'KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF ENGINEERING

DEPARTMENT OF TELECOMMUNICATIONS ENGINEERING

EFFECT OF THE WEATHER ON KU BAND DIGITAL SATELLITE TELEVISION SYSTEM IN KUMASI

A CASE STUDY OF KNUST CAMPUS

SUBMITTED FOR FULFILMENT OF THE DEGREE OF MSc TELECOMMUNICATIONS ENGINEERING

BY

AKOBRE, STEPHEN
(PG 2652108)

SUPERVISOR:

NANA KWASI DIAWUO (PhD)

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ABSTRACT

Good signal reception depends on a reliable communication link. But as the signal travels through the communication link, several factors affect the quality of the signal at the receiver. One of these factors is the weather. Propagation measurements at frequencies above 10 GHz have been carried out fairly extensively in the temperate region where most of the developed countries are located. However, the scenario in the tropical region is not as encouraging since data coverage for this region is inadequate. In this regard, the effect of rain, harmattan, sunshine and cloudy weather conditions on a Ku band satellite television system was investigated at KNUST satellite laboratory. The statistical characteristic of the signal in these weather conditions indicated that during propagation of Ku band satellite signal, rain attenuation is the primary cause of communication impairment.

The ITU-R Rain attenuation model was then used to determine the rain attenuation for KNUST-Kumasi. The results were then compared with rain attenuation for Washington DC.

KEYWORDS: Ku band, satellite, signal, propagation, rain attenuation.

DECLARATION

I hereby declare that, this submission is my own work except for specific references which have been duly acknowledged, this work is the result of my own field research and it has not been submitted either in part or whole for any degree in Kwame Nkrumah University of Science and Technology or any other educational institution elsewhere.

Signature.................................... Date 01-11-11

AKOBRE, Stephen

(Candidate)

Signature.................................... Date 01/11/2011

Nana Kwasi DIAWUO (PhD)

(Supervisor)

Signature.................................... Date 02/11/2011

Dr. P. Y. OKYERE

(Head, Department of Electrical / Electronic Engineering)

DEDICATION

I dedicate this work to my wife, Mary-Immaculate Anati and my lovely daughter Stephanie Apasum Akobre, for their support and inspiration during those difficult times. I love you.

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I would like to acknowledge my intellectual debt to Nana (Dr.) Kwasi Diawuo, my supervisor. Your suggestions, advice and directions have made this project possible.

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Finally, I should be held responsible for misinterpretation, misrepresentation, errors and all other possible flaws in this study.

AKOBRE STEPHEN

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LIST OF ABBREVIATIONS AND ACRONYMS

R^2 - Strength of Relationship

ANOVA - Analysis of Variance

BER - Bit Error Rate

C-BAND - Compromise Between S and X

DSTV- Digital Satellite Television

DVB- Digital Video Broadcasting

EIRP- Equivalent Isotropic Radiated Power

FEC- Forward Error Correction

FSL- Free Space Loss

G_r - Gain of Receiver

G_t - Gain of Transmitter

HPA - High Power Amplifier

IEEE - Institute of Electronic and Electrical Engineering

ITU - International Telecommunication Union

KNUST - Kwame Nkrumah University of Science and Technology

KU BAND - Kurz-Under frequency band

LHCP – Left-Hand Circular Polarization

LNA - Low Noise Amplifier

LNB - Low Noise Block

MPEG - Moving Pictures Expert Group

P - Significance level

PAL – Phase Alternating Line

P_r - Received Signal Power

P_t - Transmitted Power

QPSK – Quaternary Phase Shift Key

RF - Radio Frequency

RHCP – Right-Hand Circular Polarization

RSS - Received Signal Strength

SFD - Saturated Flux Density

TV - Television

UHF - Ultra High Frequency

Wi-Fi - Wireless Fidelity

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CHAPTER ONE

INTRODUCTION

1.1 APPLICATIONS OF SATELLITE TECHNOLOGY

Satellite technology can be used in inter-country long distance telephony. The technology is used in regions or places where submarine communication cables and fiber optic cables cannot be used or are not available. Satellite technology is also applied for television and radio broadcasting. It is also used in the military for communication. Ultra High Frequency (UHF) radio links, and global command and control system are some form of applications of satellite technology for military communication. Besides this, the technology is widely used for global positioning. This is helpful for mapping of regions. A detailed map of a particular region can be framed and used for various purposes. Satellite imagery has also gained much importance and has been providing many benefits to researchers. The satellite technology is beneficial for weather forecasting. With the improvement in technology and new advances being made, the weather can be predicted with greater accuracy. This has its own importance, as different research expeditions and explorations of various regions are dependent on weather forecast [1].

1.2 BACKGROUND STUDY

1.2.1 C Band

The IEEE C band has frequencies ranging from 4 to 8 GHz. C band is a name given to certain portions of the electromagnetic spectrum, as well as a range of wavelengths of light, used for communications. The IEEE C band and its variations are used for certain satellite television broadcasts, and by some Wi-Fi devices, cordless phones, and weather radars. For satellite communications, the lower frequencies used by C Band perform better under adverse weather conditions than the Ku band or Ka band frequencies [2].

1.2.2 K- under (Ku) Band

The Ku band is a portion of the electromagnetic spectrum in the microwave range of frequencies between 10 GHz and 17 GHz. Ku band is primarily used for satellite communications. Compared with C band, Ku band is not restricted in power to avoid interference with terrestrial microwave systems, and the power of its uplinks and downlinks can be increased. This higher power also translates into smaller receiving dishes and points out a generalization between a satellite's transmission and a dish's size. As the power increases, the dish's size can decrease. This is because the purpose of the dish element of the antenna is to collect the incident waves over an area and focus them onto the antenna's actual receiving element, mounted in front of the dish (and pointed back towards its face); if the waves are more intense, less of them need to be collected to achieve the same intensity at the receiving element [3].

There are, however, some disadvantages of C and Ku band systems. Especially at frequencies higher than 10 GHz in heavy rainfall areas, a noticeable degradation occurs, due to the problems caused by and proportional to the amount of rainfall (commonly known as "rain fade"). This problem can be mitigated, however, by deploying an appropriate link budget strategy when designing the satellite network, and allocating a higher power consumption to reduce rain fade loss [4]. In this thesis, the weather in Kumasi is used as a case study since Kumasi can be located in a rain forest region. And the average powers received from the transmitting satellite for the various weather conditions are measured. The data are then analyzed to see the effect of the weather on the Ku band signal.

1.3 GENERAL SATELLITE CONCEPTS

The concepts underlying satellite broadcasting are straightforward: signals beamed into space by an "uplink" dish are received by an orbiting satellite, electronically processed, re-broadcasted or "down-linked" back to earth and then detected by a dish and associated electronics. A receiving station can be situated anywhere within the satellite's footprint. The area which receives a signal of useful strength from the satellite is known as the satellite's footprint. The overwhelming strength of satellite broadcasting lies in its ability to reach an unlimited number of sites regardless of their location without the need for any physical connections [5].

1.4 BASICS OF THE GEOSTATIONARY ORBIT

One of the important classes of orbits for satellites is the geostationary orbit. Geostationary orbit is a special orbit for which any satellite in that orbit appears to be stationary over a point on the earth's surface. Unlike some other classes of orbits, where there can be a family of orbits, there is only one geostationary orbit. Only satellites with orbital period equal to the earth's rotational period and with zero eccentricity and inclination can be geostationary satellites. The advantage of a satellite in a geostationary orbit is that it remains stationary relative to the earth's surface. This makes it an ideal orbit for communication since it is not necessary to track the satellite to determine where to point an antenna. However, there are some disadvantages. Perhaps the first is the long distance between the satellite and the ground. However with sufficient power, this limitation can be overcome [6].

1.5 HOW SATELLITES WORK

The process begins at the earth station. The earth station is an installation designed to transmit and receive signals from a satellite in orbit around the earth. Earth stations send information in the form of high-powered, high-frequency (i.e. in GHz range) signals to satellites which receive and transmit the signals back to earth where they are received by other earth stations in the coverage area of the satellite. The area which receives a signal of useful strength from the satellite is known as the satellite's footprint. The transmission path from the earth station to the satellite is called the uplink and the transmission path from the satellite to the earth station is called the downlink [7]. The general architecture of a satellite system is illustrated in Figure 1.1

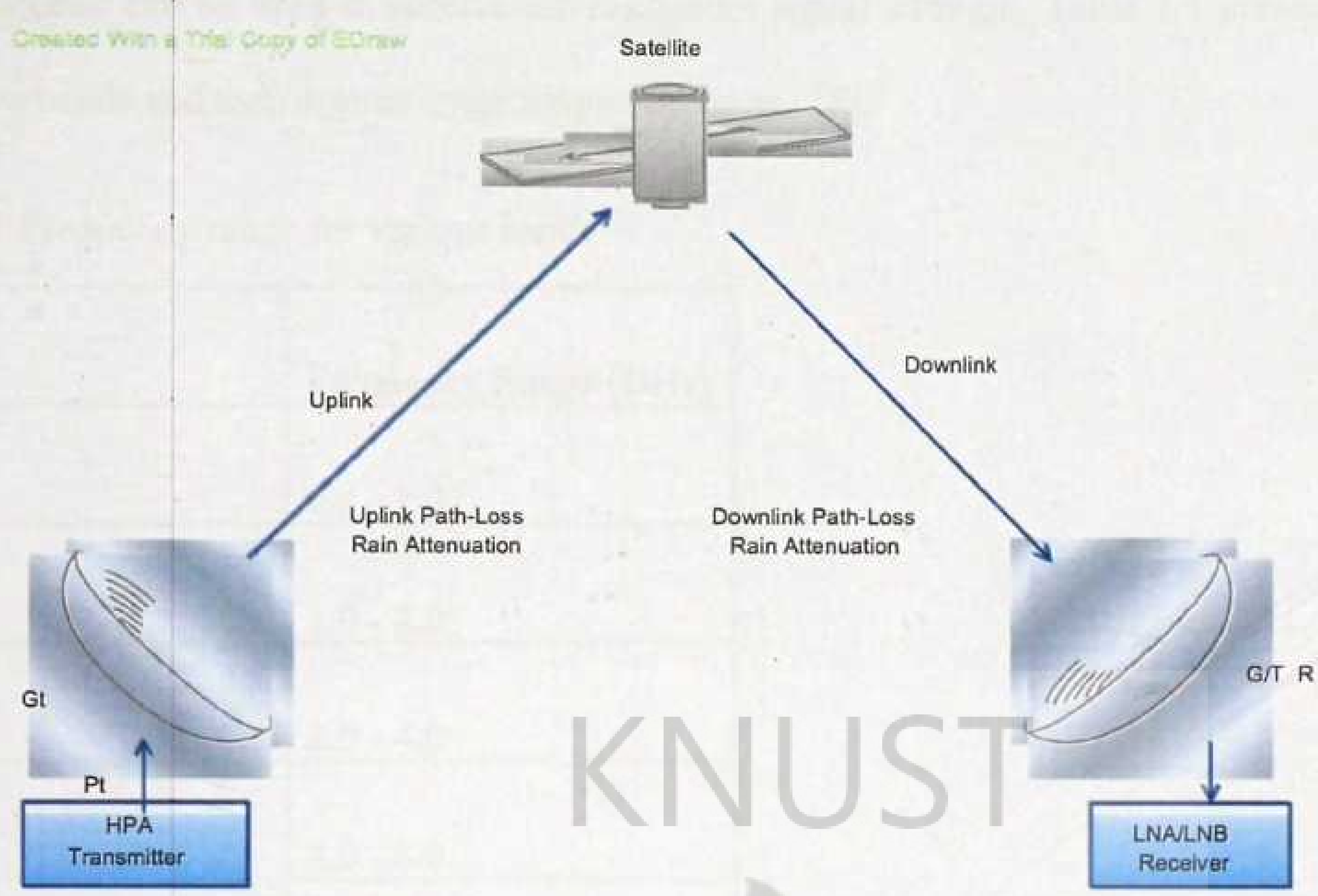

Figure 1.1 The General architecture of a satellite communication system

1.6 SATELLITE FREQUENCY BANDS

Some commonly used satellite frequencies are the C band, Ku band and Ka band. C-band and Ku band are the two most common frequency spectrums used for satellite television.

C band satellite transmission occupies the 4 to 8 GHz frequency range. These relatively low frequencies translate to larger wavelengths than Ku band or Ka band. These larger wavelengths of the C-band imply that a larger satellite antenna is required to gather the maximum signal strength. Ku band satellite transmissions occupy the 11 to 17 GHz frequency range. The relatively high frequency transmissions correspond to shorter wavelengths and therefore a smaller antenna can be used to receive the maximum signal strength. Table 1.1 presents some microwave bands and their approximate frequency ranges [8].

Table 1. 1 Frequency range for various bands

Band	Frequency Range (GHz)
P	0.2 - 1.0
L	1.0 - 2.0
S	2.0 - 4.0
C	4.0 - 8.0
X	8.0 - 10.0
Ku	10.0 - 17.0
Ka	17.0 - 22.0
K	26.0 - 40.0

1.7 COMPONENTS OF A SATELLITE RECEIVING SYSTEM

A typical satellite receiving system consists of three main parts.

1. Antenna
2. Head Unit (Consist of Feedhorn, Polarizer, LNB)
3. Satellite Receiver

1.7.1 Antenna

The purpose of the antenna is to concentrate weak incoming microwave signals from a distant satellite to a point where the signals can be located. It should do this with maximum efficiency and reject unwanted signals and noise [9].

1.7.2 Head Unit

Signals passing through a length of coaxial cable suffer attenuation per unit length due to the following:

1. Dielectric losses in the material necessary to support the inner conductor.
2. Skin resistance due to the finite diameter of the inner conductor
3. Radiation loss due to the coaxial cable operating as an aerial.

All these losses increase with signal frequency. However by correct choice of cross-sectional dimensions and materials, the attenuation due to these losses is acceptable provided the signal frequencies are not too high. Every satellite dish has a relatively large surface area which captures the incoming satellite TV signal. A group assembly positioned at the focus of a dish antenna is made up of the following parts [9]:

1. Feedhorn
2. Polarizer
3. Low Noise Block Converter (LNB)

Feedhorn

The feedhorn positioned at the focal point of an antenna, collects reflected signals from the antenna surface whilst rejecting any unwanted signal or noise coming from directions that are not parallel to the antenna axis. Feedhorns are carefully designed and precision engineered to capture and guide the incoming microwave signals to a resonant probe located at the front of the LNB. The feedhorn normally consists of rectangular or circular cross section tubes and exhibit two important properties, dictated by microwave theory. First, signals having wavelengths longer than half the internal dimensions are severely attenuated as they progress down its length. Secondly, wavelengths shorter than the waveguides designed dominant mode become rapidly attenuated: thus the feedhorn behaves like a band pass filter. The reason for the fluted horn is to match the free space impedance of the air with that of the waveguide [10].

Polarization

Current polarization techniques are classified as either linear or circular and are utilized for the following reasons:

1. Linear Polarization – A method to extend the number of channels that can occupy a given bandwidth, by using either horizontal polarization (electric field horizontal to the ground) or vertical polarization (electric field vertical to the ground). This effectively doubles the number of channels that can be provided by a satellite since two channels can share the same frequency, provided they have different polarizations.
2. Circular Polarization – This method involves spinning the electric field of the microwave signal into a spiral or corkscrew direction. It consist of clockwise or Right-Hand Circular Polarization (RHCP) and anticlockwise or Left-Hand Circular Polarization (LHCP)

Although circular polarization can be used in much the same way as linear polarization, to extend the number of channels, it is more frequently used in high power Digital satellite Broadcasting Services (DBS) satellites for different reasons [11].

The Low Noise Block (LNB)

The function of the LNB is to detect the weak incoming microwave signal via an internally tuned resonant probe, provide low noise amplification and finally down convert the whole block of frequencies to one suitable for cable transmission. The basic operation of the LNB is as follows: the short stub of waveguide is continued to a resonant probe or aerial located in the LNB throat. At this probe the incoming microwave signals are converted to minute electrical signals which are subsequently amplified and down converted to a frequency more suitable for onward transmission by the coaxial cable. The whole assembly is hermetically sealed against the ingress of moisture. If moisture gets into the unit, corrosion, and subsequent failure may result. Some head units combine feedhorn, polarizer and LNB into a single unit [11].

1.8 SATELLITE RECEIVER

The purpose of a satellite receiver is the selection of an individual channel, from the down converted block for viewing. The received signal must also be processed into a form suitable for interfacing to a conventional television set and/or stereo equipment. Receivers contain at least the following blocks of circuitry [12]:

1. Power supply
2. Satellite tuner/demodulator unit
3. Video processing circuits
4. Audio processing circuits
5. UHF modulator

1.9 TRANSMIT EARTH STATION

This is a ground based transmitting/receiving station in a satellite communications system. The counterpart to the earth station is the satellite in orbit, which is the "space station." Earth stations use dish-shaped antennas. Uplink satellite dishes are very large, as much as 9 to 12 meters (30 to 40 feet) in diameter. Antennas for space exploration have diameters reaching a hundred feet. The increased diameter results in a more accurate aiming and increased signal strength. The uplink dish is pointed toward a specific satellite and the uplinked signals are transmitted within a specific frequency range, so that the signal can be received by one of the transponders tuned to that frequency range aboard the satellite. An earth station is generally made up of a multiplexor, a modem, up and down converters, a high power amplifier (HPA) and a low noise amplifier (LNA). Almost all transmission to satellites are digital, and the digital data streams are combined in a multiplexor and fed into a modem that modulates a carrier frequency in the 50 to 180 MHz range. An up converter bumps the carrier into the gigahertz range, which goes to the HPA and dish [13].

1.9.1 Antenna Gain

Antenna gain relates the intensity of an antenna in a given direction to the intensity that would be produced by a hypothetical ideal antenna that radiates equally in all directions (isotropically) and has no losses. Although the gain of an antenna is directly related to its directivity, the antenna gain is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. In contrast, directivity is defined as a measure that takes into account only the directional properties of the antenna and therefore it is only influenced by the antenna pattern. However, if we assumed an ideal antenna without losses, then antenna gain will equal directivity as the antenna efficiency factor equals 1 (100% efficiency). In practice, the gain of an antenna is always less than its directivity [14].

1.9.2 Power of Amplifier

A separate power amplifier provides the output for each transponder channel. Each power amplifier is preceded by an input attenuator. This is necessary to permit the input drive of each power amplifier to be adjusted to the desired level. The attenuator has a fixed section and a variable section. The fixed attenuation is needed to balance out variations in the input attenuation so that each transponder channel has the same nominal attenuation, the necessary adjustments being made during assembly. The Traveling-wave tube amplifiers are widely used in transponders to provide the final output power required to the transmit antenna [14].

1.10 UPLINK

The uplink of a satellite circuit is the one in which the earth station is transmitting the signal and the satellite is receiving it. Factors to consider are [15]:

1. Saturation flux density
2. Input Back-off
3. The Earth Station HPA

1.11 THE SATELLITE

A typical satellite has up to 32 transponders for Ku band and up to 24 transponders for C band. Transponders receive signals from the transmit earth stations, process them and retransmit the signals back to earth but at a different frequency band (a process known as translation, used to avoid interference with the uplink signal). Typical transponders each have a bandwidth between 27 MHz and 50 MHz. Each geo-stationary C band satellite needs to be spaced 2 degrees from the next satellite (to avoid interference). For Ku band the spacing can be 1 degree. This means that there is an upper limit of 360/2 = 180 geostationary C band satellites and 360/1 = 360 geostationary Ku band satellites. C band is susceptible to terrestrial interference while Ku band transmission is affected by rain (as water is an excellent absorber of microwaves at this particular frequency) [16].

1.12 RECEIVING STATION

At the receiver site, a dish reflects and concentrates as much of the very weak down-linked signal as possible to its focus where a feedhorn channels the signal into the first electronic component, the low noise block converter (LNB). Within the LNB is the Low Noise Amplifier (LNA). The LNA is a weather sealed unit that provides enough gain to transport the signal from the antenna to the receiver. It is located as close to the feedhorn as possible to minimize signal loss and thereby improving signal to noise ratio. G/T is a measure of the ability of a receiving system to amplify very weak signals. The low noise amplifier has a very low noise floor. The job of this section is to amplify the signal to a level that is above the receiver's threshold. The signal is then cabled indoors to the satellite receiver and processed into a form that can be deciphered by a television, stereo or computer [17].

1.13 PATH LOSS

Path loss (or path attenuation) is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space. Path loss is a major component in the analysis and design of the link budget of a telecommunication system. Path loss can occur as a result of free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss and absorption. Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver and the height and location of antennas [18].

1.14 LINK BUDGET

A link budget is the accounting of all the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fiber, etc.) to the receiver in a telecommunication system. It accounts for the attenuation of the transmitted signal due to propagation, as well as the antenna gains, feedline and miscellaneous losses. See Appendix B for detail equations. Randomly varying channel losses are taken into account by adding sufficient margin to the link budget depending on the anticipated severity of its effects. The amount of margin required can be reduced by the use of mitigating techniques such as antenna diversity or frequency hopping [19].

A simple link budget equation looks like this:

$$Received\ Power\ (dBm) = Transmitted\ Power\ (dBm) + Gains\ (dB) - Losses\ (dB) \quad (1.1)$$

The design of a satellite communication system involves many trade-offs to obtain a cost effective solution. Factors which dominate are [19]:

1. Downlink EIRP, G/T and SFD of the satellite
2. Earth Station Antenna
3. Frequency
4. Interference

1.15 RAIN ATTENUATION

Rain attenuation refers primarily to the absorption of a microwave Radio Frequency (RF) signal by atmospheric rain, snow or ice, and losses are especially prevalent at frequencies above 11GHz. Recall equation (1.1) for losses, holding all other factors constant. It also refers to the degradation of a signal caused by the electromagnetic interference of the leading edge of a storm front. Rain attenuation can be caused by precipitation at the uplink or downlink location. However, it does not need to be raining at a location for it to be affected by rain fade, as the signal may pass through precipitation many miles away, especially if the satellite has a low look angle. Possible ways to overcome the effects of rain fade are site diversity, uplink power control, variable rate encoding, receiving antennas larger than the requested size for normal weather conditions, and hydrophobic coatings [20].

1.16 PROBLEM STATEMENT

1.16.1 Interference

Although satellite communications is very vital, there are some basic effects of propagation anomalies which influence the communication satellite systems' performance. In satellite communications, weather loss results from attenuation of the Earth-satellite signals by hydrometers as they pass through the Earth's atmosphere. Some of the losses encountered by satellite communication systems are rain attenuation, atmospheric and ionospheric losses [21].

Rain Attenuation

Above 10 GHz the rain attenuation increases, but the chances of interference with other satellite services are minimum. At certain wavelengths, signals encounter absorption bands due to atmospheric components within the range of 1-10 GHz. However, rain is the predominant loss element below 60 GHz [22].

Atmospheric Losses

Atmospheric losses result from the absorption of the communication signals as they pass through the earth's atmosphere to and from the satellite. The value of the atmospheric loss is strongly dependent on frequency. They include Beam Spreading loss, polarization loss, Rayleigh fading, scintillation loss and free-space loss [23].

Ionospheric Losses

All radio waves propagated through the ionosphere undergo energy losses before arriving at the receiving site. This is particularly common with the lower frequencies i.e. 1.5 and 2.5 GHz. The magnitude of these losses varies considerably with the time of the day and the sunspot activity level. Ground reflection loss and free-space loss also significantly affect the ionospheric propagation of radio waves. The combined effects of absorption, ground reflection loss and free-space loss account for most of the energy losses of radio signal propagated through the ionosphere [23].

1.17 OBJECTIVES

The objectives of the project described in this report are:

1. To measure the signal strength variations for different weather conditions in Kumasi for the Ku Band.
2. To measure the Average Power received by the Ku Band satellite receiver for the various weather conditions.
3. To analyze the susceptibility of Ku band signal to interference caused by rain, dust and sunshine in Kumasi.
4. To determine the fade threshold.
5. To determine the Rain Attenuation for Kumasi and recommend rain mitigation techniques that will result in optimum link reliability.

1.18 METHODOLOGY

The methodology that has been employed to achieve the above objectives are the following;

1. Advanced lectures on IEEE Satellite Communication System
2. Intensive literature review on link reliability and interference.

3. Monitoring of received signal strength (RSS) in Ku Band.
4. Data acquisition on weather pattern in Kumasi.
5. Thesis writing and presentation: Thesis has been written and a date will be fixed for its oral presentation

1.19 TOOLS NEEDED

The tools needed to achieve the above objectives are the following:

1. DSTV satellite dish and receiver
2. Spectrum analyzer
3. Television set
4. Splitter

1.20 THESIS OVERVIEW

The rest of the thesis is structured as follows. Chapter 2 deals with the literature review. This chapter discusses some related works on rain attenuation. It describes the various steps involved in the determination of rain attenuation using the ITU-R rain attenuation model.

Chapter 3 delves into the materials and methods used. The experimental setup and mode of data collection are discussed. It also describes various equipments used to acquire the data and sets the stage for proper analysis of the data.

Chapter 4 talks about the analysis of the data collected, the results obtained and some useful discussions.

And, finally, Chapter 5 deals with conclusions and recommendations.

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And, finally, Chapter 5 deals with conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 RELATED WORKS

In January 2007, Mandeep et al. conducted a research on rainfall attenuation and rain rate measurements in Malaysia and made a comparison with other prediction models [24]. It was realized that since majority of the studies on earth-space propagation have been conducted in Europe and the United States, the existing prediction models may not be sufficiently accurate to characterize the effects of attenuation on tropical and equatorial climates. Under such circumstances, an evaluation of the prediction accuracy of these models was required with the view of designing reliable communication systems. In conclusion, the regional rainfall attenuation and rainfall rate for USM (University Science Malaysia) were used to compare the ITU and VIHT (Variable Isotherm Height Technique) prediction models. Overall the ITU rainfall rate and attenuation model gave a good prediction and the VIHT model was found not to be suitable for prediction at tropical and equatorial climates.

Bobadilla-Del-Villar and Cuevas-Ruiz conducted a research on rain attenuation and their results showed that the experiments made to obtain the rain attenuation in earth-space links can be related to developing rain attenuation geographical maps. In this study, rain attenuation values were obtained for the central territory of Mexico. The possibility to calculate the attenuation based on geographical position allows the attenuation to be obtained anywhere and at any frequency by changing the latitude and longitude [25].

Sreenivas et al. worked on signal attenuation for Ku band and came out with results from their measurements using Ku band frequencies of earth-space communication link [26]. An interface software (Tropical Rain Attenuation Prediction Using Data Simulations-TRAPUDS) was developed which was useful for predicting the propagation impairments using long term measurement data.

Maitra et al. studied propagation attenuation at Ku band over an earth-space path at Kolkata in India by recording the satellite signal strength along with the rain rate measurements [27]. The results showed that there was a very good correlation between the attenuation of the satellite signal and the rain rate recorded by the optical rain gauge. However, when the experimental data was compared with the ITU-R model, it was found that the ITU-R models underestimate the occurrences of rain attenuation at Kolkata.

Another research conducted by Velasco-Casillas et al. in Mexico resulted in automatically-generated rain attenuation maps using rain rate provided by Instant Data of meteorological stations [28]. The methodology exposed in the study provided a real rain-rate value using data obtained from the Automatic Meteorological Stations (AMS) . It provided instant rain-rate each 10 minutes and the data was used to generate attenuation maps using MATLAB. The principal advantage of using the measurements given by MNS (Meteorological National System) was that, the attenuation level obtained from the methodology changes according to the real rain rate. Results of the ITU rain attenuation and AMS rain attenuation were compared. This revealed that using data from the AMS, rain attenuation at different points was always superior to the values of rain attenuation using the ITU proceedings. Thus more accurate information was obtained compared to ITU-R's data.

Also in 2000, Nelson R. A. studied how rain affects the communication link. The study explored the physical mechanism of rain degradation and compared the relative effect in various frequency bands used for satellite communication in Washington DC [29].

This thesis seeks to conduct a similar study, with KNUST satellite laboratory in Kumasi as a case study for the Ku band downlink frequency and the results are compared with that obtained for Washington DC.

2.2 DETERMINATION OF RAIN ATTENUATION USING THE ITU-R RAIN MODEL RECOMMENDED FOR KU BAND.

Attenuation due to rain is a primary cause of communication impairment on satellite-earth paths; especially above 10 GHz. Rainfall is a serious source of attenuation at such a frequency. Since rain attenuation has long been recognized as the main source of atmospheric attenuation, major efforts have been made during the last three decades to characterize the statistical and dynamic aspects of rainfall rate and rain attenuation. Knowledge of the rain attenuation at such frequency range is desirable in the planning of a reliable communication system at any location [30].

2.2.1 ITU-R Rain Attenuation Model

The ITU-R rain attenuation model is the most widely accepted international method for the prediction of rain effects on communication systems. The model was first approved by the ITU in 1982 and is continuously updated, as rain attenuation modeling is better understood and additional information becomes available from global sources. The ITU-R model has since 1999, been based on the DAH rain attenuation model, named for its authors (Dissanayake, Allnutt and

Haidara) [33]. The DAH model has been shown to be the best in overall performance when compared with other models in validation studies [34,35].

This computation uses the ITU-R model as presented in the latest version of Recommendation ITU-R P.618, (2003) [36]. Other ITU-R reports referred to in the rain model procedure are ITU-R Recommendations P.837-4 [37], P.838-2 [38], P.839-3 [39] and P.678 [40].

The ITU-R states that the modeling procedure estimates annual statistics of path attenuation at a given location for frequencies up to 55 GHz.

The input parameters required for the ITU-R Rain model are

f : the frequency of operation, in GHz

θ : the elevation angle to the satellite, in degrees

φ : the latitude of the ground station, in degrees N or S.

τ : the polarization tilt angle with respect to the horizontal, in degrees

h_s : the altitude of the ground station above sea level, in km

$R_{0.01}$: point rainfall rate for the location of interest for 0.01% of an average year, in mm/h

The step-by-step procedure follows.

Step 1: Determine the rain height at the ground station of interest

Calculate the rain height, h_R, at the ground station of interest, from

$$h_R = h_o + 0.36 \text{ (km)} \quad (2.1)$$

where h_o is the average annual 0° C isotherm height. h_o is the upper atmosphere altitude at which rain is in the transition state between rain and ice. The rain height is defined in km above sea level.

If the average annual h_o for the ITU-R model cannot be determined from local data it may be estimated from a global contour map of representative values provided in ITU-R 839-3 [41], and reproduced here as Figure 2.1. The rain height for a specific location can be determined using bilinear interpolation on the values at the four closest grid points.

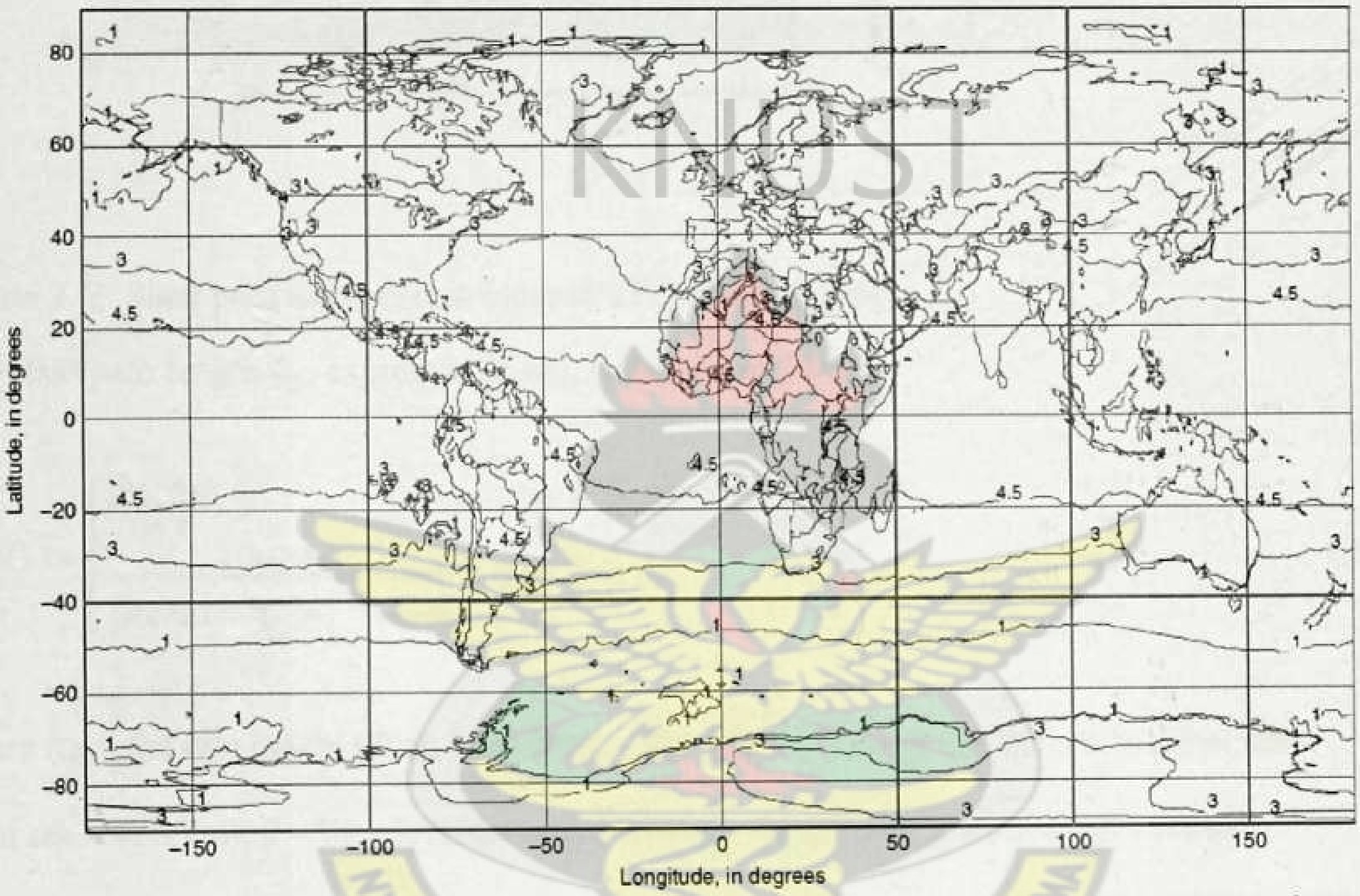

Figure 2. 1 Yearly average 0◦C isotherm height, ho, above mean sea level, in km (source: ITU-R P.839-3 [41])

Step 2: Calculate the slant-path length and horizontal projection

Calculate the slant-path length, L_S, and horizontal projection, L_G, from the rain height, and elevation angle and the altitude of the ground receiver site. Rain attenuation is directly proportional to the slant path length. The slant path length L_S is defined as the length of the satellite-to-ground path that is affected by a rain cell, as shown in Figure 2.2.

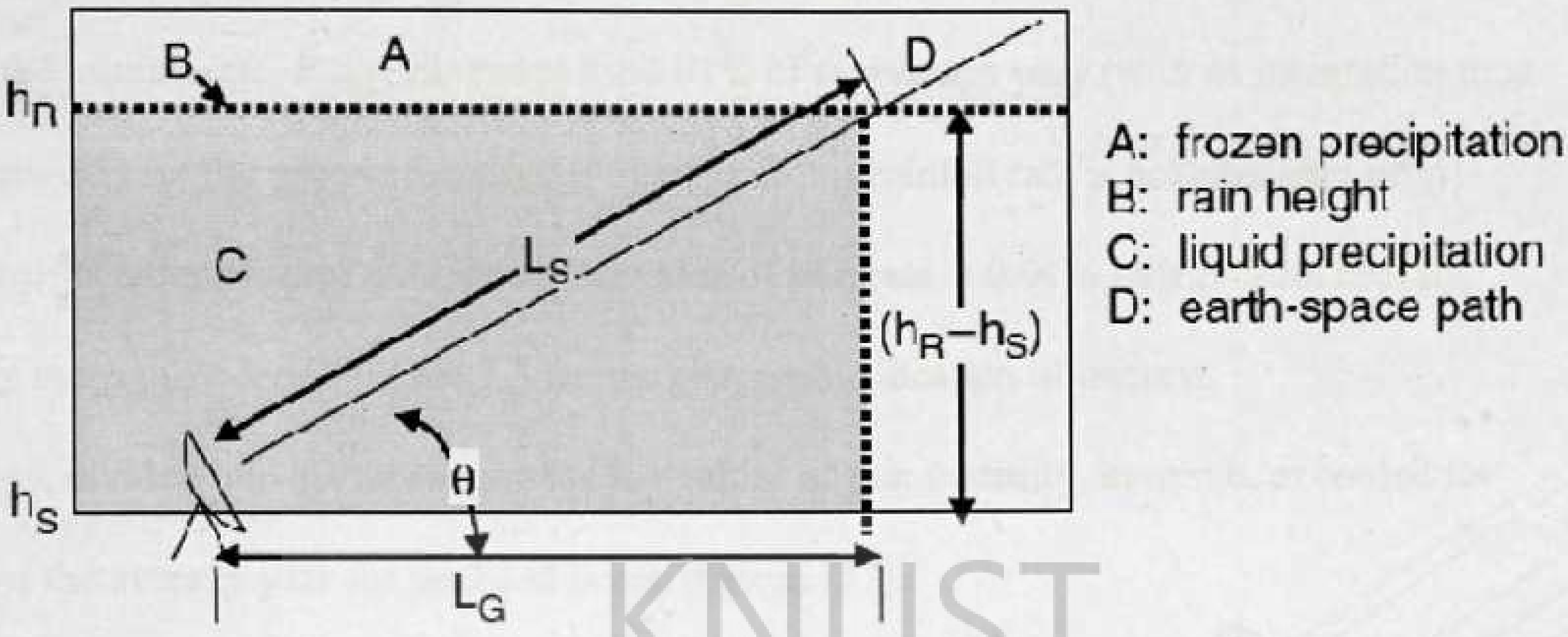

Figure 2. 2 Slant path through rain (source: ITU-R 618-8 [36])

The slant path length L_S, expressed in km, is determined from

$$L_S(\theta) = \begin{cases} \frac{(h_R-h_S)}{\sin\theta} & for\ \theta \geq 5^o \\ \frac{2(h_R-h_S)}{\left[\sin^2\theta+\frac{2(h_r-h_S)}{R_e}\right]^{1/2}+\sin\theta} & for\ \theta < 5^o \end{cases} \tag{2.2}$$

where h_R = the rain height (km), from Step 1; h_S = the altitude of the ground receiver site from sea level (km); θ = the elevation angle; and R_E = 8500 km (effective earth radius).

L_S can result in negative values when the rain height is smaller than the altitude of the ground receiver site. If a negative value occurs, L_S is set to zero.

The horizontal projection is calculated as

$$L_G = L_S \cos\theta \tag{2.3}$$

where L_S and L_G are in km.

Step 3: Determine the rain rate for 0.01% of an average year

Obtain the rainfall rate, $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of one minute) for the ground location of interest. If this rainfall rate is not available from long-term statistics of local data, select the value of rain rate at 0.01% outage from the rain intensity maps provided in Figure 2.3 for the geographic location of interest.

The maps, divided into six areas, provide iso-values of rain intensity, in mm/h, exceeded for 0.01% of the average year for land and ocean regions [37].

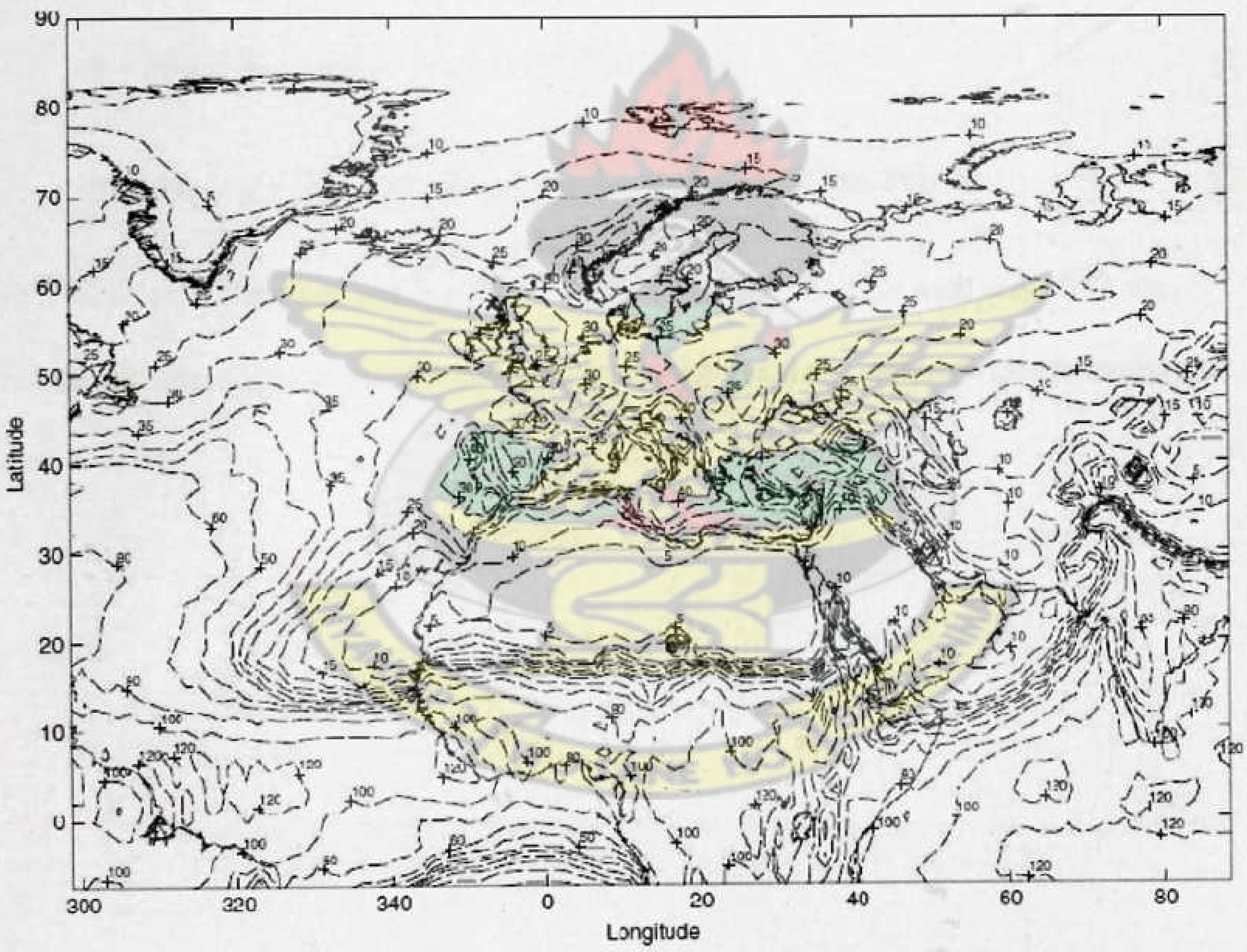

Figure 2. 3 Rain intensity exceeded for 0.01% of an average year: Area 2 (source: ITU-R P.837-4 [37])

Step 4: Calculate the specific attenuation

The specific attenuation is based on the following relationship:

$$\gamma_R = k\, R_{0.01}{}^{\propto} \qquad (2.4)$$

where γ_R is the specific attenuation in (dB/km). k and $\propto$ are dependent variables, each of which are functions of frequency, elevation angle and polarization tilt angle.

k and $\propto$ are calculated using regression coefficients k_H, k_V, $\propto_H$, and $\propto_V$, these values are provided in table 2.1, at the frequency of interest from the following:

$$k = [k_H + k_V + (k_H - k_V)\cos^2\theta\cos 2\tau\,]/2 \qquad (2.5)$$

$$\propto = [k_H \propto_H + k_V \propto_V + (k_H \propto_H - k_V \propto_V)\cos^2\theta\,\cos 2\tau]/2k \qquad (2.6)$$

where θ is the path elevation angle and τ is the polarization tilt angle with respect to the horizontal, for linear polarized transmissions. $\tau = 45°$ for circular polarization transmissions.

Table 2. 1 Regression coefficients for determination of specific attenuation (source: ITU-R P.838-3 [38])

Frequency (GHz)	k_H	k_V	α_H	α_V
1	0.0000259	0.0000308	0.9691	0.8592
2	0.0000847	0.0000998	1.0664	0.949
4	0.0001071	0.0002461	1.6009	1.2476
6	0.007056	0.0004878	1.59	1.5882
7	0.001915	0.001425	1.481	1.4745
8	0.004115	0.00345	1.3905	1.3797
10	0.01217	0.01129	1.2571	1.2156
12	0.02386	0.02455	1.1825	1.1216
15	0.04481	0.05008	1.1233	1.044

Step 5: Calculate the horizontal reduction factor

The horizontal reduction factor, $r_{0.01}$, is determined from the rain rate $R_{0.01}$ as follows:

$$r_{0.01} = \frac{1}{1+0.78\sqrt{\frac{L_G \gamma_R}{f}}-0.38\left(1-e^{-2L_G}\right)} \qquad (2.7)$$

where L_G is the horizontal projection calculated in Step 2.

Step 6: Calculate the vertical adjustment factor

The vertical adjustment factor, $v_{0.01}$, for 0.01% of the time is

$$v_{0.01} = \frac{1}{1+\sqrt{\sin\theta}\left[31\left(1-e^{-\left(\theta/_{1+\chi}\right)}\right)\frac{\sqrt{L_R \gamma_R}}{f^2}-0.45\right]} \qquad (2.8)$$

where

$$L_R = \begin{cases} \frac{L_G r_{0.01}}{\cos\theta} & km \;\; for\;\zeta > \theta \\ \frac{(h_R - h_S)}{\sin\theta} & km \;\; for\;\zeta \le \theta \end{cases} \quad (2.9)$$

and

$$\zeta = \tan^{-1}\left(\frac{h_R - h_S}{L_G r_{0.01}}\right) deg \quad (2.10)$$

$$x = 36 - |\varphi| \text{ deg} \qquad for\ |\varphi| < 36$$

$$= 0 \qquad for\ |\varphi| \ge 36 \quad (2.11)$$

Step 7: Determine the effective path length

The effective path length, L_E, is determined from

$$L_E = L_R\, v_{0.01} \qquad \text{km} \quad (2.12)$$

Step 8: Calculate the attenuation exceeded for 0.01% of an average year

The predicted attenuation exceeded for 0.01% of an average year, $A_{0.01}$, is determined from

$$A_{0.01} = \gamma_R\ L_E \qquad \text{dB} \quad (2.13)$$

The attenuation, Ap, exceeded for other percentages, p, of an average year, in the range

p = 0.001 to 5 %, can be determined from

$$A_P = A_{0.01}\left(\frac{p}{0.01}\right)^{-[0.655+0.033\ ln(p) - 0.045\ \ln(A_{0.01}) - \beta(1-p)\ \sin\theta]} \qquad \text{dB} \quad (2.14)$$

Where

$$\beta = \begin{cases} 0 & if\ p \geq 1\%\ or\ |\varphi| \geq 36^o \\ -0.005(|\varphi| - 36) & if\ p < 1\%\ and\ |\varphi| < 36^o\ and\ \theta \geq 25^o \\ -0.005(|\varphi| - 36) + 1.8 - 4.25 \sin\theta & otherwise \end{cases}$$

(2.15)

This method provides an estimate of long-term statistics due to rain. Large year-to-year variability in rainfall statistics can be expected when comparing the predicted results with measured statistics (see ITU-R P.678-1 [40]).

CHAPTER THREE

MATERIALS AND METHODS

3.1 EXPERIMENTAL SETUP

3.1.1 DSTV Installation

DSTV - Is a Digital Satellite Television company operated by MultiChoice Ghana Limited. A full installation comprising a dish, decoder and seven months subscription was acquired and installed. The decoder was a single view decoder with 20 channels.

3.1.2 Satellite Dish

A satellite dish is a type of parabolic antenna designed to receive microwave signals from communication satellites. The parabolic shape of a dish reflects the signal to the dish's focal point. Mounted on brackets at the dish's focal point is a device called a feedhorn. This feedhorn is essentially the front-end of a waveguide that gathers the signal at or near the focal point and 'conducts' them to a low-noise block down converter or LNB. Direct broadcast satellite dishes use a LNBF, which integrates the feedhorn with the LNB.

3.1.3 DSTV Decoder DSD 1131

Most pay satellite television operators such as DSTV encode their signals before transmission. Encoding is necessary to protect the digital contents from unauthorized access. A decoder is a device which performs the reverse functions of the encoder, undoing the encoding so that the original information can be retrieved. The same method used to encode is usually just reversed in order to decode. The features are:

1. Digital picture quality
2. Widescreen capability
3. Parental control
4. Integrated TV guide
5. Integrative capability
6. Extra view
7. Automatic software upgrades

and the specifications are:

1. Processor : ST5107
2. Conditional Access: Irdeto
3. Memory: 8+32 MB
4. PAL Video System
5. RF Channel 21-69 UHF Adjustable
6. 12V Power Supply Unit
7. RF Connectors: F-Type

3.1.4 Spectrum Analyzer - Rover Instruments "DL1 DIGILINE" Analyzer

A spectrum analyzer or spectral analyzer is a device used to examine the spectral composition of an electrical, acoustic or optical waveform. It may also measure the power spectrum. A spectrum analyzer is a laboratory instrument that displays signal amplitude (strength) as it varies with signal frequency. Two key parameters for spectrum analysis are frequency and span. The frequency specifies the center of the display. Span specifies the range between start and stop frequencies, the bandwidth of the analysis. Technical specifications are:

1. Frequency Band: 930-2250 MHz
2. Input Impedance: 75 ohm
3. Digital Power measurement range at RF input: 30 to 126 dBμV
4. QPSK Symbol Rate: 2.00/45 MS/s, 1 KS/s steps
5. Quality Test: Fail, Marginal, Pass
6. Digital SAT Standard selection: DVB/DSS

3.1.5 Splitter – TelSplit CAE – 102

This is a device used to split the incoming signal into two. One end is connected to the decoder and the decoder connected to the television. The other end is connected to the spectrum analyzer, its specifications are:

1. Two way Splitter
2. Frequency range : 5-2150 MHz

3.1.6 Television System – Hyundai 21" TV

This is a display unit which enables recording of signal strength and picture quality with specifications as follows:

1. Receiving System: BG,DK
2. Color System: PAL/SECAM/NTSC Playback
3. Picture tube: 54cm (21") diagonal
4. Ext. Antenna: 75-ohm coaxial cable
5. Power Consumption: AC 180-240V 50/60Hz, 80W
6. Net Weight: 22kg

3.2. MODE OF DATA COLLECTION

The Ku band satellite signal at 11.819 GHz was received to carry out propagation measurements over an earth-space path at KNUST satellite laboratory in Kumasi. The satellite signal was a digital TV broadcast signal (DSTV). A TelSplit CAE-102 splitter was used to split the incoming Ku band signal to the spectrum analyzer and the decoder which was then connected to a 21-inch Television. The average power reading of the signal was measured using a spectrum analyzer. The time of the day and weather condition were also observed and recorded. The corresponding signal strength and quality were recorded from the readings on the TV screen. This is illustrated in figure 3.1.

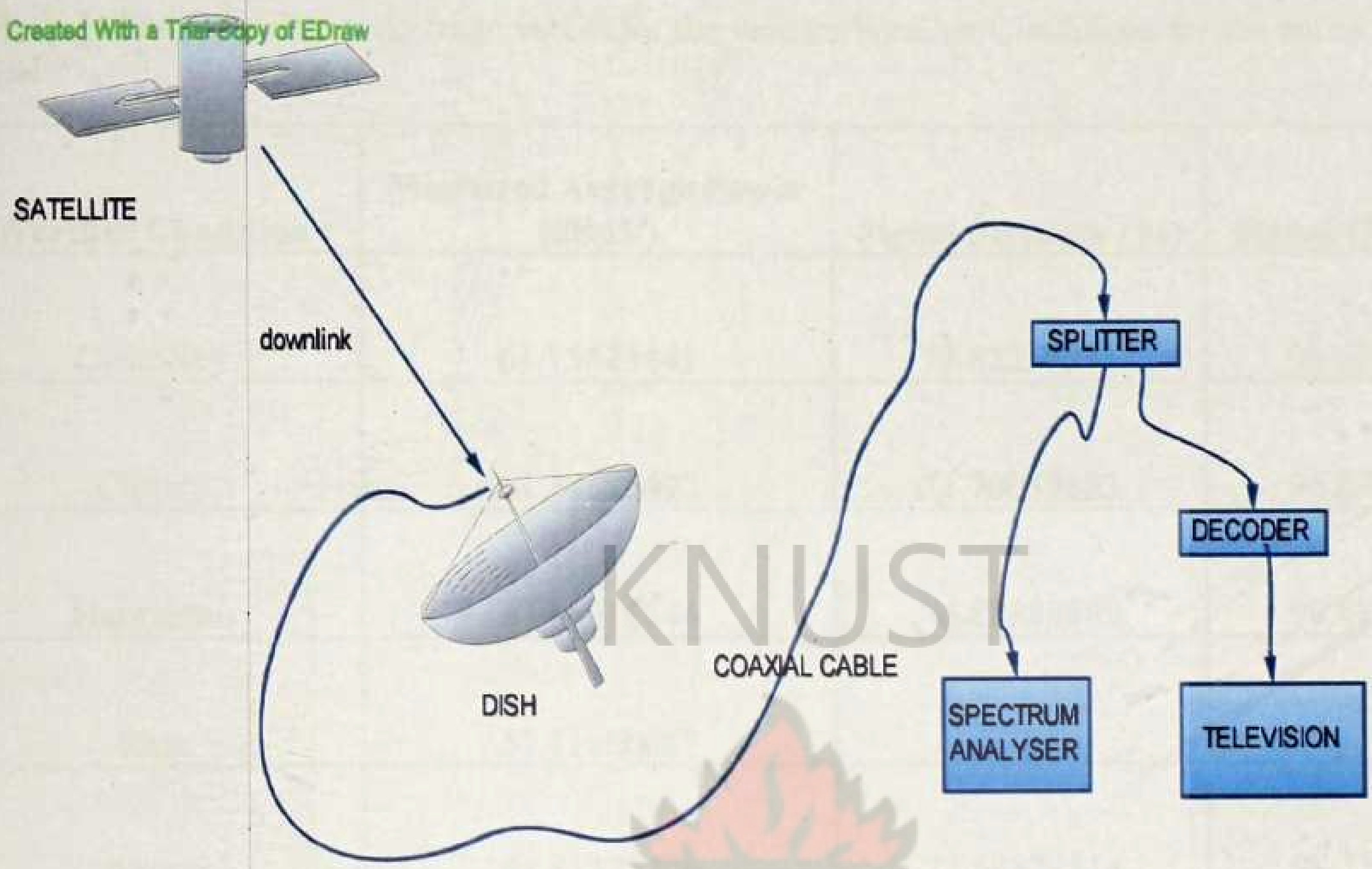

Figure 3. 1 Diagram of experimental setup

The duration of the experiment was 5 months. For each particular day the average readings were computed 9 times over an interval of 1 hour from morning to evening. The results of the cumulative average values for the various weather conditions are shown in Table 3.1. The values were obtained by finding the averages for the power, signal strength and signal quality for each weather condition from January to May 2010. See Appendix A for details.

Table 3. 1 The Cumulative Average values for the various Weather Conditions for the entire Period

Weather Condition	Measured Average Power (dBμV)	Signal Strength (%)	Signal Quality (%)
Clear Sky	61.75623441	72.82255291	98.52728647
Cloudy	61.78313492	71.70039683	96.82539683
Harmattan	67.06915344	76.88888889	99.88730159
Rain	57.11666667	0	0
Sunny	61.81572709	72.68874814	98.71394509

CHAPTER FOUR

DISCUSSION OF RESULTS AND ANALYSIS

4.1 DATA ANALYSIS

The average power level of the Ku-band satellite signal was continuously monitored at KNUST satellite laboratory in Kumasi. The variation in the received power as a result of signal attenuation was observed and measured at the receiver by using a spectrum analyzer. The signal strengths for the various weather conditions were also measured and recorded. The results are shown in Figures 4.1 and 4.2, respectively. Microsoft Excel and Minitab statistical software were used to analyze the data and the result discussed. The ITU-R Rain attenuation model was then used to determine the rain attenuation for KNUST Campus in Kumasi and the result compared with that of Washington DC. The data analyzed for this study pertain to the year 2010 and was recorded with a sampling interval of 1 hour over a 5 month period.

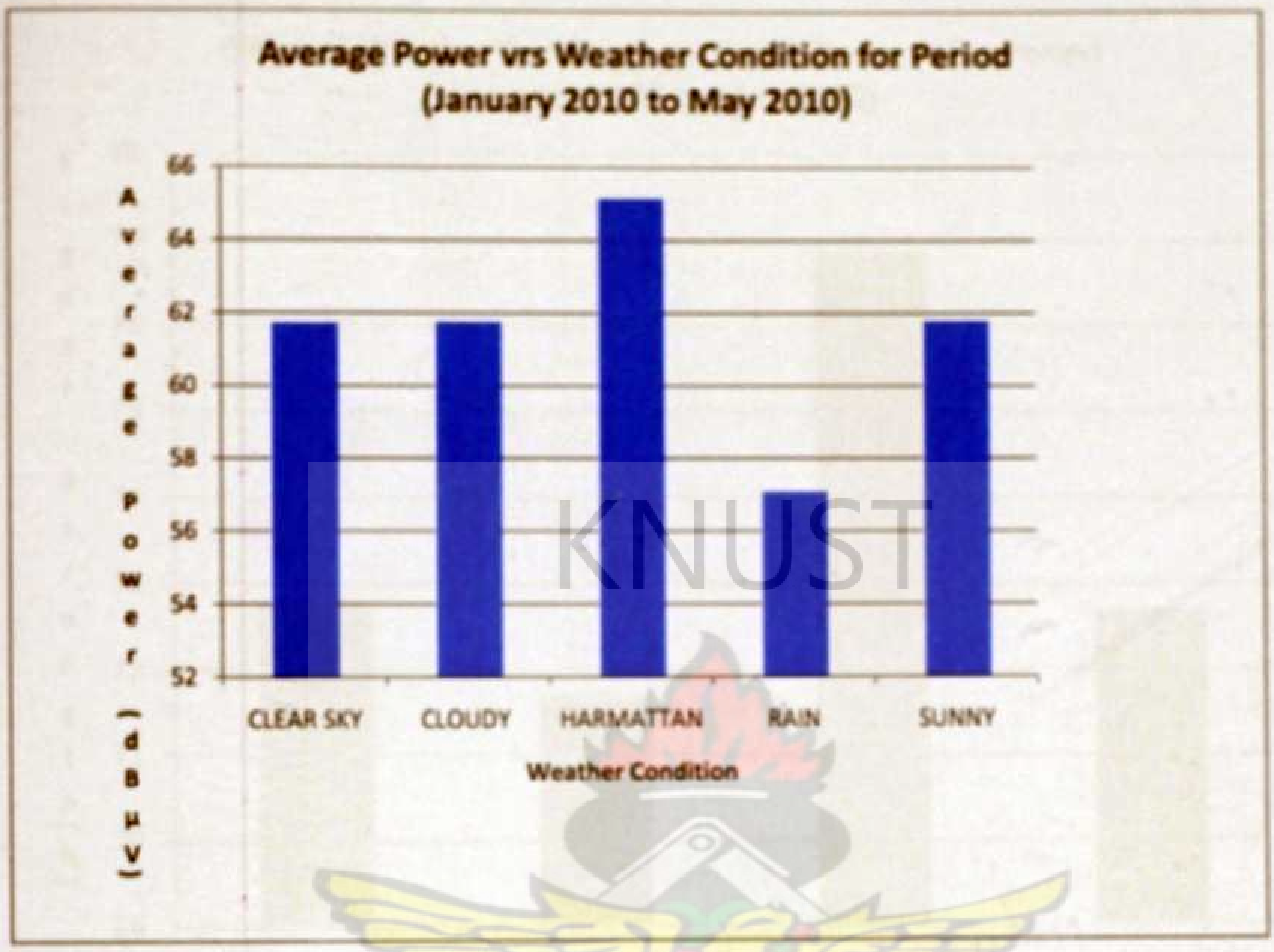

Figure 4. 1 Average power readings for the various weather conditions

For the entire period harmattan had the highest average power reading because of low levels of moisture content in the atmosphere during that period. Rainy season had the least average power reading due to the high amount of water molecules in the atmosphere which absorb the signal and leads to loss of signal power.

The fade threshold or the power level below which there is no signal at the decoder was observed to be **60.5 dBμV**. At this power level the signal strength is insufficient for the decoder to decode and hence an error message was displayed on the screen. There was no sun outages recorded.

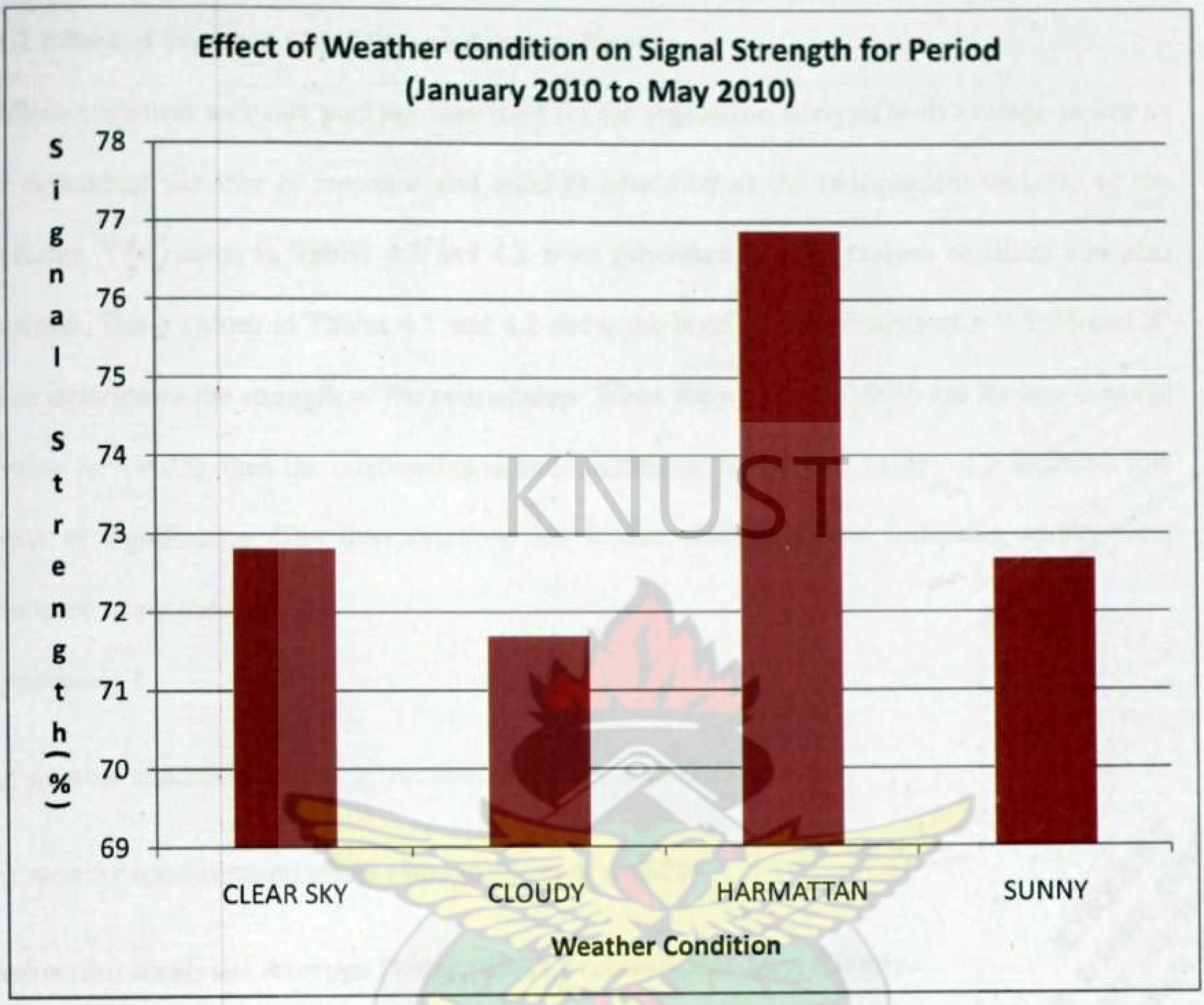

Figure 4. 2 Signal strength readings for the various weather conditions.

Again harmattan has the highest signal strength due to low humidity. Clear sky and sunny weather conditions are more conducive for Ku band signal propagation other than cloudy conditions. Cloudy weather conditions have the least signal strength since water molecules accumulate and impair the propagation of the signal. There are no signal strength readings for rain because the signal was lost through absorption by the rain.

4.1.1 Effect of Weather Condition on Average Power

Minitab statistical software package was used for the regression analysis with average power as the dependent variable or response and weather condition as the independent variable or the predictor. The results in Tables 4.1 and 4.2 were generated. The regression equation was also obtained. The p values in Tables 4.1 and 4.2 show the level of significance at $\alpha = 0.05$ and R^2 value determines the strength of the relationship. When the p values (0.000) are far less than the α value ($\alpha = 0.05$), then the relationship is very significant but greater values of p indicates low levels of significance. The interpretations are further discussed. The following results were generated using the software.

Hypothesis 1

H_0: weather conditions do not affect average power at α=0.05

H_1: weather conditions do affect average power at α=0.05

Regression Analysis: Average Power (dBμV) versus Clear Sky, Cloudy,...

Sunny is highly correlated with other X variables

Sunny has been removed from the equation.

The regression equation is

$$Average\ Power(dB\mu V) = 61.8 - 0.022 * Clear\ Sky - 0.083 * Cloudy + 5.23 * Harmattan - 4.07 * Rain \quad (4.1)$$

Table 4. 1 Regression Coefficients values

Predictor	Coef	SE Coef	T	P
Constant	61.7971	0.0872	708.67	0.000
Clear Sky	0.0225	0.1165	-0.19	0.847
Cloudy	-0.0832	0.1775	-0.47	0.640
Harmattan	5.2251	0.2026	25.79	0.000
Rain	-4.0733	0.2354	-17.31	0.000

$R^2 = 90.1\%$ R^2 *(adjusted)* $= 89.8\%$

Table 4.2 Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	385.819	96.455	288.29	0.000
Residual Error	126	42.157	0.335		
Total	130	427.976			

4.1.2 Effect of Average Power on Signal Strength

Minitab statistical software package was used for the regression analysis with Signal Strength as the dependent or response and Average Power as the independent or X variable or the predictor. The results in Tables 4.3 and 4.4 were generated. The regression equation was also obtained. The p values in Tables 4.3 and 4.4 show the level of significance at $\alpha = 0.05$ and R^2 value determines the strength of the relationship. When the p values (0.000) are far less than the α value (α = 0.05) then the relationship is very significant but greater values of p indicates low levels of significance. The interpretations are further discussed. The following results were generated using the software.

Hypothesis 2

H_0: Average Power does not affect Signal Strength at $\alpha = 0.05$

H_1: Average Power does affect Signal Strength at $\alpha = 0.05$

Regression Analysis: Signal Strength (%) versus Average Power (dBμV)

The regression equation is

$$Signal\ Strength\ (\%) = 23.5 + 0.796 * Average\ Power\ (dB\mu V) \quad (4.2)$$

Table 4. 3 Regression Coefficient values

Predictor	Coef	SE Coef	T	P
Constant	23.519	2.911	8.08	0.000
Average Power(dBμV)	0.79636	0.04679	17.02	0.000

$R^2 = 70.4\%$ R^2 *(adjusted)* = 70.1%

Table 4. 4 Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	168.37	168.37	289.65	0.000
Residual Error	122	70.92	0.58		
Total	123	239.29			

4.1.3 Effect of Weather Condition and Average Power on Signal Strength

Minitab statistical software package was used for the regression analysis with Signal Strength as the dependent or response and Weather Condition and Average Power as the independent or X variables or the Predictors. The results in Tables 4.5 and 4.6 were generated. The regression equation was also obtained. The *p* values in Tables 4.5 and 4.6 show the level of significance at $\alpha = 0.05$ and the R^2 value determines the strength of the relationship. When the *p* values (0.000) are far less than the α value ($\alpha = 0.05$) then the relationship is very significant but greater values of p indicates low levels of significance. The interpretations are further discussed. The following results were generated using the software.

Hypothesis 3

H_0: weather conditions and average power do not affect signal strength at $\alpha = 0.05$

H_1: weather conditions and average power do affect signal strength at $\alpha = 0.05$

Regression Analysis: Signal Strength (%) versus Clear Sky, Cloudy, ...

Rain has all values = 0

Rain has been removed from the equation.

Sunny is highly correlated with other X variables

Sunny has been removed from the equation

The regression equation is

$$Signal\ Strength(\%) = 37.9 + 0.221 * Clear\ Sky - 0.907 * Cloudy + 1.27 * Harmattan + 0.563 * Average\ Power\ (dB\mu V) \quad (4.3)$$

Table 4. 5 Regression Coefficient values

Predictor	Coef	SE Coef	T	P
Constant	37.95	12.09	3.14	0.002
Clear Sky	0.2212	0.1387	1.60	0.113
Cloudy	-0.9068	0.2117	-4.28	0.000
Harmattan	1.267	1.050	1.21	0.230
Average Power (dBμV)	0.5627	0.1956	2.88	0.005

$R^2 = 76.5\%$ $R^2\ (adj) = 75.7\%$

Table 4. 6 Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	182.961	45.74	96.62	0.000
Residual Error	119	56.332	0.473		
Total	123	239.293			

4.1.4 Determination of Rain Attenuation for Kumasi – Ghana

Majority of the studies on Earth-space propagation have been conducted in Europe, the United States and Asia. But it will be more crucial for studies to be conducted in a tropical location like Kumasi-Ghana because of its high rainfall intensity. In order to compute reliable rain attenuation for a given location, an appropriate distribution of rainfall rate for the site is required. Rainfall rate statistics specified on a percent of time basis, that is the percent of time in a year or a month that the rain rate equals or exceeds a specific value is used in the rain attenuation prediction model. The ITU rain attenuation prediction method is based on 0.01% of a year rain rate parameter. Data for the distribution must be based on long-term (typically more than 10 yrs) measured data with 1-minute integration time. But a large amount of rainfall data, typically collected by meteorological agencies in many countries is available for longer integration time such as 30 min., 60 min., etc. This is the case with Ghana, hence the need to rely on the data provided by ITU.

ITU-R Rain Attenuation Model

Step 1: Determining the rain height at KNUST satellite Laboratory in Kumasi

Recall from equation (2.1)

$h_R = 4.86\ km$

where $h_0 = 4.5$ from Fig. 2.1

Step 2: Calculating the slant-path length and horizontal projection

Recall from equation (2.2) and (2.3)

$L_S = 24.944\ km$

$L_G = 24.669\ km$

Step 3: Determining the rain rate for 0.01% of an average year

Recall from Fig. 2.3

$R_{0.01} = 100\ mm|\text{h}$

Step 4: Calculating the specific attenuation

Recall from equation (2.4)

$\gamma_R = 1.155 * 10^{10}$

Step 5: Calculating the horizontal reduction factor

Recall from equation (2.7)

$r_{0.01} = 8.289 * 10^{-6}$

Step 6: Calculating the vertical adjustment factor

Recall from equation (2.8)

$v_{0.01} = 0.02096$

where

$L_R = 2.06767\ * 10^{-4}\ km\ ,\ x = 29.3129\ and\ \zeta\ =\ 90^0$

Step 7: Determining the effective path length

Recall from equation (2.12)

$L_E = 4.3329 * 10^{-6}\ km$

Step 8: Calculating the attenuation exceeded for 0.01% of an average year

Recall from equation (2.13)

$A_{0.01} = 46.9927\ dB$

Recall from equation (2.14)

$A_{0.05} = 35.57199$ dB

$A_{0.10} = 28.97544$ dB

$A_{0.5} = 11.95062$ dB

$A_1 = 5.10540$ dB

$A_2 = 3.23601$ dB

$A_3 = 2.44839$ dB

Satellite Data

Name: 68.5E INTELSAT 10(IS-10) / INTELSAT 7 (IS-7), Distance: 40458 km , EIRP: 46.6 dBW

Dish Setup Data

Diameter: 90cm, Elevation: 11.26°, Azimuth (true): 92.4°, Azimuth (magn.): 96.8°

LNB Skew: -82.9° anti-clockwise, Efficiency of Aperture: 75%, Polarization: Linear,

LNB: Universal, Antenna Gain: 39 dBi

Earth Station Data

Latitude: 6.6871°, Longitude: -1.6220°, Altitude: 0.015 km, Maximum Rain Rate: 100 mm/h

Average annual 0°C isotherm height: 4.5

4.2 RESULTS AND DISCUSSION

4.2.1 Effect of Weather Condition on Average Power

Interpreting the results

The *p*-value in the Analysis of Variance table (0.000) show that the model estimated by the regression procedure is significant at an α -level of 0.05. This indicates that at least one coefficient is different from zero. The *p*-values for the estimated coefficients of Harmattan and Rain are both 0.000, indicating that they are significantly related to Average Power. The *p*-values for Clear Sky and Cloudy are 0.847 and 0.640 respectively, indicating that they are not significantly related to Average Power at an α -level of 0.05.

The R^2 value indicates that the predictors explain 90.1% of the variance in Average Power. The adjusted R^2 is 89.8%, which accounts for the number of predictors in the model. Both values indicate that the model fits the data well.

Interpreting the regression equation

From the regression equation;

For each 1% increase in Clear Sky weather, the percentage of Average Power is expected to decrease by 0.022%.

For each 1% increase in Cloudy weather, the percentage of Average Power is expected to decrease by 0.083%.

For each 1% increase in Harmattan weather, the percentage of Average Power is expected to increase by 5.23%.

For each 1% increase in Rain weather, the percentage of Average Power is expected to decrease by 4.07%.

4.2.2 Effect of Average Power on Signal Strength

Interpreting the results

From the equation, a change in Average Power will increase Signal Strength by 0.796% positively.

The *p*-value for the estimated coefficient of Average Power is 0.000, indicating that it is significantly related to Signal Strength.

The R^2 indicates that Average Power explains 70.4% of the total variation in Signal Strength.

The scatter plot diagram in Figure 4.3 shows the distribution of the data for the period. The data for the average power reading is concentrated between 61 (dBμV) and 63 (dBμV) and the corresponding signal strength for these values range between 71(%) and 74(%) respectively. Except some few high values.

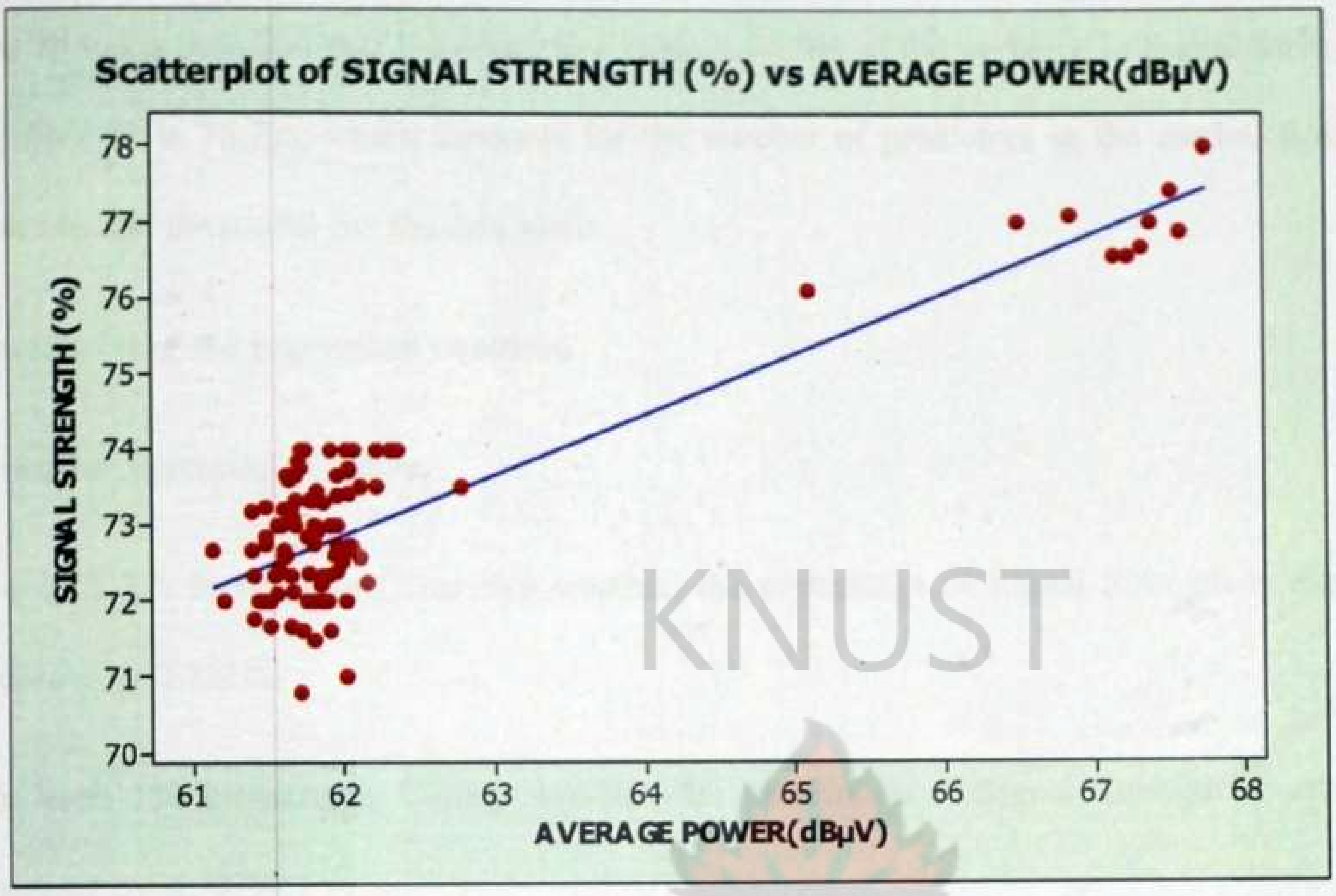

Figure 4. 3 Effect of Average Power on Signal Strength

The regression line shows that the model fits the data well.

4.2.3 Effect of Weather Condition and Average Power on Signal Strength

Interpreting the results

The *p*-value in the Analysis of Variance table (0.000) shows that the model estimated by the regression procedure is significant at an α -level of 0.05. This indicates that at least one coefficient is different from zero. The *p*-values for the estimated coefficients of Cloudy and Average Power are 0.000 and 0.005 respectively, indicating that they are significantly related to Signal Strength. The *p*-values for Clear Sky and Harmattan are 0.113 and 0.230 respectively, indicating that they are not significantly related to Signal Strength at an α -level of 0.05.

The R^2 value indicates that the predictors explain 76.5% of the variance in Signal Strength. The adjusted R^2 is 75.7%, which accounts for the number of predictors in the model. Both values indicate that the model fits the data well.

Interpreting the regression equation

From the regression equation;

For each 1% increase in Clear Sky weather, the percentage of Signal Strength is expected to increase by 0.221%.

For each 1% increase in Cloudy weather, the percentage of Signal Strength is expected to decrease by 0.907%.

For each 1% increase in Harmattan weather, the percentage of Signal Strength is expected to increase by 1.27%.

For each 1dBuV increase in Average Power, the percentage of Signal Strength is expected to increase by 0.563%.

Again the scatter plot diagram shows the distribution of the data for the period. This can be seen in Figure 4.4.The data for the average power readings are concentrated between 61 (dBμV) and 63 (dBμV). The corresponding signal strength at these values range between 71(%) and 74(%) respectively. Except few isolated higher values.

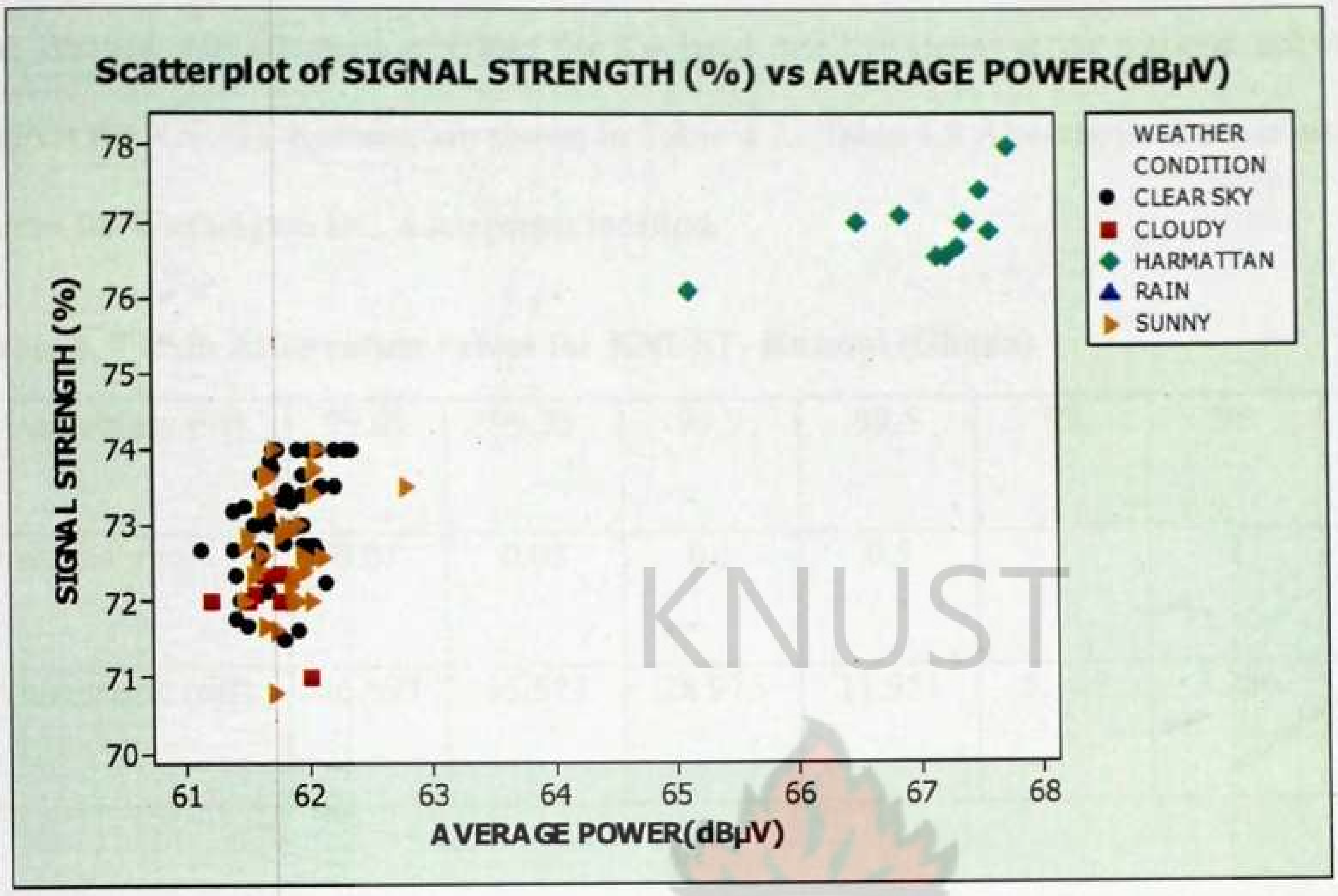

Figure 4. 4 Effect of Average Power and Weather Condition on Signal Strength

4.2.4 Effect of Rain

The most well known effect of rain is that it attenuates the signal. The attenuation is caused by the scattering and absorption of electromagnetic waves by drops of liquid water. The scattering diffuses the signal, while absorption involves the resonance of the waves with individual molecules of water. Absorption increases the molecular energy, corresponding to a slight increase in temperature and results in an equivalent loss of signal energy. Attenuation is negligible for snow or ice crystals in which the molecules are tightly bound and do not interact with the waves.

The derived rain attenuation values for Ku band satellite signal at the various unavailability periods for KNUST-Kumasi, are shown in Table 4.7. Table 4.8 Also shows the rain attenuation values for Washington DC, a temperate location.

Table 4. 7 Rain Attenuation values for KNUST- Kumasi (Ghana)

Availability (%)	99.99	99.95	99.9	99.5	99	98	97
Unavailability (%)	0.01	0.05	0.1	0.5	1	2	3
Attenuation (dB)	46.993	35.572	28.975	11.951	5.105	3.236	2.448

Table 4. 8 Rain Attenuation values for Washington DC (source: Robert A. Nelson," Rain. How It Affects the Communications Link", via satellite Magazine, May 2000)

Availability (%)	99.99	99.95	99.90	99.50	99.00	98.00	97.00
Unavailability (%)	0.01	0.05	0.10	0.50	1.00	2.00	3.00
Attenuation (dB)	10.5	4.5	2.9	0.8	0.4	0.2	0.1

Considering two geographically separate locations, Kumasi and Washington DC, it can be seen from Table 4.7 that the rain attenuation for an unavailability value of 0.01% is 46.993 dB for Kumasi. And the attenuation value for Washington DC for the same value of unavailability is 10.5 dB. This should be expected because Kumasi is in a tropical zone and Washington DC is in a temperate zone. Hence, Kumasi experiences more rainfall throughout the year with a maximum rain rate of 100 mm/h for 0.01% of an average year. Washington DC experiences less rainfall compared to Kumasi with a maximum rain rate of 47.1 mm/h for 0.01% of an average year.

From Tables 4.7 and 4.8 it is observed that the values for attenuation from 0.01% to 3% of an average year decreases for both locations which are normal. This is because the maximum rain rate decreases. The attenuation values range from 46.993 dB to 2.448 dB for Kumasi and 10.5 dB to 0.1 dB for Washington DC as shown in Tables 4.7 and 4.8 respectively.

In the design of any engineering system, it is impossible to guarantee performance under every conceivable condition. One sets reasonable limits based on the conditions that are expected to occur at a given level of probability. For example, a bridge is designed to withstand loads and stresses that are expected to occur in normal operation and to withstand the forces of wind and ground movement that are most likely to be encountered. But even the best bridge design cannot compensate for a tornado or an earthquake of unusual strength. Similarly, in the design of a satellite communications link one includes margin to compensate for the effects of rain at a given level of unavailability.

Kumasi with a probability of 0.01 % signal unavailability has an attenuation of 46.99 dB at a maximum rain rate of 100 mm/h. Thus if the total rain degradation for this rain rate is compensated by adding sufficient margin to the link budget, there will be a 99.99 % probability that the signal can be received with the specified system performance objective. That is, there is a probability of only 0.01% that the anticipated degradation will be exceeded. The rain attenuation for Washington DC at a maximum rain rate of 47.1 mm/h for 0.01% of an average year is 10.5 dB. This is a large but manageable contribution to the link budget compared to Kumasi with an attenuation of 46.99 dB for 0.01% of an average year. This will have a significant effect on the link budget requiring more power than in clear sky conditions. These losses simply cannot be accommodated and thus the availability would be much less which subsequently results in loss of signal.

From Figure 4.5 it is clear that rain attenuation is significant for tropical regions than temperate regions. The attenuation values for Kumasi are far greater than that of Washington DC for the various unavailability values.

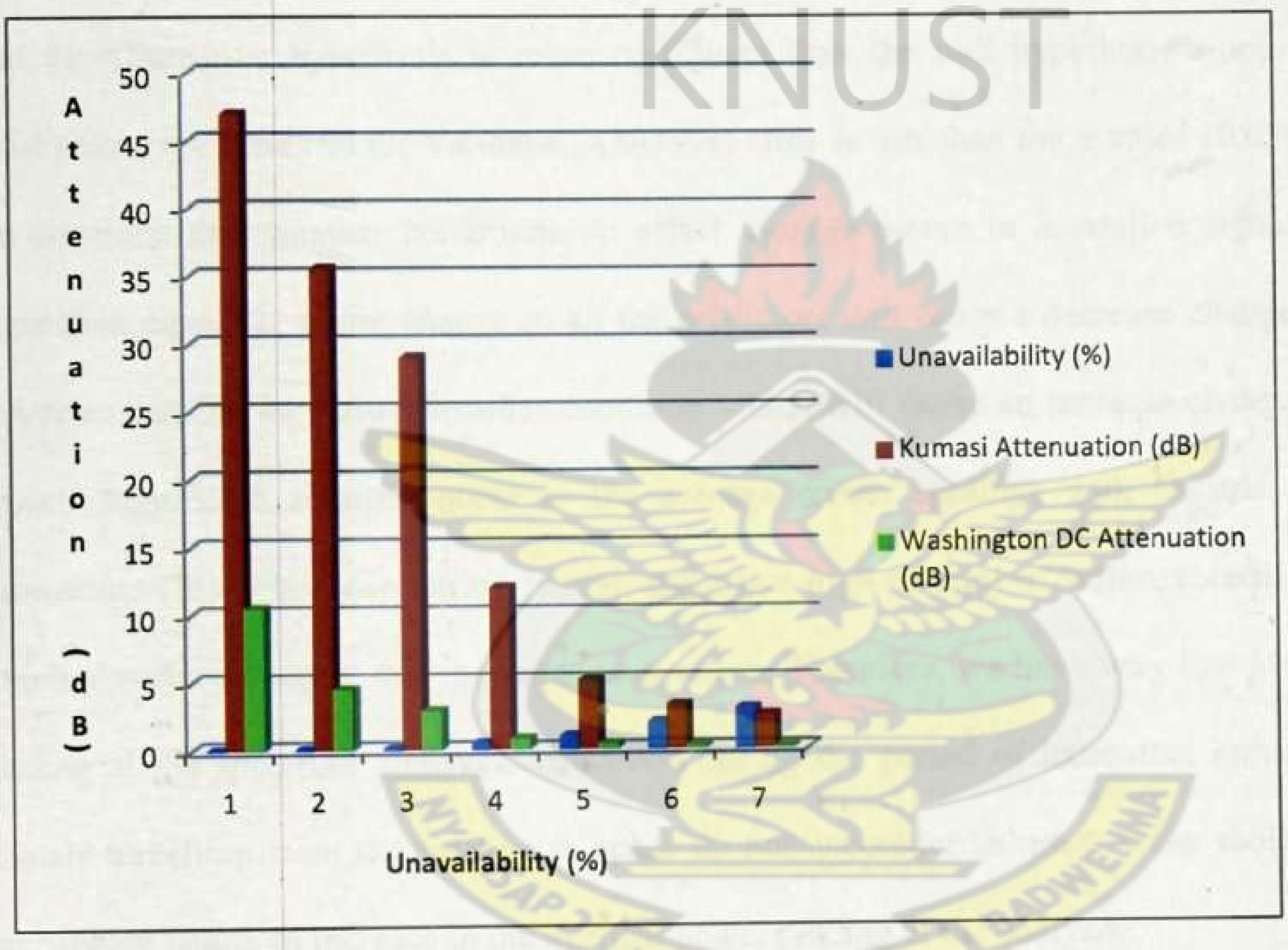

Figure 4. 5 A comparism of rain attenuation for Kumasi to rain attenuation for Washington DC

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

CONCLUSION

The results obtained from analyzing the effect of the weather condition on average power show that the alternative hypothesis is more significant than the null hypothesis since the *p*-value (0.00) from the Analysis Of Variance (ANOVA) table is less than the α value (0.05). Therefore we conclude that weather conditions do affect average power in a satellite signal. From the regression equation, a unit change in all the predictors will cause a decrease change in average power except the harmattan weather condition which will cause an increase change in average power. Significant changes occur in the average power readings with regards to rain and harmattan. This is because during rainfall there is a high amount of water molecules in the air which absorbs the signal and increases attenuation. Therefore, we have very low average power reading at the spectrum analyzer. However, during the period of harmattan humidity is low. Signals travelling from the satellite in space do not encounter so much water molecules in the atmosphere hence an increase in the average power reading at the analyzer.

When the effect of the average power on signal strength was also analyzed it was seen that the alternative hypothesis is superior since the *p*-value (0.00) from the ANOVA table is less than the α value (0.05). Therefore we conclude that average power do affect signal strength. This is because sufficient signal power is necessary for reliable data decoding at an acceptable error rate at the receiver. Therefore an increase in average power will ensure an increase in signal strength holding all other things constant. The scatter plot diagram indicates that during the entire period of the experiment the average power readings did not vary much with the signal strength. And most of the data were within a specific range.

Furthermore the results obtained from analyzing the effect of weather condition and average power on signal strength indicates the null hypothesis is not significant since the *p*-value (0.00) from the ANOVA table is less than the α value (0.05). Therefore we conclude that weather conditions and average power do affect signal strength. From the regression equation, a unit change in all the predictors will cause an increase in signal strength except cloudy weather condition which will cause a decrease in signal strength. Clear sky and harmattan weather conditions cause an increase in signal strength. Also an increase in average power does not negatively affect the signal strength. From the study it can be seen that most of the data for the experiment was collected during clear sky and sunny weather conditions. This is true because in the tropical region these weather conditions exist for most part of the time. Harmattan recorded the most significant reading for both the average power and signal strength.

The study also shows that rain attenuation is significant for tropical regions than temperate regions. The attenuation values for Kumasi are far higher than that of Washington DC for the various unavailability values. Due to the geographical location of Kumasi it experiences more rainfall throughout the year than Washington DC. Also, whenever it rains the intensity is higher with larger rain drop size than Washington DC. This study should provide sufficient information to system designers for the design of satellite systems for tropical regions like Ghana. Since Ghana is a developing country and we may launch a satellite system in the near future, these results should be considered. From the study it shows that in the design of a satellite communication link for Ku band in Kumasi-Ghana more power margin should be included to compensate for the effect of rain. This will be far greater than that allocated for Washington DC.

RECOMMENDATION

Rainfall data for tropical locations such as Ghana are unavailable. Especially the type of data needed for the computation of rain attenuation as recommended by the ITU. The purchase of a tipping bucket rain gauge with a 1 minute integration time for the satellite laboratory at KNUST will go a long way to help the collection of data for this purpose. This can be replicated in other rainfall areas across the country so that a reliable rainfall attenuation data for Ghana can be compiled. The data can be used to generate rain attenuation maps across the country.

Since rainfall is the predominant factor that affects the propagation of Ku band satellite signal, the following mitigation techniques will go a long way to improve on the signal reception at the receiver. First of all, fade levels may be constantly monitored at each ground terminal, and if a predetermined fade threshold is exceeded, then the master control station is informed, at which time corrective action is taken. Secondly, rain fade can also be compensated by using forward error correction coding on either the uplink or the downlink depending on where the fade is experienced. In addition, the affected terminal or satellite may reduce the burst rate. Also, when fading occurs, the master control station instructs the affected terminal and the satellite to increase their transmission power or change the encoding rate to maintain an acceptable bit error rate on the attenuated signal. Site diversity can also be employed. It involves the construction of two ground stations separated by a distance of 8 to 15 km, each monitoring the satellite. The purpose of this redundancy is that if one path is impaired by rain, it is possible that the other path will be less severely affected. A 50% reduction in rain attenuation can be achieved if site diversity is used.

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APPENDIX A

Table A. 1 The Average Data Collected for the Entire Period

(January 2010 to May 2010)

MONTH	WEATHER CONDITION	AVERAGE POWER(dBμV)	SIGNAL STRENGTH (%)	SIGNAL QUALITY (%)
JAN	CLEAR SKY	61.73326389	73.16805556	99.92222222
	HARMATTAN	66.83460317	77.11111111	99.77460317
	SUNNY	61.975	72.5	100
FEB	CLEAR SKY	61.80880952	73.44047619	98.30357143
	CLOUDY	61.8	72	94.5
	SUNNY	61.81192308	72.91355311	97.53076923
MAR	CLEAR SKY	61.94833617	72.73809524	97.79455782
	CLOUDY SKY	62	71	99
	HARMATTAN	67.3037037	76.66666667	100
	RAIN	55.7	*	*
	SUNNY	61.92634199	72.59891775	99.27922078
APR	CLEAR SKY	61.81833333	72.96666667	99.83809524
	CLOUDY SKY	62	71	99
	SUNNY	61.75333333	72.84	99.72666667
MAY	CLEAR SKY	61.58710317	72.56150794	97.86507937
	CLOUDY SKY	61.54940476	72.10119048	96.97619048
	RAIN	58.53333333	*	*
	SUNNY	61.61203704	72.59126984	97.03306878

APPENDIX B

B.1 SIGNAL POWER CALCULATION

B.1.1 Antenna Gain

$$G = 10\log(109.66\, f^2\, d^2\, \eta_A) \quad \text{, dBi} \qquad \text{(B.1)}$$

where

f = frequency of interest

η_A = efficiency of antenna (%)

d = diameter of antenna (m)

B.1.2 Equivalent Isotropic Radiated Power (EIRP)

The Equivalent Isotropic Radiated Power is the effective radiated power from the transmitting side, and it is the product of the antenna and the transmitting power, expressed as

$$EIRP = P_t + G_t \quad , dB \qquad \text{(B.2)}$$

where,

G_t is Transmitter Gain

P_t is Transmitter Power

B.1.3 Signal Power (Pr)

$$P_r = EIRP + G_r - L_{FS}\ ,\ dB \qquad (B.3)$$

Where,

G_r = Receiver gain

$$L_{FS}\ (Free\ Space\ Loss) = 20\log_{10}(f) + 20\log_{10}(r) + 32.44 \qquad (B.4)$$

r is the range (m)

f is frequency (GHz)

B.2 NOISE CALCULATION

B.2.1 Thermal Noise

Is the noise of a system generated by the random movement of electrons, expressed as

$$Noise\ Power = KTB \qquad (B.5)$$

where,

K = (-228.6 dBJ/K)

T = Equivalent Noise Temperature (K)

B = Noise Bandwidth of a receiver

B.2.2 Effective Temperature

$$T_e = T1 + (T2/G1) \qquad (B.6)$$

Where,

T1 = Temperature of LNA

T2 = Temperature of D/C

G1 = Gain of LNA

B.2.3 Noise Temperature

$T_s = T_{ant} / Lf + (1 - 1/L_f)\ T_f$ (B.7)

Where,

T_{ant} = Temperature of antenna

L_f = Feed Losses

T_f = Feed Temperature

B.2.4 System Temperature

$T_{sys} = T_s + T_e$ (B.8)

Being a first stage in the receiving chain, LNA is the major factor for the system temperature calculation. The lower the noise figures of LNA, the lower the system temperature. Antenna temperature depends on the elevation angle from the earth station to the satellite.

B.2.5 G/T (Gain to System Noise Temperature)

This is the figure of merit of any receiving system. It is the ratio gain of the system and system noise temperature.

$G/T = G - 10\ log\ (T_{sys})$ [dB/K] (B.9)

B.3 LINK ANALYSIS

C/N Uplink

$$(C/N)_u = (EIRP)_u - (\text{Path Loss})_u + (G/T)_{sat} - K - \text{Noise BW} \quad [dB] \qquad (B.10)$$

C/N Downlink

$$(C/N)_d = (EIRP)_{sat} - (\text{Path Loss})_d + (G/T)_d - K - \text{Noise BW} \quad [dB] \qquad (B.11)$$

C/N Total

$$(C/N)_T^{-1} = (C/N)_u^{-1} + (C/N)_d^{-1} + (C/I)_{IM}^{-1} + (C/I)_{adj}^{-1} + (C/I)_{xp}^{-1} \quad [dB] \qquad (B.12)$$

B.4 CARRIER PARAMETERS

B.4.1 Eb/No (Energy bit per Noise Power Density)

This is the performance criterion for any desire Bit Error Rate (BER). It is the measure at the input to the receiver. It is used as the basic measure of how strong the signal is. It is directly related to the amount of power transmitted from the uplink station.

$$Eb/No = (C/N)_T + \text{Noise BW} - \text{Information Rate} \qquad (B.13)$$

B.4.2 Bit Error Rate (BER)

It is used to represent the amount of errors occurring in a transmission. It expresses the link quality. It is an equipment characteristic which directly relates to Eb/No. BER improves as the Eb/No gets larger.

$$P = ½ e^{-Eb/No} \text{ (with P = Probability of error)} \qquad (B.14)$$

B.5 POWER RECEIVED AT EARTH STATION

Recall equation (1.1)

Converting from field strength at the receiver (dBμV) to Received power (dB)

we have

$$P_r\,(dBm) = E\,(dB\mu V\,|m) - 20\log f\;(MHz) - 77.2 \qquad \text{(B.15)}$$