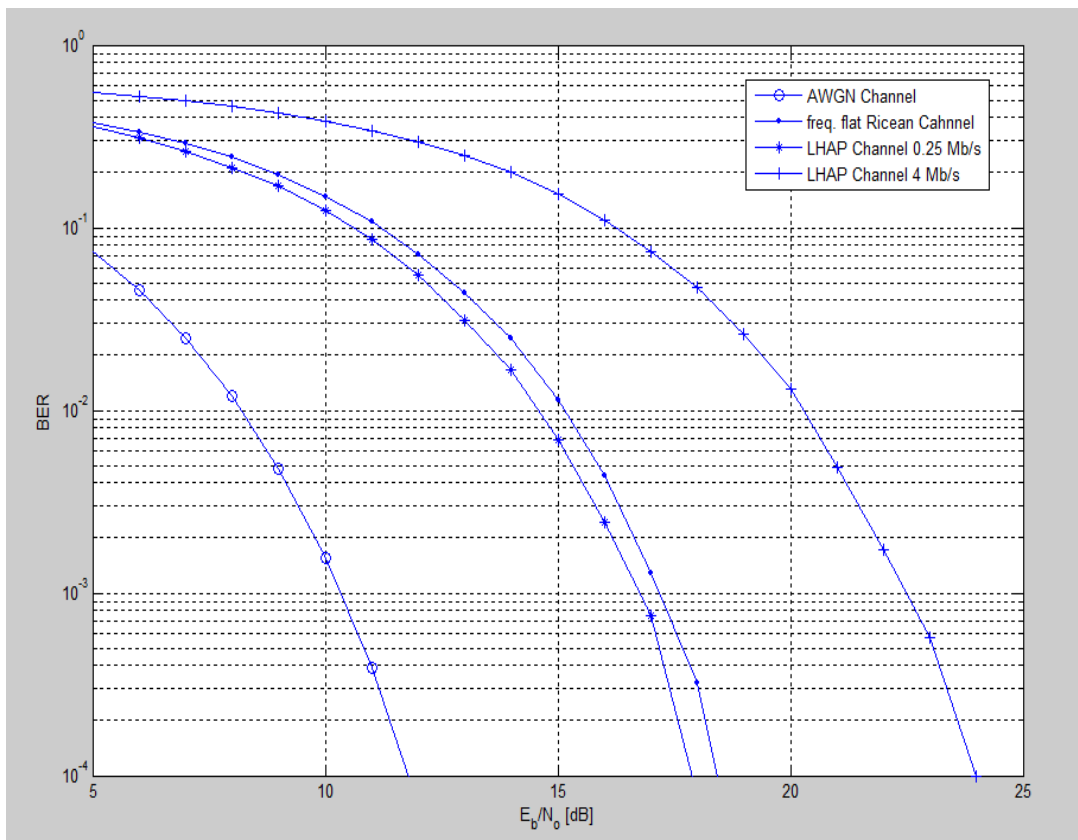


Figure 5.20 BER for a 4-DPSK modulation obtained over AWGN, frequency-flat Ricean and stratospheric channel with a C/M ratio of 6 dB, at a bit rate of 0.25, 1, 4 Mb/s.

5.3 System Capacity Results

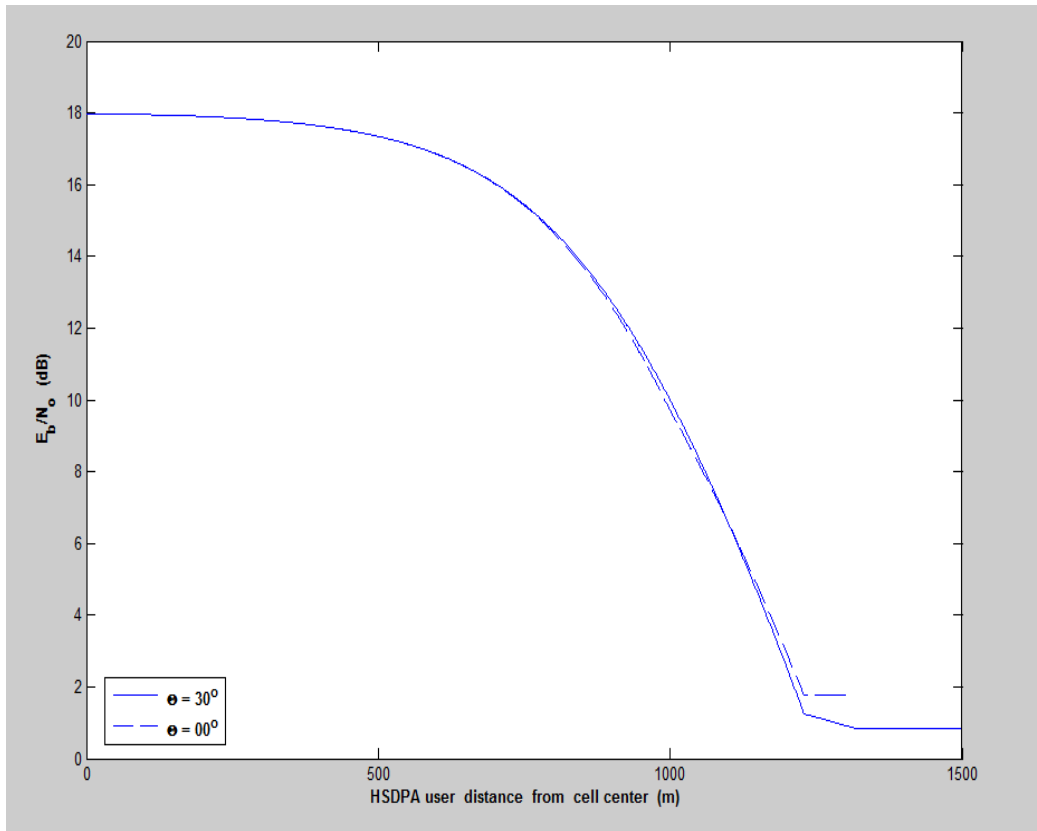


Figure 5.21 E_b / N as a function of the HSDPA user distance from the cell centre when $h = 20$ km, $R = 2$ km, $\Phi = 0.1$, $N=1$, fully loaded cell. $\Phi = 0.1$, $N=1$, fully loaded cell. (Φ is the non-orthogonality factor, N is the number of users).

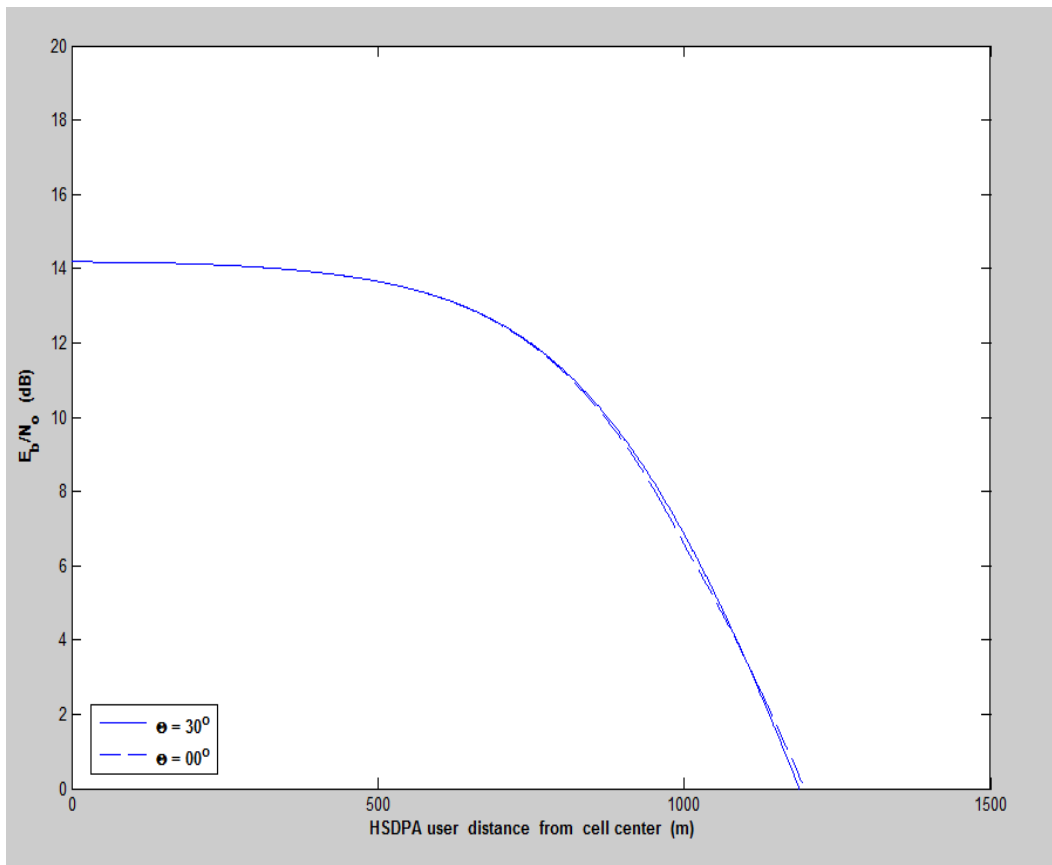


Figure 5.22 E_b / N as a function of the HSDPA user distance from the cell centre when $h = 20$ km, $R = 2$ km, $\Phi = 0.1$, $N=2$, fully loaded cell.

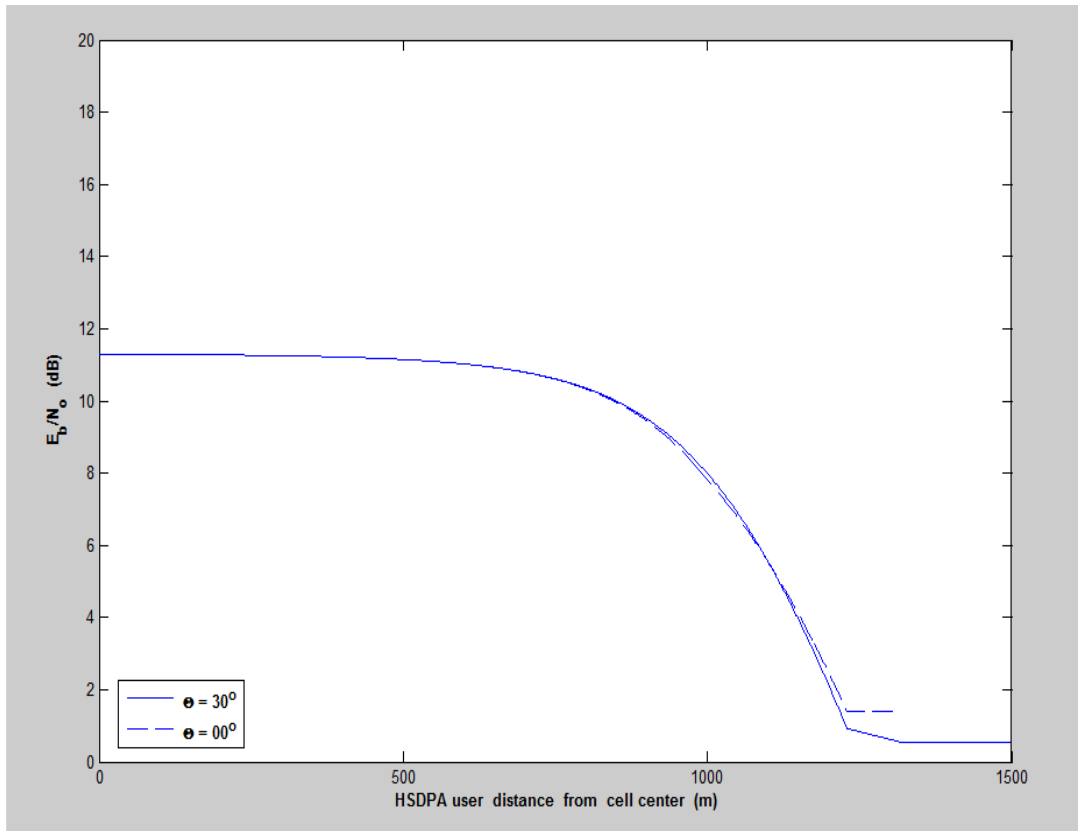


Figure 5.23 E_b / N as a function of the HSDPA user distance from the cell centre when $h = 20$ km, $R = 2$ km, $\Phi = 0.5$, $N=1$, fully loaded cell.

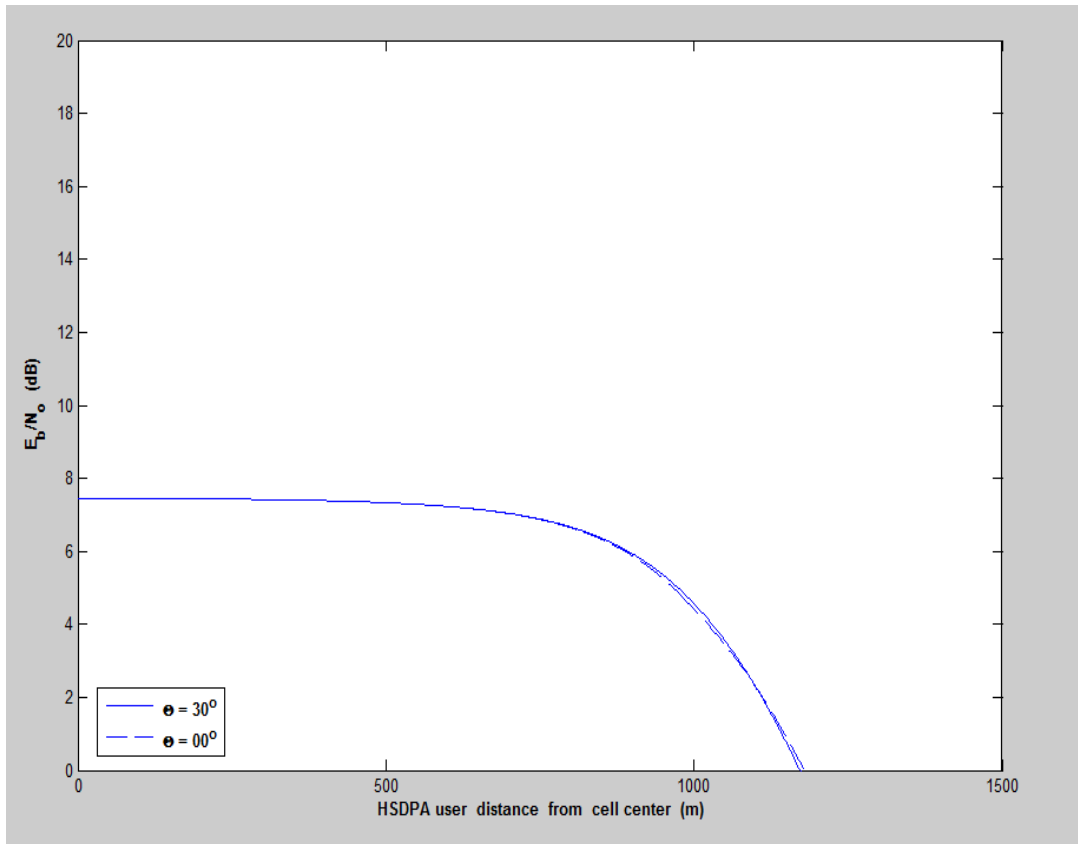


Figure 5.24 E_b / N as a function of the HSDPA user distance from the cell centre when $h = 20$ km, $R = 2$ km, $\Phi = 0.5$, $N=2$, fully loaded cell.

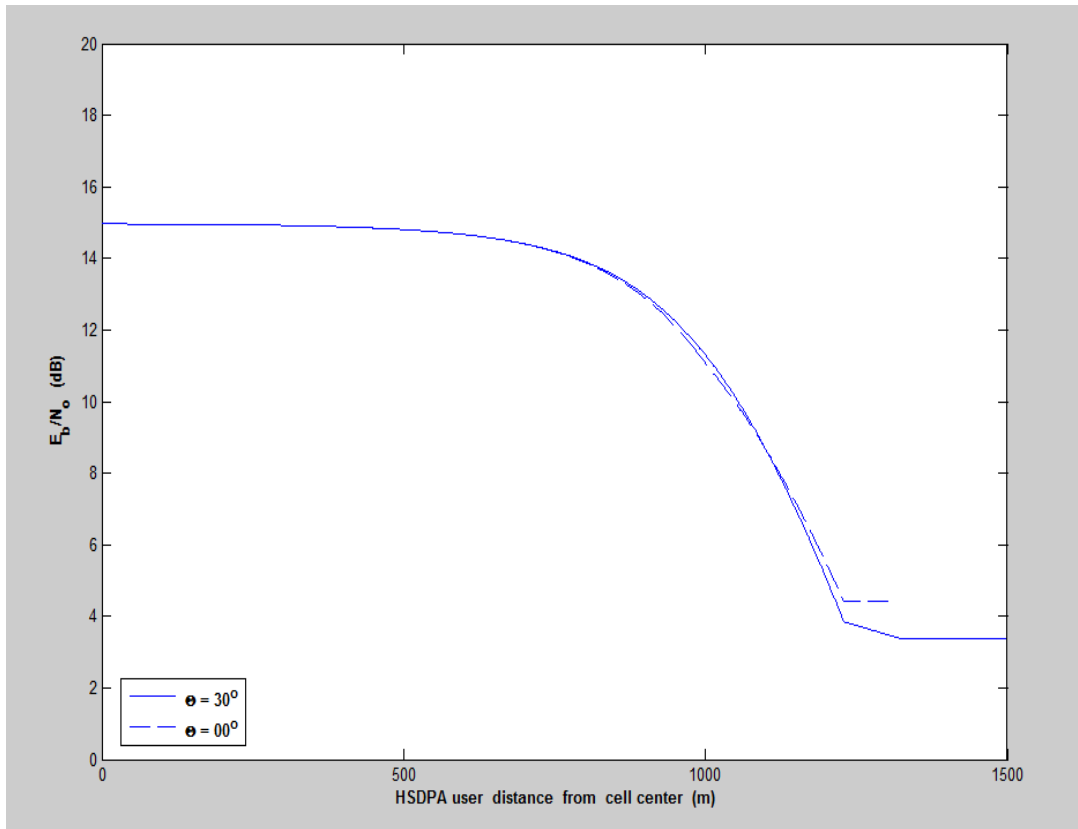


Figure 5.25 E_b / N as a function of the HSDPA user distance from the cell centre when $h = 20$ km, $R = 2$ km, $\Phi = 0.5$, $N=1$, Medium loaded cell.

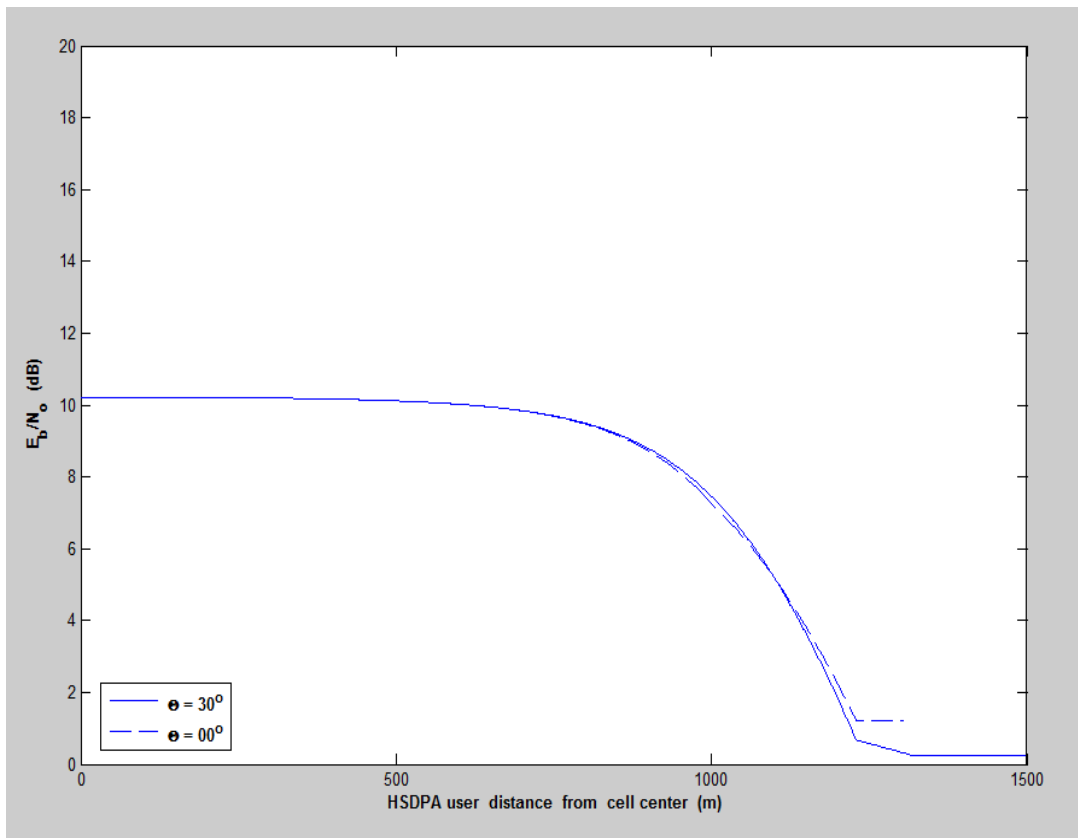


Figure 5.26 E_b / N as a function of the HSDPA user distance from the cell centre when $h = 20$ km, $R = 2$ km, $\Phi = 0.5$, $N=2$, Medium loaded cell.

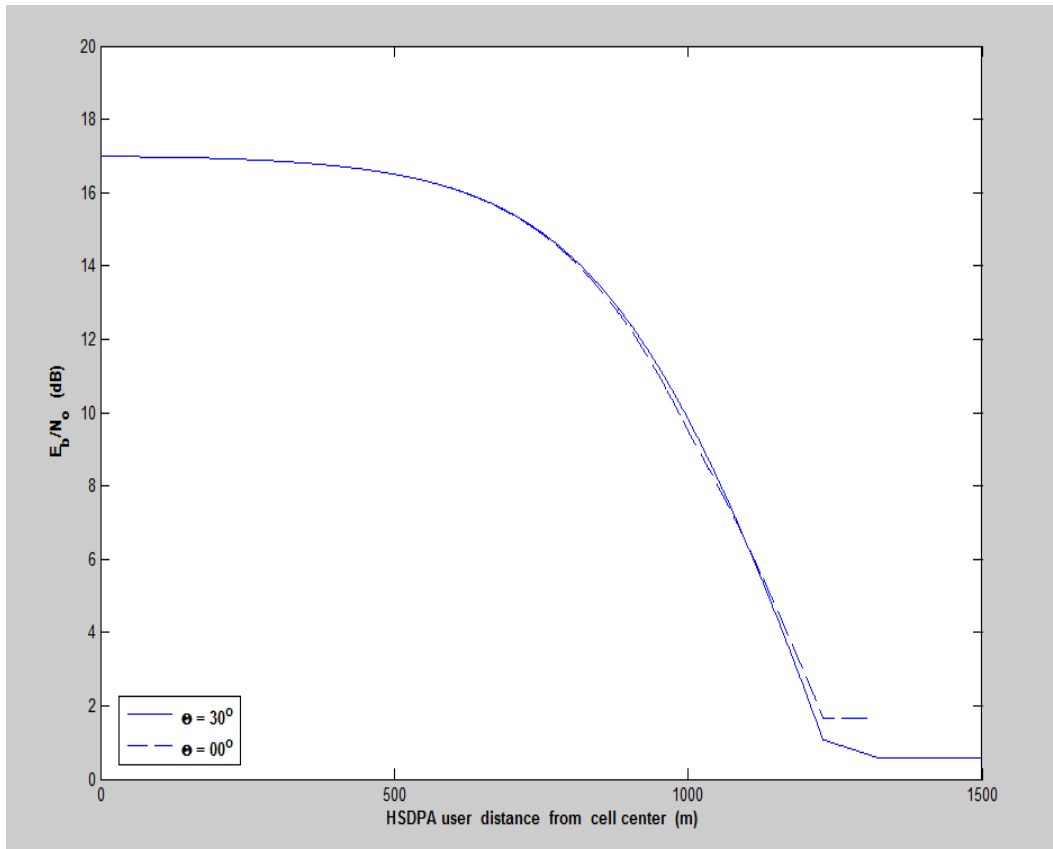


Figure 5.27 E_b / N as a function of the HSDPA user distance from the cell centre when $h = 20$ km, $R = 2$ km, $\Phi = 0.1$, $N=2$, Medium loaded cell.

6. Advantages and Future Challenges

6.1 Advantages of Integrating GOMEX-HAPs with Terrestrial UMTS

Integrating the features of terrestrial and satellite communication systems with HAPs-based systems offer a number of benefits:

The high altitude of the network provides a **wider service coverage**, approximately an area of diameter of 200-300km per HAP, and also suffers **less atmospheric influence** (attenuation and turbulence) since they are situated well above cloud altitude.

The high elevation angle means fewer problems with terrestrial obstruction and therefore **reduced shadowing**.

The mainly solar powered HAPs provide **environmental advantages** to UMTS service providers because they would be able to scale down their terrestrial infrastructure.

GOMEX-HAPs would help UMTS service providers to expand and grow rapidly because HAPs can be **deployed rapidly**, within a few hours, and would be most advantageous in emergency or disaster situations, and in services that require rapid operational availability.

GOMEX-HAPs also more **easily serviced** and upgraded, unlike a satellite, HAPS can be brought down for payload repair, upgrading or configuration, or vehicle modification.

It is more **cost effective**, since it does not require space qualification such as the instruments onboard a satellite. The procurement and launch costs are also considerably

lower. Also, for UMTS service providers, replacing the ground stations in remote regions with HAP can mean significant cost saving.

The intermediate position of a HAP between ground and satellite allows the link to be closed more easily, resulting in **negligible signal delay and loss due to atmospheric influence**, and therefore **less propagation delay**, by a factor of 1800 compared to a downlink from a GEO satellite and by a factor of 20 compared to a downlink from a LEO satellite. The high altitude, above cloud level, of HAPs/UAVs optimizes the application of HAP-to-satellite communication to optical free-space communication resulting in a very high communication capacity.

6.2 Future Challenges

In spite of the advantages which have been outlined in the previous section, there are remaining challenges yet to be addressed in the application of HAPs to the wide variety of services they can theoretically support. Several are discussed below.

A challenge to the viability of communication services via HAPs is the adverse effect of wind and other weather turbulences which can compromise the stability of antenna pointing on the HAP. To resolve this, array antenna must be electronically steered and sub-platforms mechanically stabilized.

The frequencies within which HAPs operates, that is, in the 47/48 GHz and 28 GHz (ITU Region 3) bands have not been fully characterized for propagation, and are also more affected by rain attenuation. More analysis of rain attenuation and scattering needs to be conducted to determine how to improve performance in spite of these factors, as well as the most suitable diversity technique (space, time, frequency, etc) for each traffic type.

A challenge to broadband telecommunication services is the need for optimal utilization of network capacity so that the quality of service (QoS) and bit error rate (BER) requirements under different link conditions can be supported, and the solution is to use suitable coding and modulation techniques. Another challenge is achieving optimal system capacity for the broadband wireless access (BWA) from HAPS, the quality of which is dependent on antenna technology. For instance, if sidelobe performance is inadequate then multiple spot beams will definitely be required which can affect inter-cell interference, and thereby affect system capacity.

A challenge to future multimedia services is the possibility of frequent handoffs due to the use of multiple spot beams in HAPs for greater coverage area and capacity, some of which may occur when there is wind or turbulence resulting in motion of platform and antenna beam. Stringent constraints pertaining to the size of the cells and the Hap's physical stability need to be considered for the handoff process to minimize delay due to the need for handoffs resulting from movement, which can particularly affect future multimedia services. Another challenge is to adapt channel assignment and resource allocation schemes, which have been tailored to multimedia traffic, to the HAP scenario, taking into account system topology and the coding/modulation scheme in use.

Since different spot beam layouts are subject to wide angular fluctuations and changes in link length, there is a need to develop an all-new cellular-type service that can focus on frequency planning and reuse patterns for both user and backhaul links in such a scenario. In this new network, the architecture must consider allowing for the possibility of inter-terminal switching directly on the HAP itself and the use of inter-HAP links to attain connectivity.

Last but not least, power limitations pose a challenge as well. Power availability will depend on the type of HAP payload, and will be a direct determinant of the achievable downlink RF power and thus the overall capacity. One solution would be to use power-

efficient modulation and coding techniques, and careful spot beam and antenna array design.

6.3 Conclusion

This thesis proposed that high altitude platforms (HAPs) can serve a dual purpose of providing cellular communication services and also support services for navigation satellite systems. A system was designed and the results from simulation demonstrated that HAPs can be successfully implemented to provide such services in the case of macrocells of large radii. Although standard constraints may circumscribe limits on the number of sustainable physical channels, however this can be in part overcome by obtaining more information on the user location, through notification by the user to the network using communication channels which transmit navigation messages to mobiles.

Appendix A

Basic characteristics of Terrestrial Wireless, Satellite and HAPs systems [11]

Issue	Terrestrial Wireless	Satellite	High Altitude Platform
Availability and Cost of Mobile Terminals	Huge cellular PCS market drives high volumes resulting in small, low-cost, low-power units	Specialized, more stringent requirements lead to expensive bulky terminals with short battery life	Terrestrial terminals applicable
Propagation delay	Low	Causes noticeable impairment in voice communications in GEO (and MEO to some extent)	Low
Health concerns with radio emissions from handsets	Low-power handsets minimize concerns	High-power handsets due to large path losses (possibly alleviated by careful antenna design)	Power levels like in terrestrial systems (except for large coverage area)
Communications technology risk	Mature technology and well-established industry	Considerably new technology for LEOs and MEOs; GEOs still lag behind cellular PCs in volume, cost and performance	Terrestrial wireless technology, supplemented with spot-beam antennas; if widely deployed, opportunities for specialized equipment (scanning beams to follow traffic)
Deployment timing	Deployment can be staged, substantial initial build-out to provide sufficient coverage for commercial service	Service cannot start before the entire system is deployed	One platform and ground support typically enough for initial commercial service

Issue	Terrestrial Wireless	Satellite	High Altitude Platform
System growth	Cell-splitting to add capacity, requiring system reengineering; easy equipment upgrade/repair	System capacity increased only by adding satellites; hardware upgrade only with replacement of satellites	Capacity increase through spot-beam resizing, and additional platforms; equipment upgrades relatively easy
System complexity due to motion of components	Only user terminals are mobile	Motion of LEOs and MEOs is a major source of complexity, especially when intersatellite links are used	Motion low to moderate (stability characteristics to be proven)
Operational complexity and cost	Well-understood	High for GEOs and especially LEOs due to continual launches to replace old or failed satellites	Some proposals require frequent landings of platforms (to refuel or to rest pilots)
Radio channel “quality”	Rayleigh fading limits distance and data rate, path loss up to 50 dB/decade; good signal quality through proper antenna placement	Free-space-like channel with Ricean fading; path loss roughly 20 dB/decade; GEO distance limits spectrum efficiency	Free-space-like channel at distances comparable to terrestrial
Indoor coverage	Substantial coverage achieved	Generally not available (high-power signals in Iridium to trigger ringing only for incoming calls)	Substantial coverage possible
Breadth of geographical coverage	A few kilometers per base station	Large regions in GEO (up to 34% of the earth surface); global for LEO and MEO	Hundreds of kilometers per platform (up to 200km)
Cell diameter	0.1 – 1 km	50km in the case of LEOs. More than 400km for GEOs	1 – 10 km
Shadowing from terrain	Causes gaps in coverage; requires additional equipment	Problem only at low elevation angles	Similar to satellite

Issue	Terrestrial Wireless	Satellite	High Altitude Platform
Communications and power infrastructure; real estate	Numerous base stations to be sited, powered, and linked by cables or microwaves	Single gateway collects traffic from a large area	Comparable to satellite
Aesthetic issues and health concerns with towers and antennas	Many sites required for coverage and capacity; “smart” antennas might make them more visible; continued public debates expected	Earth stations located away from populated areas	Similar to satellite
Public safety concern about flying objects	Not an issue	Occasional concern about space junk falling to Earth	Large craft floating or flying overhead can cause significant objections
Cost	Varies	More than \$200 million for a GEO system. A few billions for a LEO system (e.g. \$5 billion for Iridium, \$9 billion for Teledesic)	Unspecified (probably more than \$50 million), but less than the cost required to deploy a terrestrial network with many base stations

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