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RAIN ATTENUATION EFFECTS IN CONSIDERING THE FEASIBILITY OF STRATOSPHERIC COMMUNICATION PLATFORMS FOR RURAL AREAS OF SOUTH AFRICA

by
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Submitted to the School of Electrical Engineering in partial fulfillment of the requirements for the degree of M.Sc. (Information Technology and Telecommunications)

Supervised By
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Date of Submission
December 2006

DISSERTATION TITLE

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IN PARTIAL FULFILMENT OF THE DEGREE

Masters in Electrical Engineering in Telecommunications and Information Technology
from the University of KwaZulu-Natal (Westville Campus)

DATE OF SUBMISSION

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Mr R Sewsunker

DECLARATION

I, Anash Singh, Student Number 9707051, hereby declare that the dissertation entitled:

RAIN ATTENUATION EFFECTS IN CONSIDERING THE FEASIBILITY OF STRATOSPHERIC COMMUNICATION PLATFORMS FOR RURAL AREAS OF SOUTH AFRICA,

is a result of my own investigation and research, and presents my own work unless specifically referenced in the text. This work has not been submitted in part or in full for any other degree or to any other University.

Acknowledgements

The authors wishes to, first and foremost, thank God for his divine love and mercy which makes all things possible. Sri Gurudev, whose guiding hand has veiled me against all adversity. I would like to give sincere thanks and affection to my late father, whom I know is always looking down from the heavens and keeping an eye on me. My mother, brother and friends for their support, understanding and encouragement during the many hours of work and sleepless nights involved in the successful completion of this research study.

I would also like to thank Mr. R. Sewsunker my supervisor for his assistance during my studies. His guidance and knowledge made it possible for me to complete this research.

Finally, I would like to thank the Telkom Centre of Excellence programme for financially supporting me during my studies. Special thanks also to THRIP, Alcatel and the staff at the Westville campus for their support and patience during my Masters in Electrical Engineering.

ABSTRACT

Also known as High Altitude Platform Stations (HAPS), these systems employ unmanned or manned, solar or fuel energy airships or aircraft carrying payloads with transponders and antennas. These remote airships or aircraft offer a much more cost effective solution for coverage of certain regions including: urban, suburban, rural and other environments with low population densities. The Stratospheric Communications Platform (SCP) network offers a better solution than existing Cellular Radio Systems for telecommunication and multimedia services, with greater speed of transmission than even optical modes. It would be virtually impossible to construct land lines and microwave networks in remote, one thousand square-kilometre rural areas. There are other drawbacks to wired deployment as well. The cost of copper wire is astronomical, the terrain harsh and inaccessible and the population scattered. The aim of this dissertation is to illustrate that the use of a platform of this nature is suitable to the rural environment of South Africa. This work includes a case study to ascertain the feasibility of a high altitude platform approach to telecommunication service provision for rural areas. Realising its feasibility has led to an intensive study of rain attenuation. The specific attenuation calculated for a South African rural area (Ulundi) is compared to ITU values. A performance evaluation of the SCP has been done via a link budget calculation with the calculated attenuation values used as input parameters. The advantages of SCPs due to lower path loss, mobile power consumption and system cost are documented. A cellular network architecture is proposed and future investigations into station-keeping techniques, payload power and platform placement are discussed.

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List of Abbreviations and Acronyms

AS	Autonomous System
ATM	Asynchronous Transfer Mode
AVVID	Architecture for Voice and Video Integrated with Data
AVCS	Aerial Vehicle Communications System
CAS	Channel Associated Signaling
CDMA	Code Division Multiple Access
CODECS	Compression/decompression algorithms
CPU	Central Processing Unit
DECnet	Digital Equipment Corporation
DES	Data Encryption Standard
DISL	Dynamic InterSwitch Link
DOE	Department of Energy
DSL	Digital subscriber line
DiffServ	Differentiated Services
EIRP	Equivalent Isotropically Radiated Power
E&M	Receive and transmit
E1	Wide-area digital transmission scheme used predominantly in Europe that carries data at a rate of 2.048 Mbps
FCC	Federal Communications Commission
FTP	File Transfer Protocol
GEO	Geostationary Earth Orbit
GES	Ground Earth Stations
HAPS	High Altitude Platforms
HALO	Halostar Network
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IPv4	Internet Protocol Version 4
IPv6	IP Version 6
ISDN	Integrated Services Digital Network
ISP	Internet Service Provider
IntServ	Integrated Services
ITU	International Telecommunications Union
KZN	Kwa-Zulu Natal

LEO	Low Earth Orbit
LOS	Line of Sight
MTN	Mobile Telecommunications Network
MMW	Millimeter Wavelength
NASA	National Aeronautics and Space Administration
OSI	Open Systems Interconnection
PSTN	Public Switched Telephone Network
QoS	Quality of service
RF	Radio Frequency
RFC	Regenerative Fuel Cells
RMON	Remote Monitoring
RX	Receive Antenna
SADC	South African Development Community
SCPs	Stratospheric Communication Platforms
SHF	Super High Frequency
SONET	Synchronous Optical Network
SOR-18	Rural POTS on Open-wire
TAO	Telecommunication Advancement Organization
T1	Digital WAN carrier facility
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol/ Internet Protocol
TDM	Time Division Multiplexing
TX	Transmit Antenna
UDP	User Datagram Protocol
UHF	Ultra High Frequency
VHF	Very High Frequency
VoIP	Voice over IP
VSAT	Very Small Aperture Terminal Satellite
WAN	Wide Area Network
WCDMA	Wideband Code Division Multiple Access
WLL	Wireless Local Loop
WRC	World Radio Conference
XPD	Cross Polar Discrimination

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Introduction

1.1 Background

TELEPHONE access may be considered as an everyday service in the developed world but in the rural areas of most developing countries, it barely exists. The distinction between developed and developing countries can be seen in comparing telephone access. In many developing countries, majority of the population live in rural areas. This translates to about fifty to sixty percent of the total population in individual countries, on average.

Telecommunication development particularly in rural areas, does not receive the priority as does timely provision of food, medicine and health care. While telecommunications may not be regarded as central, it acts as a powerful means of alerting the world about an impending catastrophe, whilst also ensuring multimedia interaction between people throughout the world.

The rural areas in South Africa are often landscapes of poor services and backward technology. Many inhabitants of these areas have migrated to the cities that have more developed infrastructure [1]. New telecommunications concepts are needed to bring the entire rural community of South Africa into the digital age of the modern world. An emphasis has to be placed on deployment of services in the areas as well as stimulating demand and optimizing the rate of supply of such services. These services should be easily accessible and integrated into an overall strategy of network and services. In some rural areas in South Africa, only three percent of the population is connected to the telephone network. And while South African cities benefit from the latest in telephone technology, outlying areas suffer. Service providers have come to the realization that terrestrial solutions provide a limited solution based on difficult terrain and sparse population density.

It is believed that telecommunications can play a major role in enhancing the amenities of rural communities. Health and education will be improved and in return enhance the life of all in the region. Table 1-1 shows useful information regarding the rural traffic for the South African Development Community [2].

Country	Area (km^2)	User Population	Rural Traffic per Person
Angola	1247000	4083000	0.002
Botswana	396900	495000	0.002
DRC	1586900	15915000	0.002
Lesotho	21000	657000	0.002
Malawi	65800	3501000	0.002
Mauritius	1400	351000	0.002
Mozambique	548800	6135000	0.002
Namibia	576100	543000	0.002
Seychelles	1000	24000	0.002
South Africa	8547000	13398000	0.002
Swaziland	11900	30900	0.002
Tanzania	618800	10929000	0.002
Zambia	520100	3225000	0.002
Zimbabwe	270900	3921000	0.002

Table 1-1: Relevant information for the SADC region

Vast distances, high capital infrastructure costs, limited revenue opportunities and sparse, scattered rural populations all contribute to a challenging business case for service providers. The relative isolation of rural areas has been an inhibitor to investment but on the other hand a reasonable telecommunications infrastructure is a major boost to competitiveness of rural industry. It can provide better and timely information to rural businesses on markets and business inputs, as well as providing opportunities for rural producers and businesses to communicate with each other to share strategic information and advice [2], [3].

1.2 General information on South African rural areas

Provision of rural telecommunication services is a complex process that involves both technical and socio-economic factors. It requires the development of infrastructure for rural telecommunications, assessment procedures for the evaluation of opportunities and strategic planning in terms of financial and infrastructure rollout, and special strategies for improvement of maintenance and repair activities.

The rural areas of most Southern African countries including South Africa and countries such as Kenya, Tanzania, and Uganda have peculiar features such as:

- Low population density (typically 10-50 persons per square kilometer). This requires a deployment of technologies that can aggregate traffic from a large geographical area in a cost effective way [2], [4].
- Low and seasonal individual incomes mainly from subsistence agriculture. This makes it necessary to ascertain the investment risk for this market [5].
- Very low provision of telecommunications infrastructure in rural areas. This is the crux of the matter. There is a need to provide telecommunication services but most of the technologies available at present appear to be targeting areas where the traffic is naturally aggregated with reasonable number of customers per geographical areas to meet system commercial viability [6].
- A combination of lack of geographical location's proximity to large population centers and low potential customer densities makes telecommunications service provision in rural areas much more expensive and difficult than in urban areas. The challenge has always been the fact that the rural communities are not naturally aggregated enough as urban populations to enable deployment of high capacity networks [7], [8].

The geographical position of South Africa (in extreme co-ordinates) is: North: 22° S / South: 35° S / East: 33° E / West: 16° E.

1.3 Development with infrastructure

1.3.1 The South African telecommunications market

The South African telecommunications market is currently the largest in Africa based on customers and revenues. The market has grown substantially in the past few years from R31.7 billion ($5.7 billion) in 1998 to R47.1 billion ($6.8 billion) in 2000 [5]. As at September 30, 2002, fixed-line penetration based on population was 10.8%, while mobile penetration had risen to 26.6% [11]. While this may suggest that there is significant growth opportunity in the South African telecommunications market, the country faces numerous challenges to overcome the substantial inequality among its population in terms of geographic, economic and demographic distribution. Approximately 55% of South Africa's population is concentrated in urban areas [10]. Similarly, wealth is highly concentrated with an estimated top 10% of the population earning in excess of 45% of the national income while the poorest 20% earn less than 3%.

1.3.2 Fixed-line

The fixed-line telecommunications market in South Africa has grown approximately 28% from R20.4 billion ($3.7 billion) in 1998 to R26.1 billion ($3.8 billion) in 2000 [5]. The increase was primarily due to increased fixed-line usage by Telkom's global and corporate customer segment, increased internet traffic and the introduction of new value-added voice and data products and prepaid fixed-line services. Telkom's introduction of prepaid fixed-line services was the first prepaid fixed-line service to be made available to customers in the world [11]. Long-term growth is expected to continue to be driven by increased internet usage, increased usage of data services and the development and adoption of new data products and services. Growth, however, may be limited by further tariff reductions, the continued migration of users from fixed-line services to mobile services and a significant decrease in the rollout of new fixed access lines. As at September 30, 2002, there were 4.9 million fixed access lines in South Africa [11].

1.3.3 Internet access

South Africa is the largest internet market in Africa with an estimated 2.4 million internet users resulting in a penetration rate of approximately 5.6% as at November 30, 2002 based on the estimated population at mid year 2002 by Statistics South Africa [12]. The number of internet service providers increased rapidly from seven in 1997 to 170 at the end of 2001 as the market structure evolved to accommodate tier two internet service providers. First tier internet service providers are wholesale resellers of bandwidth while second tier internet service providers purchase international and sometimes local bandwidth from first tier internet service providers. The internet service providers include Telkom, UUNet SA, Internet Solutions, AT&T Global Network, MTN Network Solutions and DataPro.

1.3.4 Mobile access

GSM mobile services were launched in South Africa in 1994 and have experienced rapid growth in the number of mobile users increasing from 1.0 million users as of March 31, 1997 to 10.8 million users as of March 31, 2002, and 12.1 million users as of September 30, 2002, resulting in mobile penetration increasing from 2.4% to 26.6% during the same period [10], [12]. However, the overall penetration in South Africa remains low compared to Western European or Asian levels, which provides the potential for continued growth in the number of customers. South African mobile revenues were R15, 411 million in 2000, R21, 052 million in 2001 and R25, 493 million in 2002. Revenues from mobile services grew approximately 88% from R11.2 billion ($1.06 billion) in 1998 to R21.1 billion ($2.0 billion) in 2000 [5]. The increase in the number of mobile users was primarily due to the popularity of prepaid services, increased affordability of handsets and a decline in overall tariffs for mobile services. The planned allocation of 1800MHz radio frequency spectrum is expected to expand service coverage, increase network capacity and facilitate the introduction of high-end data services and mobile internet. There are currently three mobile communications network operators in South Africa: Vodacom, MTN and Cell C. As at September 30, 2002, Vodacom had an approximately 59% market share of total reported customers in the South African mobile market, while MTN had an approximately 36% share and Cell C accounted for the remaining 5% of customers as shown in Table 1-2 [11]. Cell C only commenced operations in November 2001.

	Year ended March 31										Six months ended September 30			
	1998		1999		2000		2001		2002		2001		2002	
	(in thousands, except percentages)													
South Africa														
Mobile users	**1.836**	**%**	**3.337**	**%**	**5.188**	**%**	**8.339**	**%**	**10.789**	**%**	**9.192**	**%**	**12.081**	**%**
Vodacom	1.137	62	1.991	60	3.069	59	5.108	61	6.557	61	5.657	61	7.130	59
MTN1	699	38	1.346	40	2.119	41	3.231	39	3.879	36	3.535	39	4.284	36
Cell C	-	-	-	-	-	-	-	-	353	3	-	-	667	5
Total market penetration (%)	4.5		8.0		12.1		19.1		24.2		20.6		26.6	

Table 1-2: Market Penetration by Cellular service providers

1.4 A Look at the Telecommunications Platform

The Southern Africa Development Community (SADC) consists of 14 countries of Africa: The DRC, Tanzania, Seychelles, Mauritius, Zambia, Zimbabwe, Malawi, Mozambique, Lesotho, Angola, South Africa, Swaziland, Botswana and Namibia. The SADC countries form a solid block spanning about 9 million square kilometers with a population of about 200 million giving an average population density of 22 people/sq. km. In general, the region has an underdeveloped telecommunications infrastructure with teledensities ranging from above 20% in the Seychelles and Mauritius to less than 1% in the majority of the member countries. The teledensities of the SADC can be seen in Figure 1-1 [3].

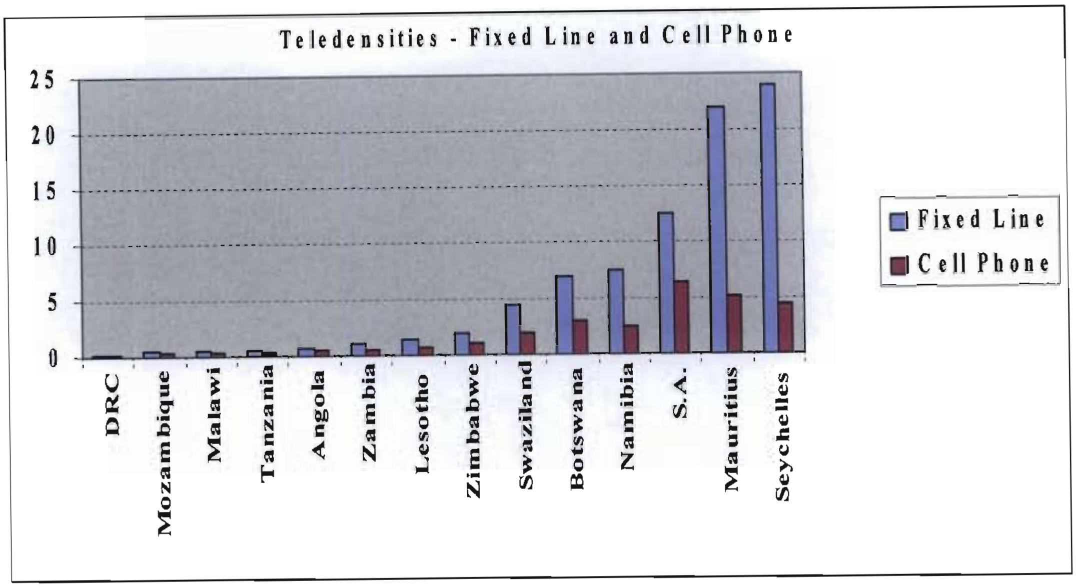

Figure 1-1: Teledensities of the SADC countries

Remote and rural communities in large or developing countries have historically been left with poor or non-existent communications due to a number of factors, although telephone service has often been considered important for regional growth. Wire-line networks are often not an economic option due to high initial investment and low financial returns, especially in small communities and isolated locations. Most current rural telephone networks exist as an obligation from governmental requirements for telephone service providers to cover low density and small remote locations. Maximum limits on mandated tariffs are often imposed, so the economics of those rural nodes have been subsidized either by the government or by urban users. Wireless communication networks are gaining an increasing amount of attention for use in such applications due to more cost-effective performance. Although analog Multiple-Access Radio has been used before in rural applications, new wireless digital systems could help bring telephone communications to remote locations through the use of Wireless Local Loops (WLL) [13]. Since wire-line service operators may not serve remote locations, high- and low- tier WLLs can provide a wireless "last-mile", but it still requires long distance access to the PSTN. This can be achieved with a satellite terminal, which has ubiquitous presence under the satellite's footprint. For that reason satellites are being considered as either a relay service (hybrid bent-pipe) or as part of an integrated cellular / satellite system [6], [8].

Rural communities without telephone service have two different problems: they can neither call their neighbors (local calls) nor the outside world (long distance calls). If a rural village has at least a single long distance telephone line placed at the local store, authority or health facility, local people can at least communicate with relatives, authorities or other government offices [2]. The calls may be for personal, emergency or important official messages, even if users have to walk to this point. Although many countries mandate their local telecommunications operators to provide long distance telephone service to certain size communities, these mandates are often ignored or delayed because of economic factors. A rural village will hardly have local service if they do not have long distance service, which has higher priority. Local telephone service will usually be implemented in villages that reach a certain minimum size and telephone traffic conditions, and only after long distance service has been operational and people are familiar with its use. A local network not connected to the Public Switched Telephone Network (PSTN) is called a private network. The local network's transmission media between the switch and the local user's premises is called the "last mile technology", and it may consist of cabled (wired) or radio (wireless) communication links [8]. Local calls are handled by a local switch office, which connects calls from one villager to another rural subscriber according to the number dialed. If a long distance number is dialed, the local rural office will switch the call to the long distance switch, or gateway, which will connect the call to the long distance transmission system and carry the call to another gateway connected to the PSTN. Thus the long distance gateways are important elements of the telephone network regarding rural telephony.

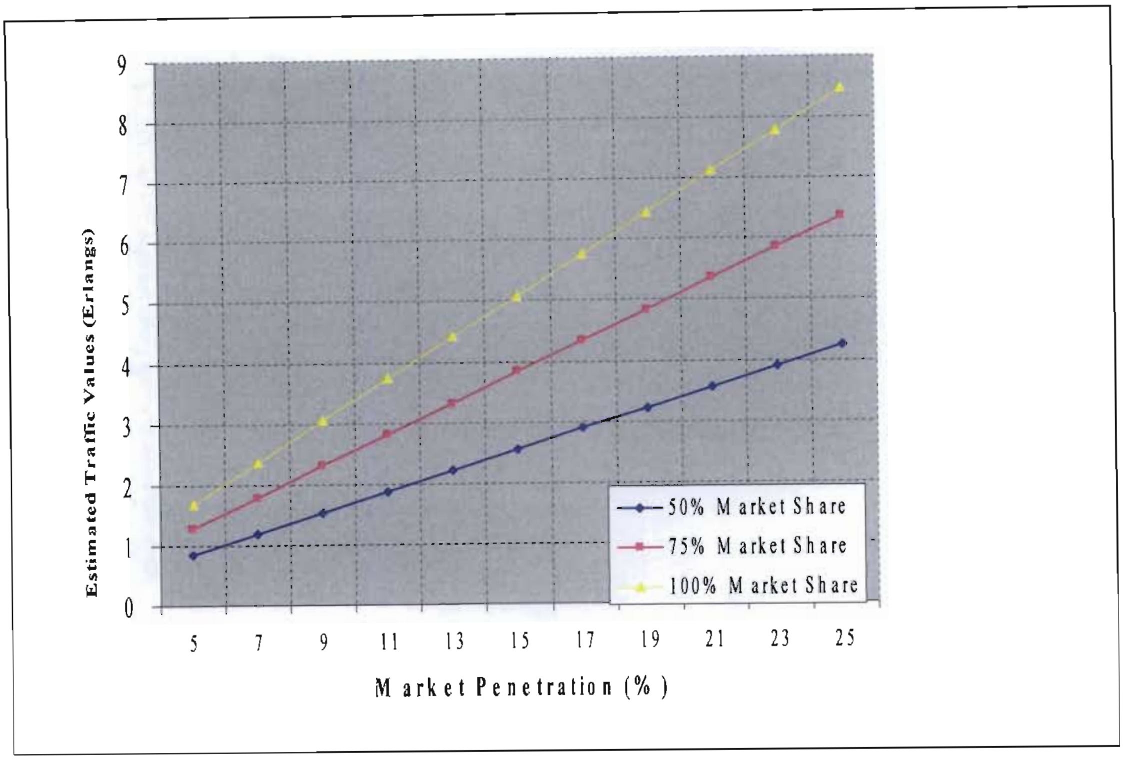

Figure 2-2: Estimated Traffic Values for Ulundi

From Figure 2-2 it can be see that the estimated traffic generated in Ulundi is relatively low taking various market penetrations and market share values into account. This is generally the norm in rural areas.

2.3 Case Study 1– Telkom S.A -Mpumalanga Province

In 1998, many parts of rural South Africa were still without telephone service. In fact, in some remote areas just three percent of the local population had access to a telephone. The new South African Government, like many governments throughout the world, was determined to answer the rural needs for modern telecommunications.

Telkom SA, the leading South African telecommunications company, won the government concession to supply fixed-line telephone service to key urban centers, and with it, took on the obligation to provide service to rural areas as well. Not only would Telkom SA need to deploy a new telephone network to remote areas covering thousands of square kilometers – including large tracts of harsh terrain and areas without electricity or running water – they would need to do so within months.

Terrestrial solutions were out of the question. It would be virtually impossible to construct land lines and microwave networks over such a large area in time to meet their deadline. Even if construction were possible, the cost of copper wire would have been prohibitively expensive.

Figure 2-3: Mpumalanga Rural Area

2.3.1 The Proposal

The clear choice was a Very Small Aperture Terminal (VSAT) rural telephony network from Gilat. Gilat's VSAT satellite based solution encompasses a telephony solution that can be deployed completely independently of communications infrastructure. This would allow Telkom SA to deploy such a large network across remote areas quickly and affordably. Telkom SA selected Gilat to develop a solar powered fixed rural satellite telephony network for use in schools, small business and public telephones in nearly three thousand communities throughout rural South Africa [13] , [14].

Gilat met the challenge in record time, deploying the first one-thousand six hundred sites in only two months. The VSAT telephony rollout brought phone service to thousands of rural residents, small business and schools for the very first time. The comprehensive solution included:

- Toll-quality telephony and Internet services on a single, low cost platform

- Reliable VSAT satellite communications equipment deployable without terrestrial infrastructure, even in the most remote locations

2.3.2 The result

Figure 2-4: VSAT Solution for Rural SA

Telkom SA telephony network meets government obligations to provide citizens with quality, affordable telecommunications no matter where they live. The major advantages of satellite solutions in this case can be seen as:

- Toll-quality phone and fax service in even the most remote locations
- E-mail connections and Internet options, linking South Africans in rural areas to modern information networks
- Fast, economical network deployment and easy, cost-effective operation
- Room to grow: quick, simple upgrades to services like distance learning and broadcast and expansion to new sites

2.4 Implications of case-study

The Mpumalanga Province case-study shows the feasibility of a satellite solution. A terrestrial copper wire solution was neither a cost effective nor time saving solution inorder to facilitate telecommunication services for this rural region. The VSAT solution was therefore chosen. This research focus is based on a High Altitude Platform (HAPS) approach to providing rural telecommunications. Here however, the platform will be at a much lower altitude than any geostationary (Geo) or low earth orbiting (Leo) satellite like VSAT.

There are many advantages to the lower platform height:

- Lower propagation path attenuation levels
- Quick launch and set-up time
- Huge reduction in system cost

A High Altitude Platform approach to providing telecommunications in rural areas of South Africa is feasible, hence the Stratospheric Communications Platform (SCP) warrants greater investigation as a 'backbone' for communication in these harsh, inaccessible regions.

Stratospheric Communications Platform

3.1 Overview

Located in the stratosphere approximately 17-25 km above the Earth, each Stratospheric Communications Platform (SCP) acts as the very low orbiting satellite, providing high density, capacity, and speed service with low power requirements and no latency to an entire metropolitan and suburban area extending out into rural areas. No other existing or proposed technology offers this combination of very high density service and low cost. Spectrum in the 47 GHz band has already been designated globally by the ITU as well as the FCC for use by high-altitude stratospheric platforms, paving the way for planned commercial service to commence in the year 2007 [15]. When deployed over a big city or metropolitan area, a Sky Station platform immediately provides the necessary communications infrastructure to combine voice, mobile data, and broadband wireless service to hundreds of thousands of users. Subscribers can transmit directly to the platform, where on board switching routes traffic directly to other Sky Station subscribers within the same platform coverage area [16]. Traffic destined for subscribers outside the platform coverage area is routed through ground stations to the public networks or in the next stage to other platforms serving nearby cities. All developing nations need low cost access to high density telecommunications links to support accelerated economic development and inclusion in the Information Revolution.

There are four general telecommunications architectures which can be used to deliver broadband wireless local loop service to consumers. Two of these architectures are space-based Geostationary (GEO) and Non-GEO satellite systems, and other two are terrestrial rooftop cellular-like millimeter wave repeaters and stratospheric relay platforms.

The SCP network could offer a better solution than Cellular systems, with speed of transmission that could match those of wire-line services. The SCP mission can be integrated with current satellite and cellular systems; the system is more autonomous and discrete and will be the best solution for military and all mobile applications. The High Altitude Long Operation (HALO) Network is a broadband wireless metropolitan area network, with a star-topology, whose solitary hub is located in the atmosphere above the service area, at an altitude higher than commercial airline traffic. For instance, HALO Broadband SCP Millimeter Wavelength (MMW) Network of Angel Company provides data densities nearly one thousand times higher than proposed satellites as shown in Table 3-1, while having round trip time delays appropriate for interactive broadband services [16].

The delays through satellite network nodes are too long for many interactive applications, the values of which are 25 to a 1000 times longer for LEO or GEO than for Halo Networks. In fact, the Halo parameters are almost similar to the variety of metropolitan environment spectrum bands of the Local Multipoint Distribution Service (LMDS) band near 28 GHz [16].

Node Type	Node Data Density		Round Trip Delay	
	Min ($Mb/s/km^2$)	Max ($Mb/s/km^2$)	Min (milliseconds)	Max (milliseconds)
LMDS	3	30	0.003	0.060
Halo	2	20	0.10	0.35
LEO (Broadband)	0.002	0.02	2.50	7.50
GEO	0.0005	0.02	200	240

Table 3-1: Comparison of Time Delays

3.2 Types of Stratospheric Communications Platforms (SCPs)

3.2.1 Aircraft SCPs

The new aircraft systems offer cost effective systems by using special unmanned and non-fuel solar-cell powered planes with an estimated endurance of several months, and piloted aircraft with fuel engine propulsion for operating on daily basis shift. Which system will be more effective and reliable will confirm future practical use of these systems such as follows: General Atomic AVCS Network; Halostar (Halo) Network; Heliplat (HeliNet) Hale Network; SkyTower Global Network and other forthcoming solutions [18].

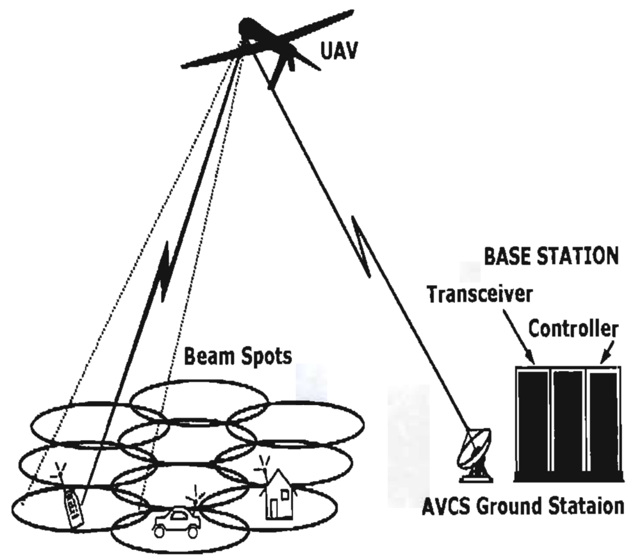

Figure 3-1: General Atomic Aerial Vehicle Communications System (AVCS) Network

The General Atomics Company is working on a special project of Global Satellite Platforms Systems called Aerial Vehicle Communications System (AVCS), shown in Figure 3-1. This system consists of a space segment of aerial vehicles as high-altitude aircraft carrying a payload. The payload is equipped with corresponding transponder and antenna systems, while the main parts of the ground segment are user terminals and AVCS Ground stations. User terminals can be fixed, mobile or mobile handheld equipment roaming within radiation of aircraft spot beam antenna system. User calls are routed through aircraft transponder and AVCS ground station to terrestrial subscribers, and vice versa [19].

The research team of group of General Atomic Company together with NASA, Department of Energy (DOE) and US Navy developed a prototype of high-altitude aircrafts Altus for the future AVCS Network project, shown in Figure 3-2. This stratospheric aircraft will be ideal for Telecommunications Relay, Cellular Relay and Commercial Applications [19].

Figure 3-2: Prototype of High Altitude Aircraft Altus

Operational with NASA and the DOE, the Altus has been at first deployed in support of atmospheric research for the DOE with future plans to use the high altitude capabilities to further atmospheric research, understand the genesis of and predict hurricane paths and damage potential, as well as many other advanced scientific applications [19], [20].

Using proven technology of previous aircraft they have developed two aircraft prototype: Altus I for operations on about 13,70km and Altus II for operations on 19,80km. Both these aircraft use fuel as a motive power, which is disadvantageous in comparison with aircraft using solar energy. The span of the aircraft is 16,76m and length of about 6,71m. They can be equipped with special transponders and antenna systems with payload capacity of about 148,5kg.

3.2.1.1 Scope of the AVCS System

Putting the array of antennas in stationary orbit high enough to avoid commercial traffic and almost all adverse weather conditions can dramatically increase the amount of ground coverage for many wireless systems. Satellite-based system obviously can cover the largest territory because they are hundreds of kilometers above the Earth. They are also very expensive and today require unique subscriber terminals and very sophisticated electronics to deal with the signal propagation delay caused by their distance from Earth. The AVCS concept will, in the near future, eliminate some of the previously mentioned and other technical problems caused by terrestrial or satellite communication systems.

In addition, launching a communications satellite is an expensive and lengthy process. The General Atomics AVCS can accomplish broader coverage, increased capacity, and deeper penetration into low-density areas at a fraction of the cost of satellite-based services and without the requirements for cell sites, towers, backhaul facilities or microwave [19]. Thus, should it be required to find out how large an area can be covered by a complement of two aircraft, which can also provide backup for each other, as an example a sample coverage overlay for the San Francisco Bay area can be considered. This area is limiting with Bodega Bay on the North and Monterey Bay on the South, covering a great part of open sea and continental territory up to the boundary line of Brentwood which is parallel with coast line [18], [19], [20]. Therefore, this is pretty impressive, especially since covering the same area with individual cell sites would require dozens of real estate parcels, obligatory permits, power systems, land lines, or microwave for backhaul or intercellular connectivity, towers, and maintenance for all of the above.

3.2.2 Airship SCP

The new airship projects offer cost effective systems for SCPs by using special unmanned and non-fuel solar cell powered balloons with an estimated endurance of several months and even up to 3 years. There are several airships SCPs such as: SkyStation Global Network; SkyLARK Network; StratCon (StratoSat) Global Network; TAO Network; etc [16]. A single Sky Station platform delivering 3G services will be able to support more than three million users in a metropolitan area. In addition, dynamically steerable antennas can automatically and instantaneously reallocate capacity as demand changes throughout the day. With this technology, commuter routes for example, will receive more capacity during rush hours, business districts during the business day, stadiums during games, etc. The System can direct 1000 variable spot beams into its 400 km diameter service area footprint [18]. There are no issues with tower placement, dead zones, the environment or bureaucratic impediments. Thus, the Sky Station system will offer better line of sight and fewer obstacles improve signal quality to the handset. Optically linked Sky Station platforms could transmit voice, data, and video at speeds and volumes comparable to fibre optic cable and provide a radio backbone link between metropolitan areas, rural communities, countries and continents worldwide.

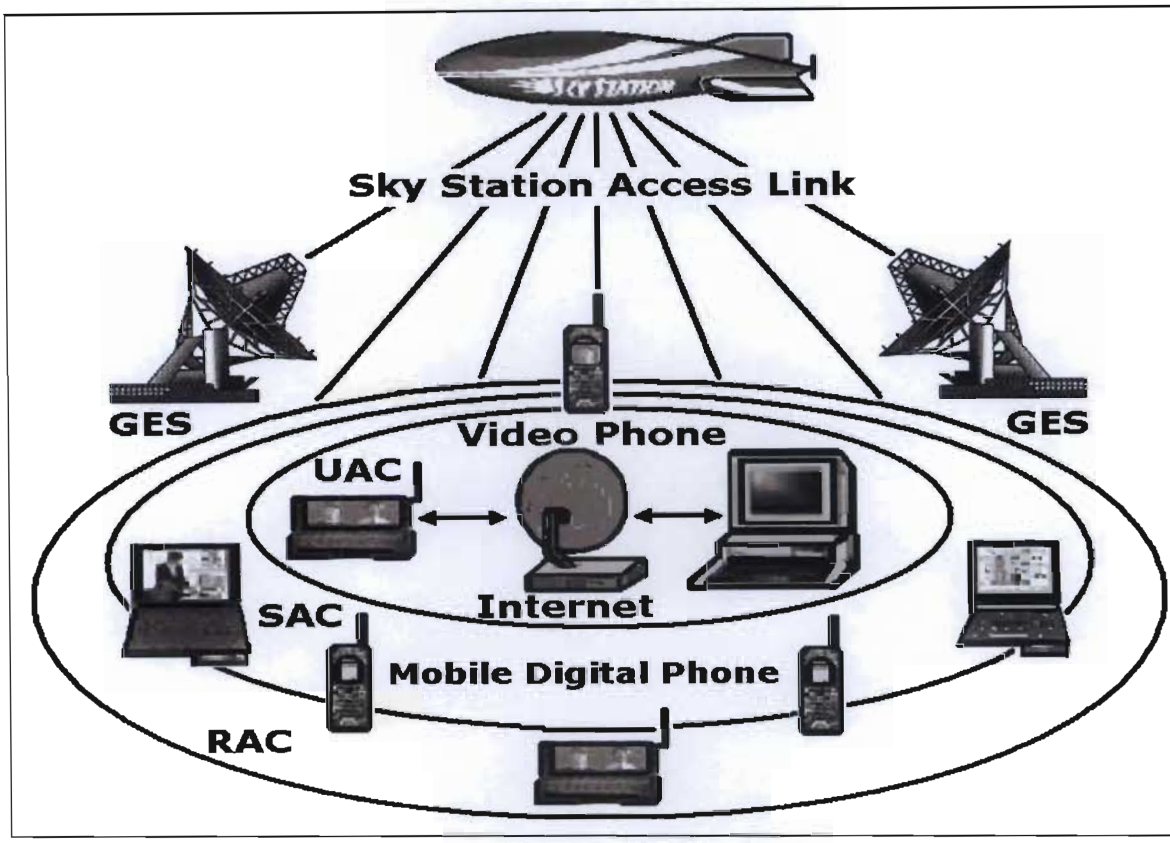

Figure 3-3: Sky Station Stratospheric Platform Configuration

The Sky Station system will provide wireless T1/E1 (2 Mb/s uplink and 10 Mb/s downlink) links directly to laptop and personal computers [18]. This kind of high speed Internet service may be used for portable videophone and Web TV applications. At this point, the SSI company is able to accomplish its personal T1/E1 service because of the ultra-high channel capacity available in metropolitan areas only from a stratospheric altitude. On the other hand, remote sensing and monitoring devices can also be installed on the stratospheric platform providing invaluable continuous data collection.

3.2.2.1 Airship Platform System Description

The stratospheric platform is an unmanned airship kept at a stratospheric altitude of about 20 km for multimedia communications and Earth observation purposes. It is equipped with communications payload, observation sensors or other equipment [16]. With the aim of quickly developing a stratospheric platform having great potential, the National Aeronautics and Space Administration (NASA) research groups began conducting the relevant research works in 1998. The SCP system is designed similar to a satellite space segment as relay station to receive signals from ground stations using feeder link and to retransmit them to subscribers using service link. Therefore, an airship like a satellite is carrying payload with corresponding transponders and antenna system.

After careful preparation in hanger space, the airship is launched in 4 Ascent phases through troposphere and Interface location point in stratosphere, and finally is shifted to the Station keeping position. The recovery phase has opposite direction, namely: the airship is slowly moved from Station keeping position towards Interface point and from there is veered down on the ground in 4 Descent phases.

The airship construction has a semi-rigid hull of ellipsoidal shape with an overall length of about 200-250 m, as shown in Figure 3-4 [16]. It is composed of an air-pressurized hull for maintaining a fixed contour, and internal special bags filled with the buoyant helium gas.

Two air ballonets are installed inside the hull to keep the airship at a required attitude. For a load balance to the lifting force, catenaries curtains are connected to a lower rigid keel, directly attached to the envelope. Propulsive propellers are mounted on both the stem and stern of the airship, and tail fins are installed on the rear end of the hull. In this sense, a solar photovoltaic power subsystem of solar cells and Regenerative Fuel Cells (RFC) is provided to supply a day/night cycle of electricity for airship propulsion.

The length of an airship which in general is about 200-250 m, and 60 m diameter, is about 4 times as long as Jumbo jet passenger airplane, and, its weight is about 32 tons. The 50% of the weight corresponds to those of structures and membrane materials. Hence, solar arrays and fuel batteries, related to electric power system, are also heavy. And the weight of mission equipment is supposed to be about 1 ton [20].

The necessary condition for an airship to float at a certain altitude is that the gravity force and buoyant force, which are exerted to the airship, are in an equilibrium state. The shape and volume of an airship are supposed to be constant, unlike a balloon, the buoyant force at altitude of 20 km becomes about 1/15 that at the sea level. Accordingly, buoyancy of 15 times as much is necessary for the equilibrium. Thus, in order to float a SCP in the stratosphere, it is necessary to make the weight of the airship light, and also to make the buoyancy large as far as possible. Inside the airship, there are several internal bags filled with He gas to get enough buoyant force.

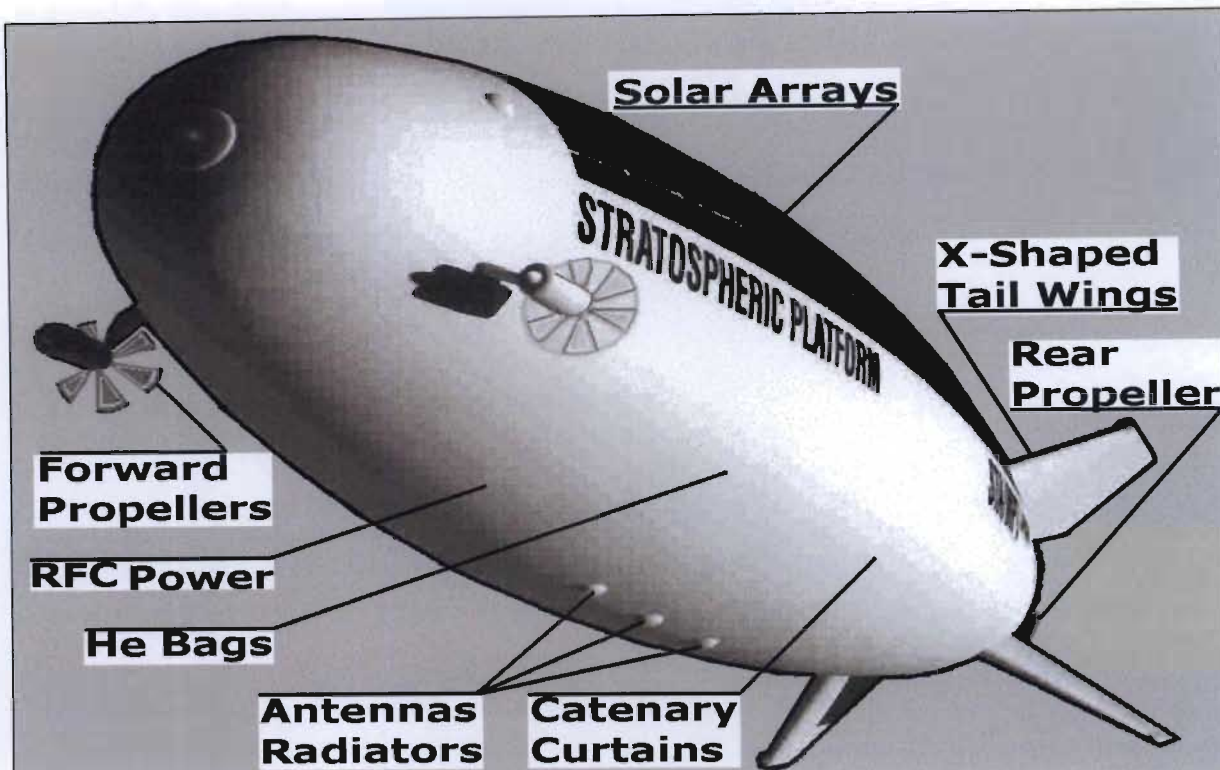

Figure 3-4: Stratospheric Platform with Main Components

3.3 SCP Network Coverage

The main question of the future system is how many airships are necessary to cover a particular territory or country and whether this System can be global? As an example: only 15 Stratospheric Platforms arrangement are necessary to cover the full territory of Japanese islands for communications and broadcasting systems, under the condition of 22 km airship altitude with minimum elevation angle of 10° [22]· Otherwise, a single airship can cover a certain service area independently, so that for example, the service can be started from an area of large population, and the number increased gradually. This possibility of flexible business development is one of the merits of SCP systems. The service area which one airship can cover depends generally on certain available numbers of transmit (Tx), receive (Rx) antennas, methods of modulation and transmission and many other factors. On the other hand, the final intention of this system is to offer service to other regions and certain countries, and if economically and technically feasible, provide global coverage. The concept of the System is very advanced and prospective in comparison with other similar projects and, is without disadvantage. On board airship there is telecommunication equipment to provide Multimedia and Broadcasting for Fixed and Mobile communications service, and Earth observation and Disaster Monitoring System. Figure 3-5 shows a scenario of typical SCP network coverage, with the many telecommunications applications associated with the platform [18].

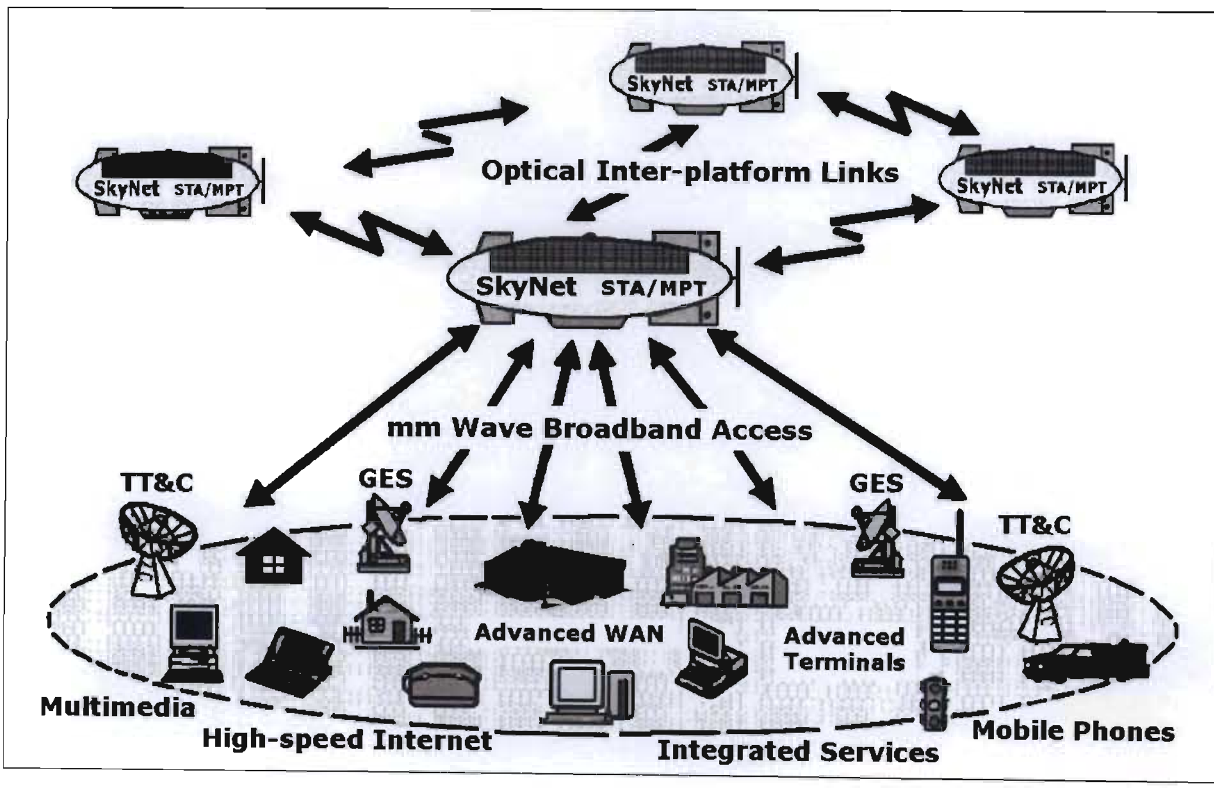

Figure 3-5: SCP network Coverage

3.4 Airship SCP Network Description and Features

The SCP network has the following features:

1) Broadband communications and broadcasting are possible with small sized and very low power terminals, because of much shorter propagation distances compared with existing satellite systems

2) High-quality and cost-effective communications and broadcasting are possible with smaller number of ground stations, due to significantly better line-of-sight conditions, less wave-blocking and multi-path effects compared with existing ground systems. Meanwhile, compared with satellite systems, the propagation distance is shorter for about 1/1800. Consequently, as EM signal propagation losses and delay distortions become much smaller, the broadband communications and broadcasting are possible with smaller sized and lower power fixed and mobile terminals.

3) By establishing inter-platform multimedia broadband links, high speed communications and broadcasting networks comparable to optical fiber systems will be possible, which may enable realization of novel communications and broadcasting systems.

4) Optimum system configurations are possible owing to the flexible operations of platform systems.

As an example: digital TV Broadcasting by SCP will use about 15 stratospheric platforms to cover Japan, where over 10 000 stations are necessary at present [22]. This system will be advanced mobile communications complement to terrestrial systems at very low cost. Thus, access to wireless fast communications system will be more cost effective than optical fibre systems. The Telecommunication Advancement Organization (TAO) system will enable much better communications and broadcasting infrastructures for developing countries and promote spreading (diffusion) in these countries [20]. Emergency communications system will keep communications link in an emergent of disaster case by moving over the place. Various remote sensing services will be available for radio wave observations, aerial photographs, and meteorological observations. The Airship SCP is designed for Fixed and Mobile Multimedia two-way communication.

The Ground segment consists of Ground Earth Stations (GES) or Gateways and fixed, semi-fixed and/or mobile terminals, with corresponding auto-tracking and focusing antenna systems [16].

The many features of Airship SCP System can be seen as:

1) The need for one platform with several GES per metropolitan area.

2) Coverage area has to be about 1.000 km in diameter footprint with >1000 spot beams per platform, with capacity of 1,77 Gb/s per 10 MHz allocation (5 MHz downlink and 5 MHz uplink) dynamically spread across footprint, and with equivalent of 316.000 simultaneous 8 Kb/s telephone calls with 50% voice activity [21].

3) This System will employ in bands identified frequency spectrum by the WRC for use with Third Generation Mobile Terrestrial Systems (1885 to 1980 MHz; 2010 to 2025 MHz; and 2110 to 2170 MHz in Regions 1 and 3; and 1885 to 1980 MHz and 2110 to 2160 MHz in Region 2) [15].

4) Signal protocols of this System will be QPSK modulation for subscriber, WCDMA and CDMA2000 multiple accesses, and also communication multiple protocols at transport and network levels will be supported.

5) Subscriber information will be transferred at the rate of 6,0 Kb/s for voice, 384 Kb/s to 2 Mb/s for data, and with Power requirements of 25 mW [18], [21], [22].

3.5 Airship SCP as a Rural Solution

One of the features of the rural environment will be the extent to which there will be integration between different telecommunications platforms like satellite, terrestrial wireless, wired, etc. or dominance by just one of them. It is important to note that this is a rapidly developing and changing environment, and that it is not at all clear in what ways different platforms and technologies will develop but a criterion that different platforms will be severely scrutinized on is development towards cost effective solutions [9]. The most cost-effective technology solution for the region will depend on a number of relevant factors including:

- *Degree of isolation*
- *Overall population*
- *Demographics of the region.*
- *Bandwidth requirements*
- *The need to ensure the best fit between technologies, applications and service needs of the region.*

The cost of conventional satellites, the launch costs involved and the tight satellite link budget have ushered many telecommunications companies to position their payloads closer to the earth. Terrestrial systems are close but very expensive. Thus, Airship SCPs satisfies this demand by delivering personal T1/E1 broadband service to the mass market at a lower cost than existing or announced alternatives. With data rates bursting to 2 Mb/s uplink and 10 Mb/s downlink, subscribers will enjoy high speed Internet browsing and hosting, as well as other broadband services such as video conferencing [16], [19]. Figure 3-5 also shows Airship Space segment which comprises one Airship with access link for three coverage ranges: Urban Area Coverage (UAC), Suburban Area Coverage (SAC), and Rural Area Coverage (RAC). The Ground segment includes several GES, mobile digital phone users, video phones, Internet access and E-mail service.

Airship SCP customers will use standard off-the-shelf 3G handsets and devices from any of the leading manufactures around the world. These 3G handsets can be used for a multitude of services, from internet browsing and e-mail, video chat/video conferencing, local and long distance telephony, on-line remote monitoring and security. Any mobile multimedia service will be compatible with Airship service [16].

The Airship System will provide both Regional in the 2 GHz frequency band and Global service in the 47 GHz band [16].

For a given platform altitude h, the diameter of the Airship SCP footprint can be computed using the formula [23]:

$$d = 2R \cdot \left(\arccos\left(\frac{R}{R+h} \cdot \cos(\gamma) \right) - \gamma \right) \tag{3.1}$$

where R is the Earth radius (6 378km),

γ the minimum elevation angle and h the altitude

Equation (3) leads to minimum elevation angle of γ = 15 degrees for footprint of diameter d = 152km and a minimum elevation angle of γ = 0 degrees for a footprint diameter of d = 1 033km (both at a platform altitude h = 21km).

3.6 Unique Features for Rural Areas

There are several unique attributes that allow Airship SCPs to offer a broad array of services with low operating costs:

1) Airship platforms do not require a launch vehicle, they can move under their own power throughout the world or remain stationary, and they can be brought down to Earth, refurbished and re-deployed without service interruption [19].

2) Every platform is independent for dedicated area of coverage. Namely, once a platform is in position, it can immediately begin delivering service to its service area without the need to deploy a global infrastructure or constellation of platforms to operate [16].

3) The altitude enables the Airship system to provide a higher frequency reuse and thus higher capacity than other wireless systems.

4) The inexpensive platforms and GES make it the lowest cost wireless infrastructure per subscriber conceived to date. The capabilities and low cost of the SCP system will revolutionize telecommunications.

5) Airship platforms are environmentally friendly, because they are powered by solar technology and non-polluting fuel cells

6) The 17-21 km altitude provides subscribers with short paths through the atmosphere and unobstructed line-of-sight to the platform. Therefore, with small antennas and low power requirements, the Airship SCP system allows for a wide variety of fixed and portable user terminals to meet almost any service need.

3.7 Case Study 2 - SCP for Rural S.A. (Ulundi)

It has already been shown in case study 1 (chapter 2) of this research that a High Altitude Platform approach to telecommunication service provision is feasible. It is more cost-effective with rapid service deployment as compared to a terrestrial solution and satellite solution.

The Ulundi region of Kwa-Zulu Natal (South Africa) has an area of 2280 square kms with a population density of 5 persons per square km. Ulundi is just beginning to enter the digital age, and is still considered a rural area. Parts of the region have undergone development and new administrative buildings and a local airport have stimulated growth and deployment of a telecommunications infrastructure. However, local inhabitants still reside away from these facilities in somewhat harsh, inaccessible regions. Figure 3-6 shows a map of KZN along with neighbouring towns.

Figure 3-6: Map of KZN

Also provided in chapter 2 (Section 2.2) is the estimated per user offered traffic of 0.002975 Erlangs. With a 100% market share and 25 % market penetration, the estimated traffic for the area reaches 8.1 Erlangs, which is relatively low. This low value is possibly as a result of the hesitation of local inhabitants to traverse many kilometers to make a simple phone call. Only cases of extreme importance may warrant these trips.

These rural dwellings occupy an area of about 1400 square kms, over 60% of Ulundi. The local population residing in these areas amount to around 7000 people, over 63% of the population of Ulundi. The conservative estimated traffic of 8.1 Erlangs presented is based on a market penetration of only 25%. Estimated traffic values will rise as market penetration increases.

Required to satisfy these traffic needs are N = 1125 channels, each with bandwidth 32 kHz [17]. The total bandwidth requirements then become 36 MHz. The frequency allocation for SCPs at 47/48 GHz offers 2 x 300 MHz of bandwidth [15]. The total coverage area of the SCP is between 60-400km in diameter. The bandwidth requirements are easily met by partitioning the coverage area into M = 121 cells, each with a nominal ground diameter of 5km.

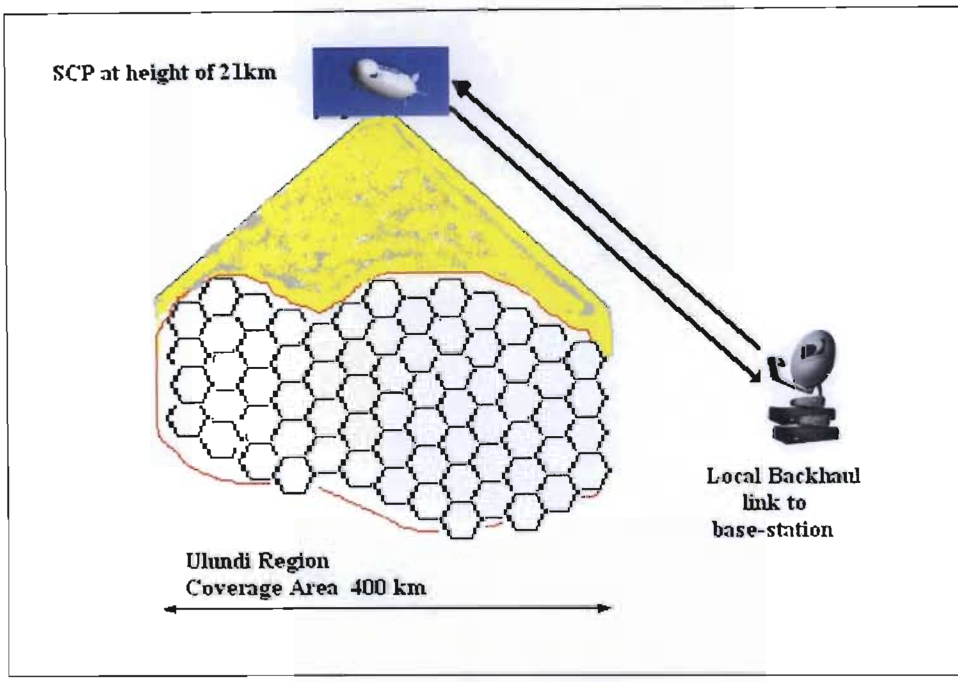

Figure 3-7: SCP Coverage of Ulundi

The proposed concept can support data rates of 2 Mbit/s uplink and upto 10 Mbit/s downlink. This is more than sufficient for voice and also supports multimedia services, internet and e-mail. A single base-station is needed to provide local backhaul to the PSTN. Integration into the PSTN is easy and for large traffic links, can be done using optical fibers. This platform will offer the opportunity to deploy next generation (3G) cellular services and use of the IMT-2000 bands have been authorized by the ITU [15]. Signal protocols of this system will be QPSK modulation for subscriber, WCDMA and CDMA 2000 multiple access. Subscriber information will transfer at a rate of 6,0 Kb/s for voice, 384 Kb/s to 2 Mb/s for data, with power requirements of 25mW [18,21,22]. Transfer rates will increase as the system evolves. It is not the intent of the research to do detailed dimensioning of the SCP for Ulundi, but to estimate so as to determine whether the technology will fit the rural need.

Rain Attenuation and SCP Performance Evaluation

4.1 Overview

Electromagnetic waves are propagated from a transmitting antenna to a receiving antenna in a number of different ways besides a direct path through the atmosphere (line-of-sight/space wave). They may also be propagated along the earth's surface (ground wave), or through refraction or reflection or scattering from natural atmospheric reflectors [23]. Significant reflecting and scattering modes of electromagnetic propagation include ionospheric and tropospheric scattering. Figure 4-1 illustrates the various types of electromagnetic propagation.

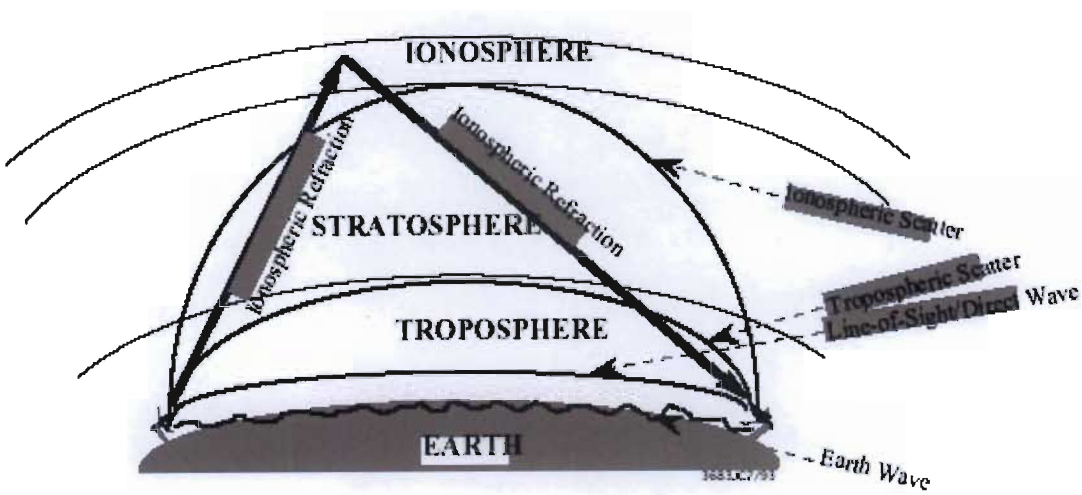

Figure 4 -1: Electromagnetic Propagation

The Super high Frequency (SHF) band (3 GHz–30 GHz) contains the so-called *microwave* frequencies and features wavelengths ranging from 1 to 10 cm (*centimeter waves*). The predominant difference between UHF and SHF characteristics is the increased absorption, scattering, and attenuation due to moisture in the signal's path. Radio-wave attenuation by atmospheric gases and water, and multipath effects become increasingly significant above 10 GHz. Applications for SHF propagation is twofold. Terrestrial LOS transmission and earth-space communications links are possible, and in wide usage today. With regard to terrestrial LOS communications at frequencies above 10 GHz, multipath can limit the bandwidth to a few tens of megahertz. Additionally, selective fading is of paramount concern. Nevertheless, diversity techniques aid in minimizing the frequency and duration of atmospheric multipath fading in LOS systems, as well as earth-space communications links. Earth-space communications links consider a value of 20 GHz to be the maximum usable frequency for ground-space communications due to atmospheric attenuation. In rainy climates, 10 GHz is recommended as the maximum. Usage of SHF today, include: satellite communications, radar microwave links, and experimental television. Currently, there exists a great amount of research and development of earthspace SHF communications system technology focusing on minimizing atmospheric losses and expanding bandwidth capabilities.

4.2 Over-the-Horizon Radio Communications

Many techniques besides the use of modern satellites exist today for performing long range over-the-horizon radio communications. Techniques used include propagating radio waves along the earth's surface, through the atmosphere, and by reflecting the radio waves off natural reflectors. Techniques in use today include:

- HF communications: Uses ionospheric reflections for transmitting signals (in the frequency range of 30-100 MHz) up to thousands of kilometers.
- Meteor bursts: Uses reflections from the ionization produced by small meteors in the high atmosphere permitting the transfers of signals ranging up to thousands of kilometers.
- Troposcatter: Uses the non-homogeneous elements in the troposphere for transmitting signals over hops on the order of hundreds of kilometers.

These techniques use the inherent characteristics of the atmosphere which consist of the following three zones:

- Troposphere: This is the zone closest to the ground extending to a height of about 10 km where clouds form and convection are predominating elements. The air is not ionized in this zone.
- Stratosphere: This zone extends from the top of the troposphere to a height of about 50 km. This is a relatively still zone without the convection or perturbations of the troposphere. Humidity is nearly absent.
- Ionosphere: This zone extends from the top of the stratosphere and features an appreciable amount of air ionization. The reflective properties of this region have been exploited for long range VHF transmissions (ionospheric scatter).

4.3 Troposcatter Transmission and Digital Troposcatter Transmission

Troposcatter transmission exploits the irregularities in the troposphere to permit a site to communicate directly with another site beyond the horizon. Propagation over tropospheric paths is characterized as multipath transmission by reflection and/or refraction from many non-homogeneous elements within the common or scattering volume of the troposphere. These multipath signals have varying levels and relative phases, such that the aggregate received signal varies rapidly over a wide range of levels, and has significant phase dispersion about its median. Only a very small proportion of the signal energy passing through the common volume will be scattered, and only a small proportion of that will be directed towards the receiving station. Therefore the loss in the scattering process is extremely large and the angle through which the signal ray has to be deflected is an important characteristic of a troposcatter path; for best results it should be no more than a few degrees. Troposcatter technology is mentioned in some texts as a 800 km technology characterized by intermittent communications at frequencies above 20 MHz, but preferably at VHF frequencies. Microwave transmission techniques developed in the early 1950s, utilizing the troposcatter propagation mode, permit microwave transmission over path lengths that extend beyond the LOS. However, when compared with LOS, troposcatter is characterized by higher path loss, greater frequency fading and limited bandwidth. Figure 4-2 illustrates the difference between conventional multiple hop line-of-site radio links and direct troposcatter links between two distant "beyond the horizon" points [24].

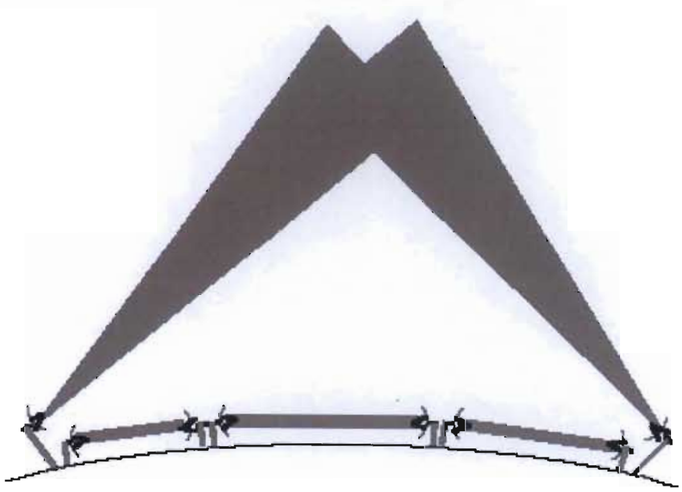

Figure 4 -2: Line-of-Site/Troposcatter Communications

These disadvantages can be countered to a certain degree by equipment design.

4.4 Factors Affecting Propagation

In any radio communication system, irrespective of frequency of operation, the propagation medium plays a vital role. In free space, spherical radio waves undergo only free space loss, which is the signal power attenuation between two isotropic antennas in free space. Free space loss increases with frequency. This loss is compensated for by the increase in the antenna gain. Atmospheric and ionospheric propagation is subject to absorption, diffusion or diffraction, refraction and rotation of the polarisation plane of the electromagnetic wave. These effects depend on the path length and hence the effects are more pronounced for small elevation angles [26]. Ionospheric propagation loss can be ignored in the design of the Stratospheric Communications Platform. The platform will be situated at a height of between seventeen and twenty five kilometers which is still within the bound of the atmosphere yet below the belt of the ionosphere. The signals from the platform therefore suffer mainly the following losses [27]:

- Free space loss
- Loss due to cross polarisation caused by propagation.
- Fading Loss
- Losses due to: atmospheric absorption, dispersion and diffraction
- Precipitation loss

Rain attenuation it seems is the major cause of loss in satellite communications systems and its affects are also significant in the Stratospheric communications platform system design. The focus on the performance calculation requires as a preamble that the rain attenuation for Kwa-Zulu Natal (KZN) be determined. International Telecommunications Union (ITU) values will suffice for all other losses [26], [27]. A comparison will be made between the ITU rain attenuation for South Africa (Region 1) and the calculated rain attenuation for Ulundi, KZN.

4.4.1 Atmospheric absorption, dispersion and diffraction

Transmission losses occur when millimeter waves traveling through the atmosphere are absorbed by molecules of oxygen, water vapor and other gaseous atmospheric constituents. These losses are greater at certain frequencies, coinciding with the mechanical resonant frequencies of the gas molecules. At these frequencies, absorption results in high attenuation of the radio signal and, therefore, short propagation distance. For current technology the important absorption peaks occur at 24 and 60 GHz [28]. The spectral regions between the absorption peaks provide windows

Not same ref.

where propagation can more readily occur. The transmission windows are at about 35 GHz, 94 GHz, 140 GHz and 220 GHz. The H_2O and O_2 resonances have been studied extensively for purposes of predicting millimeter propagation characteristics. If electromagnetic waves are propagating in media of low loss, the effect of the medium can be characterized with a complex permittivity, the imaginary part of which is significantly smaller than its real part. Loss due to the electrically neutral molecules of the air can be characterised and is usually negligible. Electrically asymmetrical molecules cause higher loss; it is reasonable to characterize them more precisely. Of this type is the molecule of water vapor and also of several gases of lower density being of little significance. Water vapor has three resonance lines in the millimeter band, about 22.3 GHz, 183.3 GHz and 323.8 GHz; these are slightly dependent on the temperature [27]. A molecule of oxygen is para-magnetic, its magnetic moment causes similar resonance phenomena. It has an isolated resonance line at 118.74 GHz and a relatively broad absorption band at 50-to-70 GHz, composed of several resonance lines. A method to compute the attenuation due to gaseous absorption is given in Recommendation 676-2 of ITU-R [27], [29]. A few figures: attenuation above 20 GHz (depending on air moisture) is nowhere lower than 0.05-0.1 dB/km. About 60 GHz it is always higher than 10dB/km [29]. Dispersion is a second potential consequence of molecular interaction. Attenuation and group delay of the medium is frequency dependent causing linear distortion. Dispersion is significant in the absorption band of 60 GHz.

4.4.2 Effects of Fading

Time-and-frequency flat fading increases path loss, decreases carrier-to-noise ratio. Its effect can be represented in two ways. We can regard carrier-to-noise ratio as a random variable; then the relationship of error probability valid in a Gaussian channel is regarded as a conditional probability and the total probability is computed. According to the other concept we define an acceptable maximal error probability; if error probability gets higher we take the connection as interrupted [23].

Frequency selective fading causes linear distortion and consequently inter-symbol interference. This can also be regarded as a delay spread exceeding the duration of one symbol; then one symbol is spread into the time slot of the adjacent one(s). Time selective, frequency flat or fast fading is characterized by a transfer function which is non-constant during one symbol time. The Signal is distorted in this case also.

A plausible countermeasure to flat fading is to increase power, i.e. to apply what is called a fade margin. Sometimes this increase is very large, even 40-60 dB. Thus fade margin can be regarded as a brute force method.

According to a different philosophy we apply a diversity method. In this we transmit the signals simultaneously over two (or more) loosely correlated channels. Then the probability of both being in outage is much lower than that for one of them. Such diversity effect can be achieved by receiving the signals by two antennas, sufficiently far away from each other (space diversity); by applying two channels of different frequency (frequency diversity); or of orthogonal polarization (polarization diversity).

4.4.3 Free space loss

The frequency and distance dependence of the loss between two isotropic antennas is expressed in absolute numbers by Equation 4.1, for free space loss .

$$L_{FSL} = (4\pi R / \lambda)^2 \tag{4.1}$$

where R is the distance between transmit and receive antennas and λ is the operating wavelength. After converting to units of frequency and putting in dB form, the equation becomes:

$$L_{FSL} dB = -147.6 + 20\log_{10} f + 20\log_{10} R \tag{4.2}$$

where f is the frequency in GHz and R is the line of sight distance in Km between the antennae.

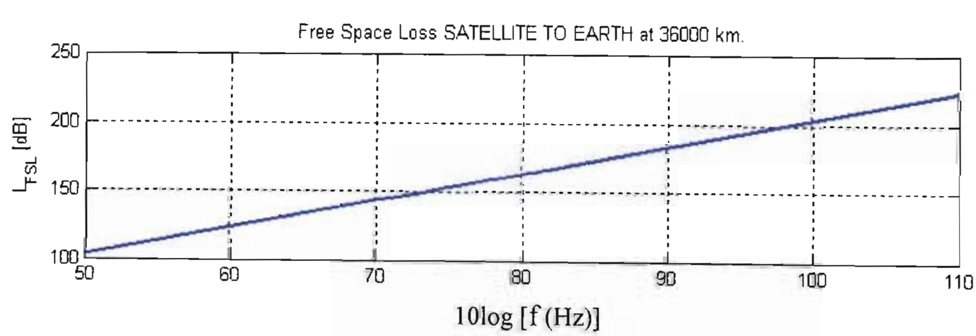

Figure 4-3: Free space attenuation as a function of frequency for geostationary satellite

Figure 4-3 shows the free space attenuation for a geostationary satellite (at approximately 36 000km above the earth's surface). Figure 4-4 shows the free space attenuation as a function of frequency for the SCP which has a geostationary position at 20 km.

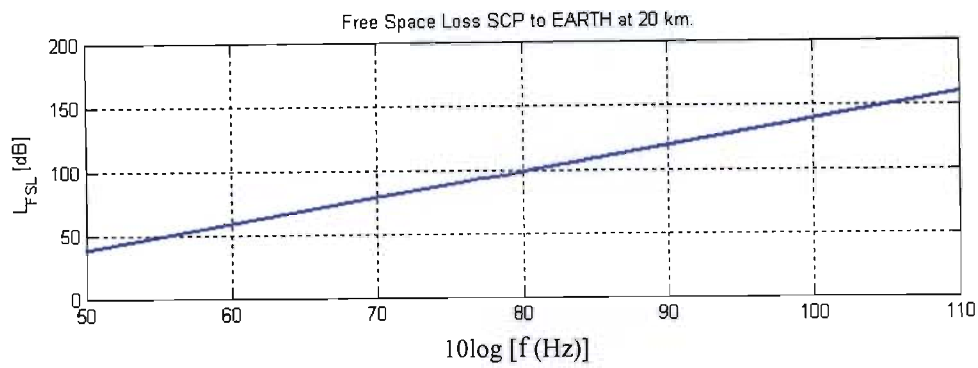

Figure 4-4: Free space attenuation as a function of frequency for SCP at a height of 20 Km

Figure 4-4 shows the free space attenuation of the SCP at a frequency of 50 GHz. The difference between geostationary satellite and SCP free space attenuation is greater than 60 dB and it would seem that this difference is smaller than expected considering that a typical geostationary satellite orbits the earth at 36 400 km and the SCP at a mere 17-25 km.

4.4.4 Effects of Precipitation

Millimeter waves interact with any form of precipitation. Rain is of overwhelming significance. It has two effects: it causes loss and changes polarization states, decreasing thus cross-polar discrimination (XPD). Rain induced loss depends mainly on rain-rate (mm/h). The usual statistical approach the problem is divided into two parts: distribution function of the single-point rain rate is determined; and loss of a path is determined, conditioned on point rain rate. Several models are available for both steps. Concerning the first one, a world map is published by ITU-R, subdividing the Earth into a few climatic zones and giving the cumulative distribution functions valid for these zones. Of course, these distribution functions are not very precise; to get more precise data, measurements have to be made in the relevant area. Note, however, that these measurements for yielding significant results are rather lengthy and rather expensive. For determination rain induced loss, method of ITU-R Recommendation 530-6 is described below [27]. The method is apt to determine fading loss of prescribed probability on a path. As input data length L of the path, R.01(1), the point rain rate averaged in one minute of probability 0,01%, further factor k and exponent α (being characteristic for the relevant frequency, geographical region and also to some extent the path itself). Then loss *A*p, occurring with probability *p* can then be computed.

Among other forms of precipitation hail causes a large loss, possibly even larger than rain. However, very heavy rain and hail are similar phenomena, both occur mainly in summer thunderstorms. Thus treating them separately is not justified [46]. Among the indirect consequences of precipitation is that during the winter months, in some countries, deep fades were experienced in periods of no precipitation at all. It turned out that these were consequences of reflections due to ice-layers on top of the snow. These can reflect millimeter waves causing similar multipath effects as over water propagation.

Problems of this nature are not inherent to the South African region. Although many of the rural areas do experience some snow during the winter months, it is intermittent and quite negligible. Polarization-related phenomena form another class of precipitation effects. These can be of importance in spectrum-efficient systems called frequency-reuse systems, applying both polarizations for the transmission of two separate channels. XPD, being in non-rainy periods determined by the antenna, can drastically be decreased due to rain. This is based on two different physical mechanisms. One of these is polarization-dependent loss of raindrops due to their non-ideal spherical shapes. The other is change of the polarization state of the wave due to slant oval raindrops. It can be mentioned only that due to heavy rain the average XPD can be decreased to 15 dB and its minimum even to 9 dB.

4.5 Rain Attenuation for Rural KZN

Rain attenuation forms a pivotal preamble of the performance evaluation. Its effect on the proposed Stratospheric Communications Platform is important. In order to determine an accurate Performance evaluation for the SCP in the KZN region of South Africa, it is necessary to determine the rain attenuation for the specific location. Comparison can be made between ITU guidelines and the exact values determined for Ulundi, KZN [27], [31].

4.5.1 The International Telecommunications Union (ITU) Guidelines

There is generally a vast amount of data on direct attenuation, rain rate and drop size distribution in Tropical regions. Consequently, many of the Recommendations of ITU-R are based on data obtained mainly from the Temperate Regions of the world. South Africa falls within the Temperate Zone classification due to its inherent climate.

The ITU-R rain climatic maps for the world are shown in Fig. A1-A7 in Appendix 1 [31], [32].

South Africa (extremes: latitude 29°53' S, longitude 30°53') is designated by two types of rain climates (namely K and E). The corresponding rainfall intensity can be seen in Table 4-1. Most of the rural areas fall within zone E. The ITU tabulated values for zone E will be used in the calculations.

Percentage of time (%)	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q
1.0	<0.1	0.5	0.7	2.1	0.6	1.7	3	2	8	1.5	2	4	5	12	24
0.3	0.8	2.0	2.8	4.5	2.4	4.5	7	4	13	4.2	7	11	15	34	49
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65	72
0.03	5	6	9	13	12	15	20	11	21	23	33	40	65	105	96
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	71	65	53	55	100	150	120	180	250	170

Table 4 -1: Rain climatic zones [32]
Rainfall intensity exceeded (mm/hr)

Table 4-1 shows the rain intensity for the various climatic zones. Table 4-1 is utilised for estimating the attenuation due to rain on both terrestrial and earth-satellite microwave links for areas without adequate data on cumulative rain intensity distribution [31], [32], [33], [34].

Specific attenuation γ_R (dB/km) is obtained from the rain rate R (mm/h) using the power-law relationship [26], [31]:

$$\gamma_R = kR^{\alpha} \tag{4.3}$$

The frequency-dependent coefficients k and α are given in table 4-2 (Appendix 1) for linear polarizations (horizontal: H, vertical: V) and horizontal paths. For linear and circular polarization, and for all path geometries, the coefficients in equation (5) can be calculated from the following equations:

$$k = [k_H + k_V + (k_H - k_V)\cos^2\theta\cos 2\tau]/2 \tag{4.4}$$

$$\alpha = [k_H\alpha_H + k_V\alpha_V + (k_H\alpha_H - k_V\alpha_V)\cos^2\theta\cos 2\tau]/2k \tag{4.5}$$

where θ is the path elevation angle and τ is the polarization tilt angle relative to the horizontal ($\tau = 45°$ for circular polarization).

These values have been tested and found to be sufficiently accurate for attenuation prediction up to frequencies of 55 GHz. Using the appropriate values from table 4-1 and the correct frequency-dependent coefficients k and α , the specific attenuation (γ) was calculated to be 7.72 dB/km. These values are based upon ITU recommendations [31]. The exact values were determined for rural South Africa with the focus being Ulundi.

4.5.2 Exact Rain Attenuation for Ulundi

Gathered rainfall data from the South African Weather Bureau (using the concept of Radiosonde), is shown below in figure 4-5. This is only an indication of the "worst month" and shows the rainfall pattern for the region. It should be noted that figure 4-5 shows the average rain rate which includes dry periods and therefore cannot be used in rain attenuation calculations. In essence, the shorter the period of averaging the more accurate the results since almost instantaneous attenuation values are required.

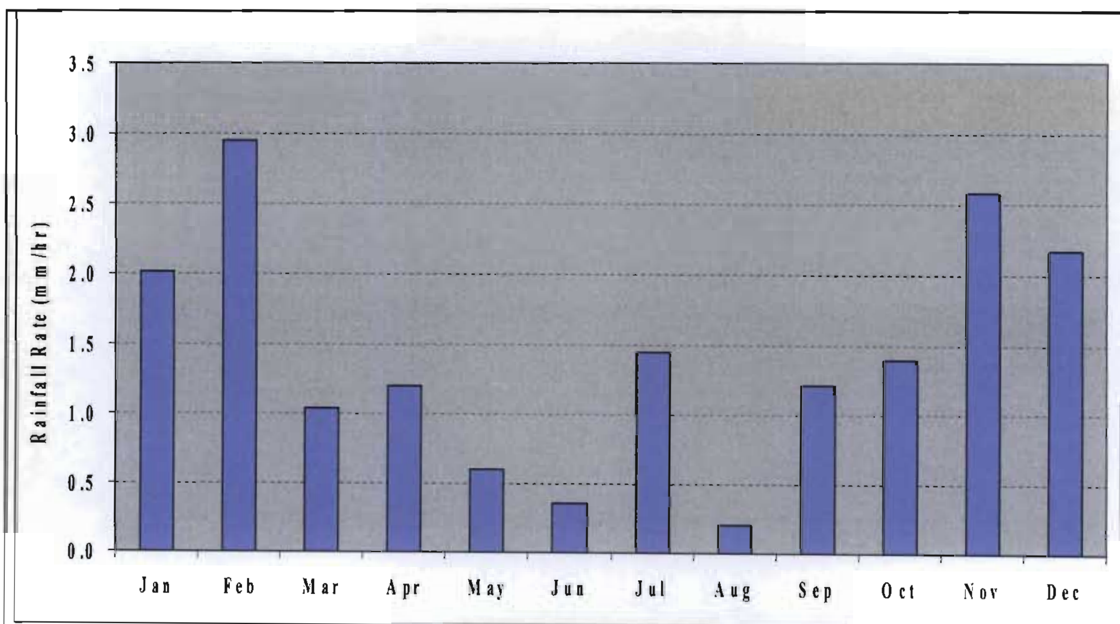

Figure 4 – 5: Average Rainfall Rate (mm/hr) per calendar month for Ulundi over a 4 year period (2001-2004)

As can be seen from figure 4-5, the month of February shows the highest average rainfall rate. The month of February was taken as being the 'worst month'. In any satellite or microwave system design, it is essential to cater for the 'worst month' scenario.

The point rainfall rate ($R_{0.01}$ in mm/hr) as supplied by the South African Weather Bureau for the "worst month" is used in attenuation calculations and can be seen in table 4-2. This gives almost instantaneous rain rate and does not include any dry periods.

Percentage of time (%)	ITU recommended values	Region specific Point Rainfall Rate values
1.0	0.6	1.5
0.3	2.4	4.2
0.1	6	12
0.03	12	15
0.01	22	24
0.003	41	42
0.001	70	71

Table 4–2: Rainfall intensity exceeded (mm/hr)
ITU values compared to determined values for Ulundi, KZN

The point rainfall rate for the Ulundi region compared with the ITU recommended values can be seen in Table 4-2 [31], [33].

Using the appropriate values from Table 4-2 and the correct frequency-dependent coefficients k and α, the specific attenuation (γ), for Ulundi was calculated to be 8.33 dB/km [35], [36], [37]. The specific attenuation (γ) values were calculated at a frequency of 50 GHz with the percentage of time the rainfall rate was exceeded being 0.01%.Table 4-3 shows the specific attenuation for various percentage of time the rainfall rate was exceeded for an average year.

Percentage of time (%)	ITU recommended values (γ)	Region specific values (γ)
1.0	0.33	0.74
0.3	1.12	1.82
0.1	2.48	4.55
0.03	4.55	5.53
0.01	7.72	8.33
0.003	13.29	13.57
0.001	21.20	21.46

Table 4-3: Specific Attenuation (γ in dB/km)

A comparison of the specific attenuation between the ITU Recommended values and Region specific values at 0.01% of the time the Rainfall rate was exceeded can be seen in Figure 4-6.

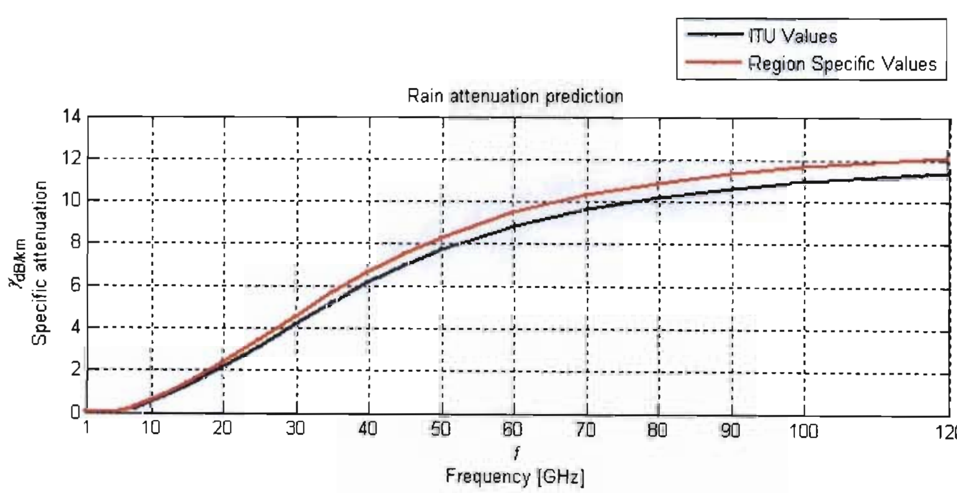

Figure 4-6: Specific Attenuation Vs Frequency at 0.01% time Rainfall Rate exceeded ITU Values compared to Region specific values

Inorder to determine the total attenuation due to rain that the Stratospheric Platform will endure, it is necessary to determine Effective Rain Height.

- Initially, the ITU-R assumed that physical rain height to be equal to the height of the 0° C isotherm, according to the intuitive concept that liquid rain can only exist below that level

[32]. The reduction coefficient developed for terrestrial links was applied only to the horizontal projection of the portion of the earth-space path below the 0° C isotherm. For the vertical paths, the equivalent path length was therefore equal to the isotherm height. Owing to the unsatisfactory results obtained when applying the prediction model to some regions, especially the tropical regions, the concept of effective rain height was developed. The effective rain height was initially equated to the 0° C isotherm height during rainy conditions, which could be obtained from Radiosonde data or other sources. However, the effective rain height h_R is now obtainable from the analysis of equiprobable measured attenuation and point rainfall data. The current ITU-R slant path attenuation procedures uses an effective rain height, h_R given by [31]:

$$h_R = 4.0 - 0.075(\varphi - 36)Km \qquad \varphi \geq 23 \qquad (4.6)$$

where φ is the latitude of the site. Using the latitude of South Africa, 29.8833, the following was found:

$$h_R = 3.54 \text{ km}$$

The total rain attenuation experienced by the SCP is given by the following:

$$\gamma_{TOTAL} = \gamma_R \times h_R \qquad (4.7)$$

where γ_R is the specific attenuation in dB/Km and h_R is the effective rain height. Hence

$$\gamma_{TOTAL} = 29.49 \text{ dB}$$

Percentage of time (%)	ITU recommended values	Region specific values
1.0	1.17	2.62
0.3	3.96	6.44
0.1	8.78	16.11
0.03	16.11	19.58
0.01	27.33	29.49
0.003	47.05	48.04
0.001	75.05	75.97

Table 4-4: Total Attenuation (dB) experienced by SCP

It can be seen in table 4-4 that for a link availability of 99.99%, the total attenuation experienced is 29.49 dB. If less stringent conditions are applied and a link availability of 99.9% is sufficient, then the total attenuation is 16.11 dB.

4.6 Performance Evaluation

A link budget ensures that the Effective Isotropic Radiated Power (EIRP) allocated to the transmitter maintains a pre-determined level of service defined by error performance and availability. The radio propagation availability of at least 99.99% is commonly used as a service level [33], [34]. In order to determine a reasonably accurate link budget, the input parameters need to be as realistic and accurate as the actual link would endure. Figure 4-7 shows some of the important parameters needed to evaluate a link budget.

Figure 4-7: Input Parameters for link budget

Figure 4-7 shows that free space path loss, gaseous absorption loss and rain attenuation loss form the bulk of the essential path loss parameters. The specific attenuation due to atmospheric gases at 50 GHz is around 0.018 dB/km as outlined in ITU-R Recommendation P.676-6. In comparison, the ITU-R specific rain attenuation at 50 GHz is 7.72 dB/km, more than 400 times larger than atmospheric gaseous attenuation. Other useful parameters have been extracted from ITU-R Recommendation F.1569

Rain attenuation has been examined as having a more appreciable impact on the SCP, and exact values for the rural Ulundi region of South Africa was determined. The effects of other path loss factors will require a more detailed study and is saved for future work.

4.6.1 Link Budget for SCP over the Ulundi region at altitude of 20 km

Elevation angle (90 degrees)	Uplink	Downlink
Frequency (GHz)	48.05	47.35
Bandwidth (MHz)	20	20
Transmitting antenna:		
– output power (dBW)	–10.3*	–15.2*
– feeder loss (dB)	0.5*	0.5*
– gain (dBi)	35*	16.5*
– e.i.r.p. (dBW)	24.2	0.8
– e.i.r.p. (per MHz) (dB(W/MHz))	1.21	0.82
Path length (km)	20	20
Free space path loss (dB)	87.95	88.07
Rain attenuation (dB)	29.49	29.49
Atmospheric gases attenuation (dB)	0.36	0.36
Total Path Loss	117.8	117.92
Availability in the zone M (%)	99.99	99.99
pfd (dB(W/m^2 · MHz))	91.15	134.39
Receiving antenna:		
– gain (dBi)	16.5*	35*
– feeder loss (dB)	0.5*	0.5*
– received power (dBW)	–116.3*	–118.6*
– noise temperature (K)	700*	500*
– noise temperature (dB(W/Hz))	–200.2*	–201.6*
– designed interference power objective (dB(W/MHz)) (I/N = 10%)	–150.2*	–151.6*
– technical receiver losses (dB)	2.5*	2.5*
Available C/N_0 (dB(Hz))	80.9*	80.1*
User data rate (Mbit/s)	13.3*	13.3*
User data rate (dB(Hz))	71.2*	71.2*
Required E_b/N_0 (dB) (QPSK, BER = 1×10^{-6})	10.5*	10.5*
Coding gain (dB) (Viterbi coding, $K = 7$, $r = 2/3$)	5*	5*
Necessary E_b/N_0 (dB)	5.5*	5.5*
Necessary C/N_0 (dB(Hz))	76.7*	76.7*
Link margin (dB)	9.2	30.52

Table: 4-5: SCP Performance Evaluation

* denotes values extracted from ITU-R F.1569 example calculation (Appendix 3)

SCP Network Architecture

5.1 Overview

As the demand grows for communication services, wireless solutions are becoming increasingly important. Wireless can offer high-bandwidth service provision without reliance on fixed infrastructure and represents a solution to the 'last mile' problem, i.e. delivery directly to a customer's premises. In many scenarios wireless may represent the only viable delivery mechanism. Wireless is also essential for mobile services, and cellular networks. Fixed wireless access (FWA) schemes are also becoming established to provide telephony and data services to both business and home users. The emerging market is for broadband data provision for multimedia, which represents a convergence of high-speed Internet (and e-mail), telephony, TV, video-on-demand, sound broadcasting, etc. Broadband fixed wireless access (B-FWA) schemes aim to deliver a range of multimedia services to the customer at data rates of typically at least 2 Mbit/s [38]. B-FWA should offer greater capacity to the user than services based on existing wirelines, such as ISDN or xDSL, which are in any event unlikely to be available to all customers. The alternative would be cable or fibre delivery, but such installation may be prohibitively expensive in many scenarios, and this may represent a barrier to new service providers. B-FWA is likely to be targeted initially at business, including SME (small–medium enterprise) and SOHO (small office/home office) users, although the market is anticipated to extend rapidly to domestic customers. However delivering high-capacity services by wireless also presents a challenge, especially as the radio spectrum is a limited resource subject to increasing pressure as demand grows. To provide bandwidth to a large number of users, some form of frequency reuse strategy must be adopted, usually based around a fixed cellular structure. Figure5-1*a* illustrates the cellular concept, where each hexagon represents a cell having a base-station near its centre and employing a different frequency or group of frequencies represented by the colour. These frequencies are reused only at a distance, the reuse distance being a function of many factors, including the local propagation environment and the acceptable signal-to-interference-plus-noise ratio. To provide increased capacity, the cell sizes may be reduced, thus allowing the spectrum to be reused more often within a given geographical area, as illustrated in Figure 5-1*b* [39]. This philosophy leads to the concept of microcells for areas of high user density, with a base-station on perhaps every street corner. Indeed, taking the concept to its extreme limit, one might envisage one cell per user, the evident price in either case being the cost and environmental impact of a plethora of base-station antennas, together with the task of providing the backhaul links to serve them, by fibre or other wireless means, and the cost of installation. Pressure on the radio spectrum also leads to a move towards higher frequency bands, which are less heavily congested and can provide significant bandwidth.

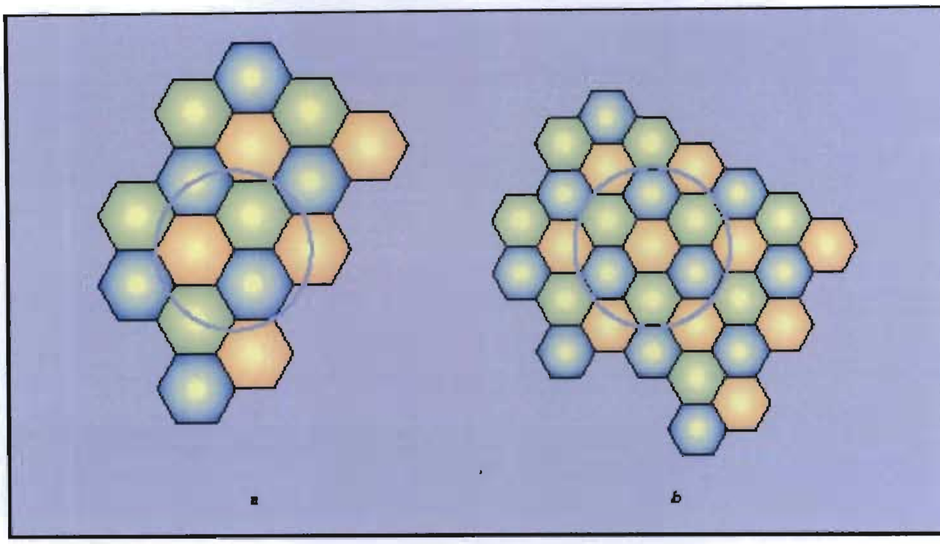

Figure 5-1: Cellular frequency reuse concept

In Figure 5-1b the smaller cells provide greater overall capacity as frequencies are reused a greater number of times within a given geographical area.

An alternative delivery mechanism is via satellite, which can provide line-of-sight communication to many users. Indeed, broadband services from geostationary (GEO) satellites are projected to represent a significant market over the next few years. However, there are limitations on performance due partly to the range of the platform (40000 km), which yields a free-space path loss (FSL) of the order of 200dB, as well as to physical constraints of on-board antenna dimensions. The latter leads to a lower limit for the spot-beam (i.e. cell) diameter on the ground, and these minimum dimensions constrain the frequency reuse density and hence the overall capacity. Additionally, the high FSL requires sizeable antennas at ground terminals to achieve broadband data rates. A further downside is the lengthy propagation delay over a geostationary satellite link of 0.25s, which not only is troublesome for speech but also may cause difficulties with some data protocols. Low earth orbit (LEO) satellites may circumvent some of these limitations in principle, but suffer from complexities of rapid handover, not only between cells but also between platforms. The need for large numbers of LEO satellites to provide continuous coverage is also a significant economic burden. To enable services that take advantage of the best features of both terrestrial and satellite communications, the Stratospheric Communications Platform (SCP) concept can be employed. A single SCP can replace a large number of terrestrial masts, along with their associated costs, environmental impact and backhaul constraints. Site acquisition problems are also eliminated, together with installation maintenance costs, which can represent a major overhead in many regions of the world. These Stratospheric Communications Platforms may be aeroplanes or airships and may be manned or unmanned with autonomous operation coupled with guidance control from the ground.

5.2 The SCP network

The principal application for SCP's is seen as B-FWA, providing potentially very high data rates to the user. The frequency allocation for SCP's at 47/48GHz offers 2 x 300MHz of bandwidth, which might be apportioned 50:50 to user and backhaul links, and again 50:50 to up- and down-links [15], [40]. (An exception might be where links are mainly used for Internet traffic, which would warrant an asymmetric apportionment). These platforms have the advantage that the cell configuration may be determined onboard the platform and thus reconfigured and adapted to suit traffic requirements. Indeed, the SCP architecture lends itself easily to adaptive resource allocation techniques, which can provide efficient usage of bandwidth and maximise capacity.

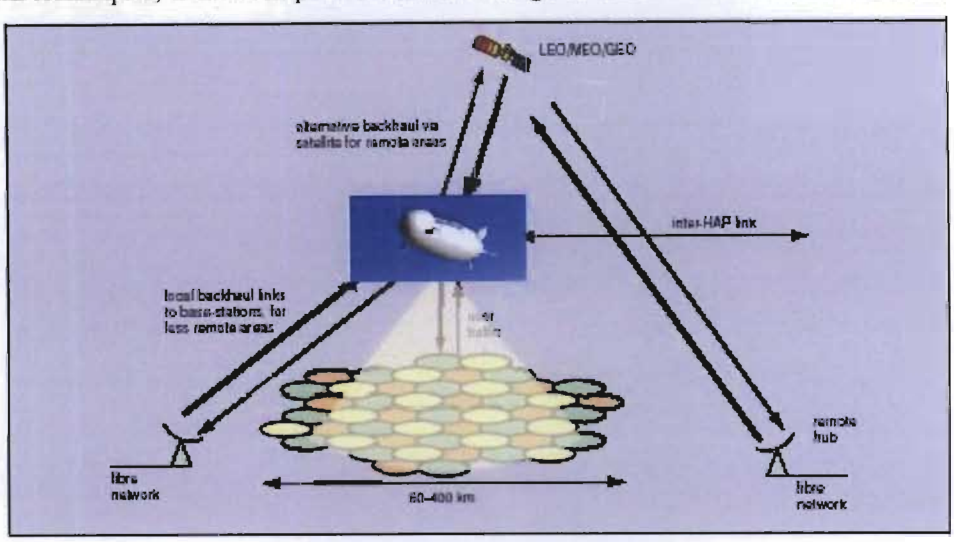

Figure 5-2: SCP Cellular Architecture

The proposed concept can have an overall coverage region of diameter 60 - 400km, having 121 cells, each with a nominal ground diameter of 5Km. Downlink SCP power is 1W per cell, and this can support data rates of up to 60 Mbit/s which is well within the bandwidth required per cell of 25 MHz when using 16-QAM or higher order modulation schemes. The total payload throughput in this conservative demonstrator example is in excess of 7Gbit/s [41], [42].

It is evident that the backhaul requirements are as stringent as the user links themselves. No single wireless link can provide the full backhaul capacity, so this will also need to be handled via a cellular scheme. Thus there will need for a number of distributed backhaul groundstations, although these can be far fewer than the number of user cells served since the backhaul links will have higher specification and handle greater capacity, with higher order modulation schemes. Fortunately these groundstations can nevertheless be modest and unobtrusive and their location within the coverage region is non-critical; they will probably be situated on the roofs of buildings.

SCPs may offer opportunity to deploy next generation (3G) mobile cellular services, or indeed current (2G) services, and use of the IMT-2000 (3G) bands from SCPs has been specifically authorised by the ITU [30], [43]. A single base-station on the SCP with a wide-beamwidth antenna could serve a wide area, which is advantageous over sparsely populated regions like the rural areas of South Africa. Alternatively, a number of smaller cells could be deployed with appropriate directional antennas. The benefits would include rapid roll-out covering a large region, relatively uncluttered propagation paths, and elimination of much ground-station installation.

	Terrestrial	SCP	LEO satellite	GEO satellite
Station coverage (typical diameter)	< 2.5 Km	Up to 200 Km	> 500 Km	Up to global
Cell size (diameter)	0.1-1 Km	1-10 Km	50 Km	400 Km
Total service area	spot service	national/regional	quasi-global	global
Maximum transmission rate per user	155 Mbit/s	25-155 Mbit/s	< 2 Mbit/s up 64 Mbit/s down	155 Mbit/s
System deployment	several base stations before use	flexible	many satellites before use	flexible
Estimated cost	US$ 1 – 5 million	US$ 50 million	US$ 3 billion	> US$ 300 million
Estimated cost for Ulundi, KZN [47] – [49]	> US$ 10 million	US$ 5-10 million	> US$ 75 million	> US$ 75 million

Table 5-1: Comparison of Broadband Terrestrial, SCP and Satellite Services

Table 5-1 shows an interesting comparison between broadband delivery systems [44]. The SCP network is an ideal choice to facilitate broadband communications for rural areas. It provides exceptional transmission rates, services a sufficiently large coverage area and has a relatively low cost.

Conclusion

Human communication dates back to the time of cavemen who uttered sounds to express their ideas. As society has evolved, so has the complexity of communication media from simple verbal communication, to writing, to wires carrying electrical signals, to terrestrial radio waves, microwaves and satellites. Satellites are used to connect the world by acting as a "bent pipe"; re-transmitting microwave signals to and from terrestrial receiving/transmitting stations. They are also used to predict weather and monitor disaster zones.

Communication is an inherent right to all citizens of the world. Rural areas throughout the world have very little access to any form of communication with the outside world. These areas represent an 'untapped' market with great economic potential for telecommunications companies. However these areas are often inaccessible, with harsh terrain and scattered population.

South Africa has over 50% of the population residing in rural areas. Providing any form of telecommunication has always proved difficult due to the sparse population distribution over the large area of harsh terrain. A case study presented in chapter 2 of this research shows that a high altitude platform approach to providing telecommunications access to these rural areas is feasible. The VSAT approach is quick to setup and integrates well with current PSTN infrastructure. Still it has flaws as well. It is costly and during times of intense rainfall, outages are experienced.

Exploring the satellite approach further, the Stratospheric Communications Platform (SCP) has emerged as an ideal candidate for provision of telecommunications services. This system will act as a 'backbone' for telecommunications services in rural areas and can be linked optically to the nearest base-station. Orbiting the earth at a height of around 21 Km, which is significantly lesser than conventional satellites which have an orbit of 36 400 Km, these SCPs have enormous potential for service provision over a certain region whether urban or rural.

In any communication system there are losses incurred which affect power, quality of service and service availability. An important aspect to consider when designing satellite systems is the attenuation due to rain. The ITU has recommended certain methods for rain attenuation calculations as well as useful values. These are however a guideline and in order to ascertain accurate values for regions of concern, an analysis of rainfall rates is necessary. This has been carried out in chapter 4 of this research and the specific attenuation (γ) due to rain for the Ulundi region of South Africa was found to be 8.33 dB/Km as compared with the ITU value of 7.72

dB/km. This investigation was done at a frequency of 50 GHz with the percentage of time the rainfall rate was exceeded being 0.01%.
Rain attenuation values form an important parameter in the link budget calculation. The determined values for rain attenuation served as input parameters for the link budget calculation of the SCP for the Ulundi region. A example was used to calculate the link budget and is presented in chapter 4.

The SCP has been shown to be a feasible solution to providing telecommunications services in rural areas of South Africa. Having a sufficiently large enough coverage area (50-200Km), low power requirements on the user-end and exorbitant savings in launch costs and deployment, coupled with meeting the specific requirements of rural areas, is making the SCP concept the highlight of much research in many countries throughout the world.

There are however many aspects that need to be investigated much further before the SCP becomes a reality. The novelty of HAP communications calls for some new concepts in terms of delivery of services, raising critical issues for development. And the platforms themselves present some challenges and potential problems. These include:

System level requirements: SCP networks for broadband communication service delivery will require a rethink of the basic design of cellular-type services, with development focusing upon the 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 network architecture will need to exploit opportunities of inter-terminal switching directly on the SCP itself as opposed to on the ground, and the use of inter-platform links to achieve connectivity.

Platform station-keeping and stability: The ability of a SCP to maintain position reliably in the face of variable winds is a challenge and could affect the viability of communication services. Platform positioning is likely to be represented as a certain statistical probability of remaining within a particular volume, e.g. a location cylinder. Some new thinking will be required, perhaps based on the use of multiple platforms and diversity techniques along with platform station keeping mechanisms.

Payload power: An important distinction between the different types of SCPs is the power available to the payload. Typically an airship may have in excess of 20 kW available for the payload, due to the large surface area on which to deploy solar cells. Planes powered by conventional fuel sources (e.g. the HALO scheme by Angel Technologies) will similarly have high power available. By comparison, solar powered planes (e.g. HeliPlat) may have significantly less available payload power; this is a limitation similar to that experienced by satellites, and means that the achievable downlink RF power, and hence overall capacity, will be constrained.
Indeed, solar powered planes have much in common with communication satellites, in terms of available power from the solar panels, payload weight and space available on the platform. Power will need to be used more efficiently, particularly through careful spot beam and antenna array design and power-efficient modulation and coding schemes. Compared with a satellite, a SCP will require a higher proportion of the power to charge the batteries (fuel cells) because it must cope with long periods of darkness each night. At higher latitudes both the variation in the angle of the sun relative to the solar panels between summer and winter, and the winter days will have an additional significant effect. There is also the issue of long-term reliability, with manufacturers postulating on-station lifetimes of 5 years or more, which is far longer than those of any current aerial devices. Current aerial devices like HALO, HeliPlat and AVCS are faced with power supply problems and storm endurance effects, which reduce station lifetime to a greater extent. These factors need to be balanced with the economic benefits of the service provided and the cost of through-life operation. High link availability may not be required of a single HAP in many scenarios, whether due to diversity techniques or because '99·99%' service is not demanded. And with the opportunity to bring SCPs back to ground for maintenance, the issue of long lifetime may be less critical.
Although much can be learned from scale SCP prototypes, not all of the aerodynamic, structural and energy issues scale linearly, thus full-size SCP prototypes will need to be built and tested in order to convince users and investors of their commercial viability. With the evident opportunities for enhanced communication services, as outlined in this research, it is to be anticipated that we will see significant developments in SCPs for communication service delivery over the next few years. These developments will enable the much needed provision of telecommunication and multimedia services in rural areas. By virtue of its feasibility, as shown by the results presented in this research, the SCP network will enhance the lives of millions of rural dwellers in South Africa.

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Appendix One

Figure A1: ITU Rain Climatic Map

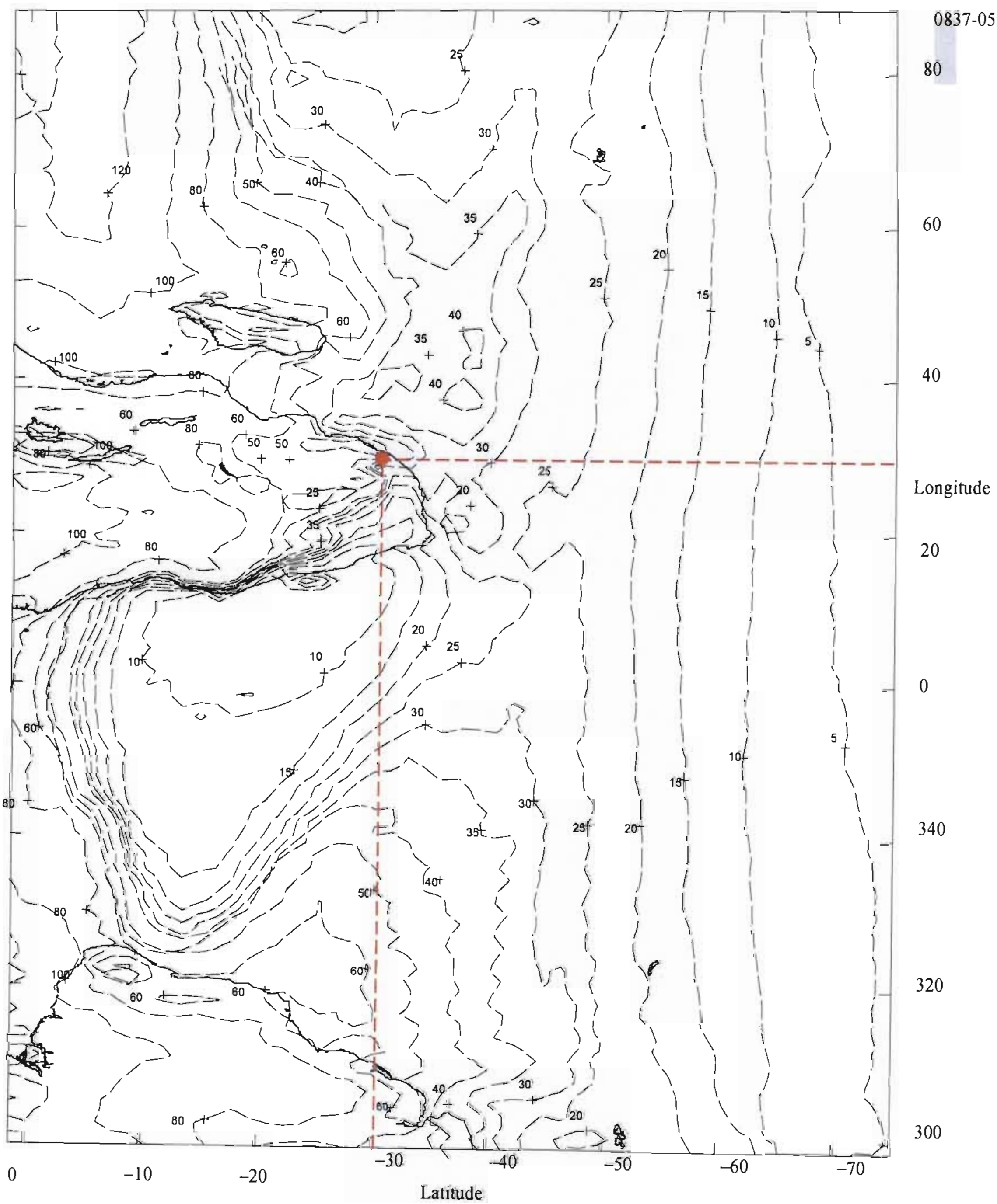


Figure A2: ITU Rain Climatic Map

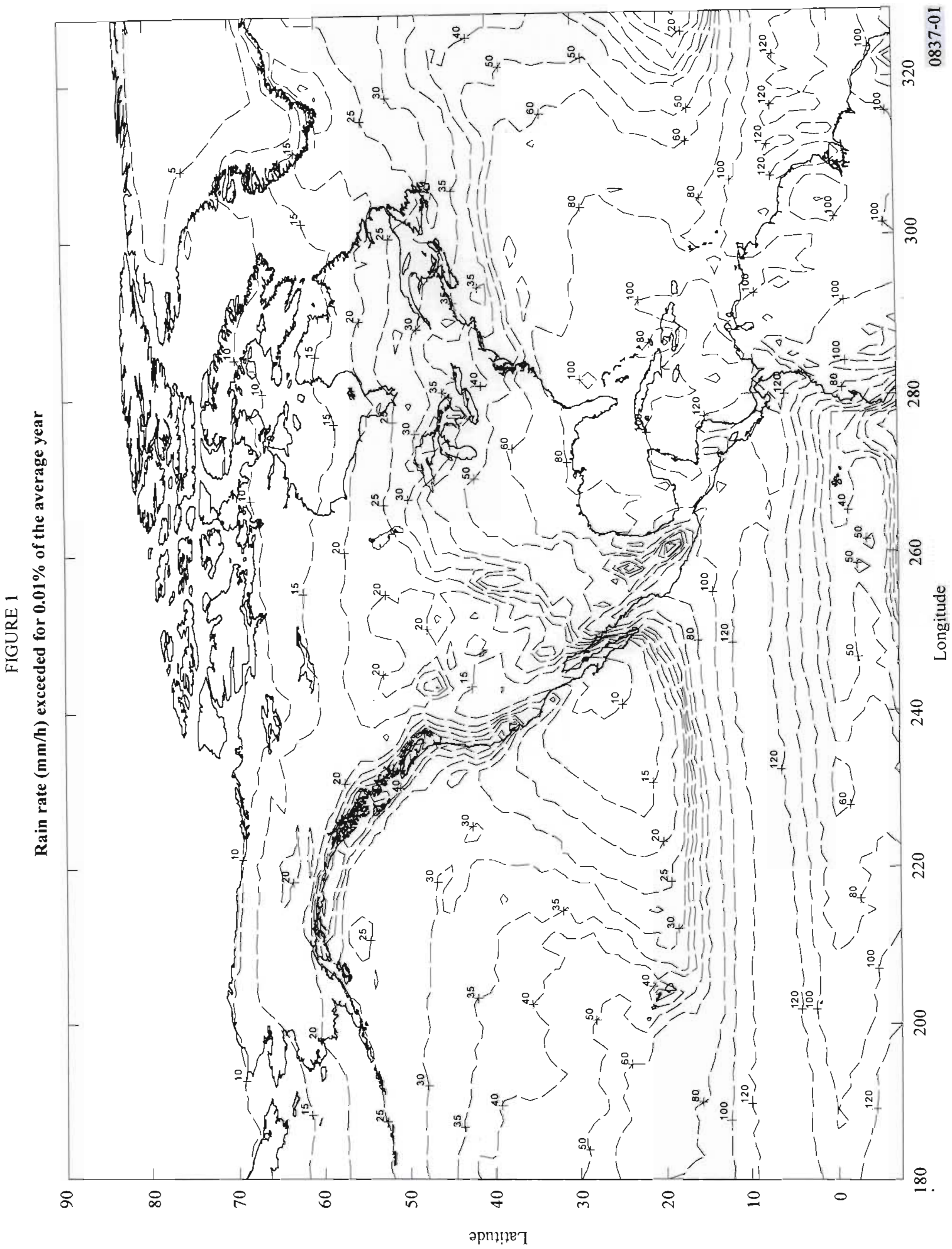


Figure A3: ITU Rain Climatic Map

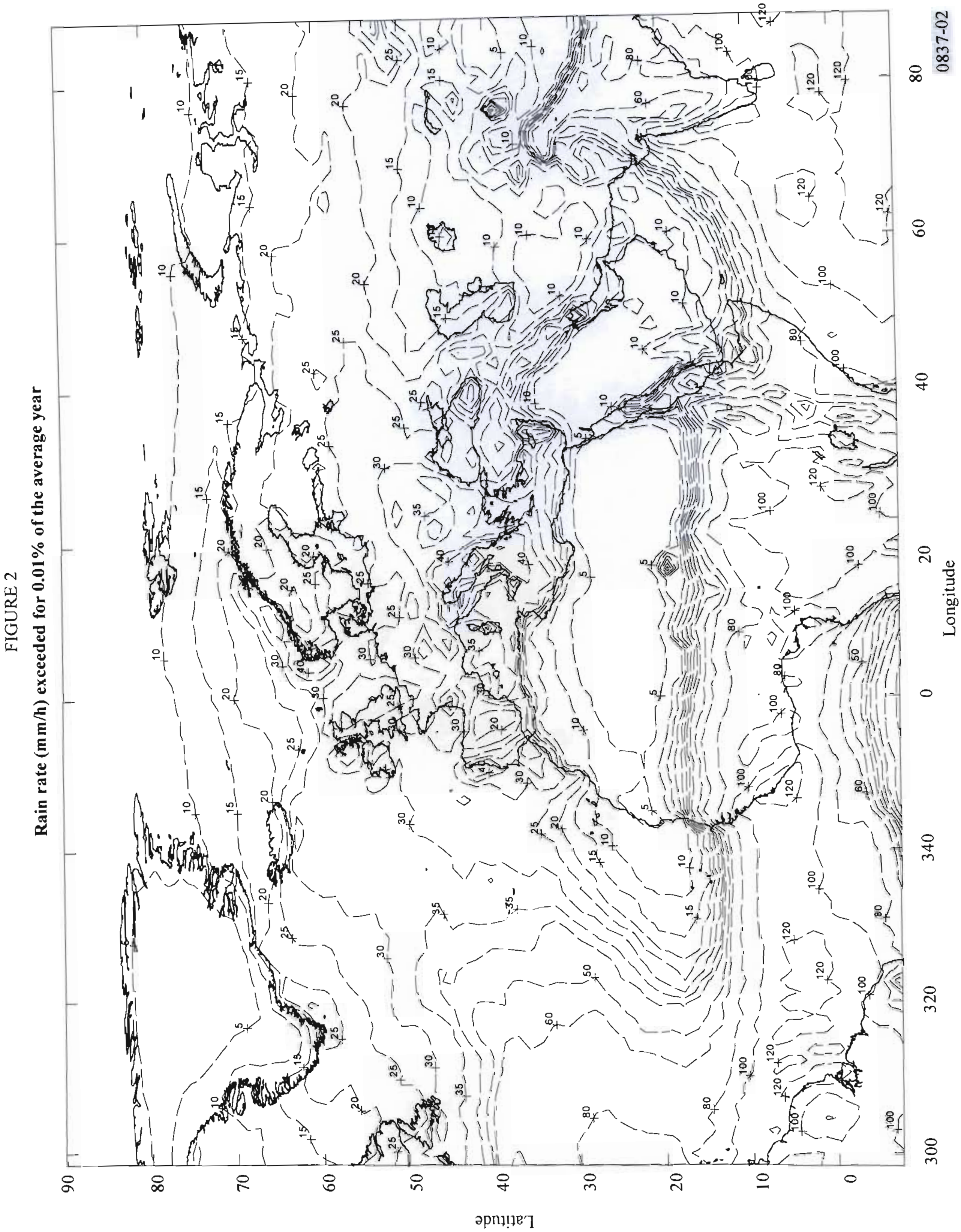


Figure A4: ITU Rain Climatic Map

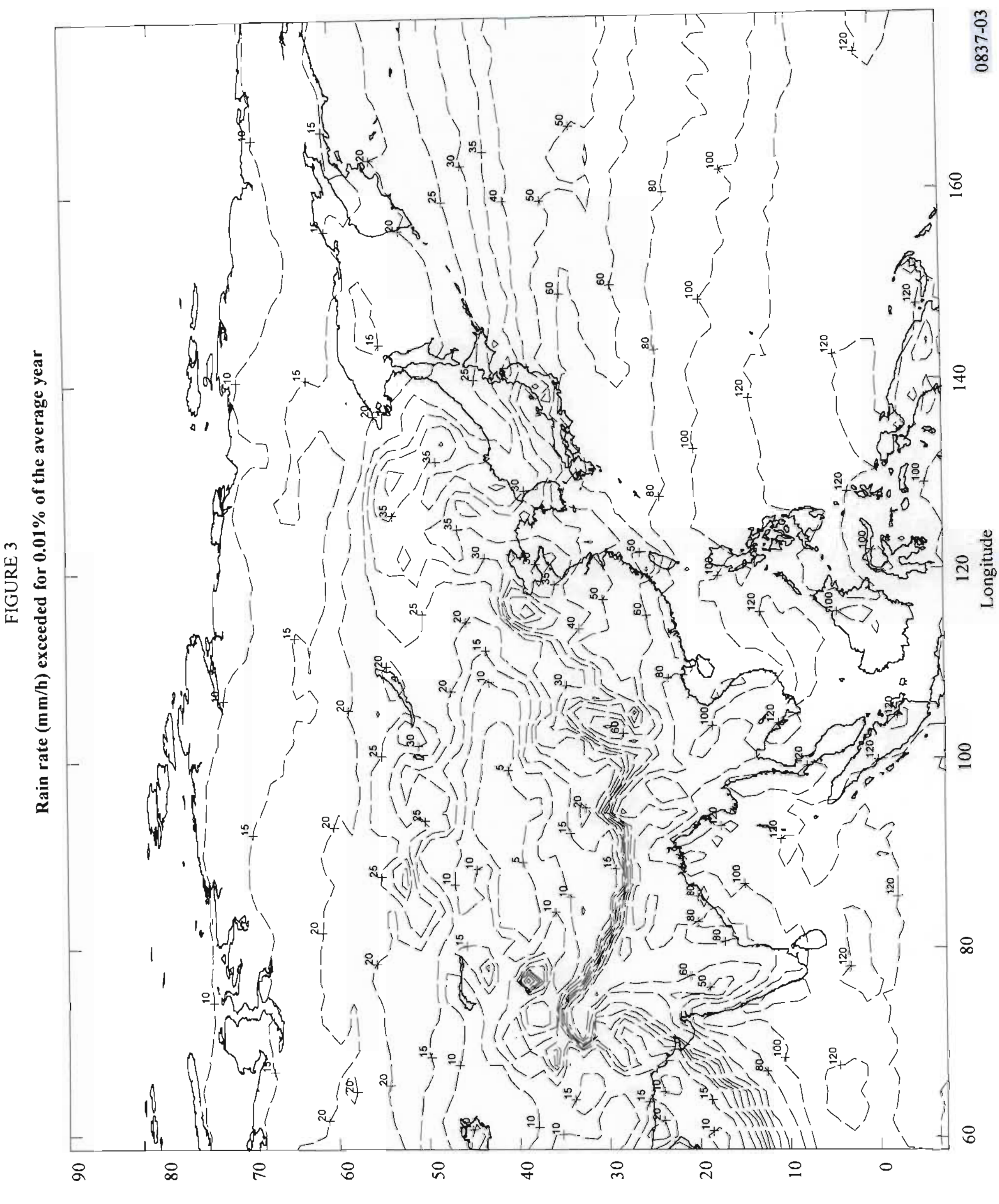


Figure A5: ITU Rain Climatic Map

FIGURE 4

Rain rate (mm/h) exceeded for 0.01% of the average year

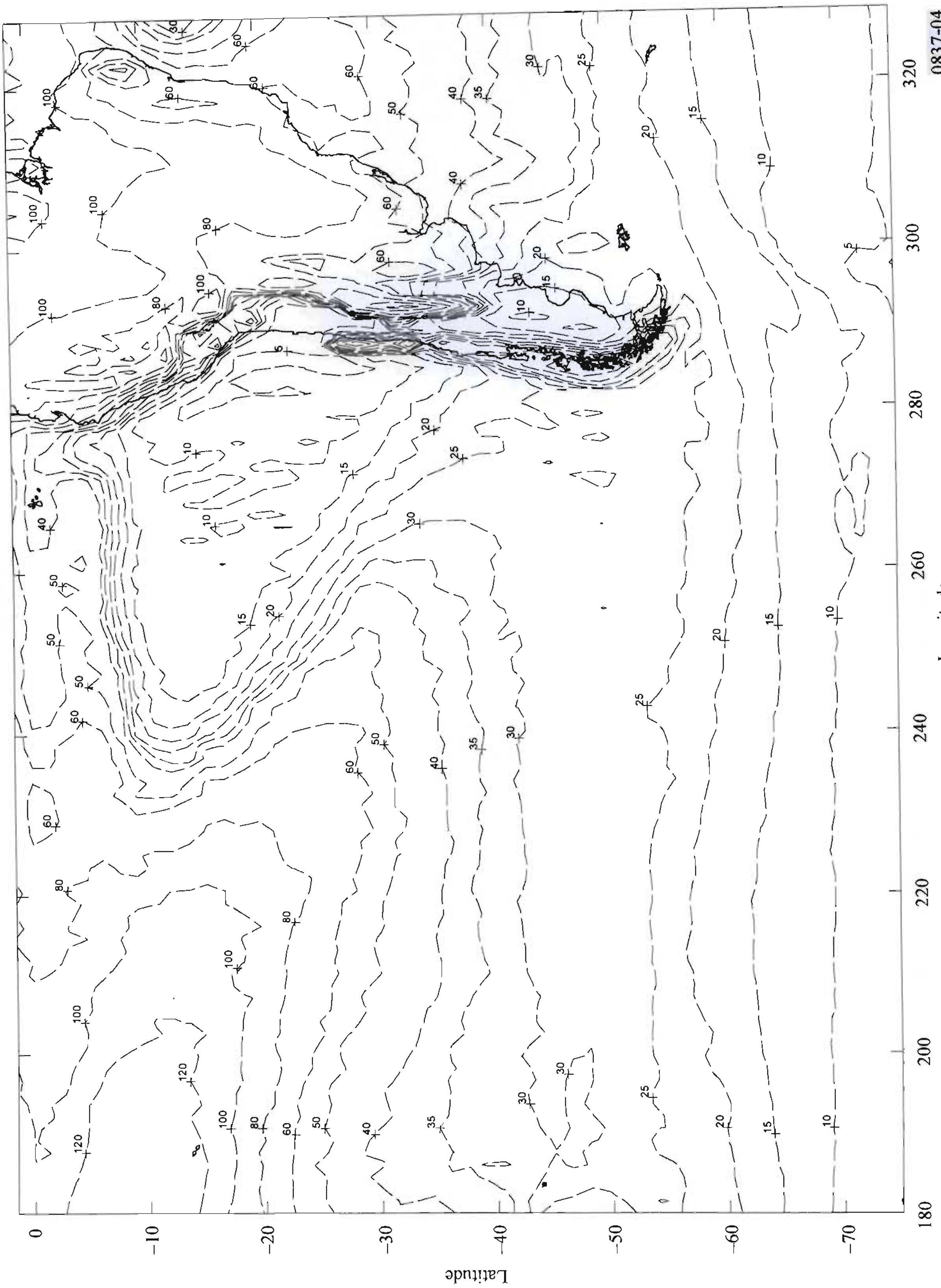


Figure A6: ITU Rain Climatic Map

FIGURE 5

Rain rate mm/h) exceeded for 0.01% of the average year

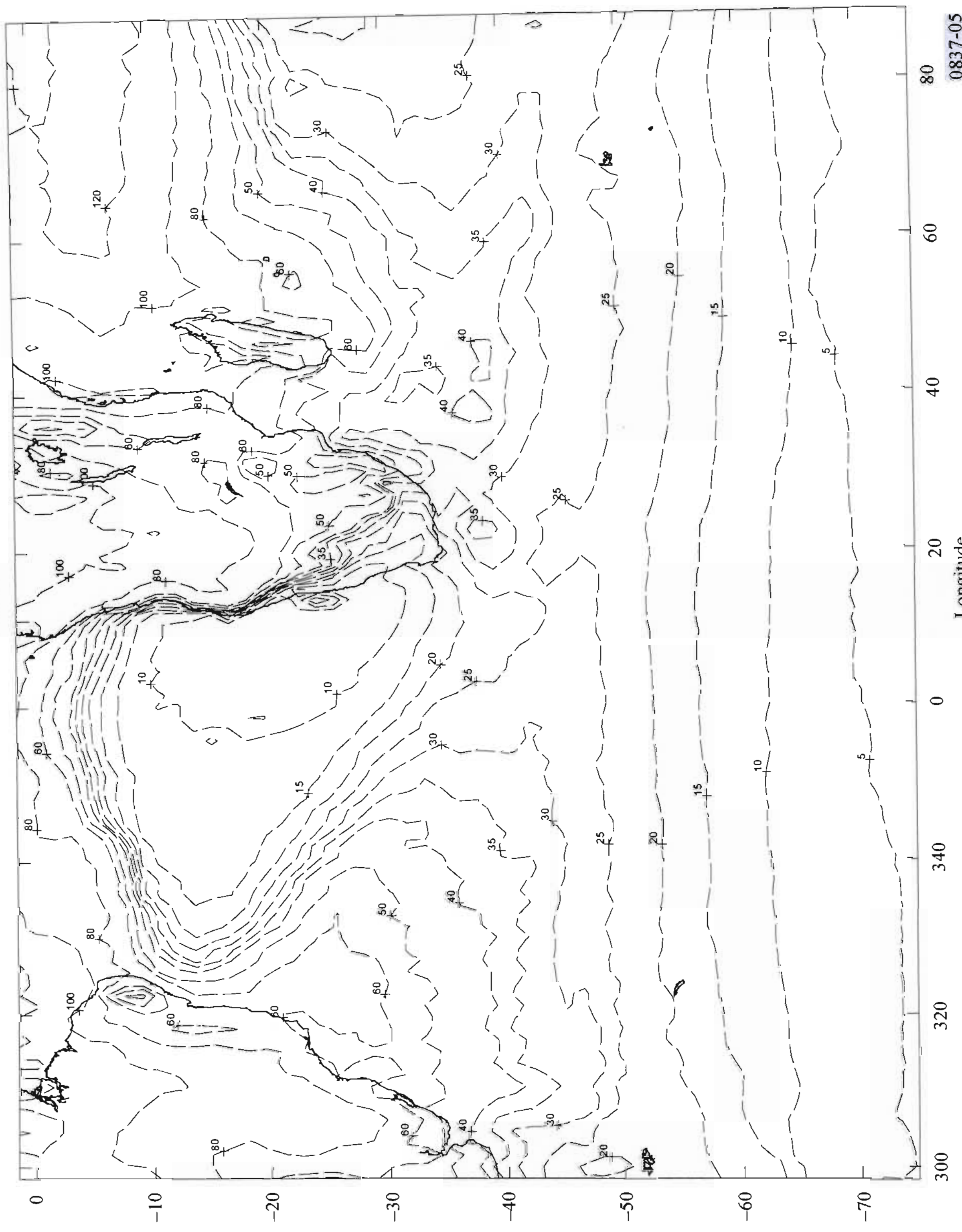
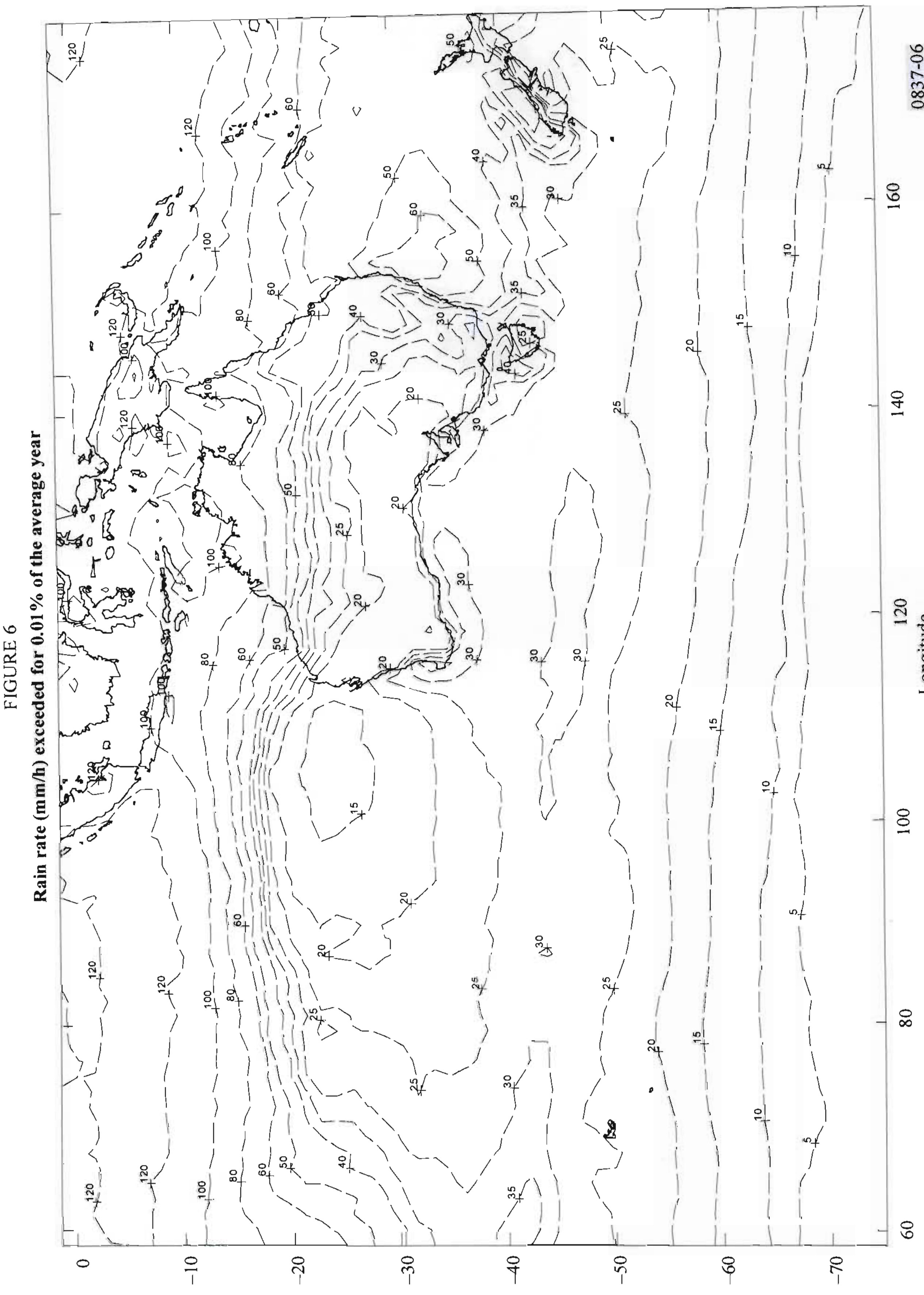


Figure A7: ITU Rain Climatic Map



RECOMMENDATION ITU-R P.837-4

Characteristics of precipitation for propagation modelling

(Question ITU-R 201/3)

(1992-1994-1999-2001-2003)

The ITU Radiocommunication Assembly,

considering

a) that information on the statistics of precipitation intensity is needed for the prediction of attenuation and scattering caused by precipitation;

b) that the information is needed for all locations on the globe and a wide range of probabilities,

recommends

1 that the model in Annex 1 be used to obtain the rainfall rate, R_p, exceeded for any given percentage of the average year, p, and for any location (with an integration time of 1 min). This model is to be applied to the data supplied in the digital files ESARAINxxx.TXT; (the data files may be obtained from that part of the ITU-R website dealing with Radiocommunication Study Group 3);

2 that, for easy reference, Figs. 1 to 6 in Annex 2 be used to select the rainfall rate exceeded for 0.01% of the average year. These Figures were also derived from the model and data described in Annex 1.

Annex 1

Model to derive the rainfall rate exceeded for a given probability of the average year and a given location

The data files ESARAINPR6.TXT, ESARAIN_MC.TXT and ESARAIN_MS.TXT contain respectively the numerical values for the variables P_{r6}, M_c and M_s while data files ESARAINLAT.TXT and ESARAINLON.TXT contain the latitude and longitude of each of the data entries in all other files. These data files were derived from 15 years of data of the European Centre of Medium-range Weather Forecast (ECMWF).

Step 1: Extract the variables P_{r6}, M_c and M_s for the four points closest in latitude (Lat) and longitude (Lon) to the geographical coordinates of the desired location. The latitude grid is from +90° N to –90° S in 1.5° steps; the longitude grid is from 0° to 360° in 1.5° steps.

Step 2: From the values of P_{r6}, M_c and M_s at the four grid points obtain the values $P_{r6}(Lat,Lon)$, $M_c(Lat,Lon)$ and $M_s(Lat,Lon)$ at the desired location by performing a bi-linear interpolation, as described in Recommendation ITU-R P.1144.

Step 3: Derive the percentage probability of rain in an average year, P_0, from:

$$P_0(Lat,Lon) = P_{r6}(Lat,Lon)\left(1 - \mathrm{e}^{-0.0117(M_s(Lat,Lon)/P_{r6}(Lat,Lon))}\right) \quad (1)$$

If P_{r6} is equal to zero, the percentage probability of rain in an average year and the rainfall rate exceeded for any percentage of an average year are equal to zero. In this case, the following steps are unnecessary.

Step 4: Derive the rainfall rate, R_p, exceeded for p% of the average year, where $p \le P_0$, from:

$$R_p(Lat,Lon) = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \quad \text{mm/h} \quad (2)$$

where:

$$A = a\,b \quad (2a)$$

$$B = a + c\ \ln(p/P_0(Lat,Lon)) \quad (2b)$$

$$C = \ln(p/P_0(Lat,Lon)) \quad (2c)$$

and

$$a = 1.11 \quad (2d)$$

$$b = \frac{(M_c(Lat,Lon) + M_s(Lat,Lon))}{22932 P_0} \quad (2e)$$

$$c = 31.5b \quad (2f)$$

NOTE 1 – An implementation of this model and the associated data in MATLAB is also available from the ITU-R website dealing with Radiocommunication Study Group 3.

RECOMMENDATION ITU-R P.838-2

Specific attenuation model for rain for use in prediction methods

(Question ITU-R 201/3)

(1992-1999-2003)

The ITU Radiocommunication Assembly,

considering

a) that there is a need to calculate the attenuation due to rain from a knowledge of rain rates,

recommends

1 that the following procedure be used.

Specific attenuation γ_R (dB/km) is obtained from the rain rate R (mm/h) using the power-law relationship:

$$\gamma_R = kR^{\alpha} \tag{1}$$

The frequency-dependent coefficients k and α are given in Table 1 for linear polarizations (horizontal: H, vertical: V) and horizontal paths.

The values in Table 1 have been tested and found to be sufficiently accurate for attenuation prediction up to frequencies of 55 GHz.

The coefficients k and α may alternatively be determined, as a function of frequency, from the following equations, which have been derived from curve-fitting to power-law coefficients derived from scattering calculations:

$$\log k = \sum_{j=1}^{3}\left(a_j \exp\left[-\left(\frac{\log f - b_j}{c_j} \right)^2 \right] \right) + m_k \log f + c_k \tag{2}$$

$$\alpha = \sum_{i=1}^{4}\left(a_i \exp\left[-\left(\frac{\log f - b_i}{c_i} \right)^2 \right] \right) + m_\alpha \log f + c_\alpha \tag{3}$$

where:

f: frequency (GHz)

k: either k_H or k_V

α: either α_H or α_V.

TABLE 1

Frequency dependent coefficients for estimating specific attenuation using equations (4), (5) and (1)

Frequency (GHz)	k_H	k_V	α_H	α_V
1	0.0000387	0.0000352	0.9122	0.8801
1.5	0.0000868	0.0000784	0.9341	0.8905
2	0.0001543	0.0001388	0.9629	0.9230
2.5	0.0002416	0.0002169	0.9873	0.9594
3	0.0003504	0.0003145	1.0185	0.9927
4	0.0006479	0.0005807	1.1212	1.0749
5	0.001103	0.0009829	1.2338	1.1805
6	0.001813	0.001603	1.3068	1.2662
7	0.002915	0.002560	1.3334	1.3086
8	0.004567	0.003996	1.3275	1.3129
9	0.006916	0.006056	1.3044	1.2937
10	0.01006	0.008853	1.2747	1.2636
12	0.01882	0.01680	1.2168	1.1994
15	0.03689	0.03362	1.1549	1.1275
20	0.07504	0.06898	1.0995	1.0663
25	0.1237	0.1125	1.0604	1.0308
30	0.1864	0.1673	1.0202	0.9974
35	0.2632	0.2341	0.9789	0.9630
40	0.3504	0.3104	0.9394	0.9293
45	0.4426	0.3922	0.9040	0.8981
50	0.5346	0.4755	0.8735	0.8705
60	0.7039	0.6347	0.8266	0.8263
70	0.8440	0.7735	0.7943	0.7948
80	0.9552	0.8888	0.7719	0.7723
90	1.0432	0.9832	0.7557	0.7558
100	1.1142	1.0603	0.7434	0.7434
120	1.2218	1.1766	0.7255	0.7257
150	1.3293	1.2886	0.7080	0.7091
200	1.4126	1.3764	0.6930	0.6948
300	1.3737	1.3665	0.6862	0.6869
400	1.3163	1.3059	0.6840	0.6849

The remaining coefficients are given in Tables 2 and 3.

TABLE 2

Coefficients in equations (2) and (3) for horizontal polarization

	a	b	c	m_k	c_k	m_α	c_α
$j = 1$	0.3364	1.1274	0.2916	1.9925	–4.4123	–	–
2	0.7520	1.6644	0.5175				
3	–0.9466	2.8496	0.4315				
$i = 1$	0.5564	0.7741	0.4011	–	–	–0.08016	0.8993
2	0.2237	1.4023	0.3475				
3	–0.1961	0.5769	0.2372				
4	–0.02219	2.2959	0.2801				

TABLE 3

Coefficients in equations (2) and (3) for vertical polarization

	a	b	c	m_k	c_k	m_α	c_α
$j = 1$	0.3023	1.1402	0.2826	1.9710	–4.4535	–	–
2	0.7790	1.6723	0.5694				
3	–1.0022	2.9400	0.4823				
$i = 1$	0.5463	0.8017	0.3657	–	–	–0.07059	0.8756
2	0.2158	1.4080	0.3636				
3	–0.1693	0.6353	0.2155				
4	–0.01895	2.3105	0.2938				

For linear and circular polarization, and for all path geometries, the coefficients in equation (1) can be calculated from the values in Table 1 using the following equations:

$$k = [k_H + k_V + (k_H - k_V)\cos^2\theta\cos 2\tau]/2 \tag{4}$$

$$\alpha = [k_H\alpha_H + k_V\alpha_V + (k_H\alpha_H - k_V\alpha_V)\cos^2\theta\cos 2\tau]/2k \tag{5}$$

where θ is the path elevation angle and τ is the polarization tilt angle relative to the horizontal ($\tau = 45°$ for circular polarization).

For convenience, a quick estimate of values of k and α at frequencies other than those in Table 1, can be obtained from Figs. 1 to 4.

FIGURE 1

k coefficient for horizontal polarization as a function of frequency

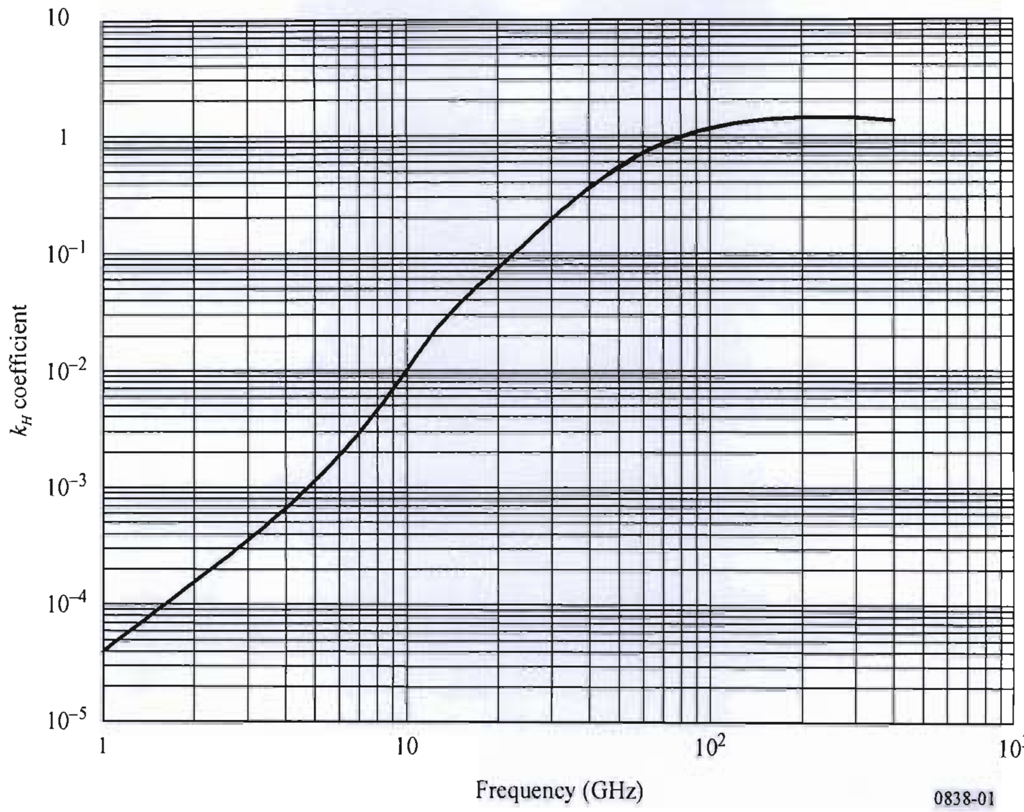


FIGURE 2

α coefficient for horizontal polarization as a function of frequency

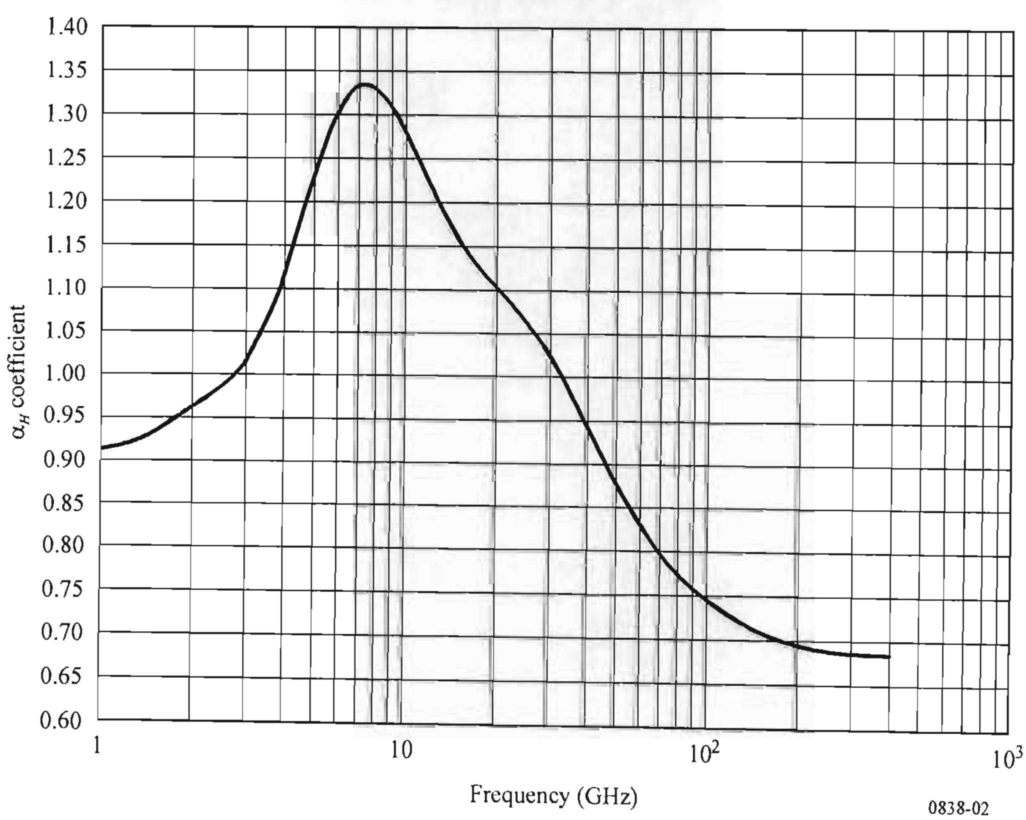


FIGURE 3

k coefficient for vertical polarization as a function of frequency

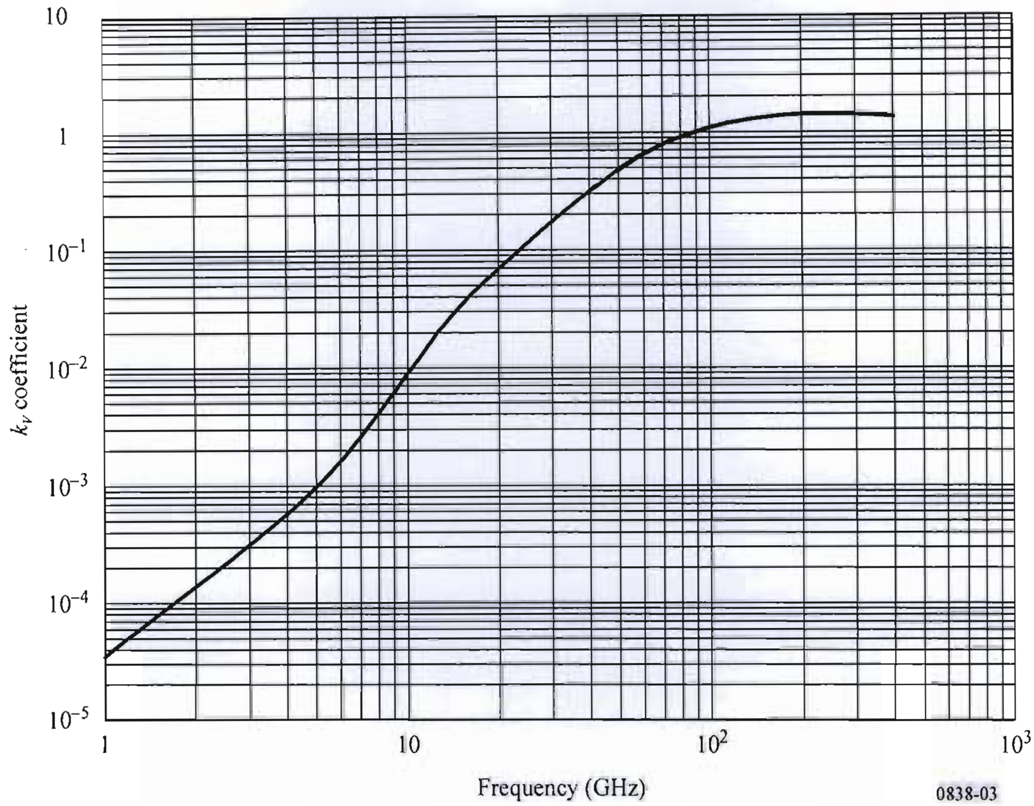
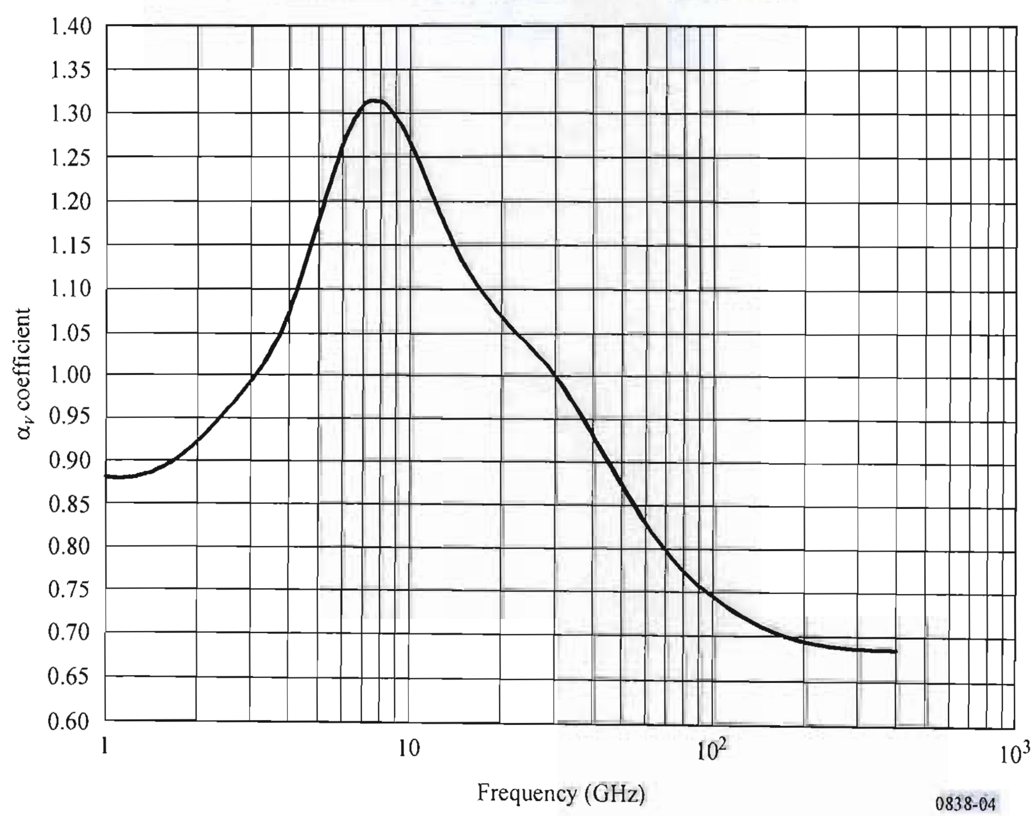


FIGURE 4

α coefficient for vertical polarization as a function of frequency



RECOMMENDATION ITU-R P.1409

PROPAGATION DATA AND PREDICTION METHODS REQUIRED FOR THE DESIGN OF SYSTEMS USING HIGH ALTITUDE PLATFORM STATIONS AT ABOUT 47 GHz

(1999)

The ITU Radiocommunication Assembly,

considering

a) that the Radio Regulations include provisions for the use of systems in the fixed service employing high altitude platform stations at about 47 GHz;

b) that the frequency bands identified are also allocated for use by the fixed service and by the fixed-satellite service (Earth-to-space),

recommends

1 that the propagation mechanisms and effects set out in Annex 1 should be taken into account in the design of systems using high altitude platform stations at about 47 GHz, and in studies of sharing and compatibility.

ANNEX 1

1 Introduction

The following mechanisms and effects should be considered when undertaking system design or sharing studies for systems employing high altitude platform stations at about 47 GHz:

- free-space path loss;
- atmospheric attenuation due to gaseous absorption in the troposphere; (it is sufficient to assume that all this attenuation occurs at heights below that of a platform);
- rain attenuation;
- cloud attenuation; (for time percentages smaller than about 1% the effects of cloud attenuation are included within the rain attenuation prediction method);
- back scatter from the Earth's surface; (back scatter from the top of rain cells or from the melting layer is expected to be less important);
- rain scatter;
- tropospheric scintillation.

The effects of ducting within the troposphere are not expected to be important as an interference mode for the slant paths (elevation angles well above 1°) from platform stations.

2 Prediction methods

For most cases other information contained in ITU-R Recommendations should be used as follows:

2.1 Frequency sharing between ground-based stations of high altitude platform networks and other terrestrial stations

The method of Recommendation ITU-R P.620 should be used for the evaluation of coordination distance, and Recommendation ITU-R P.452 should be used for detailed evaluation.

2.2 Frequency sharing between space stations and ground-based stations of high altitude platform networks

The method described in Recommendation ITU-R P.619 provides relevant information.

2.3 Frequency sharing between platform stations and other terrestrial stations

The method described in Recommendation ITU-R P.619 provides relevant information for this case also, since all losses except those due to free-space spreading occur below the height of the platform.

2.4 Frequency sharing between platform stations and space stations

For the direct path between a platform station and a space station it is only necessary to consider free-space path loss.

In addition, paths should be considered which involve ground scatter or ground reflection. Until further information becomes available the following guidance can be given.

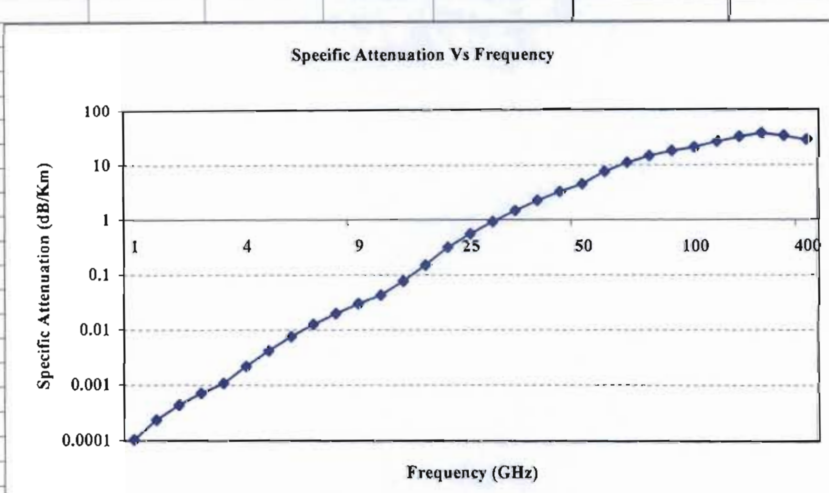
In some cases, smooth surfaces with areas of more than about $100/\sin^2 \theta$ m^2 (where θ is the elevation angle) may cause glints of good reflection with specular geometry. The signal in such cases may be determined from the e.i.r.p. in the appropriate direction, including the atmospheric attenuation loss due to two traverses of the troposphere for the slant angle involved, and assuming a reflection coefficient of –10 dB (some particular cases may have higher reflection coefficients).

More generally the Earth's surface may be considered as rough. In this case it may be appropriate to assume radiation from the area wholly illuminated by the beam from the platform station into the half-space above the Earth's surface, again with a typical scatter coefficient of –10 dB, i.e. assume a source on the Earth's surface radiating isotropically with a power given by: the actual transmitter power, reduced by the atmospheric attenuation loss due to the two traverses of the troposphere for the slant angles involved, further reduced by 10 dB for the reflection coefficient, and then increased by 3 dB since the radiation is only into a half space.

3 The prediction of system performance for systems using high altitude platform stations

The method of Recommendation ITU-R P.618 should be used, noting that the use of diversity as described in § 2.2.4 may not be appropriate, and that Faraday rotation due to the ionosphere will not apply.

	A	B	C	D	E	F	G	H	I
1				Appendix Two: Rain Attenuation Prediction Calculation					
2	Frequency					K	α	R = 5	Y
3	(GHz)	k_H	k_V	α_H	α_V	θ = 5°, τ = 0°	θ = 5°, τ = 0°	R^α	R = 5
4	1	0.0000387	0.0000352	0.9122	0.8801	3.86867E-05	0.91208907	4.340331506	0.000167913
5	1.5	0.0000868	0.0000784	0.9341	0.8905	8.67681E-05	0.933950375	4.495761848	0.000390089
6	2	0.0001543	0.0001388	0.9629	0.923	0.000154241	0.962763628	4.709154047	0.000726345
7	2.5	0.0002416	0.0002169	0.9873	0.9594	0.000241506	0.98720483	4.898087788	0.001182919
8	3	0.0003504	0.0003145	1.0185	0.9927	0.000350264	1.018412015	5.150382108	0.001803992
9	4	0.0006479	0.0005807	1.1212	1.0749	0.000647645	1.121042327	6.075401162	0.003934702
10	5	0.001103	0.0009829	1.2338	1.1805	0.001102544	1.233619531	7.282207486	0.008028953
11	6	0.001813	0.001603	1.3068	1.2662	0.001812202	1.3066636	8.19065554	0.014843126
12	7	0.002915	0.00256	1.3334	1.3086	0.002913652	1.333317241	8.549658295	0.024910726
13	8	0.004567	0.003996	1.3275	1.3129	0.004564831	1.327451458	8.469324079	0.038661036
14	9	0.006916	0.006056	1.3044	1.2937	0.006912734	1.304364397	8.160402655	0.05641069
15	10	0.01006	0.008853	1.2747	1.2636	0.010055416	1.274662883	7.779489889	0.078226005
16	12	0.01882	0.0168	1.2168	1.1994	0.018812328	1.216740983	7.087049237	0.133323894
17	15	0.03689	0.03362	1.1549	1.1275	0.03687758	1.154805126	6.414667409	0.236557413
18	20	0.07504	0.06898	1.0995	1.0663	0.075016984	1.099384052	5.867275423	0.440145305
19	25	0.1237	0.1125	1.0604	1.0308	0.123657462	1.060297721	5.509552207	0.681297241
20	30	0.1864	0.1673	1.0202	0.9974	0.186327457	1.020122247	5.164578126	0.962302709
21	35	0.2632	0.2341	0.9789	0.963	0.263089476	0.978846265	4.832637038	1.271415948
22	40	0.3504	0.3104	0.9394	0.9293	0.350248077	0.939366004	4.535118713	1.58841661
23	45	0.4426	0.3922	0.904	0.8981	0.442408578	0.903980135	4.284054613	1.895302507
24	50	0.5346	0.4755	0.8735	0.8705	0.534375534	0.873489861	4.078901446	2.17966514
25	60	0.7039	0.6347	0.8266	0.8263	0.703637174	0.826598972	3.782403765	2.661439896
26	70	0.844	0.7735	0.7943	0.7948	0.843732236	0.794301741	3.590815501	3.029686793
27	80	0.9552	0.8888	0.7719	0.7723	0.954947808	0.771901414	3.463665427	3.307619709
28	90	1.0432	0.9832	0.7557	0.7558	1.042972116	0.755700358	3.374519037	3.519529261
29	100	1.1142	1.0603	0.7434	0.7434	1.113995284	0.7434	3.308371731	3.685510507
30	120	1.2218	1.1766	0.7255	0.7257	1.221628327	0.725500732	3.214424648	3.926832206
31	150	1.3293	1.2886	0.708	0.7091	1.329145419	0.70800405	3.125169622	4.153804887
32	200	1.4126	1.3764	0.693	0.6948	1.41246251	0.693006662	3.050639361	4.30891373
33	300	1.3737	1.3665	0.6862	0.6869	1.373672654	0.686202645	3.017415143	4.144940668
34	400	1.3163	1.3059	0.684	0.6849	1.3162605	0.684003391	3.006753696	3.957671123



	J	K	L	M	N	O	P	Q	R	S	T
1											
2	K	α	R = 12	Y	R=22	Y	R=0.6	R=0.5	Y	Y	R=2.4
3	θ = 90°	θ = 90°	R^a	R=12	R^a	R=22	R^a	R^a	R=0.6	R=0.5	R^a
4	0.00003695	0.419244	2.834263486	0.000104726	3.654287	0.000135	0.807219	0.747816	2.98E-05	2.76E-05	1.443448
5	0.0000826	0.422691	2.858646601	0.000236124	3.693434	0.000305	0.805799	0.746032	6.66E-05	6.16E-05	1.447811
6	0.00014655	0.437243	2.963906741	0.000434361	3.863359	0.000566	0.799831	0.738545	0.000117	0.000108	1.466374
7	0.00022925	0.454096	3.090668197	0.000708536	4.069953	0.000933	0.792975	0.729967	0.000182	0.000167	1.48817
8	0.00033245	0.469907	3.214513626	0.001068665	4.273802	0.001421	0.786596	0.722011	0.000262	0.00024	1.508913
9	0.0006143	0.50878	3.540508701	0.002174934	4.819451	0.002961	0.77113	0.702817	0.000474	0.000432	1.561147
10	0.00104295	0.557626	3.997417798	0.004169107	5.604925	0.005846	0.752127	0.679419	0.000784	0.000709	1.629355
11	0.001708	0.596549	4.403364646	0.007520947	6.321514	0.010797	0.737321	0.661334	0.001259	0.00113	1.685834
12	0.0027375	0.615762	4.618689068	0.012643661	6.708305	0.018364	0.73012	0.652585	0.001999	0.001786	1.714429
13	0.0042815	0.618739	4.652985226	0.019921756	6.770324	0.028987	0.72901	0.65124	0.003121	0.002788	1.718904
14	0.006486	0.612987	4.586953566	0.029750981	6.651016	0.043138	0.731155	0.653841	0.004742	0.004241	1.71027
15	0.0094565	0.604303	4.489028772	0.042450501	6.474854	0.061229	0.734406	0.657789	0.006945	0.00622	1.697316
16	0.01781	0.588591	4.317146218	0.076888374	6.167915	0.109851	0.740324	0.664992	0.013185	0.011844	1.67413
17	0.035255	0.58021	4.228158717	0.149063736	6.010166	0.211888	0.7435	0.668867	0.026212	0.023581	1.66189
18	0.07201	0.593223	4.36711866	0.314476215	6.256851	0.450556	0.738574	0.66286	0.053185	0.047733	1.680931
19	0.1181	0.622133	4.692386308	0.554170823	6.841712	0.808006	0.727747	0.64971	0.085947	0.076731	1.724018
20	0.17685	0.661935	5.180218181	0.916121585	7.737432	1.368365	0.7131	0.63203	0.126112	0.111774	1.785152
21	0.24865	0.710971	5.851491855	1.45497345	9.003754	2.238784	0.69546	0.610909	0.172926	0.151902	1.863456
22	0.3304	0.765689	6.703744834	2.214917293	10.66298	3.523049	0.67629	0.588172	0.223446	0.194332	1.954896
23	0.4174	0.82205	7.711528721	3.218792088	12.69223	5.297737	0.657097	0.565638	0.274272	0.236097	2.053773
24	0.50505	0.876757	8.834454668	4.46184133	15.03068	7.591243	0.638988	0.54459	0.322721	0.275045	2.154532
25	0.6693	0.973636	11.23904218	7.522290931	20.27825	13.57223	0.608135	0.509221	0.407025	0.340822	2.34524
26	0.80875	1.050468	13.60334125	11.00170223	25.71416	20.79633	0.584729	0.482811	0.4729	0.390474	2.508418
27	0.922	1.109564	15.75508679	14.52619002	30.86768	28.46001	0.567342	0.463434	0.523089	0.427286	2.64161
28	1.0132	1.155057	17.64069887	17.87355609	35.52832	35.99729	0.554309	0.449048	0.561626	0.454976	2.748942
29	1.08725	1.190783	19.27837868	20.96041722	39.67655	43.13833	0.544285	0.438065	0.591774	0.476286	2.836279
30	1.1992	1.242428	21.91818746	26.2842904	46.54393	55.81548	0.530114	0.422661	0.635712	0.506855	2.967461
31	1.30895	1.290182	24.67973647	32.30454106	53.94733	70.61436	0.517338	0.408899	0.67717	0.535229	3.094153
32	1.3945	1.321823	26.6984635	37.23100735	59.49011	82.95896	0.509044	0.400029	0.709862	0.557841	3.18106
33	1.3701	1.285181	24.3748922	33.3960398	53.11968	72.77928	0.518662	0.410319	0.710619	0.562179	3.080634
34	1.3111	1.241441	21.86451469	28.6665652	46.4022	60.83792	0.530381	0.42295	0.695382	0.55453	2.964898
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2	**R=2.0**	**Y**	**Y**	**R=6**	**R=3**	**Y**	**Y**	**R=12**	**Y**	**R=41**	**R=21**	**Y**	**Y**
3	**R^a**	**R=2.4**	**R=2.0**	**R^a**	**R^a**	**R=6**	**R=3**	**R^a**	**R=12**	**R^a**	**R^a**	**R=41**	**R=21**
4	1.337227	5.334E-05	5E-05	2.119509	1.585003	7.83E-05	5.86E-05	2.834263	0.000105	4.744057	3.583707	0.000175	0.000132
5	1.340426	0.0001196	0.0001	2.132641	1.591018	0.000176	0.000131	2.858647	0.000236	4.80518	3.621517	0.000397	0.000299
6	1.354014	0.0002149	0.0002	2.188977	1.616657	0.000321	0.000237	2.963907	0.000434	5.071992	3.78557	0.000743	0.000555
7	1.369925	0.0003412	0.0003	2.256086	1.646869	0.000517	0.000378	3.090668	0.000709	5.399573	3.984879	0.001238	0.000914
8	1.385021	0.0005016	0.0005	2.320914	1.675725	0.000772	0.000557	3.214514	0.001069	5.726102	4.18139	0.001904	0.00139
9	1.422846	0.000959	0.0009	2.488328	1.748838	0.001529	0.001074	3.540509	0.002175	6.615336	4.706722	0.004064	0.002891
10	1.471845	0.0016993	0.0015	2.715923	1.84525	0.002833	0.001925	3.997418	0.004169	7.931042	5.461399	0.008272	0.005696
11	1.512095	0.0028794	0.0026	2.912095	1.925867	0.004974	0.003289	4.403365	0.007521	9.164417	6.148495	0.015653	0.010502
12	1.532367	0.0046933	0.0042	3.014088	1.966949	0.008251	0.005385	4.618689	0.012644	9.842171	6.51887	0.026943	0.017845
13	1.535533	0.0073595	0.0066	3.030209	1.973393	0.012974	0.008449	4.652985	0.019922	9.95159	6.578227	0.042608	0.028165
14	1.529423	0.0110928	0.0099	2.99914	1.960962	0.019452	0.012719	4.586954	0.029751	9.741278	6.464033	0.063182	0.041926
15	1.520244	0.0160507	0.0144	2.952834	1.942342	0.027923	0.018368	4.489029	0.042451	9.432135	6.295366	0.089195	0.059532
16	1.503778	0.0298162	0.0268	2.870867	1.909103	0.05113	0.034001	4.317146	0.076888	8.897554	6.001321	0.158465	0.106884
17	1.495066	0.0585899	0.0527	2.828074	1.891604	0.099704	0.066689	4.228159	0.149064	8.624871	5.850113	0.30407	0.206246
18	1.508613	0.1210439	0.1086	2.89479	1.918842	0.208454	0.138176	4.367119	0.314476	9.051911	6.086543	0.651828	0.438292
19	1.539149	0.2036065	0.1818	3.04869	1.980764	0.36005	0.233928	4.692386	0.554171	10.07779	6.64654	1.190187	0.784956
20	1.582204	0.3157041	0.2798	3.274053	2.069299	0.579016	0.365956	5.180218	0.916122	11.68311	7.502802	2.066158	1.326871
21	1.636905	0.4633484	0.407	3.574728	2.183833	0.888856	0.54301	5.851492	1.454973	14.0166	8.710832	3.485227	2.165948
22	1.700182	0.6458976	0.5617	3.942957	2.319138	1.302753	0.766243	6.703745	2.214917	17.17478	10.28985	5.674548	3.399767
23	1.767916	0.8572449	0.7379	4.361932	2.467274	1.82067	1.02984	7.711529	3.218792	21.17329	12.21602	8.83773	5.098968
24	1.836243	1.0881462	0.9274	4.811158	2.620109	2.429875	1.323286	8.834455	4.461841	25.94296	14.42996	13.10249	7.28785
25	1.963783	1.5696688	1.3144	5.723159	2.914354	3.83051	1.950577	11.23904	7.522291	37.1761	19.38027	24.88196	12.97121
26	2.071202	2.0286827	1.6751	6.567849	3.171033	5.311748	2.564573	13.60334	11.0017	49.45135	24.48778	39.99378	19.80449
27	2.157804	2.4355647	1.9895	7.301443	3.383737	6.731931	3.119806	15.75509	14.52619	61.58673	29.31481	56.78296	27.02826
28	2.226931	2.7852284	2.2563	7.921529	3.55715	8.026093	3.604105	17.6407	17.87356	72.92177	33.66965	73.88433	34.11409
29	2.282766	3.0837449	2.4819	8.445185	3.699541	9.182027	4.022326	19.27838	20.96042	83.26746	37.53842	90.53255	40.81365
30	2.365963	3.5585788	2.8373	9.263959	3.915513	11.10934	4.695483	21.91819	26.28429	100.8712	43.93006	120.9648	52.68093
31	2.44559	4.0500918	3.2012	10.09153	4.12642	13.20931	5.401277	24.67974	32.30454	120.444	50.8047	157.6552	66.50081
32	2.499817	4.4359881	3.486	10.68017	4.272378	14.89349	5.957832	26.69846	37.23101	135.461	55.94219	188.9004	78.01139
33	2.437125	4.2207764	3.3391	10.00149	4.103807	13.70305	5.622626	24.37489	33.39604	118.2275	50.03691	161.9835	68.55557
34	2.364346	3.8872784	3.0999	9.247596	3.911271	12.12452	5.128067	21.86451	28.66657	100.5023	43.7983	131.7686	57.42395
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2	**R=70**	**R=32**	**Y**	**Y**	
3	**R^a**	**R^a**	**R=70**	**R=32**	
4	5.936715	4.275875	0.000219	0.000158	
5	6.024303	4.327267	0.000498	0.000357	
6	6.408499	4.5511	0.000939	0.000667	
7	6.884184	4.824844	0.001578	0.001106	
8	7.362499	5.096607	0.002448	0.001694	
9	8.684577	5.83163	0.005335	0.003582	
10	10.68746	6.907339	0.011146	0.007204	
11	12.60932	7.904892	0.021537	0.013502	
12	13.68173	8.44917	0.037454	0.02313	
13	13.85589	8.536802	0.059324	0.03655	
14	13.5214	8.36831	0.0877	0.054277	
15	13.03161	8.120197	0.123233	0.076789	
16	12.19014	7.689857	0.217106	0.136956	
17	11.76369	7.469687	0.414729	0.263344	
18	12.43238	7.814287	0.895256	0.562707	
19	14.05709	8.637792	1.660143	1.020123	
20	16.64698	9.915434	2.944018	1.753545	
21	20.50271	11.75217	5.097999	2.922177	
22	25.86853	14.20617	8.546962	4.69372	
23	32.86715	17.27062	13.71875	7.208756	
24	41.46701	20.87617	20.94291	10.54351	
25	62.58254	29.2057	41.88649	19.54738	
26	86.73948	38.11643	70.15056	30.82666	
27	111.4948	46.78002	102.7982	43.13118	
28	135.2674	54.76889	137.053	55.49184	
29	157.4385	61.98788	171.1751	67.39632	
30	196.0654	74.13785	235.1216	88.90611	
31	240.1667	87.48182	314.3662	114.5093	
32	274.7214	97.62059	383.099	136.1319	
33	235.117	85.97841	322.1338	117.799	
34	195.2452	73.88476	255.986	96.87031	
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Appendix Three

RECOMMENDATION ITU-R F.1569

Technical and operational characteristics for the fixed service using high altitude platform stations in the bands 27.5-28.35 GHz and 31-31.3 GHz

(Question ITU-R 212/9)

(2002)

The ITU Radiocommunication Assembly,

considering

a) that new technology utilizing high altitude platform stations (HAPS) in the stratosphere is being developed;

b) that the World Radiocommunication Conference (Geneva, 1997) (WRC-97) made provisions for operation of HAPS within the fixed service (FS) in the bands 47.2-47.5 GHz and 47.9-48.2 GHz;

c) that since the 47 GHz bands are more susceptible to rain attenuation in those countries listed in Nos. 5.537A and 5.543A of the Radio Regulations (RR), the frequency range 18-32 GHz has been studied for possible identification of additional spectrum in ITU-R;

d) that the World Radiocommunication Conference (Istanbul, 2000) (WRC-2000) made a provision for the use of HAPS in the FS service in the bands 27.5-28.35 GHz and 31-31.3 GHz in certain countries on a non-interference, non-protection basis in order to address issues of rain attenuation associated with the 47 GHz bands (RR Nos. 5.537A and 5.543A), under the condition that the use of the band 31-31.3 GHz is limited to the lower half of the band (31-31.15 GHz) until WRC-03;

e) that Resolution 122 (Rev.WRC-2000) urgently requested studies on technical, sharing and regulatory issues in order to determine criteria for the operation of HAPS in the bands referred to in *considering* d) above;

f) that the 31.3-31.8 GHz band is allocated to the radio astronomy, Earth exploration-satellite service (EESS) (passive) and space research service (passive), and it is necessary to appropriately protect these services from unwanted emissions from HAPS ground stations operated in the band 31-31.3 GHz, taking into account RR No. 5.340 and the interference criteria given in Recommendations ITU-R SA.1029 and ITU-R RA.769,

noting

a) that receivers in the HAPS-based system in the bands 27.5-28.35 GHz and 31-31.3 GHz are designed to operate under the maximum aggregate interference of 10% of the receiving system thermal noise at HAPS platforms and HAPS ground stations, *recommends*

1 that HAPS using the bands 27.5-28.35 GHz and 31-31.3 GHz be operated between the altitude of 20 to 25 km;

2 that the frequency reuse factor of the cell illuminated by the spot beams of HAPS antenna be equal to or more than four in the bands 27.5-28.35 GHz and 31-31.3 GHz (see Note 1);

3 that, the signal power attenuation due to the shielding effect of the metal-coated airship body in the frequency range 18-32 GHz be calculated with the following equations:

$$\begin{array}{lll} 0 & \text{dB} & \text{for} \quad 0° \leq \theta < 90° \\ 0.5(\theta - 90) & \text{dB} & \text{for} \quad 90° \leq \theta < 120° \\ 15 & \text{dB} & \text{for} \quad 120° \leq \theta \leq 180° \end{array}$$

where θ is the separation angle to the direction of interest from the nadir direction of HAPS;

4 that automatic transmitting power control (ATPC) technique may be used to reduce probability of unacceptable interference to other services and to increase link availability in the HAPS-based system;

5 that the upper bound of the number of simultaneously transmitting carriers at the ground station in the HAPS-based system determined by available bandwidth in the uplink and the bandwidth of each transmitting signal be taken into account for sharing study;

6 that the HAPS-based system in Annex 1 be used for the relevant studies in ITU-R in the bands 27.5-28.35 GHz and 31-31.3 GHz.

NOTE 1 – The term "frequency reuse factor" in *recommends* 2 means the number of divided frequency sub-bands for the effective frequency use in the communication system with cellular configuration. For example, when the frequency reuse factor is 4, one of the divided frequency sub-bands is used repeatedly in every 4 cell.

ANNEX 1

Typical technical parameters for the FS using HAPS in the bands 27.5-28.35 GHz and 31-31.3 GHz

1 Introduction

This Annex provides typical technical characteristics for the FS using HAPS in the frequency range of 18-32 GHz focusing on the bands 27.5-28.35 GHz and 31-31.3 GHz, which may be used in the relevant studies.

2 Outline of a typical HAPS-based system

A typical HAPS system in the frequency range 18-32 GHz may have the following features:

– a HAPS is mounted on an airship controlled to be located at a nominal fixed point at the altitude of 20 to 25 km;

– the airship is supplied with electric power necessary for the system maintenance and the operation of communication mission from solar batteries being put on the upper surface of the airship and second batteries being charged for night-time use;

– the airship is equipped with a multi-spot beam antenna under its bottom providing access links to the ground stations with a certain minimum elevation angle;

– each beam formed by the multi-spot beam antenna corresponds to a cell on the ground with at least four times frequency reuse;

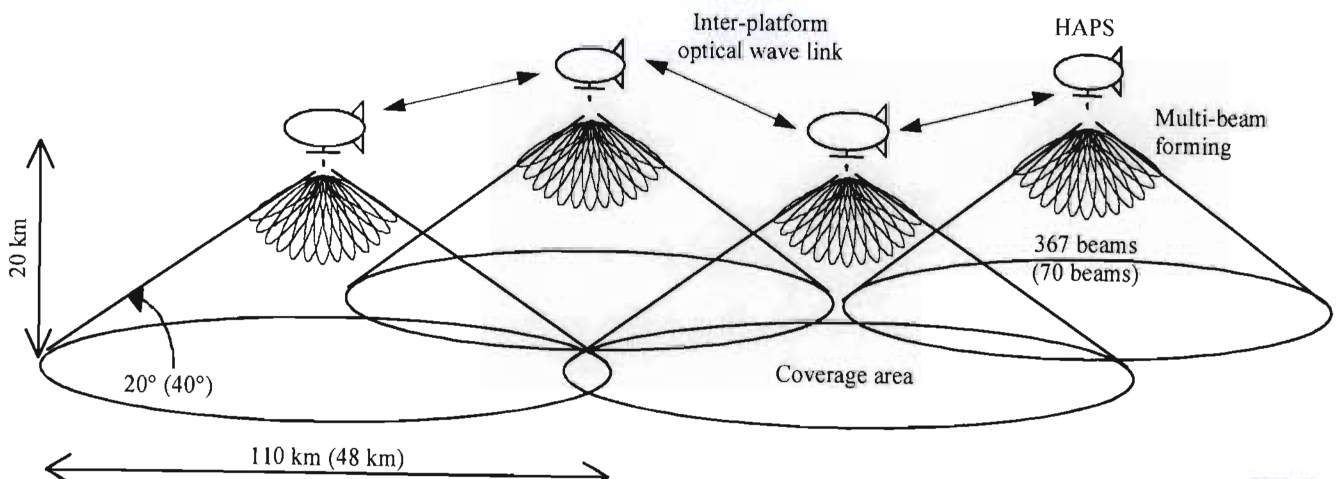
– the gas envelope of the airship is made of the skin material with metal layer such as that of aluminium, which is expected to block electromagnetic waves in the frequency around 18-32 GHz or higher;

– multiple airships are deployed to cover a wide range of area on the ground and the stations on board them are connected by wireless links such as optical wave links to build an all-wireless mesh-like network.

Figure 1 illustrates an image of communication system using HAPS. Two examples for minimum elevation angle, 20° and 40°, are shown in the Fig. 1.

FIGURE 1

Communication system using HAPS



3 Altitude of HAPS

The altitude of HAPS is defined in RR No. 1.66A as 20-50 km. The line-of-sight coverage from a HAPS becomes large at higher altitude. The atmospheric density, however, decreases significantly at higher altitude. Table 1 shows the atmospheric density and pressure at various altitudes. The atmospheric density at the altitude of 50 km is much lower than that at the altitude of 20 km by about 1/90. This means the airship at the altitude of 50 km needs Helium gas as 90 times as that at the altitude of 20 km and needs the body length as 4.5 times. Assuming that a 200 m long airship is needed at the altitude of 20 km to carry a certain weight a 900 m long airship is needed at the altitude of 50 km to carry the same weight. It is absolutely impossible to build such a huge airship with the current and near-future technology.

TABLE 1

The atmospheric density and pressure in the stratosphere

Altitude (km)	**Atmospheric density (kg/m^3)**	**Pressure (hpa)**
0	1.22	1 013
15	0.195	121
20	0.0889	55.3
25	0.0401	25.5
30	0.0184	12
50	0.00103	0.798

Figure 2 shows an average wind profile in the upper atmosphere. The wind speed has a local minimum around the altitude of 20-25 km. It becomes larger at the altitude higher than 25 km and is four times larger at the altitude of 50 km than at that of 20 km. To keep the position of the airship at a nominal fixed point against the wind, much larger propulsion power is necessary, which also requires heavier batteries for night operation. On this point of view, the operation of an airship at an altitude less than 25 km is reasonable reflecting the current technology.

Taking into account the above considerations, it can be concluded that the altitude of HAPS is less than about 25 km from a technical viewpoint.

4 Minimum operational elevation angle

The minimum operational elevation angle determines the area of service coverage by a single HAPS. If the smaller minimum elevation angle is assumed, the larger the service coverage can be obtained. The rain path, however, becomes longer and the required e.i.r.p. increases because the larger rain margin is needed.

The typical value of the minimum operational elevation angle for a HAPS system using 28/31 GHz band may be more than 20°. An operation with a smaller elevation angle needs higher e.i.r.p. in uplinks and downlinks because of a longer propagation path and larger rain attenuation. It could cause a difficult sharing situation between HAPS system and other systems such as satellite systems, fixed service, space science services and so on. Moreover, shadowing by buildings or mountains will degrade site availability for lower elevation angle in the urban or mountain areas.

Elevation angles smaller than 20° could be introduced under the conditions that:

– e.i.r.p.s in uplinks and downlinks with the elevation angle more than 20° are kept to constant values and these can be increased only for links with smaller elevation angle;

– appropriate minimum operation angle is determined in accordance with sharing requirement with other services at each area; and

– ATPC is appropriately used in uplinks and downlinks.

A larger minimum elevation angle, for instance 40°, is also possible in order to reduce interference to/from other services and to increase the site availability against shadowing by buildings or mountains. The larger the minimum elevation angle is, the more the number of HAPS will be needed to cover a certain area on the ground, while the total number of the spot beams for all the HAPS is unchanged.

TABLE 2

APPENDIX 1

TO ANNEX 1

Typical link budgets for HAPS system

Typical link budget for HAPS at the altitude of 20 km

a) Clear-sky condition

	Uplink	Downlink	Uplink	Downlink
Elevation angle (degrees)	20		90	
Frequency (GHz)	31.28	28	31.28	28
Bandwidth (MHz)	20	20	20	20
Transmitting antenna:				
– output power (dBW)	–16.3	–14.5	–16.3	–15.2
– feeder loss (dB)	0.5	0.5	0.5	0.5
– gain (dBi)	35	29.5	35	16.5
– e.i.r.p. (dBW)	18.2	14.5	18.2	0.7
– e.i.r.p. (per MHz) (dB(W/MHz))	5.2	1.5	5.2	–12.3
Path length (km)	58.5	58.5	20	20
Free space path loss (dB)	157.7	156.7	148.4	147.4
Rain attenuation (dB)	0	0	0	0
Availability in the zone M (%)	100	100	100	100
Atmospheric gases attenuation (dB)	0.4	0.4	0	0
pfd ($dB(W/m^2 \cdot MHz)$)	–	–105.2	–	–109.3
Receiving antenna:				
– gain (dBi)	29.5	35	16.5	35
– feeder loss (dB)	0.5	0.5	0.5	0.5
– received power (dBW)	–110.9	–108.1	–114.2	–112.2
– noise temperature (K)	700	500	700	500
– noise temperature (dB(W/Hz))	–200.2	–201.6	–200.2	–201.6
– designed interference power objective (dB(W/MHz)) (I/N = 10%)	–150.2	–151.6	–150.2	–151.6
– technical receiver losses (dB)	2.5	2.5	2.5	2.5
Available C/N_0 (dB(Hz))	86.3	90.6	83	86.5
User data rate (Mbit/s)	13.3	13.3	13.3	13.3
User data rate (dB(Hz))	71.2	71.2	71.2	71.2
Required E_b/N_0 (dB) (QPSK, BER = 1×10^{-6})	10.5	10.5	10.5	10.5
Coding gain (dB) (Viterbi coding, $K = 7$, $r = 2/3$)	5	5	5	5
Necessary E_b/N_0 (dB)	5.5	5.5	5.5	5.5
Necessary C/N_0 (dB(Hz))	76.7	76.7	76.7	76.7
Link margin (dB)	9.6	13.9	6.3	9.8

TABLE 5 (*end*)

b) Rainy condition (ATPC is used in uplink)

	Uplink	**Downlink**	**Uplink**	**Downlink**
Elevation angle (degrees)	20		90	
Frequency (GHz)	31.28	28	31.28	28
Bandwidth (MHz)	20	20	20	20
Transmitting antenna:				
– output power (dBW)	–10.3	–14.5	–10.3	–15.2
– feeder loss (dB)	0.5	0.5	0.5	0.5
– gain (dBi)	35	29.5	35	16.5
– e.i.r.p. (dBW)	24.2	14.5	24.2	0.7
– e.i.r.p. (per MHz) (dB(W/MHz))	11.2	1.5	11.2	–12.3
Path length (km)	58.5	58.5	20	20
Free space path loss (dB)	157.7	156.7	148.4	147.4
Rain attenuation (dB)	12.2	10.1	8.05	6.43
Availability in the zone M (%)	99.4	99.4	99.4	99.4
Atmospheric gases attenuation (dB)	0.4	0.4	0	0
pfd (dB(W/m^2 · MHz))	–	–105.2	–	–109.3
Receiving antenna:				
– gain (dBi)	29.5	35	16.5	35
– feeder loss (dB)	0.5	0.5	0.5	0.5
– received power (dBW)	–117.1	–118.2	–116.3	–118.6
– noise temperature (K)	700	500	700	500
– noise temperature (dB(W/Hz))	–200.2	–201.6	–200.2	–201.6
– designed interference power objective (dB(W/MHz)) (I/N = 10%)	–150.2	–151.6	–150.2	–151.6
– technical receiver losses (dB)	2.5	2.5	2.5	2.5
Available C/N_0 (dB(Hz))	80.1	80.5	80.9	80.1
User data rate (Mbit/s)	13.3	13.3	13.3	13.3
User data rate (dB(Hz))	71.2	71.2	71.2	71.2
Required E_b/N_0 (dB) (QPSK, BER = 1×10^{-6})	10.5	10.5	10.5	10.5
Coding gain (dB) (Viterbi coding, K = 7, r = 2/3)	5	5	5	5
Necessary E_b/N_0 (dB)	5.5	5.5	5.5	5.5
Necessary C/N_0 (dB(Hz))	76.7	76.7	76.7	76.7
Link margin (dB)	3.4	3.8	4.2	3.4

BER: bit error ratio