Stratospheric Channel Modeling

Submitted by

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Abstract

High Altitude Platform Stations (HAPs) are communication facilities situated at an altitude of 17 to 30 km and at a specified, nominal, fixed point relative to the Earth. They are mostly solar-powered, unmanned, and remotely-operated. These platforms have the capability of carrying multipurpose communications relay payload, which could be in the form of full base station or, in some cases, a simple transponder as is being used in satellite communication systems. HAPs, when fully deployed will have the capability of providing services and applications ranging from broadband wireless access, navigation and positioning systems, remote-sensing and weather observation/monitoring systems, future generation mobile telephony etc.

HAPs are also known to be low cost when it comes to its implementation and are expected to be the next big provider of infrastructure for wireless communications. There have been a lot of ongoing and exciting research works into various aspects of this emergent technology. As radio Engineers, the need to predict the channel quality and analyze the performance evaluation of such stratospheric propagation has generated quite a few models. Although some of the models under consideration are from the existing terrestrial and satellite communications which in some way, have some relationships with this new technology. This thesis work provides some insight into this new aspect of wireless communications in terms of the need for a new system, its benefits, challenges services provided and applications supported. Existing models already researched and developed for HAPS are reviewed; one of them was picked and deeply looked into as regards the propagation and channel efficiency. The analysis of the choice model is presented using one of the performance test for channel models, the bit error rate (BER).

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CHAPTER 1

INTRODUCTION

Wireless communication has stood out as one of the fastest and rapidly growing segment of the communications industry with the ability to provide high-speed, quality and real-time information exchange between portable devices globally. It is defined basically as information transfer over a distance (may be a short distance or very long distance) without the use of known electrical conductors or cables. It is convenient and often less expensive to deploy relative to the fixed network. This technology has in no little way improved the level and standard of our living in this modern age. Since the development of the cellular concept in the 1960s and 1970s, Wireless communications networks have become extremely common and ubiquitous than the thinking was originally. It's cut across almost every trend and facet of life. Research has shown that the worldwide cellular and personal communication subscriber base went beyond half a billion users in the late 2001 and it's been projected to attain a 2 billion mark which is like 30% of the world population by the end 2007. The speedy growth in cellular telephony worldwide has shown convincingly that wireless communication is a robust, practicable voice and data transport mechanism. A very good example is the design of next generation cellular networks to facilitate high speed data communications traffic in addition to voice calls. New technologies and standards are also being implemented to make wireless networks replace fiber optic and/or copper lines between fixed points that are several kilometers apart known as fixed wireless access. In many geographical areas, mobile telephones are the only economical way for providing phone service to subscribers. Base stations are erected quickly and with low cost compared to the cost involved when digging the ground to lay copper especially in some harsh terrain. Mobile telephones are only a small part of the cellular development; many new types of wireless devices are being introduced.

Presently, there can't be said to be a single cellular network. Devices support one or two of a countless number of technologies and generally work within the boundaries of a single operator's network. Standards need to be defined and implemented in order to move beyond this model. This is one major task the **ITU** is taking up i.e developing a family of standards for the next generation wireless devices which will use higher frequencies to increase capacity and also help eradicate the problem of incompatibility issues encountered presently.

The most renowned first-generation digital wireless network in North America was the Advanced Mobile Phone system (AMPS) which offers data services using the cellular digital packet data (CDPD) overlay network giving te subscriber a data rate of up to 19.2 kbps. The second-generation wireless systems are the Global system for Mobile communications (GSM), Personal Communication Service (PCS) and development have been on the latest generation of wireless networks which is the Third Generation (3G) wireless networks. This system promises an unparalleled wireless access in ways that have never been possible before.

Wireless communication has not only been effective in the area of voice and cellular networks, it's been greatly used in the area of computer and data networks. In the homes and offices, wireless networks have been extensively used as replacements for cables through the development and deployment of wireless local area networks (WLANS), Bluetooth, Zig-bee.   .

1.1 HISTORY OF WIRELESS COMMUNCATIONS

Wireless networks has been in existence even before the industrial age when information was transmitted over line-of-sight distances by smoke signals, torch signaling and other means long before the first piece of powered machinery was invented. Hilltop-situated observation stations were commonly used to relay messages so as to achieve coverage over longer distances. However, these old systems were gradually phased out when Samuel Morse invented the telegraph in 1838, and in the 19th century, the invention of the telephone into the world had a great impact.

Shortly after the telephone was invented in 1895, an Italian scientist, Guglielmo Marconi, started some laboratory experiments in his father's home and succeeded in transmitting wireless signals over a distance of 1.5 kilometers. By 1899, he was able to achieve the same feat between England and France across the English Channel. These ground-breaking work marked the birth of radio communications and ever since, there have been rapid advancements that have supported transmission over larger distances with better quality, less power, smaller and cheaper devices.
In the earlier years, the transmission of radio signals was popularly analog. However, in the modern world of today, it is very common to find radio systems that transmit digital signals. The transmission can then be either in a continuous bit stream or as bits grouped into packets.

Several systems have been developed to support radio-based networks. ALOHANET, developed at the University of Hawaii in 1971 was a predecessor to several systems that would come later. The US Defense Department showed great interest in ALOHANET due to its inherent benefits and substantial support was provided for research into it. By the 1970's when the wired Ethernet technology was introduced, many companies moved away to this 'new' system because the 10Mbps data rate was a lot more than that offered by the fastest wireless networks. The added cost and inconvenience of setting up an Ethernet-based network was not enough to dissuade those who migrated. However, by the time the US-based Federal Communications Commission (FCC) licensed the public use of the Industrial, Scientific and Medical (ISM) frequency bands in 1985, the development of wireless LANs was set in motion. Even though we still do not have wireless LANs that match the wired LANs in terms of data rate and coverage area today, the ease of use and mobility have made wireless LANs increasingly popular in homes, offices and schools.

1.2 WIRELESS SYSTEMS AND SERVICES

Having talked about the history of Wireless networks, it's expedient to talk a bit about the services it supports and some of the systems it works with. Some of the more popular wireless communications systems are briefly described below.

1.2.1 BROADBAND WIRELESS ACCESS

Over the years, there has been a great need for wireless access that provides high data rates at high speed. Broadband wireless access has in a way done justice to this. Broadband wireless access is a technology that is designed to provide high-rate wireless access over a large area between a fixed access point and multiple terminals. Work on the WiMAX broadband wireless technology based on the IEEE 802.16 standard is getting to the final stages. WiMAX is billed to operate at radio frequencies between 10GHz and 66GHz and will provide data rates of up to 44Mbps and 15Mbps for fixed users and mobile users respectively with a range of up to 50km. There are 2 widely used BWA technologies and are discussed below.

Local multipoint distribution service (LMDS) which is widely referred to as the 'wireless cable' is aimed at providing broadband internet and video services to homes.

Multichannel multipoint distribution service (MMDS) band makes use of microwave frequencies in the 2GHz to 3GHz range. This technology is a television and telecommunication delivery service and has the ability to deliver over 100 digital video TV channels alongside telephony services and high-speed interactive internet-based services.

1.2.2 WIRELESS LANs

Wireless Local Area Networks are LANs set up without the use of cables for connectivity. They are relatively easy to set up and they can have a star architecture with wireless access points strategically located throughout the coverage area for range extension or they can be set up as a peer-to-peer (ad-hoc) network in which the wireless terminals configure themselves automatically into the network.

This type of wireless systems have the capability of providing high-speed network services for mobile users within a small region,, e.g. a home, campus or office complex. The majority of the users of this system/service are either stationary or moving at pedestrian speed. Worldwide, it is a common practice to operate wireless LANs in the unlicensed frequency bands, e.g. the 2.4GHz and 5.8GHz bands. Wireless LANs have the IEEE 802.11 a, b and g as set of standards governing their operation at different frequencies, with different carriers and giving different data rates. For easy adaptation and integration, PCs are rolled out with wireless LAN cards installed on them supporting the 3 standards governing the WLANs.

1.2.3 BLUETOOTH AND ZIGBEE

The development of the Bluetooth standard was aimed at providing short range connections between wireless devices by using a radio transceiver built on a tiny microchip in the devices. This system operates in the license-free ISM band at 2.4GHz and the normal range of operation is 10m (at transmit power of 1mW) which is extendable to 100m (with transmit power increased to 10mW).
Bluetooth uses frequency hopping dividing the frequency band into 79 channels (23 in Japan and some other countries) each of which is 1MHz wide and changing channels 1600 times every second to achieve multiple access. Bluetooth devices form ad-hoc networks known as **piconets** with one device acting as master while there can be a maximum of 7 active slaves. Bluetooth has been found extremely useful especially in the areas of wireless communication between PCs and input and output devices, wireless control and communication between mobile phone sets and hands-free kits, file transfer between devices, ad-hoc computer networks when bandwidth is not an issue and so on.

Zigbee is a set of specifications based on IEEE 802.15.4 standard and uses low-cost, low-power radios for wireless personal area networks. When compared to Bluetooth, Zigbee devices cost considerably less and are less power consuming. The major disadvantage is that they give lower data rates but can cover a larger transmission range. Some other properties of the Zigbee are that they operate in the ISM band and can have up to 255 devices in a network.
By design Zigbee is expected to provide radio operation for long periods of time without any need for recharging and thus they will eventually prove useful in such applications as inventory tagging and sensor networks.

1.2.4 MOBILE TELEPHONY

Mobile telephony is a major area in which the lives of people have greatly been affected positively. In the '80's, the first generation (1G) of mobile telephone technology was deployed with the most popular standard then known as the Advance Mobile Phone Service (AMPS). This standard employed frequency division multiple access (FDMA) with 30 KHz FM-modulated voice channels.

After the initial deployment of the first generation of mobile telephony, there was the need for improvement and upgrade on it and this led to the launching of the second generation (2G) mobile telephony system. The Global System for Mobile communications (GSM) is the most popular and renowned 2G standard. It uses a combination of time division multiple access (TDMA) and slow frequency hopping with frequency-shift keying for the voice modulation.

2G mobile telephony systems not only use digital signaling between the radio towers (which are listening for the handsets) and the rest of the network (like the 1G systems) they also use digital radio signals. They have also been enhanced to support high rate packet data services. For instance, the GSM system can provide data rates of up to

100Kbps by aggregating all timeslots for a single user as we have it in the General Packet Radio Services (GPRS). In the Enhanced Data Services for GSM Evolution (EDGE), a high-level modulation technique (8 Phase Shift Keying – 8PSK) is used along with Forward Error Correction (FEC) to further enhance the data rate of the GSM system. The GPRS and EDGE flavors of the GSM system are generally referred to as 2.5G and 2.75G respectively.

The third generation (3G) mobile telephony services were first launched in Japan in 2001. They are largely based on the wideband code division multiple access (W-CDMA) standard and they provide different data rates as mobility and location demands. Example data rates are; 384Kbps for pedestrian use, 144Kbps for vehicular use and 2Mbps for indoor use. There are several new services such as video telephony and music download that have been made possible as a result of this increase in data rate.

1.2.5 SATELLITE NETWORKS

One of the oldest means of wireless communication provision is the Satellite networks. The technology have been useful in the area of TV and radio broadcast, international telephony, amateur radio, broadband internet connection link for remote areas where conventional backbones cannot or have not reached, and so on.

TRANSMITTER AND
TRANSMIT ANTENNA/
RECEIVER AND RECEIVE
ANTENNA

ORIGINATING
GROUND
STATION

DESTINATION
GROUND
STATION
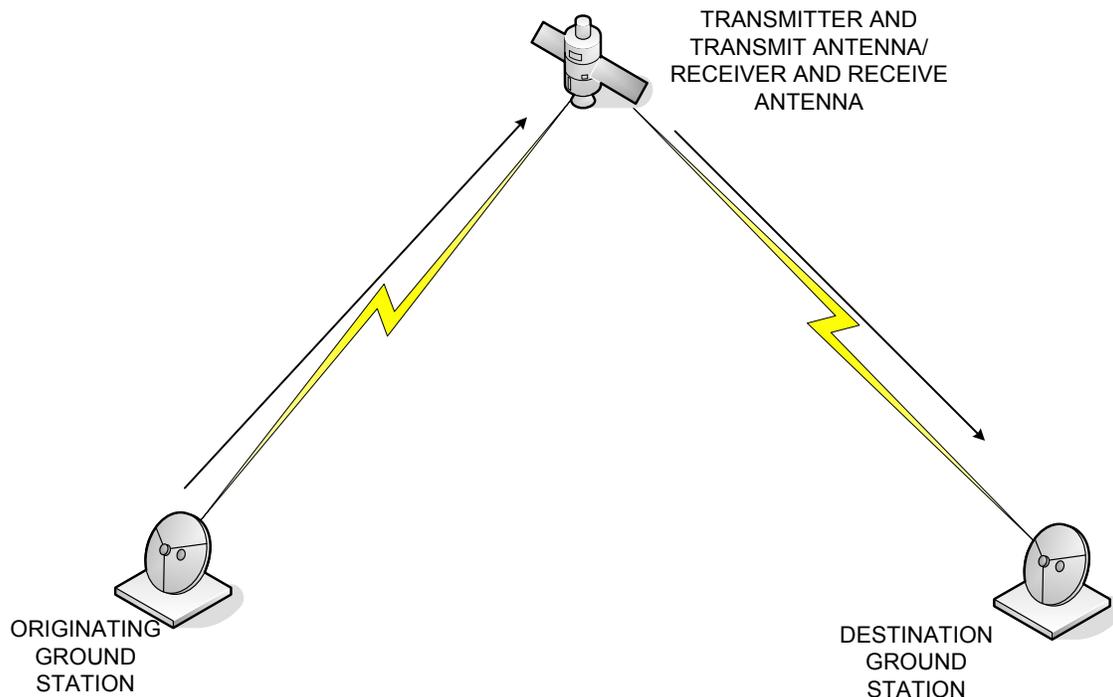
Fig. 1.1   Basic components of a communication satellite link [13]

Satellites are broadly classified as one of the following.

1.2.5a Geostationary Orbit Satellites (GEO)

GEO satellites appear to be stationary to an earth-based observer, hence the name. This is achieved by placing the satellite in orbit above the equator at an altitude of 35786Km thus ensuring that it makes one complete revolution in a day. These types of satellites are very useful for communications applications since the earth stations that relay to and from them do not need any special device to keep track of the satellite's motion. GEO satellites have been particularly useful in direct TV distribution. Due to the distance of the GEO satellites above the earth, they are inherently bogged by the fact that a great deal of power is required on the link leading to large and bulky receivers. By the same token, there is a large round-trip propagation delay. For these reasons, GEO satellites are not used for voice and certain data services.

1.2.5b Low Earth Orbit Satellites (LEO)

LEO satellites are generally defined to be those within an orbit covering altitudes from 200km to 2000km above the earth's surface. Traveling at a speed of 27400Km/h, LEO satellites typically complete an orbit around the earth in 90 minutes. As such, if they will be useful for any communication applications, a constellation of these satellites is required and a means of hand-off from one satellite to the other is also necessary as well to guarantee seamless communications. The upside is that due to their elevation above the earth, considerably less energy is required to put them in orbit and less power-consuming transceivers are needed for successful communications.

1.2.5c Medium Earth Orbit Satellites (MEO)

MEO satellites are those satellites that are above the 2000Km upper-limit of the LEO satellites and below the GEO satellite orbit. Depending on their altitude, MEO satellites usually have orbital periods ranging between 2 to 12 hours. They are widely used for navigation purposes, as we have it in global positioning systems and to provide communications coverage for areas in the Polar region which fall in the blind spot of GEO satellites.

1.2.6 HIGH ALTITUDE PLATFORM STATIONS (HAPS)

HAPS are, generally, solar-powered, unmanned, remote-operated and electric motor-propelled aerial platforms held in a quasi – stationary position, at altitudes between the 17 – 22 Km range above the earth's surface (stratospheric layer of the atmosphere). They are somewhat new and are being proposed as means of providing wireless multimedia communications infrastructure for both metropolitan and remote areas. These platforms carry multipurpose communications relay payload, which can range from a complete base station to just a simple transponder, like we have on most satellites.

The ITU has allocated different frequency bands for HAPS-based services, particularly for broadband wireless access and for 3G mobile telephony services.

CHAPTER 2

STRATOSPHERIC PROPAGATION / HAPS

The need to improve on the existing bandwidth available for mobile communication devices and application has made researchers and telecommunication experts delve into more technologies that can provides the needed bandwidth. There has been several works on improving the bandwidth provision from satellite and terrestrial communication. While these are unfolding, there has been several other technologies been looked into that could possibly provide a better bandwidth as required by users of these mobile services.

The advantages and disadvantages of terrestrial and satellite systems are well known and have been extensively documented in several works over the years. The drawbacks, in particular, have made engineers continuously search for alternative means of making broadband fixed wireless access available to the ever-growing population of users worldwide.

2.1 Why HAPS

Is it possible to have a system which combines most of the advantages of satellite and terrestrial systems while avoiding many of the pitfalls identifiable in either of them? In searching for an answer to this question, the attention of wireless communications engineers has shifted to a system known under different names as High Altitude Platforms (HAPs), Stratospheric Platforms (SPFs), High Altitude Aeronautical Platforms (HAAPs) and High Altitude Long Endurance (HALE). The term 'HAPs' will be used throughout the rest of this work.

These are, generally, solar-powered, unmanned, remote-operated and electric motor-propelled aerial platforms held in a quasi – stationary position, at altitudes between the 17 – 22 Km range above the earth's surface (stratospheric layer of the atmosphere).

Atmospheric Layer	Altitude/Height	Existing objects in layer
Troposphere	Up to 18 km	Mountains, buildings, commercial airplanes, etc
Stratosphere	Between 18 km and 50 km	Weather balloons, HAPs
Mesosphere	Between 50 km and 80 km	Meteors
Thermosphere	Between 80 km and 690 km	Aurora, shuttles
Exosphere	Between 690 km and 800 km	

Table. 2.1 The different atmospheric layers

These platforms carry multipurpose communications relay payload, which can range from a complete base station to just a simple transponder, like we have on most satellites.

The idea of floating a 'big balloon' in space is not an altogether new one. As far back as the 18th century, the Montgolfier brothers invented a lighter-than-air craft using hot air and they demonstrated its use in a manned flight in 1783. Ever since then, aerial platforms have been an attractive option to the military and in the early 20th century, Ferdinand Zepelin, a German officer, developed the rigid dirigible, lighter-than-air vehicle. However, after some high profile accidents and due to evident implications for air-traffic safety, the use of such dirigibles has been largely restricted to recreational and meteorological purposes, with the majority of them operating at altitudes below that used by commercial airplanes. Due to a resurgence of interest in aerial platforms and due to advancement in technology which have yielded better and stronger materials which are UV resistant and leak-proof to helium, these airships are making their way back to our world.

The main goal in the current efforts is more business-oriented and it focuses on developing an economically viable and highly reliable HAP that can serve communication applications. The purpose of such a system should include, but not be limited to, the following;
- provision of the bandwidth that can support services like multimedia applications (telephony, TV, video-on-demand, high-speed internet, etc)
- ability to operate in a high frequency band on the radio spectrum so as to avoid congestion and to provide the much-needed bandwidth

- provision of increased capacity, over and above what already obtains, particularly for terrestrial telecommunication networks, either by supporting more users/cell without degrading performance or by providing greater bandwidth.

The stratosphere has been chosen as the layer of deployment because it presents relatively mild wind turbulence in most regions of the world and because airships in this region of the atmosphere are above the jet stream.

Although the behavior may indeed vary considerably with time of the year and latitude, these are long-term averages. Also, an airship within the stratospheric altitude is well above commercial air traffic and would pose no danger to such traffic.

2.2 Aerial Platforms

The history of HAPS has brought about three distinguishable types of proposed aerial vehicles. These types of platforms can be balloons, aircrafts or airships. They are categorized depending on the way they are managed and maintained.

1. Unmanned Airships: these are mainly balloons and are semi-rigid or non-rigid huge and mainly solar powers balloons which can be well over 100m in length and could carry a payload of about 800kg or more. This typed of aerial vehicle is aimed at staying up for a period of 5 years or more.

2. Solar-powered unmanned aircraft: These types of aerial vehicles are also known as High Altitude Long Endurance platforms (HALE Platforms) and they make use of Electric motors and propellers as propulsion while during the day, they get power supply from solar cells mounted on their wings and stabilizers which also charge the on-board fuel cells. There has not been an agreed span of flight duration for this category of vehicles but proposals declare that they can stay aloft for six months or more.

3. Manned aircraft: this category of vehicles has an average flight duration of some hours which is mainly due to the fuel constraints and human factors.

Collectively, Solar powered unmanned aircraft and manned aircraft are referred to as High Altitude Aeronautical Platforms (HAAPs). The diagrams below show different types of aerial vehicles manned and unmanned.

The table below shows a breakdown of general comparison of Airships, Solar powered unmanned and manned aircrafts.

	Airships (unmanned)	Solar-powered unmanned Aircraft	Manned Aircraft
Size	Length 150 ~ 200 m	Wingspan 35 ~ 70 m	Length ~ 30 m
Total weight	~ 30 ton	~1 ton	~ 2.5 ton
Power source	Solar cells (+Fuel cells)	Solar cells (+Fuel cells)	Fossil Fuel
Environmentally friendly	Yes	Yes	No
Response in Emergency situations	No	Yes	Yes
Flight duration	Up to 5 years	Unspecified (~ 6 months)	4 – 8 hours
Position keeping (raduíus)	Within 1km cube	1 – 3 km	~ 4 km
Mission payload	1000 – 2000 kg	50 – 200kg	Up to 2000 kg
Power for mission	~ 10 kW	~ 3 kW	~ 40 kW
Example	Japan, Korea, China, ATG, Lockheed Martin, Skystation etc	Helios, Pathfinder Plus (AeroVironment). Helipat (European project)	HALO (Angel Technologies) M-55 (Geoscan Network)

Table 2.2 General comparison of Airships, Solar powered unmanned and manned aircrafts. [8]

2.3 HAPS compared with other systems

From the outset, HAPs have not been modeled as the successor to either the terrestrial or satellite systems but as a complementary system. However, the potential of stand-alone HAPs systems still remains an attractive one in communications research. In providing cellular network coverage for impervious or remote areas, deploying xDSL or fiber is not economical but HAPs constitute a real asset to operators to reach users in such areas.

The most important similarities and differences of stratospheric platforms vis-à-vis terrestrial and satellite systems are summarized in the table below.

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 intelligent 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	Power levels like in terrestrial systems (except for large coverage areas)
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	System cannot start before the entire system is deployed	One platform and ground support typically enough for initial commercial service
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	Free-space-like channel with Ricean fading; path loss	Free-space-like channel at distances comparable to terrestrial

	loss up to 50 dB/decade; good signal quality through proper antenna placement	roughly 20 dB/decade; GEO distance limits spectrum efficiency	
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 kilometres per base station	Large regions in GEO (up to the 34% of the earth surface); global for LEO and MEO	Hundreds of kilometres 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
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
Esthetic 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 raise significant objections
Cost	Varies	More then $200 million for a GEO system. Some billion 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

Table 2.3 Similarities and differences of stratospheric platforms vis-à-vis terrestrial and satellite systems. [8]

As the need for mobile and ubiquitous access to multimedia services grows, there is a need for the development of new generation wireless systems. As a result, 4G networks have been billed to provide the always-on, globally available optimal connectivity with higher bit rates at low cost and this is where HAPs can play an important role in the post-3G evolution. Multicast services are one of the most interesting in the wide spectrum of services that 4G networks are called to support. Terrestrial systems will generate very high traffic load if they were to be deployed to support such services. Although satellite systems have some nice features, those features are negated by the large propagation delays, for MEO and GEO satellites, the complex handover, for LEO satellites, and the unpredictability of the satellite channel. In this very area, HAPs represent a solution which preserves most of the merits of the satellite systems while also avoiding most of their drawbacks.

HAPs can be said to be a means of providing communications in an inexpensive manner. Development and deployment of satellite communication systems is highly expensive relative to the deployment of HAPs and it is economically more efficient to cover a wider range or larger area with many HAPs rather than with many terrestrial base stations or with a satellite system. Moreover, satellite systems always run the risk of becoming obsolete by the time they are in orbit due to their long development period. Also when considering the path-loss characteristics of these systems, HAPS have a better advantage.

Aside these notes, some of the other advantages stratospheric platforms hold over their terrestrial and satellite counterparts are discussed below.

- They provide large-area coverage compared with terrestrial systems because their deployment geometry provides relatively little rain attenuation on long-range links due to shorter slant path through the atmosphere. This can yield significant link budget advantages within large cells at shorter mm-wave bands.
- HAPs are well suited for the provision of centralized adaptable resource allocation, i.e. flexible and responsive frequency reuse patterns and cell sizes which are not constrained by the location of base stations.
- Going by projections, HAPs will be cheaper to procure and launch than a GEO satellite or a constellation of LEO satellites. It will also be cheaper to deploy a HAP network than a terrestrial network of several base stations.
- HAPs can be incrementally deployed to provide coverage for an area based on the expansion of the network or capacity requirements. A LEO satellite network, in contrast, requires a large number of satellites to achieve seamless coverage while a terrestrial system will also require several base stations to become fully functional.
- Designing, implementing and deploying a HAP-based system is easier and quicker compared to satellites which may take several years from procurement to launch or terrestrial systems which require a lot of time-consuming procedures. This makes HAPs systems well-suited for providing emergency services e.g. natural disasters, restoration of service in case of a terrestrial system failure or at large events which will only last for a while like sporting events.
- Due to the low propagation delay and high capacity provided by HAPs, they are well-suited for broadband and broadcast/multicast service provision.

- HAPs can be brought down relatively readily for maintenance or upgrading of the payload.
- Power supply for HAPs is largely from solar cells and thus emissions from burning of fuel are eliminated. This and the elimination of terrestrial masts also make HAPs rather environmental friendly.

There are also a few challenges and issues that have arisen due to the novelty of communication via HAPs. Some of them are highlighted below.

- Maintaining the nominal position of HAPs in the face of variable prevailing wind is a challenge that will critically affect the viability of communications services via HAPs. Also, the turbulence in the stratosphere will lead to roll, pitch and yaw of the platform and here, larger crafts are likely to exhibit greater stability.
Electronic steering of an array antenna and mechanically stabilized sub-platforms are 2 of the methods being proposed for maintenance of stability for antenna pointing on the HAP.
- Most HAP schemes will use multiple spot beams over the coverage area leading to greater capacity through frequency reuse. Thus, provision will have to be made for the possibility of handoff which may arise when platform motion leads to movement of the antenna beam. The size of the cells and the physical stability of the HAP will govern how often handoffs will occur.
Using fixed antennas on the HAP and accommodating motion simply through some handoff technique is a possibility but it may introduce delay and jitter limitations for future multimedia services. Consequently, much more stringent constraints are imposed on the handoff process than with conventional 2G or 3G services.
- HAPs services have been allocated frequencies in the 47/48 GHz and 28 GHz (ITU Region 3) bands. However, propagation from HAPs is not fully characterized at these higher frequencies and rain attenuation is significant in these bands. Therefore, there is a need for the extensive collection and analysis of rainfall attenuation and scattering statistics. The most appropriate diversity technique e.g. space, time and frequency for each traffic type will also need to be determined.
- To optimally utilize network capacity, suitable coding and modulation techniques will be required to support the broadband telecommunication services within the specified quality of service (QoS) and bit error rate (BER) requirements obtainable under different link conditions.
- At a planned frequency of 48 GHz, antenna technology is a demanding one for both HAP-based and ground terminals, one that is very critical to broadband wireless access (BWA) from HAPs. Several spot beams will be needed and if the sidelobe performance is not worked out properly, it may affect inter-cell interference and, consequently, system capacity.
- Due to its uniqueness, channel assignment and resource allocation schemes tailored to multimedia traffic will have to be developed for the HAP scenario. The schemes will also need to take into account the system topology and coding/modulation scheme in use.
- There is a need for an all-new cellular-type service which focus on frequency planning of different spot beam layouts, which are subject to wide angular variations

and changes in link length, and frequency reuse patterns for both user and backhaul links. The new network architecture must cater for the possibilities of inter-terminal switching directly on the HAP itself rather on ground-based systems and the use of inter-HAP links to attain connectivity.

- The available payload power will be a function of what type of HAP is carrying the payload. The lower the available power, the lower the achievable downlink RF power, and thus, the overall capacity.

  Careful spot beam, antenna array design and power-efficient modulation and coding techniques will be required for the efficient use of power on the platforms.

2.4 HAPS Architecture
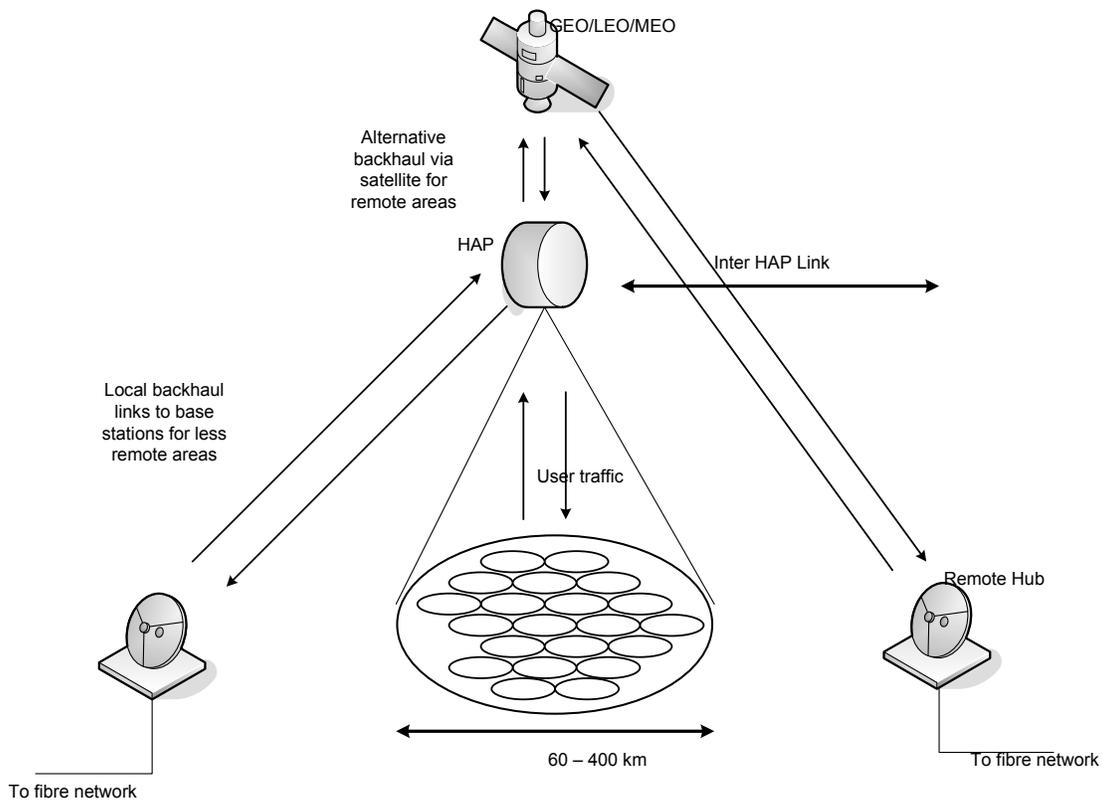
Fig. 2.1   HAPS Structural model [8]

The figure depicts a general HAP Architecture and communication scenario. A single HAP with up- and down-links to user terminals can be used to provide services along with a backhaul link if required. HAPs may also be interconnected in a network of HAPs and a satellite link may also provide direct connections from the HAP.

The ITU has a proposal that footprints of a radius more than 150Km can be served from a HAP. Some researchers and authors have found out that HAPs could cover a whole country giving specific examples of 16 HAPs covering the whole of Japan with a

minimum elevation angle of 10° and that 18 HAPs would cover the whole of Greece including all the Islands. The lower the minimum elevation angle of HAPs, the larger the coverage area enjoyed but this gives rise to a higher propagation or blocking loss at the edge of the servicing area. Practically for Broadband Wireless Access, a minimum elevation angle of 5° is expected but it is more commonly acceptable to have a minimum elevation angle of 15° to avoid or guard against excessive ground clutter problems. This implies that for example, a platform placed at an altitude of 20Km (HAPs altitude) will have a coverage of 200km approximately. However, ground stations that connect HAPs network with other terrestrial networks can be placed on roofs of buildings. Satellite usage can be employed as backhaul in rural and remote areas where there is not sufficient terrestrial infrastructure.

The diagram below depicts the radius of the maximum coverage area with respect to HAP altitude.

The coverage region served by a high altitude platform is essentially determined by line-of-sight propagation (particularly at higher frequency bands) and the minimum angle of elevation at the ground terminal. In general, user terminals in a HAPs system are classified along the broad line of elevation angles as follows;

- **Urban area coverage (UAC)**
  The relative elevation angle is from 30° to 90° and there are line-of-sight (due to the short distance of the user terminal from the HAP) and diffuse multi-path components (consisting of many reflections from obstacles in the area each of them being independent and randomly phased) of the transmitted signal.

- **Suburban area coverage (SAC)**
  The relative angle of elevation is from 15° to 30° and the obstacles near the receiver cause signal shadowing and attenuation of direct signals. Attenuation of direct signals varies due to moving obstacles e.g. vehicles and undergoes log-normal distribution.

- **Rural area coverage (RAC)**
  The relative angle of elevation is between 5° and 15°. The practical lower elevation limit for broadband wireless access (BWA) is 5° and to avoid excessive ground clutter problems, the elevation angle should be 15° at the minimum.
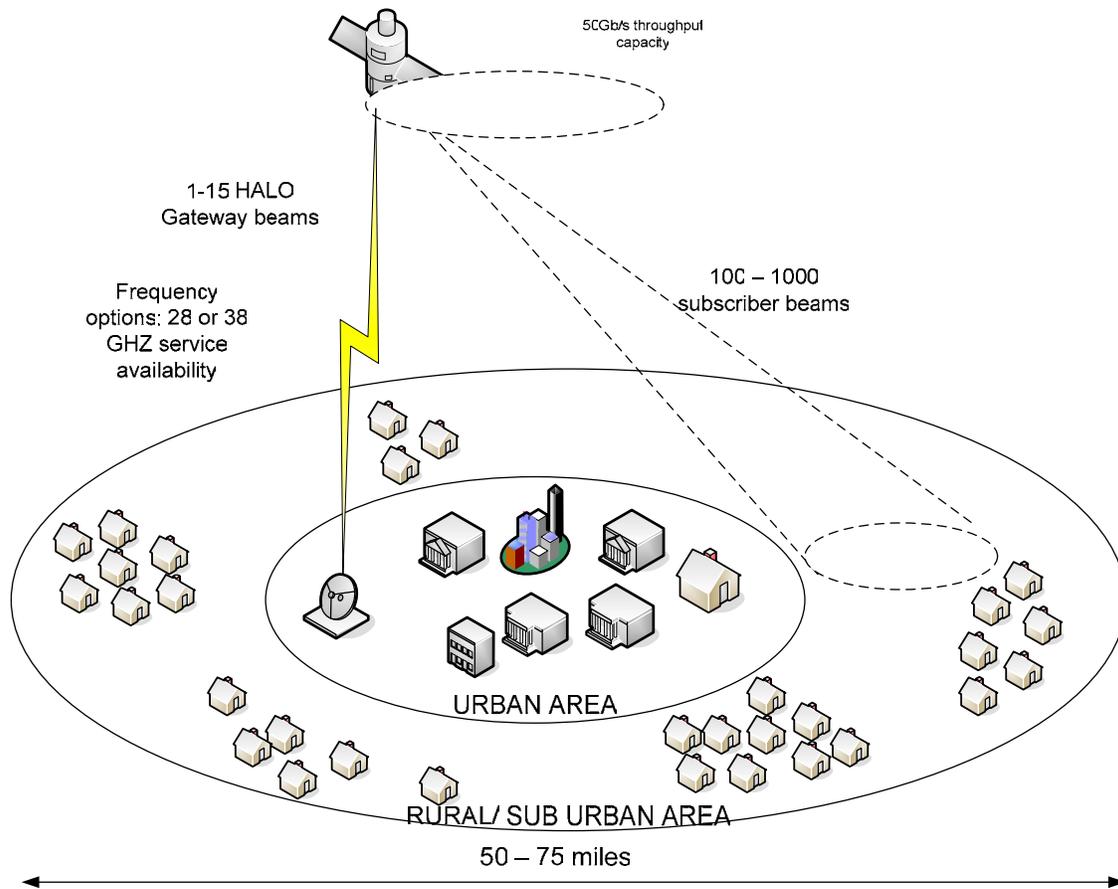
Fig.2.2 HAPS coverage analysis for different areas

2.5 Services and Applications

HAPs have an advantage over terrestrial networks in the area of multicasting where the many of the benefits of GEO satellites are provided in addition to uplink channels for interactive video and internet access. HAPs also serve well in areas with low population e.g. islands, oceans, developing towns, etc where the cost per subscriber in terrestrial systems will be too high for the low traffic densities because of the access points needed to cover these areas. Communication services provided by HAPs are broadly divided into low data rate services for mobile terminals and high data rate services for fixed terminals. Some of them are listed below;

1. The main application for HAPs is the Broadband Fixed Wireless Access (B-FWA) which is capable of providing very high data rates to the user to the tune of 2 X 300MHz bandwidth provided that the links are not used for internet traffic basically.
2. The use of the IMT-2000, i.e. 3G bands, from HAPs has been authorized by the ITU. Even the 2G services can be comfortably deployed via HAPs. One HAPs base-station fitted with a wide-beamwidth antenna or a number of directional antennae covering smaller cells can serve a very wide area.

3. HAPs are very useful for such 'developing world' applications like rural telephony, broadcasting and data services where existing ground infrastructure is lacking or difficult.
4. HAPs can be quickly deployed to provide extra service coverage in the event of a disaster e.g. earthquake, flood, etc or as a restoration following failure in a core network.
5. A number of HAPs may be deployed in a network to cover an entire region. It is also possible to achieve Inter-HAP links at high Extremely High Frequencies (EHF) or through the use of optical links.
6. Military communications is also another major are that has enjoyed the deployment of HAPS

2.6 HAPS Spectrum Allocation.

The Local Multipoint Distribution Systems (LMDS) types of services (which include services such as high-speed internet and other data services) have frequency band of over 24GHz allocated to them. HAPs services operate at 600MHz at 48/47 GHz frequency worldwide allocation from the ITU except in Asia where it operates at 31/28 GHz, though it can be deployed in some 3G services which is around the 2GHz range. There is also the possibility of using the band range of 18 – 32 GHz for fixed services. This range is allocated in Region 3 for broadband wireless applications.

The breakdown of these services and frequency allocations is shown in the table below.

Frequency Band	Areas	Direction of the Link	Services	Services to be shared with
47.9-48.2 GHz 47.2-47.5 GHz	Global	Up and downlinks	Fixed service	Fixed and mobile services Fixed satellite service (uplink) Radio astronomy band neighboring
31.0-31.3 GHz	40 countries worldwide (20 countries in Asia, Russia, Africa, etc and in Region 2)	Uplink	Fixed service	Fixed and mobile services Space science service in some areas Space science service band (passive) neighbouring
27.5-28.35 GHz1	40 countries worldwide (20 countries in Asia, Russia, Africa, etc and in Region 2)	Downlink	Fixed service	Fixed and mobile services Fixed satellite service (uplink)
1885-1980 MHz 2010-2025 MHz 2110-2170 MHz	Regions 1 and 3	Up and downlinks	IMT-2000	Fixed and mobile services (in particular, terrestrial IMT-2000 and PCS)

1885-1980 MHz 2110-2160 MHz	Region 2	Up and downlinks	IMT-2000	Fixed and mobile services (in particular, terrestrial IMT-2000 and PCS)

NOTE**
Region 1: Europe, Africa, Russia, the middle East and Mongolia
Region 2: North and South America
Region 3: Asia except for the Middle East, Pacific countries and Iran

Table 2.4 Services and frequency allocations [8]

2.7 Capacity Analysis of HAPS

When discussing HAPs, one of the most important design consideration is the available bandwidth. An important bandwidth calculation tool is the Shannon equation which deals with the relationship of the Carrier Signal to Noise.

$$\frac{R}{B_w} = \log_2\left[1 + \frac{C}{N_o}\right]$$

In this equation:
      R = Maximum Data rate (Symbol rate)
      B_w = Nyquist Bandwidth = samples/Sec
      C = Carrier Power
      N = Noise power

HAPS have been found never to be as spectral efficient as terrestrial broadband systems due to the fact that the minimum size of their cell is limited by the maximum size of the antenna that can be accommodated on the platform. To mitigate this, the user antenna can be highly directive, giving rise to a good spatial discrimination between HAPs in a HAP constellation.

Research actually showed that the level of bandwidth saving is dependent on the transmitter power. An increase in the transmitted power gives rise to an increase in bandwidth saving. The minimum received $\frac{C}{N_o}$ (on the edge of the coverage area) is deteriorated by the displacement of the platform but does not affect the peak minimum bandwidth requirements. The maximum $\frac{C}{N_o}$ (with a rain rate of 28mm/h) is the same in all cases and achieved in the cell at the sub-platform point.

2.8 Transmission impediments for HAPs

Rain Effects
It is a known fact that rain attenuation effects are negligible at the range of 2GHz, they are prevalent at higher frequencies especially above 20GHz. The higher the frequency, the higher the attenuation and the impact on the QoS.
 Rain attenuates the signal by scattering or absorbing radiation. Research has shown that for HAP availability of 99.9% and above, rain is the dominant attenuation factor at
28 GHz and above. Other factors, such as clouds, water vapour, oxygen and scintillation offer less variability and hence do not contribute at availabilities above 99%.

However, with this effect known, it is possible to ameliorate the rain effects. An increase in the signal power has been found to be a good method to overcome rain attenuation but it does not reduce interference whereas, an increase in the number of reuse channels reduces interference by reducing the number of neighboring co-channel cells affected by rain.

2.9 Analysis of Interference in HAPS

Another important issue when discussing communication system is Interference. Considering our present study, HAPS, interference is caused by antennas serving cells on the same channel and arises from overlapping main lobes or side loves. Two main kinds of interference can be said to happen in HAPS. The first is the interference originating from the users of the HAP-based network and the other one is the one from and to terrestrial or satellite systems sharing the same adjacent frequency bands.

When discussing the first case of interference, we need to take into consideration the differences between the interference that occurs in HAPs network and what happens in the Satellite and Terrestrial network. It's been discovered that Terrestrial systems are generally interference limited but not easy to say what the interference level will be in different places as they greatly depend on terrain and building patterns. In disparity, propagation in HAPS systems is achieved mainly through free space (free space loss and so on) thus the interference levels can be predicted and assumed easily and successfully.

2.10 Antennas for HAPS

A very good performance factor for HAPS lies in the Antenna system. Researchers in HAPS systems have stated some required functions for a successful broadband HAP antenna and they are listed below:

a) Use of high radio frequency in order to secure a sufficient bandwidth.

b) Directional antenna with a high gain to cope with attenuation in high frequencies. It's been found out that co-channel cells are interference limited by antenna beam overlap. Minimization of interference can be attained by side lobe minimization. Beam-forming can use either phased-array antennas or lightweight, possible inflatable parabolic dishes with mechanical steering.

c) Multibeam antenna that accommodates 100 beams or more, both for transmission and reception, to cover views as wide as 120º or more from the stratosphere with a high gain and to achieve effective use of the frequencies involved..

d) Cancellation of the influences of altitude/position variations of the HAP on the footprint on the ground by means of beam control.

e) Reduced weight, size, and power consumption of the mission payload.

f) Must operate reliably in the stratospheric environment.

Considering the movement of HAPs, it is necessary to compensate this movement by mechanical or electronic steering. A serious limitation is the available payload aperture. As the size of cells decreases, the number of cells increases and also the required payload aperture increases.

The size of the antenna array is also determined by the altitude of the platform for a specified radius of the central cell. As the altitude of the platform increases, the size of the array also increases. However, the higher the operating frequency, the smaller the array.

For ground terminals, highly directive antennas are required for high data rate application. When the terminal is on a moving vehicle, it is compulsory it has should have a steering capability. Theoretically, the easiest and simplest solution is the mechanically steered antennas, which gives good performance at low cost.
However, high-speed steering may become challenging due to the large mass of such an antenna. Digital beam-forming (DBF) antennas can achieve rapid scanning, but this advantage is made of no effect by the cost associated with the very large number of antenna active elements which is required to achieve a high gain aperture.
Part of the issues being considered in the ongoing CAPANINA project is the concentration on the development and assessment of hemispherical lens antennas. Hemispherical lens antennas offer several advantages, such as that only the feed, which has much less mass than the lens, has to be steered, multiple feeds can be employed for multiple beams and there is no scan loss. With all these in place, there are still some disadvantages associated with any mechanically steered solution; these are improved by the light weight of the feed.

2.11 Transmission and Coding techniques for HAPS

In every communication system, it is very important to consider the Transmission/Coding techniques used. The known modulation techniques in communication systems are QPSK, QAM, GMSK, BPSK e.t.c. The main goal is to develop a range of modulation/coding schemes, suitable to serve the broadband telecommunication services (with specified QoS and BER requirements), applicable under different attenuation conditions. These will have to vary from low rate schemes involving powerful Forward Error Correction (FEC) coding when attenuation is severe, up to high rate multilevel modulation schemes when channel conditions are good.

A very good and acceptable approach is the use of adaptive coding and modulation based on channel conditions. Know that HAP has a kind of centralized nature, the base station on-board the HAP is aware of the channel losses to the subscribers, and can select the most appropriate modulation and coding scheme. The modulation parameters can be controlled either dynamically, i.e. slot-by-slot, and can be changed during the connection or they can be assigned at the call setup and remain invariable during the call duration. A bandwidth efficient coding and modulation scheme can be used for LOS conditions, whereas power efficient schemes can be employed to counteract shadowing. The adaptive coding and modulation schemes can be combined with space and platform diversity techniques, giving an increased system throughput and a more reliable system, especially in the case of providing broadband services to passengers in high-speed public transport vehicles.

The HeliNet project tried out the investigation of power- and bandwidth-efficient coding and modulation schemes. Three modulation schemes were examined for low, medium and high data rate applications: GMSK, 16-QAM and rounded 64-QAM respectively.

The table below shows a summary (got from the HeliNet project) of four transmission options and the associated coding techniques used.

	Modulation and coding	Max. Bit rate per cell	Availability	Internet Access (60 Mbps)	Video-on-demand (36 Mbps)	Video conference (18 Mbps)	Telephony (6 Mbps)
Option 1	64-QAM uncoded	120 Mbps	Clear air	YES	YES	YES	YES
Option 2	16-QAM uncoded	80 Mbps	99.0%	YES	YES	YES	YES
Option 3	16-QAM coded	55 Mbps	99.9%	NA	YES	YES	YES
Option 4	GMSK coded	23 Mbps	99.90 – 99.99 %	NO	NO	YES	YES

Figure 2.5   Transmission options and the associated coding techniques used. [8]

CHAPTER 3

CHANNEL MODELS

Propagation and channel models are aimed at predicting the average received signal power at given distance(s) from the transmitter(large scale propagation models) and also the fluctuations of the received power over very short travel distances or short time durations in the order of seconds (small-scale propagation or fading models). Fading occurs in areas mostly dominated by tall buildings and obstructions because they block the line-of-sight expected to occur between the transmitter and the receiver. In the existence of line-of-sight however, multipath (bouncing of signals before final destination) exists and it results in small-scale fading. In situations where there exists fixed receivers, received power varies (fading still occurs) due to the movement of surrounding objects. Propagation takes place via many paths in the transmission of signals from a satellite or HAP to a ground station terminal. A good amount of the received power gets to the receiver by way of a direct wave. The other part is received by way of a **specular** ground reflected wave and the randomly scattered rays which form a diffuse wave. The signals that arrive at the receiver are replicas of the same transmitted signal but come with different amplitude, phases, delays and arrival angles. The addition of these different signals can be constructive or destructive.

For the analysis of channel models, the free-space propagation model is used, particularly when a clear, unobstructed line-of-sight path is assumed between the transmitter and the receiver. As with most large-scale propagation models that have been developed, the free-space propagation model predicts that the power measured at the receiver decays as a function of the transmitter-receiver separation distance to an *nth* exponential. This is referred to as the **nth-power law**.

HAPs communications links typically undergo free-space propagation. This is a situation whereby the received power decays according to the nth-power law as a function of the transmitter-receiver distance raised to a power of 2. This serves as one of the many advantages HAPS has got from the satellite communication system. The fact is that in most HAPs-related studies, existing satellite channel models have been used. On this score, the HAPs link compares very favorably with the terrestrial wireless link where the received power decays as a function of the transmitter-receiver distance raised to a power of 4. Also in HAPs links, there exists a dominant signal component, usually a line-of-sight component, and the small-scale fading envelope distribution is a Rice distribution. A rice distribution is one that has a value for the factor of the line of sight and multipath received signal. Some of the important parameters of HAPS and terrestrial wireless links are summarized in the table below.

	Path loss	Fast fades distribution	Dynamic range in a cell-based system
Wireless terrestrial	r^{-4}	Rayleigh	60 – 80 dB (40 – 50 dB due to propagation-induced difference and 20 -30 dB due to fading)
HAP	r^{-2}	Ricean	12- 22 dB (2 dB due to propagation-induced difference and 10 – 20 dB due to fading)

Table 3.1: Path Loss and Fading Characteristics of Terrestrial And HAP Systems. [8]

3.1 Small scale fading

The type of fading experienced by a signal propagating through a mobile radio channel depends on the nature of the transmitted signal with respect to the characteristics of the channel. Depending on the relation between the signal parameters such as bandwidth , symbol period e.t.c, and the channel parameters such as rms delay spread and Doppler spread (all discussed later in chapter 5), different transmitted signals will undergo different types of fading. The time dispersion and frequency dispersion mechanisms in a mobile radio channel lead to four possible distinct effects, which are highly depended on the nature of the transmitted signal, the channel and the velocity. While multi-path delay spread leads to time dispersion and frequency selective fading, Doppler spread leads to frequency dispersion and time selective fading. The two propagation mechanisms are independent of one another.

3.2 Fading effects

Signals undergo either a flat of frequency selective fading as a result of time dispersion due to multi-path. This different fading are very important when discussing and modeling channels suitable for mobile communications.

3.3 Flat fading

A received signal is said to have undergone a flat fading if it is passed through a mobile radio channel that has a constant gain and linear phase response over a bandwidth which is greater than the bandwidth of the transmitted signal. In this type of fading, due to fluctuations in the gain of the channel caused by multi-path, the strength of the received signal changes with time.
To achieve low BER during times of deep fades that flat fading channels cause as compared to systems operating over non fading channels, the use of 20 or 30 dB more transmitter power is employed.

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3.4 Frequency selective fading

If a signal goes through a channel that has a constant gain and linear phase response over a bandwidth that is smaller than the bandwidth of the transmitted signal, the received signal is said to have undergone frequency selective fading. In this type of fading, the received signal includes multiple versions of the transmitted waveform which are attenuated and delayed in time and therefore the received signal gets distorted.

A channel is classified as being a fast fading channel or slow fading channel depending on how rapidly the transmitted baseband signal changes with respect to the rate of change of the channel. If the channel impulse response changes rapidly within the symbol duration, then it's said to be *fast fading channel* i.e the coherence time of the channel is smaller than the symbol period of the transmitted signal

In the other type of classification known as the slow fading, the channel impulse response changes at a rate much slower than the transmitted baseband signal.
These two categories are the types of fading effects experienced due to Doppler spread.

The small scale fading experienced by the user is caused by some factors. Theses are discussed briefly below.

Multipath propagation – a communication terrain is always known to be full of scatterers (objects that cause changes in amplitude and some properties of transmitted signals). These scatterers bring about a constantly changing environment that causes the dissipation of signal energy in amplitude, phase and time. These leads to having multiple copies of the transmitted signal received and displaced both in time and space from one another. This then leads to the fluctuation in received signal strength which brings about small-scale fading and/or signal distortion.

Speed of the surrounding scatterers – when the scatterers present in the radio channel are in motion, there is the induction of some time-varying Doppler shifts on the multipath components. A greater speed by the scatterers as compared to that of the mobile makes it have an edge over the mobile and it's dominance is seen in the small-scale fading otherwise, it can be neglected and only the speed of the mobile need be considered.

Speed of the mobile – the relative motion measured between the mobile user and the base station (which can also be mobile in the case of certain HAPs scenarios) causes random frequency modulation due to the different Doppler shift experienced on each multipath. The Doppler shift will be positive when the receiver is moving toward the transmitter and negative when the receiver is moving away from the transmitter.

Transmission bandwidth of the signal – as will be discussed in subsequent sections, the bandwidth of the radio channel can be characterized by the *coherence bandwidth* and this is directly related to the specific multipath structure of the channel. The coherence bandwidth is the frequency range over which signals are strongly correlated in amplitude

and it is a statistical measure of the range of frequencies for which the channel is considered 'flat'. If the transmitted signal has a narrower bandwidth than that of the channel, the amplitude of the signal will undergo rapid changes but there will be no distortion in time.

As a result, achieving good communications in such an environment where small-scale fading is being experienced can prove to be very difficult even though the movement of the surrounding scatterers will make it such that deep fade is not sustained for too long. Unless the channel is properly modeled, it may be difficult to put adequate measures in place that will combat the effect that this fading could have on the receivers within the communication terrain.

CHAPTER 4

CHANNEL MODEL FOR HAPS

Given that the HAPs system has an architecture that shares some similarities with both the satellite and terrestrial wireless systems, channel models already developed for these systems have being applied to the HAPs system. It has however been observed that due to the peculiar broadband nature of the services that will be provided by HAPs, classic narrowband models like Lutz, Rice or Rayleigh cannot be used to model the system. Hence, an analysis of existing models for broadband systems, which are usually built up from narrowband models, is necessary albeit with some fine-tuning to accommodate the broadband capabilities of HAPs.

In recent studies, analyses of the mobile radio channel are based on the impulse response of the channel and an assumption of a discrete and finite number of scatterers around the receiver. Furthermore, the channel impulse response is assumed to be both time-invariant and wide-sense stationary. Consider the following equation;

$$h(t,\tau) = \sum_{i=0}^{N-1} A_i(t)\delta(t - t_i(t))e^{j\theta_i(t)} \tag{4.1}$$

In the summation in equation 3.1, the term $i = 0$ represents the LOS component of the transmitted signal while the other $N - 1$ terms are representative of the echoes due to multipath. The other focus in this approach is correctly modeling the distribution for the real amplitude A_i that corresponds to the ith echo, the delay time τ_i and the Doppler spectrum. A commonly used approach is the tapped delay line in which the above equation is interpreted and modeled.

The communications channel is always band-limited and this leads to the dispersion or spreading of the signal passing through it. As a result, care must be taken in the process of transmission to ensure that interference caused by improper sampling and pulse shape does not lead to system degradation (higher error rates). Briefly, the problem of intersymbol interference, ISI, is one that is particularly important in digital communications. When the channel has a bandwidth that is much greater than that of the signal, the spreading will only be slight. When the channel bandwidth is just close to that of the signal, then the spreading will exceed a symbol duration and cause signal pulses to overlap and interfere with their neighbouring pulses, hence the term intersymbol interference. The presence of ISI in a system introduces errors at the receiver and therefore one design goal for transmitters and receivers is to minimize the effects of ISI and deliver data across to the destination with the smallest error rate possible.

One way of avoiding ISI as used in practice is what is known as pulse-shaping. As proposed by Nyquist, zero ISI can be achieved by choosing a pulse shape that has

nonzero amplitude at the center, e.g. at $t = 0$ and zero amplitudes at $t = \pm nT_b$ (n=1, 2, 3,….) where T_b is the separation between successive transmitted pulses.

In this thesis work, a number of HAPs-specific channel models have been reviewed and one of them has been simulated in MATLAB in order to evaluate the system performance using the bit error rate (BER)

4.1 Channel Model I

In their paper titled 'A Statistical Switched Broadband Channel Model for HAPS links', Cuevas-Ruiz and Delgado-Penin developed a channel model for the HAPs system that is largely based on the ITU-R Recommendation P.681-6. In this model, the LOS and diffuse components consisting of independent, randomly-phased reflected signals are combined together as a Ricean probability distribution given by;

$$p(r) = 2kre^{(-k(r^2+1))}I_0(2kr) \qquad (4.2)$$

where k is the Rice factor defined as the ratio between the average power of the LOS component and the average power of the multipath components and is calculated by;

$$k = s^2/2\sigma^2 \qquad (4.3)$$

and I_0 is the zeroth-order modified Bessel function of the first kind.

The change in environmental properties result in the fluctuations in received signals. Hence, a finite-state Markovian chain is used model the channel. Three (3) channel states and the transition from one state to the other are defined. In accordance with the ITU-R Recommendation P.681-6, the channel states are;

- A state: LOS condition
- B state: slight shadowing
- C state: Total obstruction

The transitions between states are determined by a matrix **P** where the elements P_{ij} represents the probability of channel change from state i to j

$$\mathbf{P} = \begin{bmatrix} P_{AA} & P_{AB} & P_{AC} \\ P_{BA} & P_{BB} & P_{BC} \\ P_{CA} & P_{CB} & P_{CC} \end{bmatrix} \qquad (4.4)$$

Using the properties of the Markov chain, a state vector π is also defined as;

$$\pi = (\mathbf{I}-\mathbf{P}) \qquad (4.5)$$

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and

$$\pi e = 1 \qquad\qquad (4.6)$$

In equations 4.4, 4.5 and 4.6, I is the identity matrix, P the transition matrix and e = [1 1...] ^{T}. Each element π_i represents the percentage of the time that the process spends in the given state.

A new semi-Markovian process is derived from this Markov chain where the time between the transitions are random and defined for some kinds of distribution. This process has a new transition matrix **r** and it is defined as;

$$r_{ij} = \frac{Pij}{1 - Pii} \qquad \text{for } i \neq j \text{ and } r_{ii} = 0 \qquad\qquad (4.7)$$

This process can be represented by the following schematic;
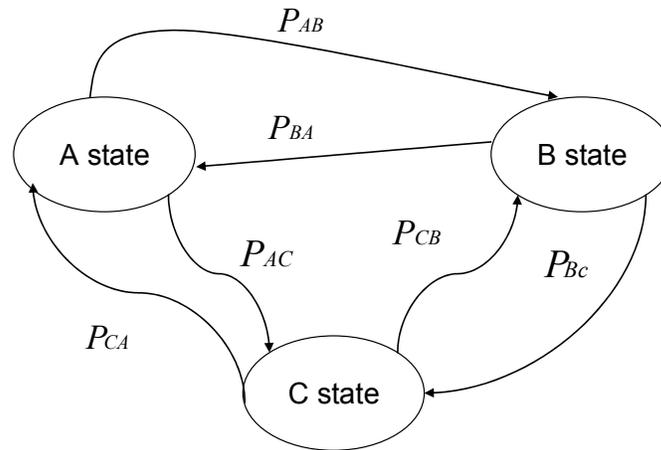
Figure 4.1: A 3-state Semi-Markovian Process

The ITU-R Recommendation P.681 spells out the parameters for the duration of these states and also for the distributions of these durations.

The duration for the state A has an exponential distribution which is given by;

$$P_A(D \leq d) = 1 - \beta d^{-\gamma} \qquad\qquad \text{(4.8)}$$

where the parameters β and γ are indicators of the level of shadowing and the condition $d > \beta^{1/\gamma}$ holds.

Also, the states B and C have lognormal distributions which are given by;

$$P_{B,C}(D \leq d) = (1 + erf[(\ln(d) - \ln(\alpha))/\sqrt{2\sigma}])/2 \qquad\qquad \text{(4.9)}$$

The above expression is valid only for values of the duration *d > 0.1 m*. Also, the natural logarithm of the duration *ln(d)* has a standard deviation of σ and a mean value of *ln(α)*
Finally, in the first instance, a 2-state model is considered with possibilities of being in either a good state (characterized by Rice fading) to a bad state (total obstruction of the signal). In the 3-state model, there is the possibility of transition between 2 adjacent states.

In this switched channel approach, the channel is considered with two and three states respectively. However, the values of delay spread used in the tapped delay line are typical and set values reported in literature for urban and suburban coverage area scenarios. Another important point to note is that the power delay profile used in the model is one obtained in a previous study for mobile satellite systems in L and S bands and at a fixed elevation angle of 45°. It can be said that this model is rather inflexible and as such may not be suited to easy and wide implementations.
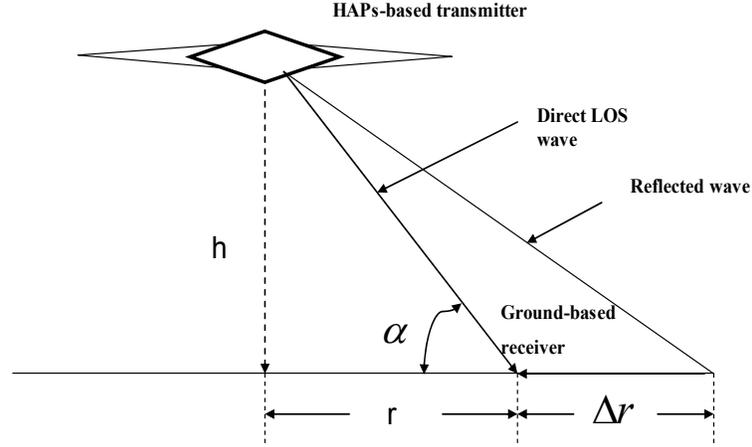
4.2 Channel Model II

In another paper by Delgado-Penin and Ulloa-Vasquez titled 'Performance Simulation in High Altitude Platforms (HAPs) Communications Systems' a HAPs channel is modeled considering the angle of elevation and horizontal distance of the terrestrial reflectors and some statistical arguments.

From the platform-to-earth station downlink transmission path, three points are particularly considered. They are;

- The presence of direct line-of-sight signal from the platform
- The elevation angle α which is a function of the flight height *h* and the horizontal distance *r* of the receiver from the sub-platform point. Changes in the value of α result in variations in the multipath and in the delay of the received signal.
- The shadows that cause reflection positioned at a distance Δr from the receiver.

The figure below shows the airborne transmitter, a receiver and the LOS and reflected signals, both of which are picked up at the receiver.

Figure 4.2: Geometrical Representation For Channel Model II

Using the laws of geometry on the schematic above, a few parameters can be evaluated as follows;

- The distance traveled by the LOS component

$$d_{LOS} = h/\sin(\alpha) \qquad (4.10)$$

- The distance traveled by the reflected component

$$d_{ECHO} = \sqrt{(\Delta r + r)^2 + h^2} + |\Delta r| \qquad (4.11)$$

- The horizontal distance of the receiver from the sub-platform point (SPP)

$$r = h/\tan(\alpha) \qquad (4.12)$$

Considering this particular geometry, it follows that the propagation delay time will correspond to the distances (including detours) traveled by the signal. Thus, using the basic formula

$$c = f\lambda$$

where c is the speed of light

The echo delay can be calculated by;

$$\Delta\tau = \tau_{ECHO} - \tau_{LOS} \qquad (4.13)$$

or

$$\Delta\tau = \frac{1}{c}\left(\sqrt{(\Delta r + \frac{h}{\tan\alpha})^2 + h^2} + |\Delta r| - \frac{h}{\sin\alpha}\right) \qquad (4.14)$$

As h tends to ∞, the above formula reduces to;

$$\Delta\tau_{min} = (1 + \cos\alpha)|\Delta r|/c \qquad (4.15)$$

Also, when h tends to 0, the formula reduces to;

$$\Delta\tau_{max} = 2|\Delta r|/c \qquad (4.16)$$

The second consideration is the amplitude of the received echo. This is related to the free space loss by the formula;

$$\Delta FSL = 20\log(d_{echo}/d_{LOS})dB \qquad (4.17)$$

By substituting equations 4.10 and 4.11 in equation 4.17, the above expression can be rewritten as;

$$\Delta FSL = 20\log\frac{\left(\sqrt{(\Delta r + r)^2 + h^2} + |\Delta r|\right)}{h}\sin\alpha \ dB \qquad (4.18)$$

It can thus be deduced from equation 4.18 and also intuitively that:

when $h \Rightarrow \infty$, then $\Delta FSL \Rightarrow 0$ and when $h \Rightarrow 0$, $\Delta FSL \Rightarrow \infty$

Considering the statistical peculiarities if the mobile radio channel, the so-called Rice factor can be defined as:

$$K = 10 \cdot \log \cdot \left(\frac{r_s^2}{2\sigma^2} \right) dB \qquad (4.19)$$

And using the particular geometry of our communication model, we can say:

$$K = 10 \cdot \log \left(\frac{a}{c} \right)^2 dB \qquad (4.20)$$

Where a is related to the LOS component d_{LOS} and c is related to the reflected ray d_{echo}. Hence, we can say that:

$$K(\alpha) = 20 \log \left[\frac{(h/\sin\alpha)}{\sqrt{(\Delta r + r)^2 + h^2} + |\Delta r|} \right] dB \qquad (4.21)$$

An analysis of the relationship between the elevation angle α and the Rice factor K shows that:

$\alpha \Rightarrow 90° \rightarrow K \Rightarrow \infty$. This can be said to be a Gaussian channel.
$\alpha \Rightarrow [12° < \alpha < 90°] \rightarrow K$ has a finite value >>0. This is a Rician channel.
$\alpha < 12° \Rightarrow K \leq 0$. This is a Rayleigh channel.

Using the above analyses, a tapped delay line simulation model is used to evaluate the performance of the channel in communications between the platform and mobile/fixed terrestrial receivers. In the model, $\tilde{x}$ (t) is the complex envelope of the input signal, $\tilde{g}$ (t) is the unitary power fading process, K (α) is the multiplicative factor used to vary the ratio of the LOS component to the diffuse components in the system and $\tilde{n}$ (t) the white noise process.

It is however noted that in this model, the power adjustments from the platform and the effects of shadows that are coplanar with the receiver are not considered. Also, the fact that certain parameters such as the height of the platform, the angle of elevation and the horizontal distance of the reflectors from the receiver are fixed, it is easy for this model to be over-optimistic in its evaluation of the channel.

4.3 Channel Model III

In the third HAPs channel model considered, the authors of the paper 'The Channel Characterization and Performance Evaluation of Mobile Communication Employing Stratospheric Platform' admittedly define and analyze a narrowband wireless channel based on experiments carried out in a 'semi-urban' environment.

Field experiments were carried out in clear LOS highways for high elevation angles and in shadowed areas for low elevation angles. However, little is said about the mathematical relationships and expressions that have been used to characterize the system. Also, during measurements, only total power is said to be collected without identifying which is attributable to the LOS and multipath components of the transmitted signal. Finally, it is not clear if the model so developed can be adapted and applied to other scenarios and in other communication environments other than those in which the study was carried out.

4.4 Channel Model IV

The fourth and last channel model considered in this work is that proposed by Fabio Dovis et al in their work titled 'Small-Scale Fading for High-Altitude Platform (HAP) Propagation Channels'. This channel model was simulated and results got. It will be discussed in depth in the next chapters. The simulation explanations and results obtained will be discussed.

The Dovis-Fantini model for HAPs channel focuses on the theoretical derivation of the small-scale fading model for the communication link between the terrestrial user (fixed or mobile) and the platform based on the presence of scatterers in the terrain. This model is made even more attractive by the fact that the model is derived in the 2 GHz frequency range which is widely used for cellular telephony and localization services. In addition, at this selected frequency range, rain attenuation effects are not taken into consideration as they are negligible while they are predominant at higher frequencies set aside for some other HAPs applications. This channel model will be considered due to the identified properties it posses and consideration it has taken.

CHAPTER 5

THE DOVIS-FANTINI HAPS MODEL

5.0   INTRODUCTION

One of the most promising telecommunication applications of HAPs is cellular telephony. The International Telecommunications Union (ITU) has thus approved the use of several frequency bands for various HAPs applications. In particular, the 1885 – 1980 MHz, 2010 – 2025 MHz, 2110 – 2170 MHz bands have been allocated to third-generation wireless communications systems in Regions 1 and 3 countries while the Region 2 countries have been assigned the 1885 – 1980 MHz and the 2110 – 2160 MHz bands for the same purpose.

The Dovis-Fantini model for HAPs channel focuses on the theoretical derivation of the small-scale fading model for the communication link between the terrestrial user (fixed or mobile) and the platform based on the presence of scatterers in the terrain. This model is made even more attractive by the fact that the model is derived in the 2 GHz frequency range which is widely used for cellular telephony and localization services. In addition, at this selected frequency range, rain attenuation effects are not taken into consideration as they are negligible while they are predominant at higher frequencies set aside for some other HAPs applications.

5.1   THE LAND – HAP MODEL

As far as small-scale fading is concerned, the mobile radio channel can be characterized by two parameters: its power delay profile (PDP) and the Doppler spectrum (coherence bandwidth and coherence time). Since power delay profile measurements at ground level are site-specific, they can not be adapted to the HAPs case. Therefore, in obtaining a more realistic PDP, the model proposed by Rappaport and Liberti for a ground station is extended to the platform case. Hence, the transmitter and receiver are no longer considered to be on the same horizontal plane and the height of the transmitter is taken into account as well.

In the figure below, the transmitter (TX) is placed at a point with coordinates $(0, 0, z_0)$ and the receiver (RX) at a point with coordinates $(x_0, 0, 0)$. The ellipsoid $\sum$ is the volume containing the scatterers that cause excess delays $< \tau$ e.g. S, with a height $z_s < h$. The length of the of the direct transmission path r_0 is calculated by:
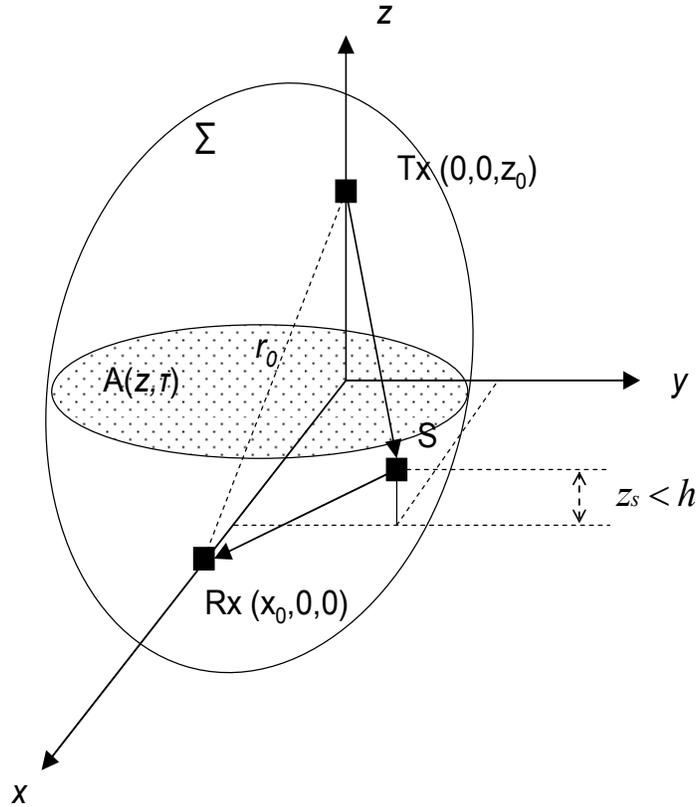
$$r_0 = \sqrt{(x_0^2 + z_0^2)} \qquad\qquad (5.1)$$

and consequently, the propagation delay is obtained as:

$$\tau_0 = \frac{r_0}{c}$$ where c is the speed of light.

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

$$k(\tau) = r_0 + c\tau \qquad\qquad \textbf{(5.2)}$$

Figure 5.1: The LHAP Model Showing The Volume Containing All Scatterers Giving Excess Delays $<\tau$

The points TX and RX form the foci of the ellipsoid Σ and it is the set of points for which the sum of the distance from TX and RX equals $k(\tau)$. Thus, all the scatterers in Σ generate a total path length $< k(\tau)$. Therefore, 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. An important assumption is in the uniform distribution of scatterers in a thin layer close to the ground. This is because objects that cause scattering e.g. tall

buildings, trees, poles, hills, etc are typically under a certain height h. The area $A(z,\tau)$ is the intersection of the ellipsoid $\sum$ with an horizontal plane at the height z.

The volume V (τ) is defined as the set of points (x, y, z) that satisfies the condition:

$$\begin{cases} \sqrt{(x-x_0)^2 + y^2 + z^2} + \sqrt{x^2 + y^2 + (z-z_0)^2} < k(\tau) \\ 0 < z < h \end{cases} \tag{5.3}$$

V (τ) contains the obstacles that cause scattering with an excess delay smaller than τ and it is obtained from the intersection between the ellipsoid $\sum$.and the plane $z = h$. An evaluation of the area A (z, τ) of the ellipse due to the intersection of the ellipsoid with a horizontal plane of height z and an integration of A (z, τ) w.r.t. z from 0 to h yields

$$V(\tau) = \frac{-\pi w(\tau)(r_0 + c\tau)}{4\sqrt{(z_0^2 + w(\tau))^3}} \left[\frac{4}{3}h^3 - 2z_0 h^2 - w(\tau)h \right] \tag{5.4}$$

where $w(\tau) = c^2\tau^2 + 2r_0 c\tau$.

The cumulative distribution function (cdf) of the excess delay, F_{PS} (τ) is then expressed as the ratio between the volume V (τ) and that corresponding to the maximum excess delay of the system, V (τ_m). That is:

$$F_{PS}(\tau) = \frac{V(\tau)}{V(\tau_m)} \tag{5.5}$$

In evaluating F_{PS} (τ), a good knowledge of the maximum excess delay τ_m beyond which the received power P (τ) is very small, is required. Although, values of τ_m for the terrestrial case are well-known, there still are no available measurements for the HAPs case. Therefore, in this work, a nominal value which is approximated from estimated values obtained with conventional aircrafts is used.

5.2 POWER DELAY PROFILE

The power delay profile of a multipath channel shows the arrival time in [ns] of the different ray paths against the received power in [*dBm*] between the transmitter and the receiver. It is usually normalized *w.r.t.* to the power of the LOS component P_{LOS}. The range of values of τ for which the PDP is non-zero is known as the multipath delay spread. A good measure of this delay spread is the rms delay spread σ_τ .

If the ith signal with excess delay τ_i has an amplitude A, then the first moment of the PDP is:

$$\bar{\tau} = \frac{\sum_n A_i^2 \tau_i}{\sum_n A^2} = \frac{\sum_n P(\tau_i)\tau_i}{\sum_n P(\tau_i)} \tag{5.6}$$

And the second moment of the PDP is:

$$\sigma_\tau = \sqrt{\left(\bar{\tau}^2 - (\bar{\tau})^2\right)} \tag{5.7}$$

Where $\bar{\tau}^2 = \dfrac{\sum_n A_i^2 \tau_i^2}{\sum_n A^2} = \dfrac{\sum_n P(\tau_i)\tau_i^2}{\sum_n P(\tau_i)}$ \hfill (5.8)

In a digital communication system, if the delay spread is greater than or equal to the symbol duration, then the delayed multipath components will arrive in different symbol intervals thereby leading to intersymbol interference (ISI). This is has the same effect as when the channel bandwidth is less than the signal bandwidth as mentioned earlier. In this case, the channel is said to be frequency-selective.

In this model, the power of a single echo having excess delay τ, $P_s(\tau)$ is calculated using the free-space model taking into consideration the modified path lengths traveled. The power delay profile of the system is then obtained as the product of the number of echoes $n(\tau)$ and $P_s(\tau)$. That is:

$$P(\tau) = n(\tau).P_s(\tau) \tag{5.9}$$

5.3   THE DOPPLER SPECTRUM

Having obtained the power delay profile, we can then go ahead and evaluate the coherence bandwidth and the coherence time of the system.

5.3.1 Coherence bandwidth

The coherence bandwidth B_c is the frequency-domain parameter analogous to the time-domain delay spread parameters earlier discussed. The rms delay spread and the coherence bandwidth are inversely proportional although the exact relationship between the two may vary from one multipath structure to another. The coherence bandwidth is a statistical measure of the range of frequencies over which the channel passes all spectral components with equal gain and linear phase, i.e. over which the channel is 'flat'. In other words, within the coherence bandwidth, 2 frequency components are strongly likely to be amplitude correlated. As a rule of thumb, if a frequency correlation function of 0.9 is chosen, then the coherence bandwidth is:

$$B_c \approx \frac{1}{50\sigma_\tau} \qquad\qquad (5.10)$$

5.3.2 Coherence time

The Doppler spread and the coherence time are the parameters which describe the time-varying nature of the channel in a small-scale region. They offer information about the changes caused by relative motion between the platform and the mobile receiver or by the movement of the objects in the channel.

As a mobile receiver moves through a channel, or by virtue of other movement identified above; the resultant Doppler shift gives rise to an apparent shift in the center frequency of the transmitted signal. This Doppler shift f_d can be positive or negative depending on the direction of motion of the transmitter, receiver or objects in the channel.
While the Doppler spread is defined as the range of frequencies over which the received Doppler spectrum is essentially non-zero, the coherence time T_C is the statistical measure of the time duration over which the impulse response of the channel is invariant, i.e. it is the time duration within which two received signals are strongly likely to be amplitude correlation. It is important to ensure that the coherence time $T_C <$ the symbol period T_S if we are to have distortionless communication.

If the maximum Doppler spread f_m at the carrier frequency f_0 is expressed as:

$$f_m = f_{d,p} + f_{d,u} = \left[v_p + v_u\right]\frac{f_0}{c} \qquad\qquad (5.11)$$

(where the subscripts p and u represent the platform and the user respectively)

then, the coherence time can be expressed as:

$$T_C = \frac{9}{16\pi f_m} \qquad\qquad (5.12)$$

Having obtained the mathematical expressions for the most important relations in the model, we can go on and employ the tapped delay line model to simulate our channel.

CHAPTER 6

MODEL SIMULATION, TESTS AND RESULTS

6.0 INTRODUCTION

A tapped delay line model is used to simulate the multipath fading channel. The model is assumed to be wide-sense stationary with uncorrelated scattering (WSSUS). In the model below, $\tilde{x}(t)$ is the complex envelope of the input signal. There are N finite taps in the model each of which represent each of the paths, both LOS and multipath, from the transmitter to the receiver.
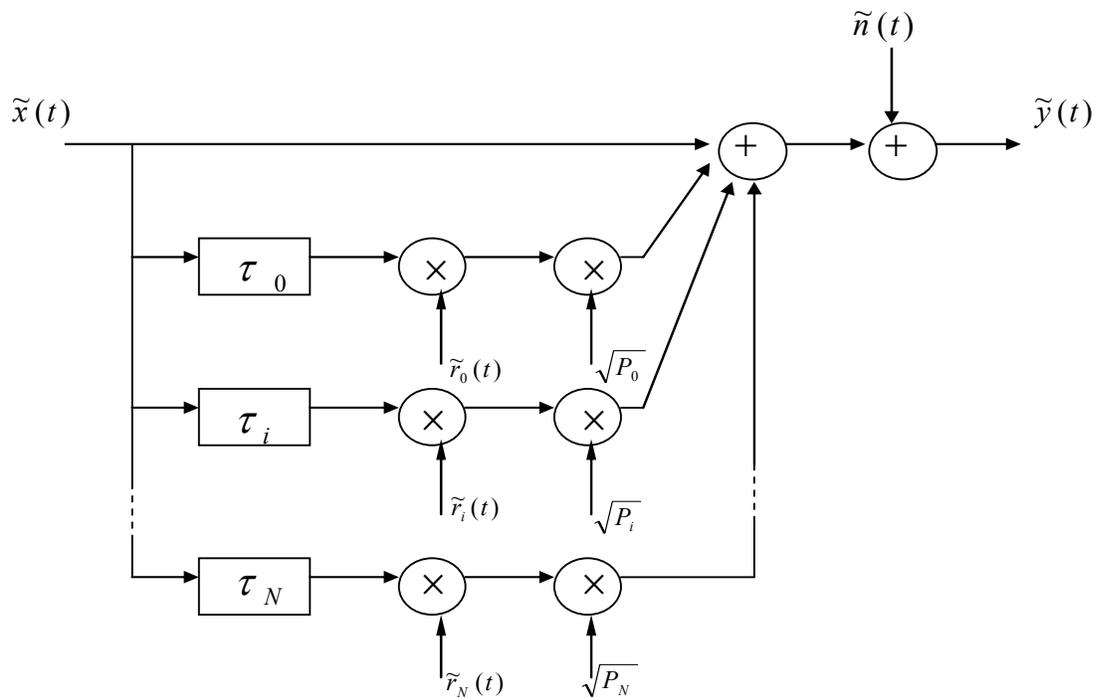

Figure 6.1: Tapped Delay Line Model Used For The Simulation Of The Fading Channel

In MATLAB, the paths are simulated as an equally-spaced array from $\tau \approx 0$ to $\tau = \tau_m$. The first line in the block corresponds to the LOS component at which the delay $\tau \approx 0$. Every other copy is delayed in time in the N consecutive blocks of the model to achieve the multipath reception. This delayed input is next multiplied by a unity power fading process $\tilde{r}_i(t)$ to obtain the time-varying effect of the channel. The fading process is simulated as a Gaussian distributed array which is then band-limited with an FIR filter with a bandwidth that corresponds to the maximum Doppler spread f_m. The next step is multiplying the delayed and fading input with the corresponding gain factor $\sqrt{P_i}$ according to the power delay profile. The outputs from all the N taps are then summed together and additive white Gaussian noise (AWGN) is added to this sum to obtain the final output.

An initial assumption made in the development of the channel model is that a given nominal choice of the height of the scatterers h and the distance of the receiver from the sub-platform point x_0 can be used to represent the entire class of the cumulative distribution functions of the excess delay. This is seen from the plots shown below which, though plotted for different values of x_0 with h fixed and then for different values of h with x_0 fixed, yield similar general shape regardless of the actual values of the parameters used.
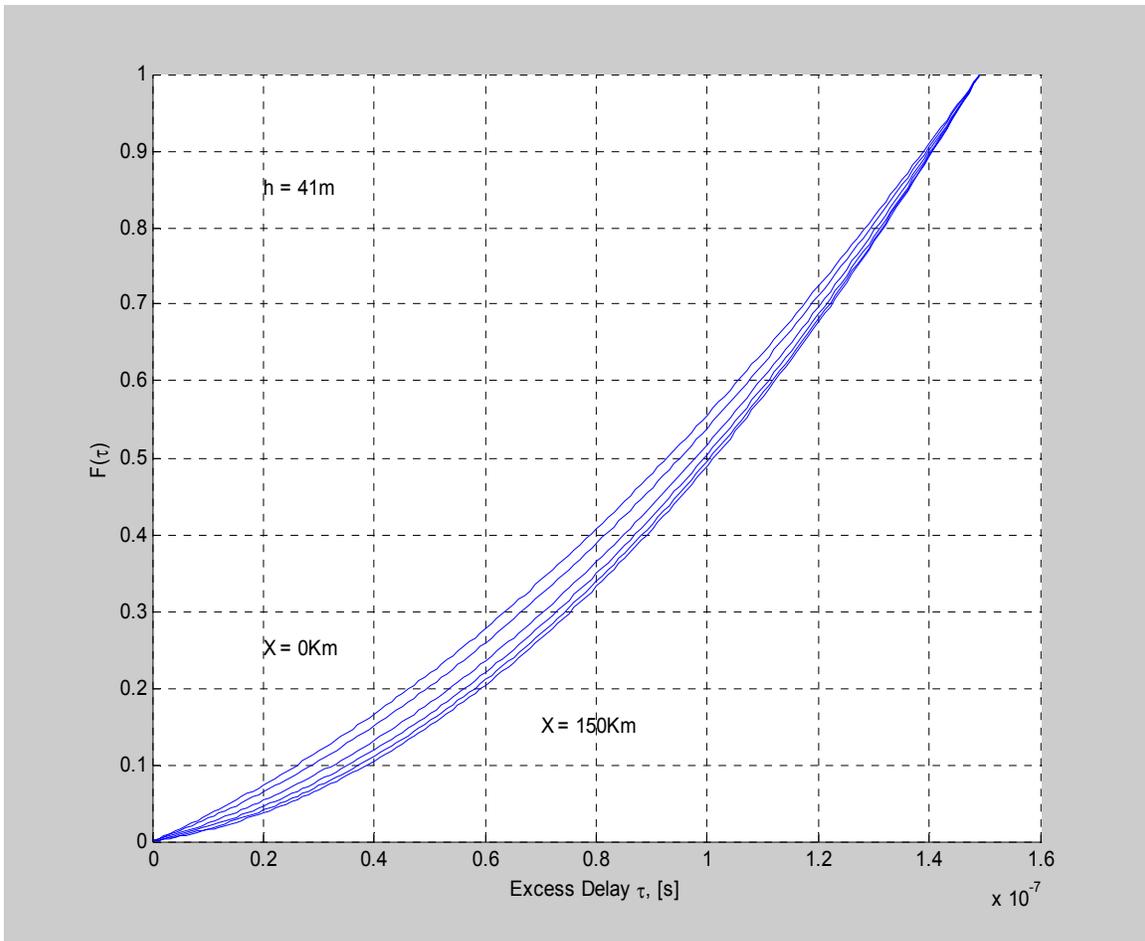
Figure 6.2: Excess Delay Cumulative Distribution With τ_m = 150 ns, h=41 m, z_0=21km and x_0 Varying From 0 To 150 Km With Step 20 Km.
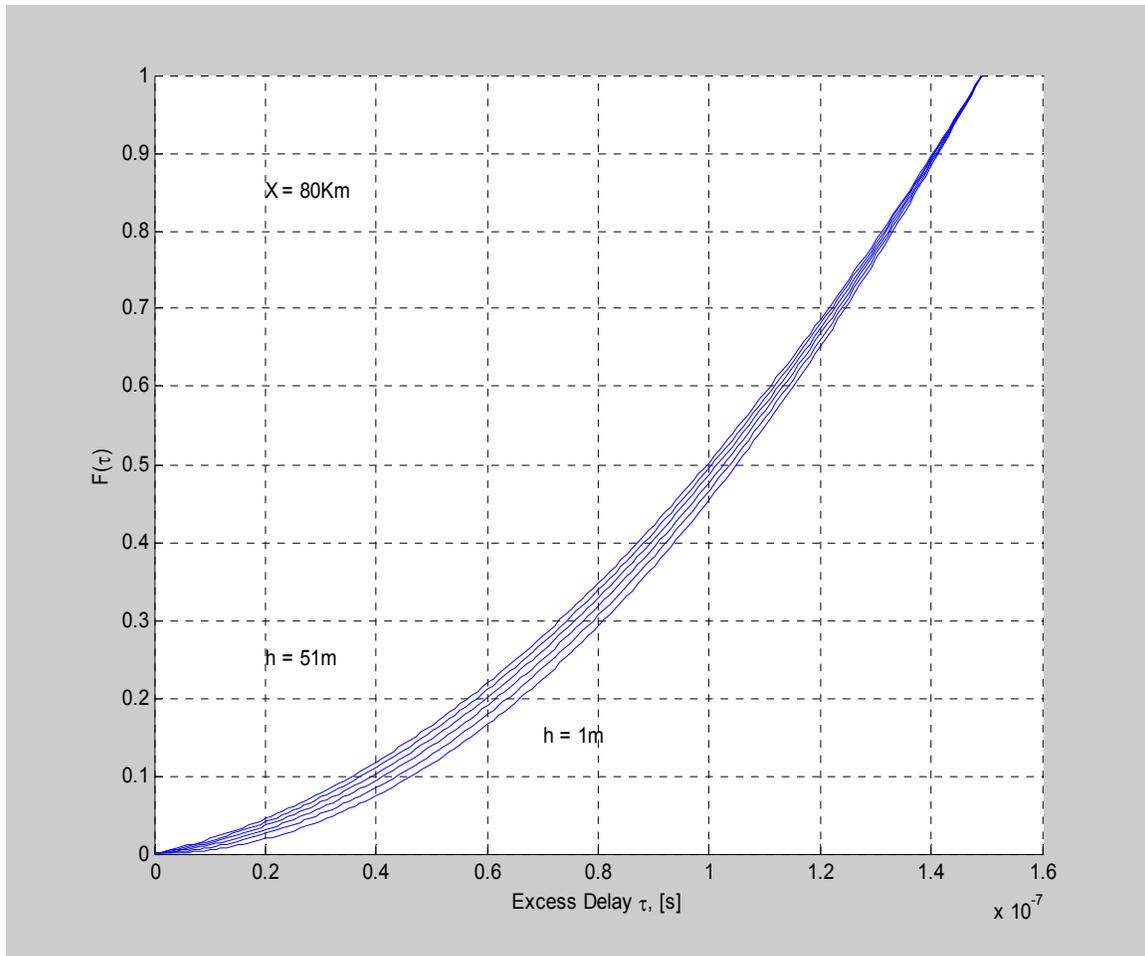
Figure 6.3: Excess Delay Cumulative Distribution With $\tau_m = 150$ ns, x=80 Km, z_0=21km and h Varying From 1 To 51 m With Step 10 m.

In order to obtain a finite number of N of delays τ_i and the corresponding gain factors $\sqrt{P_i}$ used in the simulation model, the power delay profile obtained is discretized. However in discretizing, the sampling interval $\Delta\tau$ has to be carefully chosen to allow for correct representation of the delays. In other words, $\Delta\tau$ must not be greater than the minimum separation between two discernable delays.
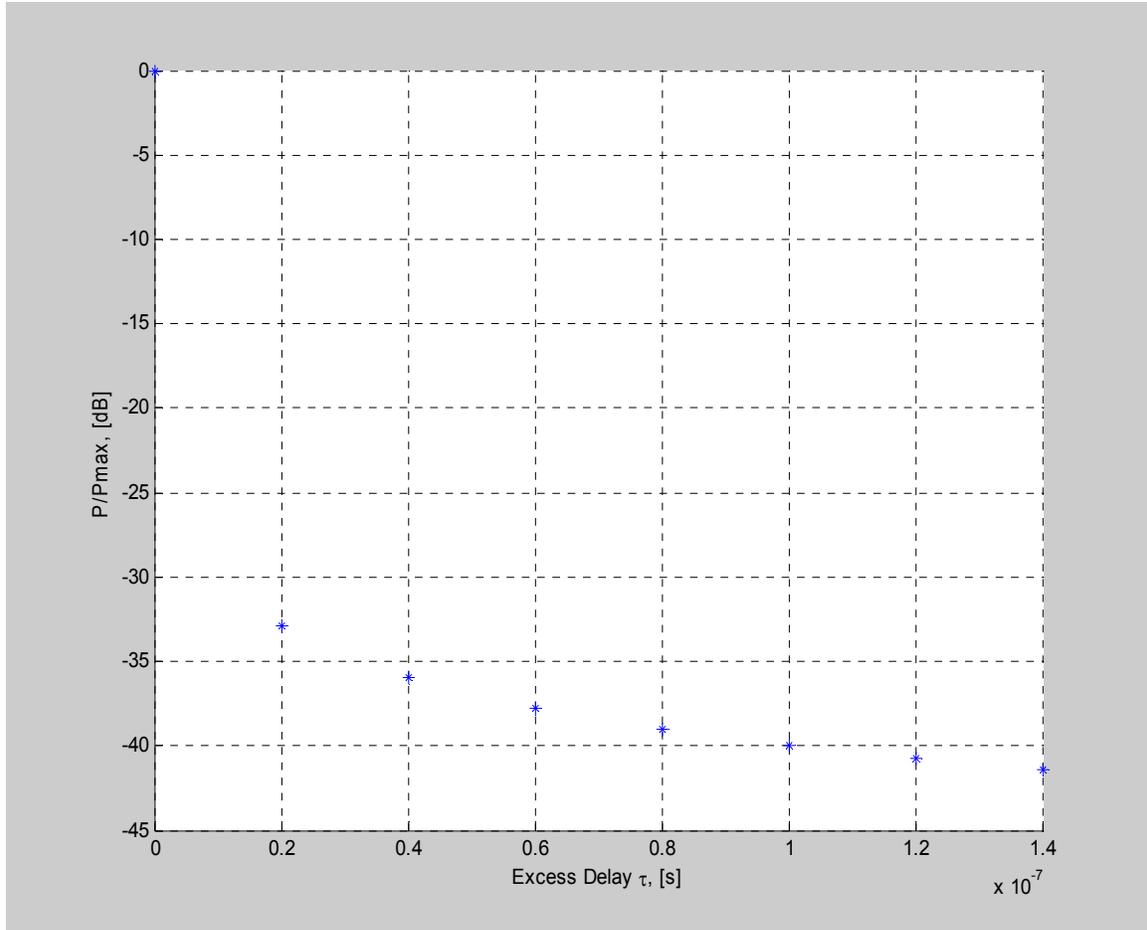
Figure 6.4: A Discretized And Normalized Power Delay Profile For The Platform-Based System.

As an application example, we consider a QPSK modulated signal at a carrier frequency of 2 GHz. The platform is assumed to have a speed, v_p, of 150 Km/h or 41.67 m/s while the speed of the user, v_u, is 50 Km/h or 13.89 m/s.

From the simulation, the maximum Doppler spread f_m is calculated as 370.37 Hz. From this, the coherence time T_c is calculated as 0.483ms. In calculations leading to the power delay profile, we obtain the rms delay spread σ_τ as 42ns and the coherence bandwidth B_c as 477.81 KHz

The last part of the simulation results obtained is the generation and comparism of the BER for the AWGN and the model. The channel is tested with different bitrates of 0.25 Mbps, 1 Mbps and 4 Mbps.
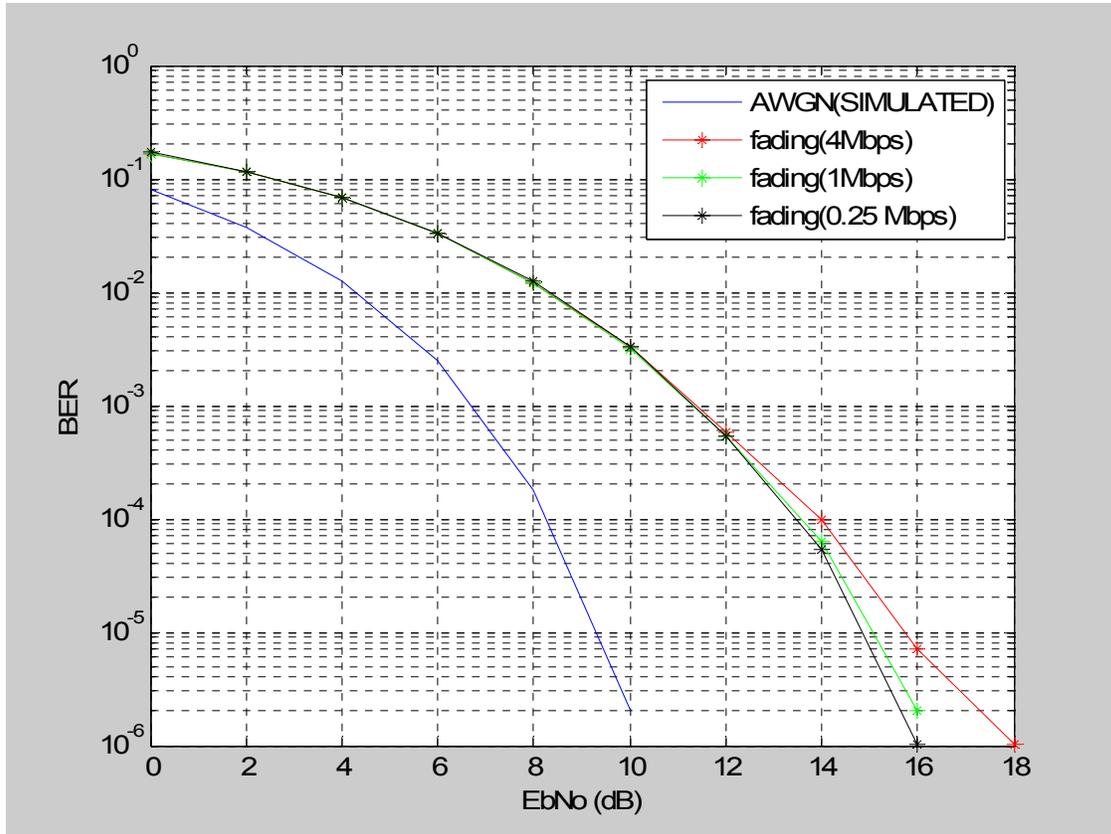
Fig 6.5 BER for a 2-PSK modulation scheme for AWGN and LHAP channel model with C/M = 18 dB, Rb= 0.25, 1, 4 Mbps
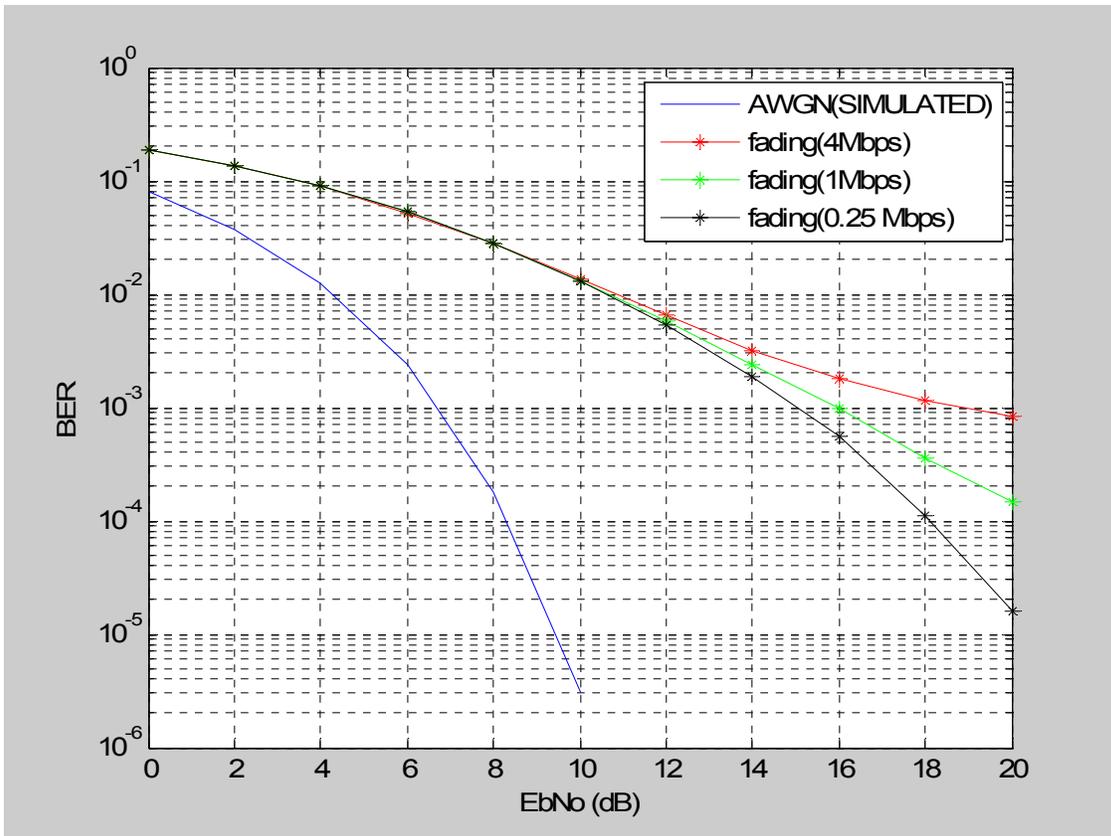
Fig 6.6 BER for a 2-PSK modulation scheme for AWGN and LHAP channel model with C/M = 6 dB, Rb= 0.25, 1, 4 Mbps

CHAPTER 7

CONCLUSION

HAPS, which is a rather developing, low-cost and efficient communication technology has been considered in this thesis work as to how it could be used as substitution to or complement Satellite and terrestrial communication which have been in existence before now.

The main simulation tool used in this thesis was MATLAB and the channel model suitable for HAPS' use was carefully considered. There have been some existing channel models used the existing telecommunication technologies. These were reviewed and considered for HAPS with one of them implemented in MATLAB. The scatter plots were plotted and the performance evaluation was done using the bit error rate (BER). The simulation was done with a center frequency of 2 GHz which is the ITU operating frequency designed for IMT-2000 services via HAPs.

From the BER plots, it can be seen that Rician model does not give a good representation of the channel when noise is present. This is because the scaterrers close to the ground were not considered; hence we can't rightly conclude that the true results have been obtained.

CHAPTER 8

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[15]   http://www.itu.int

Appendix A

Acronyms

AWGN   Additive White Gaussian Noise.

BER   Bit Error Rate.

HAP   High Altitude Platform

DQPSK   Differential Quadrature Phase Shift Keying

QPSK   Quadrature Phase Shift Keying