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Link Budget Analysis and Architecture of a Proposed VSAT Based E-Learning System for ARCSSTE-E

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Abstract. E-Learning is a derivative of information technology and has been generally recognized as a modern tool for learning and teaching other than the conventional method of learning (which involves physical contact between the student and the instructor). The case study for the proposed system is the African Regional Centre for Space Science and Technology Education in English (ARCSSTE-E) in Nigeria. The purpose of the centre is to develop quality indigenous space scientists in English speaking African countries for the development of various application of space science and technology for sustainable national and regional development. Therefore, to accomplish this, the centre plans to develop the skills and knowledge of candidates in four significant areas of space science and technology such as; Remote Sensing & GIS, Satellite Meteorology and Global Climate, Satellite Communication and Basic Space and Atmospheric Sciences. This paper presents the VSAT architecture, link margin calculations and link budget analysis done to implement the proposed VSAT based E-learning system for the Centre. This is a conceptual frame work. The proposed system is to enhance the centre with tremendous potential to reach out to people within Anglophone countries that cannot make it down to ARCSSTE-E due to lack of sponsorship, constraint in time, distance, Financial or other challenges.

Keywords: Link budget, Propagation losses, electromagnetic waves, VSAT technology, e-Learning, ARCSSTE-E.

1. INTRODUCTION

In satellite communications, microwaves, radio waves, infrared and visible light are used to carry information or data such as text, sound, pictures and videos [1-2]. The information is called the signal. The electromagnetic waves also known as the carrier waves that transmit the signal from the transponder to the receiver. The signals are of two types; the analogue and the digital. The analogue signal is being encoded to digital signal (0s and 1s streams) which is sent to the carrier wave and then transmitted. When the transmitted signal has been received it is decoded to analogue to recover the original signal. This phenomenon is applicable to the proposed VSAT based e-Learning system. The speedy expansion of ICTs in Nigeria offers an opportunity to contemplate its use in the promotion of Distance Education. E-learning, is a modern tool that emerged from information technology and has been integrated in several universities education programs, shifting from conventional way of education to electronic medium. [3], defined E-learning as an innovative method for providing electronically mediated, well-designed and interactive learning environments to anyone, anyplace, anytime by utilizing the internet and digital technologies along with instructional principles.

ARCSSTE-E is an institution established in Nigeria 24th November, 1998 and it is allied to United Nation (UN) Office for Outer Space Affairs (OOSA).

The major aim of the center is to build critical mass and a high quality capacity of indigenous space scientists in Anglophone countries for the development of various Space Science and Technology applications for sustainable national and regional development .Hence, the Centre plans to accomplish this by developing skills and knowledge in four crucial areas of space science technology which are; Satellite Communication, Satellite Meteorology & Global Climate, Remote Sensing / GIS and Basic Space and Atmospheric Sciences.

Hitherto, Arcsste-e has graduated Four Hundred and Twenty One (421) students in Post Graduate program in the above-mentioned areas of discipline since its establishment. (Arcsste-e Postgraduate Unit, 2016). According to Arcsste-e statistics, the number of participants from other African countries even up to the current year (2019) is very low when compared to the number of participants in the host country (Nigeria). Thus, to achieve the Centre's goal, the Centre will need to employ a VSAT based e-Learning system to reach out and develop the skills and knowledge of candidates within Anglophone African countries that cannot make it to ARCSSTE-E due to several reasons.

The aim of this study is to design a conceptual framework of a VSAT based e-learning system for ARCSSTE-E in Nigeria. The following are theobjectives of this study; to determine the antenna size of the VSAT, the link margin, estimate the link budget analysis and model the VSAT link-architecture that will be used to implement the proposed system.

2.   THEORETICAL BACKGROUND

This segment gives a review of the research study that had been done in the aspect of VSAT technology, radio wave propagation and link budget analysis.

Link margin for wireless radio communication link research work was carried out by [4]. In the article, the methodicalassessment of the link budget analysis for the terrestrial communication and satellite was presented and several equations for link budget calculation and a comparative table at different frequency bands are shown.

Satellite Link Design: A Tutorial. The journal was presented by [5]. This paper explains the rudiments of a satellite radio link design in a tutorial form with mathematical examples.

Development of a VSAT Based Virtual E-Learning System (ARCSSTE-E as a Case study) project work was carried out by [6]. The study presented the design phase for the virtual classroom application developed in Visual Studio 6.0 environment using VISUAL BASIC 6.0 Programming Language (Enterprise Edition). Also, the TDMA calculation was done for each station using the VSAT based virtual e-learning platform.

Radio-wave propagation basics. The article was written by [7]. In the study, the author elaborated on the operation of wireless local area networks. All these journals were reviewed to guide the present study.

2.1   OVERVIEW OF VSAT TECHNOLOGY

VSAT is a satellite communications system that serves bothhome-based and corporate users. VSAT simply means Very Small Aperture Terminal. A VSAToperator needs a box that interfaces between the user's computer and an outside antenna dish with a transceiver. The transceiver receives or sends a signal to a satellite transponder in the sky. The satellite transmits and receives signals from an earth station computer that acts as a hub for the system. Each end user is connected with the hub station via the satellite in a star architecture form [8]. For two end users in different locations to communicate with each other, the transmission of one end user has to first go through the hub station which is also known as the master control station of the VSAT system. The hub station will therefore, re-transmits the signals via the satellite to the other end user's VSAT. VSAT handles data, audio, and video signals.

2.1.1   *Motivation to use VSAT*

1) VSAT is very reliable; it can transmit data between an unlimited numbers of geographically dispersed sites [8].
2) Fast Deployment: it can be deployed within 2weeks compared to optical fiber which takes up to 4- 6 months and hard to reach remote areas.
3) VSAT is very flexible. It has expansion capabilities, unrestricted and unlimited reach.
4) VSAT solution is more cost-effective as compared to the optical fiber if distance is more than 500 km.
5) VSAT networks provide multipoint- to-point, point-to-multipoint (broadcast), point-to-point communications and broadband multimedia services [8].

2.1.2   *VSAT satellite network configurations*

The fundamental parts of a VSAT configuration are the outdoor units and indoor units. The antenna, up or down converters and amplifiers are outdoor units and other remaining parts are indoor unit including modem. The downlink receiving VSAT earth station consists of four major parts; VSAT antenna, filters, low noise amplifier and downconverter and as shown in Figure 1. In the basic block diagram illustration of a VSAT receiving earth-station, the signal from satellite transponder through the terrestrial network is received with the VSAT prime focus antenna and it is converted to downlink frequency by low noise amplifier and downconverter [9]. Finally, it is demodulated by demodulator and the baseband signal is out to the remaining parts of VSAT unit. According to the international telecommunication frequency standard, the precise application and link design must be optimized. The losses needs to be taken into account when passing through the space network and rain effects. For that reason, band selection is very important for the particular application and designing of antenna. In this work, C band is chosen because rain attenuation and atmosphere noise is reduced at 4 GHz downlink frequency of C band to build a VSAT receiving antenna system [9].
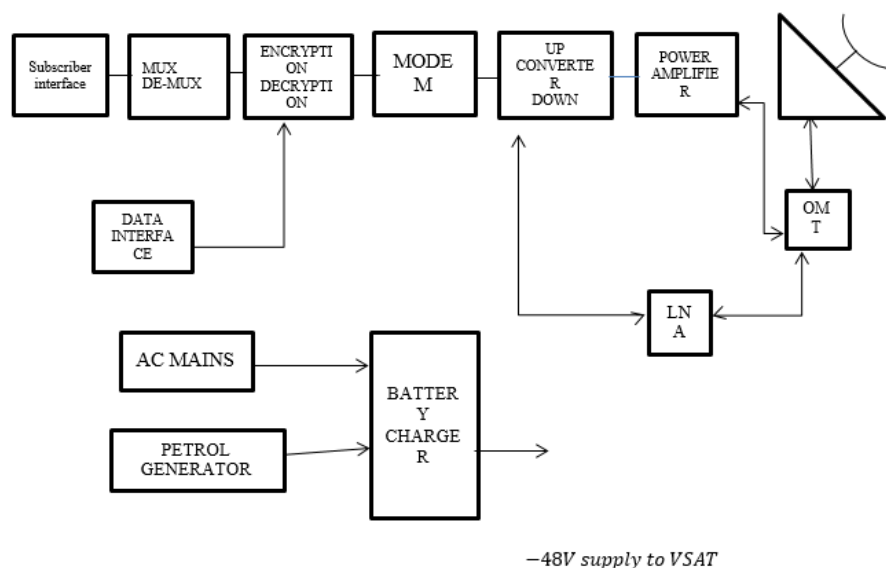

−48V supply to VSAT

Figure 1: Following diagram describes typical schematic VSAT subsystems.
http://www.rfwirelessworld.com/Articles/VSAT_system_overview.html

3.   DESIGN CALCULATION AND METHODOLOGY
This section shows the procedures used to analyze the antenna dish size, the link budget, the link margin, and the VSAT architecture for the proposed VSAT based e-Learning system for ARCSSTEE.

3.1 Link Margin Calculation and the Link Budget Analysis
Link budget analysis and the link margin were calculated for both uplink & downlink using NIGCOMSAT 1R C band parameters [11-12].

NIGCOMSAT 1R – C band transponder (In clear air)

C-Bandwidth $= 36\ MHz$

Power transmitted (Output power) $P_t\ = 20W$

Gain of transponder (Antenna Gain) $G_t\ = 20dB$

Receiving earth station (Antenna Gain) $G_r\ = 49.7dB$

Earth station distance to satellite, $R\ = 39,000km = 3.9\ \times 10^7 km$

Power received $P_r\ = \dfrac{P_t \times G_t \times G_r}{(4\pi R/\lambda)^2}$

Path Loss $\quad L_P\ = \left(\dfrac{\lambda}{4\pi R}\right)^2$

Wavelength $\lambda\ = \dfrac{c}{F}$

Receiver Noise Power (N) $= KT_s B_n$ ($in\ decibel\ = k\ + T_s\ + B_n$)

Boltzmann's constant $K= -228.6dB/K/Hz$

System noise temperature, $T_s\ = 75$ K = 18.8 dBK

Noise bandwidth, B_n =27 MHz = 74.3 dBHz

Carrier to Noise ratio $C/N\ = P_r\ - N$

I.   *C- BandAntenna dish size for the receiving earth station is calculated using the formula;*

$$G_r\ = \frac{4\pi A}{\lambda^2}(1)$$

$$A\ = \frac{G_r\ \times \lambda^2}{4\pi}$$

In Decibel; $A\ = G_r + 10\log(\lambda)^2\ - 10\log(4\pi)(2)$

$$A\ = 49.7dB\ + 10\log(0.05)^2\ - 10\log(4 \times 3.142)$$

$$A = 49.7dB\ + (-26.02dB)\ - 10.99dB$$

$$A\ = 12.689dBm^2$$

Convert to m²; $A\ = 10^{\left(\frac{12.689}{10}\right)}\ = 18m^2$

$$A = 2\pi r^2$$

$$18m^2 = 2 \times 3.142 \times r^2$$

$$r^2 = \frac{18m^2}{2 \times 3.142}$$

$$r = \sqrt{2.8644} = 1.692$$

Diameter; $D = 2r$

$$D = 2 \times 1.692 = 3.4m$$

Therefore, Antenna dish size $= 3.4m$

II. *Calculation for the Uplink Antenna for C-band;*

Uplink frequency = 6 GHz

$$\text{Wavelength } \lambda = \frac{c}{F} = \frac{Speed\ of\ light}{frequency} \quad (3)$$

$$\lambda = \frac{3 \times 10^8 ms^{-2}}{6 \times 10^9\ Hz} = 0.05\text{m}$$

$$\text{Path Loss} \quad L_P = \left(\frac{\lambda}{4\pi R}\right)^2 (4)$$

$$= \left(\frac{0.05}{4 \times 3.142 \times 3.9 \times 10^7}\right)^2$$

$$= 1.04 \times 10^{-20}$$

$$P_r = [P_t \times G_t \times G_r] - L_p \ (5)$$

$$\frac{P_r + L_p}{G_t G_r} = \frac{P_t G_t G_r}{G_t G_r}$$

$$\text{Therefore;} \quad P_t = \frac{P_r + L_p}{G_t G_r}(6)$$

$$P_t = [P_r + L_p] - [G_t + G_r](7)$$

$$P_t = [13.01dB - 10log(1.04 \times 10^{-20})] - [20dB + 49.7dB]$$

$$|P_t| = 256.52dbW$$

Received power at earth station; $P_{r1} = \frac{P_t \times G_t \times G_r}{\left(\frac{4\pi R}{\lambda}\right)^2}(8)$

$$P_{r1} = P_t + G_t + G_r - L_p$$

$$= 256.52dB + 20dB + 49.7dB - 10log(1.04 \times 10^{-20})dB$$

$$= 13.01 + 20 + 49.7 - 199.83$$

$$P_{r1} = -117.1dB$$

III. *Calculation for the Downlink Antenna for C-band;*

Downlink frequency = 4 GHz

Recall equation (12) & (13)

Wavelength; $\lambda = \frac{c}{F} = \frac{speed\ of\ light}{frequency}$

$$\lambda = \frac{3 \times 10^8\ ms^{-2}}{4 \times 10^9 Hz}$$

$$= 0.075m$$

$$Path\ Loss\ Lp = \left(\frac{\lambda}{4\pi R}\right)^2$$

$$= \left(\frac{0.075}{4 \times 3.142 \times 3.9 \times 10^7}\right)^2$$

$$= 2.34 \times 10^{-20}$$

Received power at earth station; $P_{r2} = \frac{P_t \times G_t \times G_r}{\left(\frac{4\pi R}{\lambda}\right)^2}$ (9)

$$P_{r2} = P_t + G_t + G_r - L_p (10)$$

$$= 10log20dB + 20dB + 49.7dB - 10log(2.34 \times 10^{-20})dB$$

$$= 13.01 + 20 + 49.7 - 196.31$$

$$P_{r2} = -113.6dB$$

Receiver Noise Power N; $(N) = K + T_s + B_n (11)$

$$= -228.6 + 18.8 + 74.3$$

$$= -135.5dBW$$

Carrier to Noise ratio; $\frac{C}{N} = P_r - N (12)$

$$= -113.6dB - (-135.5dBW)$$

$$= 21.9$$

IV. *Calculation for the Link Margin;* $L_m = |P_{r2}| - |P_{r1}|$ (13)

$$= 117.1dB - 113.6dB$$

$$= 3.5\ d$$

4. RESULT AND DISCUSSION

This section presents the VSAT link architecture and results gotten from the calculations of the antenna dish size, link budget and link margin analysis in a tabular form.

4.1 VSAT Architecture for ARCSSTE

The VSAT architecture in fig 4.0, demonstrates the connection or link through which ARCSSTE e-Learning application software can be launched using VSAT technology and satellite system. The instructor is connected to the satellite via an uplink using the network facilities in the studio. The satellite relays the data via the downlink to the various receiving earth stations. Thetransmitteddatafrom the instructor may be inform of text, audio or video is converted using the modem in the system. The modem helps to modulate the analogue signal into digital signal and sends to the uplink antenna which transmit the IF (Intermediate Frequency) signal to the satellite. The satellite receives the signal, amplifies itand re-transmits the signal to all the receiving earth stations via down link antenna. The modem demodulates the RF (Radio Frequency) signal and transmits the signal to the server which is connected to the wireless antenna via which the various users access the information.
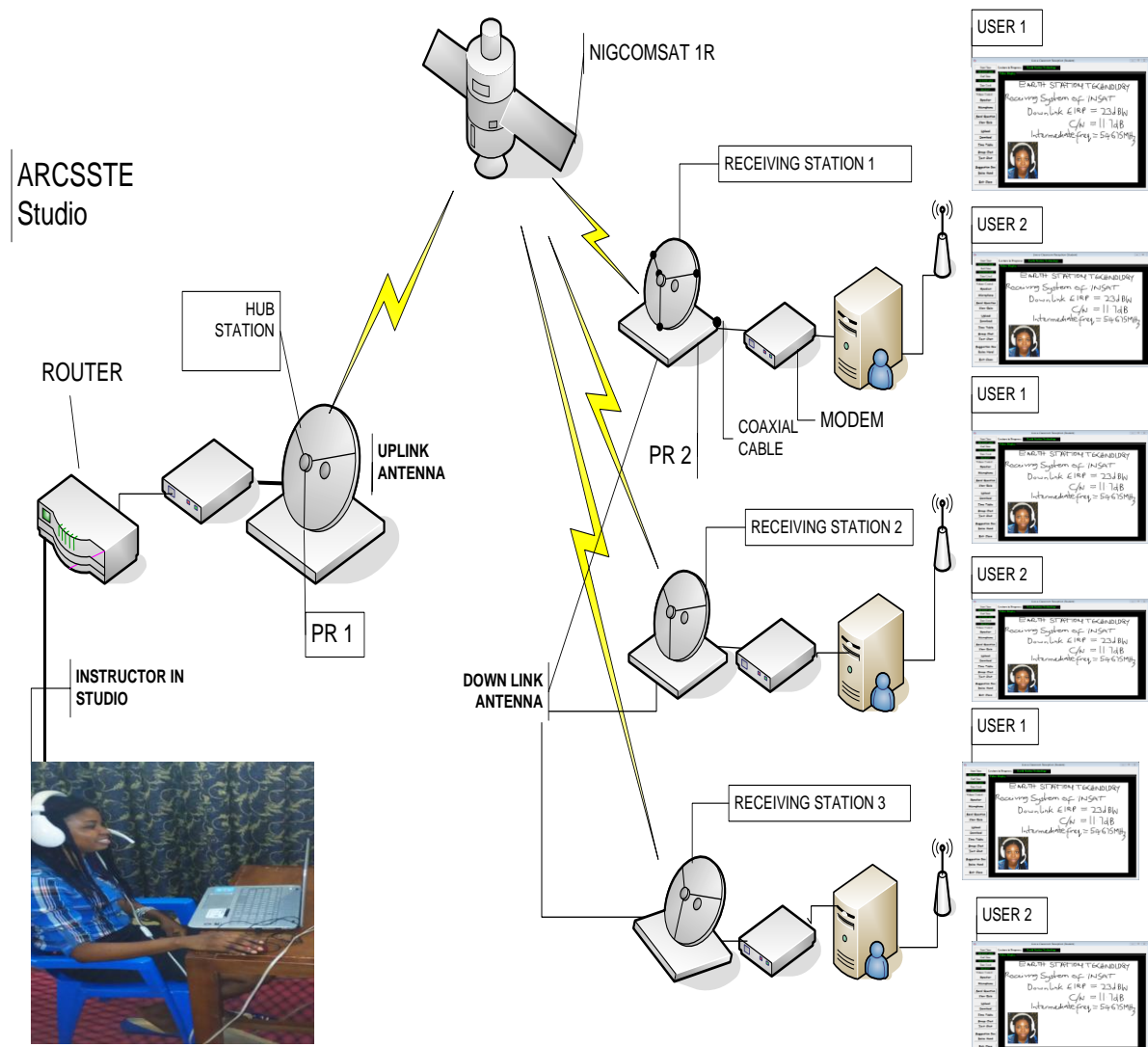

Figure 2: VSAT LinkArchitecture for ARCSSTE-E e-learning platform.

Table 1:   **Link Budget Analysis of the VSAT architecture**

C – Band Satellite Parameters	
C-Bandwidth	$36\ MHz$
Power transmitted (Output power), P_t	$20W$
Gain of transponder (Antenna Gain), G_t	$20dB$
Distance of Earth station to satellite , R	$39,000km = 3.9 \times 10^7 m$
Antenna dish size,	$3.4m$
For Uplink Antenna for C-band budget	
Uplink frequency	$6GHz$
Free space path loss at 6GHz, L_p	$= 1.04 \times 10^{-20}$
Satellite transponder output power, P_t	$256.52dbW$
Received power at earth station, P_r	$-117.1dB$
For Downlink Antenna for C-band budget	
Downlink frequency	$4GHz$
Free space path loss at 4GHz, L_p	2.34×10^{-20}
Received power at earth station, P_r	$P_{r2} = -113.6dB$
For Downlink Noise Power Budget in clear air	
Boltzmann's constant, k	$-228.6dB/K/Hz$
System noise temperature, T_s	$75K = 18.8dBK$
Noise bandwidth, B_n	$27\ MHz\ =\ 74.3\ dBHz$
Receiver Noise Power, $N = k\,T_s\,B_n$	$-135.5dBW$
Carrier to Noise ratio at the receiving station in clear air	
Carrier to Noise ratio, $\frac{C}{N} = P_r - N$	21.9
Link Margin, $L_m = \|P_{r2}\| - \|P_{r1}\|$	$3.5dB$

The link budget analysis in table 4.0 shows the parameters and the estimates of what is needed to design the radio communication link for the proposed VSAT based e-learning system for ARCSSTEE. In link budget analysis, two types of links were calculated, the uplink and downlink. Each link has its free space path losses due to clear weather condition. The result from the calculations implies that the antenna at the transmitting earth station requires an output power of 256.52dbW to transmit the information from the instructor via the uplink to NIGCOMSAT 1R satellite as shown in Fig 4. The satellite receives the information, amplifies and transmits it via the downlink to the receiving earth station antenna (VSAT) with output power of 113.6dB. The link margin derived from the calculation is $3.5\ dB$ and this means that the system could take an additional $3.5\ dB$ of attenuation between the transmitter and the receiver, and it would still barely work.

5   CONCLUSION

In this paper, we have presented the VSAT architecture, link margin and link budget analysis needed to implement the proposed VSAT based E-learning system for ARCSSTEE. This is a conceptual frame work. The proposed system if implemented will enhance ARCSSTE-E to reach out to candidates of the Post-Graduate program within Anglophone countries that may not be able make it to the location due to physical disability, constraint in time, distance, and lack of sponsorship or other challenges.

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