



**Sudan University of Science and
Technology**
College of Graduate Studies



**PRACTICAL EVALUATION OF
CARRIER IN CARRIER TECHNIQUE
FOR SPECTRUM UTILIZATION**

تقويم عملي لتقنية الناقل في الناقل لتوفير عرض النطاق

*A Thesis Submitted in Partial Fulfillment for the Requirements of
the Degree of M.Sc in Electronics Engineering(Communications)*

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*Practical Evaluation of
Carrier in Carrier Technique
for Spectrum Utilization*

(إله السماء يعطينا النجاح

ونحن عبده نقوم ونبني)

سفر نحميا (٢: ٢٠)

To

The soul of my Father,

my beloved Mother,

my Brothers & Sisters,

and to the one who's going to

be my wife to my fiancé ...

Acknowledgement

Above all, to the Great Almighty, the source of knowledge and wisdom, for his countless love and guidance, praise and gratitude be to our God, Who has constantly been by my side through the best and toughest years of my life.

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Abstract

The wide use of satellites in communication systems technique has become motivated for the next satellite technique. In satellite communication, the bandwidth is limited. So the radio spectrum is being utilized more efficiently, by using different multiple access techniques but still the dedicated bands for each satellite services remain limited. A new Technique called Carrier in Carrier (CnC) or sometimes Paired Carrier Multiple Access (PCMA) is being proposed by Comtech Modems. It allows the use of the same spectrum for downlink and uplink, thus results in saving 50% of the bandwidth.

In this thesis, Matlab software was used to calculate CnC link budget, and BW utilized for CnC and SCPC. A practical evaluation that compares the CnC and SCPC utilization has been done.

The results for simulation and practice evaluation proved that CnC technique reduce the BW consumed by SCPC technique to 50%.

المستخلص

أصبح استخدام الأقمار الصناعية بصورة واسعة في تقنية نظم الاتصالات دافع لوجود تقنية أقمار صناعية قادمة. عرض النطاق الترددي محدود في الاتصالات عبر الأقمار الصناعية. لذلك يجري استخدام الطيف الترددي بكفاءة أكبر، وذلك باستخدام تقنيات وصول متعددة مختلفة ولكن مع ذلك لا يزال النطاق الترددي المخصص لخدمات الأقمار الصناعية محدد. قامت شركة كومتك باختراع تقنية جديدة في أجهزة المودم الخاصة بها تسمى الناقل في الناقل وأحيانا يسمى بتقنية زوج الناقل للوصول المتعدد والتي تتيح استخدام نفس الطيف كناقل الصاعد والهابط للحفاظ على النطاق الترددي مما أدى إلى توفير ٥٠٪ من عرض النطاق الترددي مقارنة مع ما تستخدمه التقنيات القديمة من نطاق.

في هذه الأطروحة تم استخدام برنامج ماتلاب لحساب ميزانية استهلاك القدرة للإشارة المرسله بتقنية الناقل في الناقل، كما استخدم لحساب عرض النطاق المستخدم بتقنية الناقل في الناقل و تقنية زوج الناقل للوصول المتعدد. كما تم أخذ قراءات فعلية واستخدامها لمقارنة استهلاك النطاق بتقنية الناقل في الناقل وتقنية زوج الناقل للوصول المتعدد.

كما أثبتت النتائج أيضا أن تقنية الناقل في الناقل تقلل من عرض النطاق التي تستهلكها تقنية زوج الناقل للوصول المتعدد بنسبة ٥٠٪.

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Abbreviations

- No.** 8PSK 8 Phase Shift Keying
16QAM 16 Quadrature Amplitude Modulation
- B** BER Bit Error Rate
BPSK Binary Phase Shift Key
BUC Block-Up Converter
BW Band Width
- C** CAPEX Capital Expenditures
CDMA Code Division Multiple Access
CnC Carrier in Carrier
CNR Carrier to Noise Ratio
CRIS Centre for Railway Information Systems
- D** DAMA Demand Assigned Multiple Access
- E** EIRP Equivalent Isotropic Radiated Power
ERP Enterprise Resource Planning
- F** FDD Frequency Division Duplex
FDMA Frequency Division Multiple Access
FEC Forward Error Correction
- G** GEO Geostationary Earth Orbit
GUI Graphical User Interface

-
- H** HPA High Power Amplifier
- I** IDU Indoor unit
IF Intermediate Frequency
IFL Inter Facility Link
IP Internet Protocol
- L** LANs Local Area Networks
LEO Low Earth Orbit
LNA Low Noise Amplifier
LNB Low Noise Block converter
- M** MEO Medium Earth Orbit
- O** ODU Outdoor Unit
OMT Orthogonal Mode Transducer
OPEX Operating Expenses
- P** PAMA Pre Assigned Multiple Access
PCMA Paired Carrier Multiple Access
PSK Phase Shift Keying
- Q** QAM Quadrature Amplitude Modulation
QoS Quality of Service
QPSK Quadrature Phase Shift Keying
- R** RF Radio Frequency
RS Reed Solomon

<u>S</u>	SCPC	Single Carrier Per Channel
	SDMA	Spatial Division Multiple Access
	SFD	Saturation Flux Density
	SIR	Signal-to-Interference Ratio
	SNR	Signal to Noise Ratio
	SSPAs	Solid State Power Amplifiers
<u>T</u>	TDM	Time-Division Multiplexed
	TDMA	Time-Division Multiple Access
	TPC	Turbo Product Code
	TWTAs	Traveling Wave Tube Amplifiers
<u>V</u>	VoIP	Voice over IP
	VPN	Virtual Private Network
	VSAT	Very Small Aperture Terminal
<u>W</u>	WCDMA	Wideband Code Division Multiple Access



Chapter one

Introduction

1.1 Background

Satellites are an essential part of our daily life, and they have a very large usage ranging from Search and Rescue Operations to Environmental Monitoring. Satellites can cover vast areas on the world; therefore, they are the nodes where all links pass through in a communications network. Many users can access such a network simultaneously while they are widely separated geographically[1].

Advancement in satellite transmission technology have led to the development of low-cost, compact, integrated earth station called the Very Small Aperture Terminals (VSATs). VSATs are used in a star or mesh network configuration to provide information directly to the user's premise. A VSAT network can be used for a one-way communication to broadcast video, audio or data, or two-way communication to carry interactive data or voice between the hub and VSATs. VSAT networks provide economical private communication networks with high reliability, distance-insensitive service and flexibility to accommodate growth with predictable cost over the lifespan of the network. Therefore, VSAT network are widely used by many private organizations and developing countries as an alternative to terrestrial communication[2].

VSATs provide economical private communication networks. They are reliable and their ability to be used across very distant geographical locations makes them very attractive both for commercial and military organizations. VSATs are flexible in architecture, and they have limited and known components. Therefore diagnosing problems and maintaining the network is easy. A VSAT network can work with different capacities in each direction, thus the nonsymmetrical feature can be an advantage and reduce the costs[1].

VSAT provides Point to Point or Point to Multi Point data connectivity using Geostationary Satellite as repeater location. As satellite is being used as repeating stations, the data originating and terminating point can be anywhere on the earth. Railway is using them to provide data connectivity between various goods terminals and Centre for Railway Information Systems (CRIS) as well as for video conferencing applications[3].

In Sudan, VSAT systems are supplied by Sudasat, Canar, and MTN Companies. However, this study will be focusing on VSAT systems supplied by Sudasat company which is the biggest VSAT company in Middle East and North and East of Africa. Presently, Sudasat are operating at C-band (6/4 GHz) frequencies.

1.2 Problems Statement

For satellites, the bandwidth is limited. Although the developers use high modulation techniques to save the bandwidth (BW), the limitation of using the maximum power prevent the satellite from using high modulation techniques easily.

1.3 Proposed Solutions

A new Technique called Carrier in Carrier (CnC) or sometimes Paired Carrier Multiple Access (PCMA) proposed by Comtech Modems that utilizes the spectrum by using the same spectrum for downlink and uplink will be analysed.

1.4 Objectives

The objectives of this thesis are as follow:

- To understand VSAT and its equipment

- To calculate the link budget of the Carrier in Carrier (CnC) technique.
- To compare the bandwidth (BW) utilization of the CnC with the Single Carrier Per Channel (SCPC) technique.
- To carry out a practical evaluation that compares CnC to SCPC.

1.5 Methodology

In this thesis MATLAB program used to design a Graphical User Interface (GUI) that calculate the CnC link budget. The GUI used to compare the bandwidth utilization of the CnC with the traditional Single Carrier Per Channel (SCPC) technique. A practical analysis will also be carried out to compare the performance of both techniques.

1.6 Research Outlines

This thesis consists of five chapters presented as follow;

Chapter 2: Presents a literature review on VSAT and its components, its services and applications and finally the VSAT link budget.

Chapter 3: Provides the VSAT network configurations, and the CnC technique as the newest VSAT technique.

Chapter 4: Provides the simulation and discusses the results.

Chapter 5: Provides the conclusion of the work done, and a list of recommendations.



Chapter two

Literature Review

2.1 Introduction

Though the prevalence and quality of telecommunication, networking has undergone leaps and bounds since the telephone was first invented in 1847, yet the adaptation of large-capacity networking in developed countries remain rather limited and in certain fixed areas. This has turned the majority of the developing countries to continue searching for solutions through Virtual Private Network (VPN) and remote area high-quality communications applications. The VSAT technology that began in the 90s not only serves to provide regional services through intangible wiring routes but also provides comparable competitiveness in functionality, service types, accessibility, transmission cost, expansion cost and so forth when compared with tangible wiring routes.

VSAT, the acronym of very small aperture terminal, signifies a “small-diameter ground terminal” in straight interpretation, deriving from the fact that the wiring diameter of a VSAT system’s ground tends to be smaller, usually between 0.3m and 2.4m. A new satellite communications system was developed in the mid 90s utilizing the modern technology. VSAT systems come with characteristics of a dynamic flexibility, dependability, low cost, easy to use, and a direct link up to the user through a local station. A VSAT user terminal can link up directly to a remote server through satellite channel to complete data transmission, document exchange or even remote processing to resolve the problem of ground station signal interruptions. In light of which, in remote spots where the ground networking-infrastructure may be less than perfect, the quality of communications wiring may be poor, or in the absence of a high-speed transmission networking, the adaptation of the VSAT system would poise to improve the foresaid problems [1].

2.2 Related Works

Several research have been done on this topic some of which are;

In [1] the authors analyzed the information theoretical bound of blind detection for CnC using simulation based information rate computation method. Signal fading, propagation delay, filter coefficients and other parameters were considered. Based on the information theoretical bound obtained, Viterbi detection method was applied to CnC signal blind detection. The simulation showed the result of spectrum utilization of CnC over SCPC and the power differences needed by both multiple access.

In [2] the author described the satellite communication system Carrier in Carrier (CnC) technologies, including self-interference signal parameter estimation, interference reconstruction and interference rejection. Simulation results on interference cancellation showed that the algorithm overcomes the spectrum limitations of the previous multiple access, and has a relatively stable estimates of performance for the system under different signal-to-noise ratio conditions.

In [3] A self interference cancellation method based on subsection weighting process was proposed. In this paper Carrier in Carrier multiple access technology (CnC) is applied in helicopter satellite communications for the issue that the frequency and amplitude in return signal is unsteadiness. Computer simulation results show that the method can reduces the random error of the CnC estimate algorithms effectively, and the E_b/N_0 of the desired signal is always less than 0.2dB in the asymmetric systems.

In [4] the authors described that Carrier-in-Carrier can provide significant savings in operational expenses. As a result of his research,

the author found that Carrier-in-Carrier can be used in both bandwidth limited and power limited situations; For Carrier-in-Carrier to provide savings in a power limited case, the original link is either using a non-Turbo Product Code (TPC) FEC or if using TPC has a spectral efficiency of at least 1.5 bits/Hz or better, i.e. QPSK, R=3/4 TPC or better

2.3 Overview on VSAT

The distance over which two terminals can connect is limited by the earth's curvature, and how satellites can overcome these limitations. For example these wireless devices could theoretically communicate directly with each other.

If the transmitter and receiver are too far apart to receive each other, the signal will be blocked by the earth's horizon.

A repeater station is added on a high tower, both devices can communicate again. But as the devices get further apart, the tower must get higher and higher. Even a tower 100m high can cover only about 50 km radius. To cover all of Africa, the tower would have to be 400 km high - obviously impossible.

The solution is to place the repeater on an orbiting satellite. Satellite can be anywhere from 200 km to 40,000 km high, so clearly they have no problem with global coverage.

One satellite can cover almost half of the earth. Arthur C. Clarke pointed out in 1945 that the entire world could be served by just three satellites in "geostationary" orbits (except for the poles)[15].

2.4 Networked VSAT Earth Station Hardware

Figure 2.1 shows the block diagram of the electronic components in a typical VSAT:

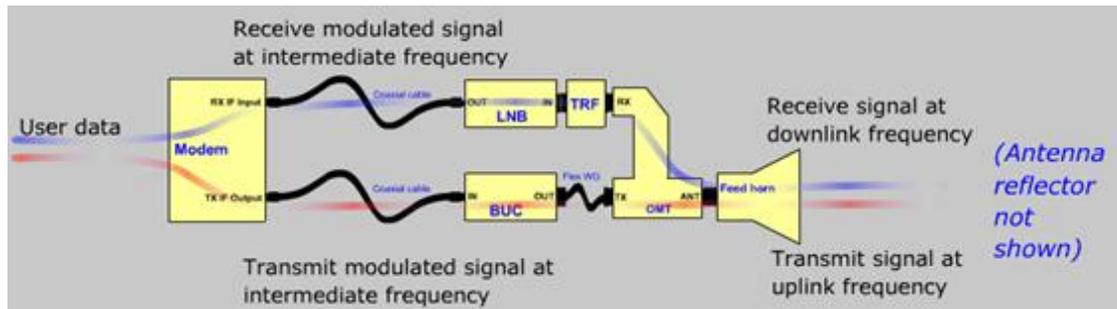


Figure 2.1 : Typical VSAT block diagram

In VSAT antenna, the horn collects the downlink signals that are focused into it by the reflector. It also launches the transmitted (uplink) waves in a wide "spray" towards the antenna reflector, which then focuses them into a narrow beam.

The feed horn and combiner together are called the feed system. The antenna manufacturer usually includes the feed system with the antenna.

The combiner connects to the feed horn and separates the transmitted signals "which is goes Block-Up converter (BUC)" from receive signals "which is goes to Low Noise Block converter (LNB)".

The LNB accepts the downlink signal from the antenna, amplifies it with a built-in Low Noise Amplifier (LNA), and translates it down to the receiver as IF frequency required by the modem. The demodulator accepts the IF signals and demodulated to create the received data.

In the opposite direction the modulator modulates the signal (data) to be transmitted as IF signal (usually at L-band). Then the BUC accepts the transmitted IF Signal from the modem and translate it to the uplink frequency, that is why a microwave signal is needed, because the signal power is high now to guide the signal to the Orthogonal Mode Transducer (OMT) and then to the feed horn to be reflected by antenna to the space[5].

VSAT earth station consist of :

1. Outdoor Unit (ODU).
2. Inter Facility Link (IFL) cables.
3. Indoor unit (IDU).

2.4.1 Outdoor Unit

Figure 2.2 shows the VSAT Outdoor Units. It consists of; a Low Noise Block converter (LNB), Block Up-Converter (BUC), Feeder and Parabolic Antennas[8].

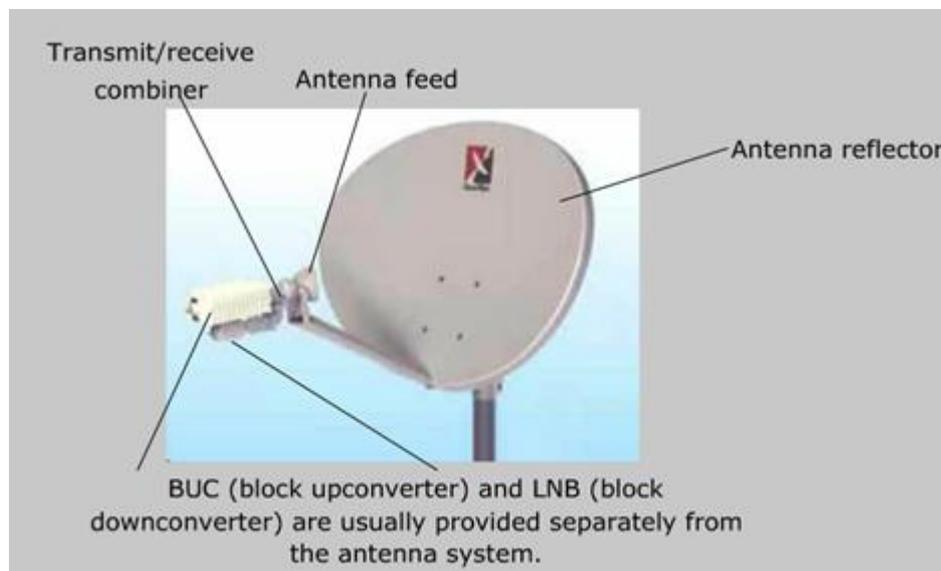


Figure 2.2 : VSAT Outdoor Unit

1. Low Noise Block Converter

The Low Noise Block converter (LNB) is relatively inexpensive receiver component, which converts broadband data and video signals on satellite downlinks to L band frequencies. It receives its power via the coaxial cable and no external local oscillators signals are required for down-conversion. The LNB amplifies the extremely weak downlink signal from the antenna. It also converts the receive signals, in a block covering the entire satellite band. LNB's are made in various frequency bands and performance levels[6].

2. Block Up-Converter

A Block Up-Converter (BUC) is used in the transmission (uplink) of satellite signals. The BUC performs the reverse function of the LNB. It up-converts the signal from the indoor unit to the desired frequency band, then it amplifies the signal to a high power level. It converts a band of frequencies from a lower frequency to a higher frequency. Modern BUCs convert from the L band to Ku band, C band and Ka band. Older BUCs convert from a 70 MHz intermediate frequency (IF) to Ku band or C band.

VSAT BUCs are generally rated from 1W to 5W, but high-power options up to 100W or more are available. BUCs used in remote locations are often 2 or 4 W in the Ku band and 5 W in the C band. The 10 MHz reference frequency is usually sent on the same feed line as the main carrier[17].

3. Feed/Combiner

The feed horn focuses the uplink and downlink signals into the antenna reflector. It is usually integrated with the combiner, which separates the uplink (transmit) and downlink (receive) microwave signals [19].

4. Parabolic Antennas

There are two main types of parabolic antennas; the center feed antenna and the offset antenna.

Center feed antennas have the feed in the paraboloid as shown in Figure 2.3. The major advantage of such configurations is that they are mechanically relatively simple, reasonable compact and, in general, fairly inexpensive. The prime focus antenna is round and has its feed/

LNA/B/C assembly at the focal point directly in front of the antenna. A prime focus antenna is easy to manufacture [5] .

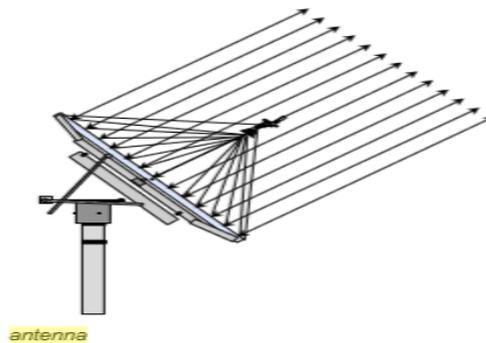


Figure 2.3 : Prime Focus Antenna

Offset antennas are oval and the feed/ LNA/B/C has an offset from the center of the reflector as shown in Figure 2.4 is. Because of its oval form, this type is more difficult to manufacture. Offset fed antennas have smaller diameters (30 cm-4 m) and the feed is located below the lower edge of the offset block the antenna aperture. Offset antennas achieve a better radiation pattern because of less aperture blockage.

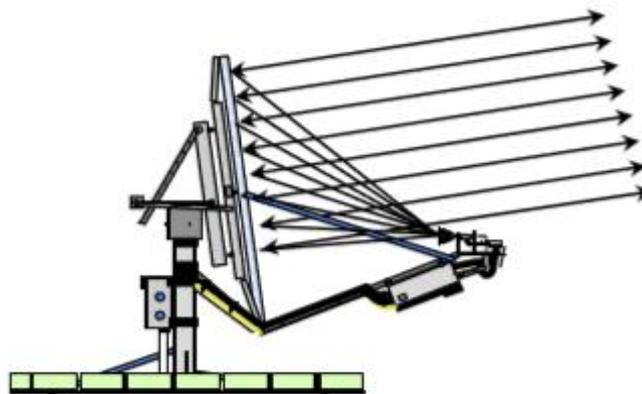


Figure 2.4 : Offset Antenna

Dual antenna can be either center feed or offset feed and is a parabolic dish using a secondary hyperbolic sub-reflector, the sub-reflector can be Cassegrain (has a convex shape) or Gregorian (has a concave shape) . It achieves higher efficiency (because of better side lobe performance) than

the primary types because the angle of the wave front entry to the feed horn is less. (The antenna principle is a sub reflector at the focal point that reflects energy to or from a feed located at the apex of the main reflector). The bigger earth station dishes are usually of this type of antenna[7].

2.4.2 Inter-Facility Link

The inter-facility link (IFL) cables are typically low-cost coaxial cable, up to about 100m long. In most VSATs two IFL coax cables are required. Type F and N connectors are the most popular for VSAT IFLs. The most common types are called "RG-6" and "RG-11[12]"

2.4.3 Indoor Unit

The indoor unit (IDU) is a modem that is compatible with the VSAT hub. A modem is a combined modulator-demodulator. The modulator accepts the user's transmit data, applies Forward Error Correction (FEC), and modulates a carrier at an Intermediate Frequency (IF). The demodulator accepts an IF signals and demodulates it, and decodes the FEC to create the received data. It also contains other functions such as user interface circuits and power supplies for the outdoor equipment[10].

2.5 Satellite Orbits for VSAT Services

A satellite high above the earth should be an ideal place to put a repeater that would provide a wide coverage area.

For satellite, which are above the earth's atmosphere, that force is gravity. Gravity continuously pulls the satellite towards the center of the earth.

As of 2007, there are roughly 850 active satellites in orbit around the earth as shown in Figure 2.5. Satellites in orbit today use a variety of orbits[8].

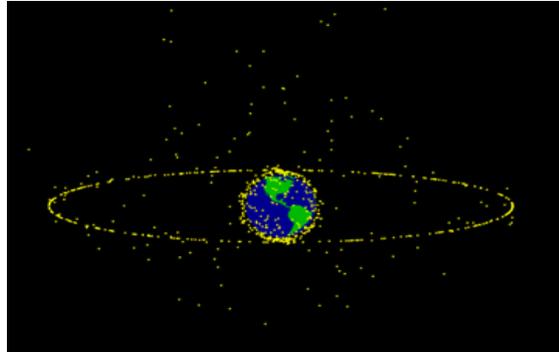


Figure 2.5 : Satellites around the earth

2.5.1 Low Earth Orbit (LEO)

Low Earth Orbit satellites have an altitude between 250 km and 1500 km. Each orbit takes 1.5 to 2 hours. A LEO is simplest and cheapest for satellite placement. It provides high bandwidth and low communication time lag (latency), but satellites in LEO will not be visible from any given point on the earth at all times. LEO satellites are mainly used for mobile communications services, earth observation, science, and military missions[8].

2.5.2 Medium Earth Orbit (MEO)

Medium Earth Orbit satellites usually have an altitude between 20,000 km. Each orbit takes 10 to 12 hours. MEO satellites are commonly used for navigation such as Global Positioning System (GPS), as well as mobile communications and other services. Communications satellites that cover the North and South Pole are also put in MEO[8][17].

2.5.3 Geostationary Earth Orbit (GEO)

A Geostationary Earth Orbit is also called the "Clarke Belt" after Arthur Clarke who originated the idea of using this orbit for communications satellites in 1945. Any satellite in this orbit appears to hang motionless 22,247 miles (35,800 km) above the equator. The signal from one satellite can cover up to 40% of the earth's surface.

Geo satellites are placed at an altitude of about 35,800 km. This makes the orbit period exactly 24 hours, so the satellites appear to stand still when observed from the earth. Geo satellites are the workhorses of satellite communications. They are used for broadcasting, VSAT, and other communications, as well as earth observation and science missions [8].

2.5.4 Elliptical Orbit

Elliptical orbit satellites swing close to the earth, and then fly far out into space before returning. They are generally used to get coverage of the polar regions of the earth, which cannot be seen from the GEO orbit. They are also used for satellite radio services to provide a wider spacing of the satellites across the sky than GEO[8][17].

2.6 Characteristics of VSAT System

VSAT satellite communication system has very evident characteristics, which mainly includes the following aspects [16]:

- 1) Ground (remote) station antenna has small diameter which is generally meters below. Now it mostly adopts 1.2~1.8m diameter. Climbers sometimes use flyaway personal earth station with 0.3m diameter.
- 2) Transmission power is low, which is generally between 1 and 3w.

- 3) Weight is light. It is always dozens of kilograms and some are a few kilograms. And they are easy to carry.
- 4) Price is low and it is economical and practical. This system has low price and its economic efficiency is greater than equipment price.
- 5) Construction cycle is short. It is simpler than traditional ground communication means. Cable and optical cable are not needed to set up. It doesn't need a relay station setting up every 50km, unlike microwave communication. In VSAT satellite communication system, just install necessary device at both ends of communication and equipment assembly is simpler.
- 6) Communication cost is irreverent to communication cost. As for common communication system, the longer the distance is, the higher is the cost. But VSAT satellite communication is not related to distance. The longer the distance is, the more adaptable is VSAT communication.
- 7) VSAT satellite communication is not affected by terrain and climate because it is not needed to set up ground facilities and it is little interfered by ground.
- 8) The biggest advantage of VSAT satellite communication technology is flexible in network combination, convenient maintenance and easy to expand, for it doesn't have complex ground equipment.

2.7 VSAT Applications

VSAT station can easily make up flexible and economical network system of different scale, different rate, and different application. A VSAT network can contain 200~500 small stations, which has a wide range of application including broadcast type, point-to point type, two-way interactive type and collection type. It can be applied not only in

developed countries, but also in less technologically advanced countries and undeveloped countries, especially in remote areas of complex terrain, less population and inconvenient lines. It can be equipped directly to the individual, so it has important significance for the military. Generally, VSAT technology can be applied in the following aspects [9]:

- 1) It can be applied for popularizing satellite television broadcast and satellite television, and transmitting signal of broadcast television and business television. This application mode has a vital role in both the material and spiritual civilization for remote areas in our country.
- 2) It can be applied for financial system and securities system to dynamically track and manage market situation, which greatly shortens cash conversion cycle.
- 3) It can be applied for water conservancy to manage and hydrological change in order to prevent and reduce natural disaster. VSAT system can timely transmit the information obtained by meteorological satellite, maritime satellite, resource satellite and ground detection station.
- 4) It can be applied for transportation system. Oversea developed countries use it on railway operation and dispatching, which greatly ease transport tense.
- 5) It can be applied for military. In Gulf war in 1999, the international military used VSAT for a large amount of mobile communication and equipped it to each soldier.
- 6) It can be applied for emergency communication and communication in remote areas. VSAT is the most convenient emergency communication backup system for natural disaster or emergency incident.

2.8 VSAT Links Budget

To ensure proper coverage in a particular location, a Link Budget calculation may need to be done. A Link Budget is a calculation involving the gain and loss factors associated with the antennas, transmitters, transmission lines and propagation environment. It is used to determine the maximum distance at which a transmitter and receiver can successfully operate. A Link Budget takes into account the location (latitude and longitude) of the satellite, the size of the satellite dish (.74, 1.0, 1.2, etc), BUC size (2W, 3W, 6W) and modem for acceptable QoS [13][21].

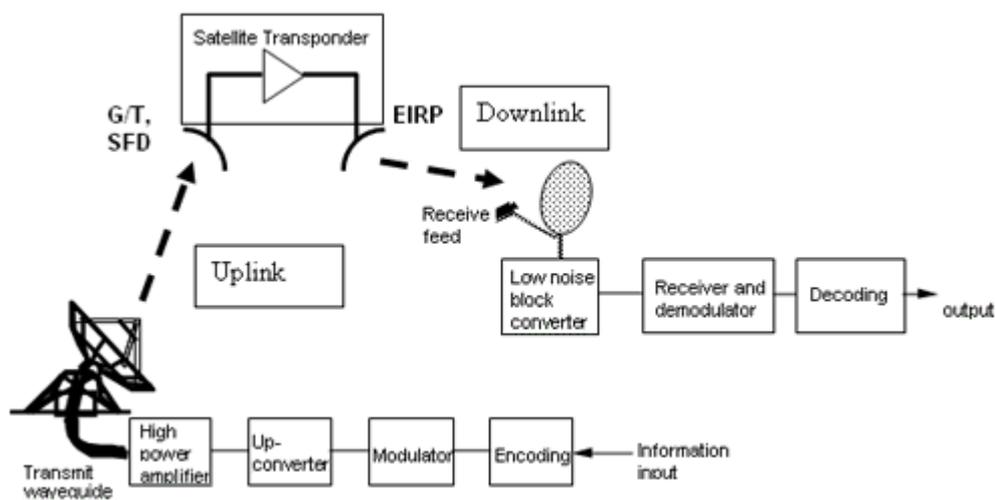


Figure 2.6 : Basic elements of satellite link

As shown in figure 2.6 Basic elements of a satellite link, showing the transmitting earth station, satellite transponder, and receiving terminal. Satellite EIRP determines receiving dish size and satellite receive G/T and SFD determine transmitting earth station uplink power[21].

1. Information Data

First of all the calculation of information rate is needed as shown in equation 2.1:

$$\mathbf{Information\ Rate = 10\ log(DR)\ dB} \quad (2.1)$$

Where

DR : is Data Rate

Noise BW is defined as the BW of perfect rectangular filter that passes the same amount of power as the cumulative BW of the channel selective filters in the receiver. Noise BW shown in equation 2.2.

$$\mathbf{Noise\ BW = \frac{DR*RS*SF}{FEC*MF}} \quad (2.2)$$

Where

RS : is RS coding ratio is a ratio of Reed Solomon coding.

SF : Spacing factor, is the carrier roll-of factor.

FEC : is Forward Error Correction technique enables the receiver to both Detect and correct errors without needing to inform the transmitter.

MF : is Modulation factor, is the order for modulation.

2. Calculation of Uplink Path Loss

Uplink path loss (U_{PL}) depends on the up link frequency [f] which is the frequency at which Ground Station is communicating with Satellite and the distance [d] between the satellite and the ground station. For C band up link frequency is in the order of 6 G Hz as shown in equation 2.3.

$$U_{PL} = 10 \log\left(\frac{4\pi dC}{U_f}\right)^2 dB \quad (2.3)$$

Where

d : is the distance between satellite & ground station

U_f : is the uplink frequency

C : is the velocity of light

3. Calculation of the Transmitting Antenna

The isotropic power gain of the antenna [G_T] is defined as the power density in the maximum direction, denoted by [P_D] to the power density archived by a 100% efficient isotropic radiator as shown in equation 2.4.

$$G_T = \frac{4\pi P_D}{P_T} \quad (2.4)$$

Where

P_T : the total power radiated.

P_D : power density

$$G_T = 10 \log\left(\frac{\pi^2 D_T^2 \eta_T}{(3/U_f)^2}\right) dB \quad (2.5)$$

Where

D_T : is the transmitting antenna diameter

η_T : is the Tx antenna efficiency, it is the ratio of input power to the radiated power of the antenna. It has a value between 0.55 and 0.73.

4. Calculation of Transmit EIRP (in dB W) & Operating FD

The actual power given to transmitting antenna and its power gain are used to calculate the Transmit Equivalent Isotropic Radiated Power (EIRP), as expressed in equation 2.6.

That the equivalent isotropic power (EIRP) may be defined as :

$$EIRP = P_T G_T \quad (2.6)$$

Where

EIRP : The Equivalent Isotropic Radiated Power

P_T : Transmitted Power

G_T : Transmitted Gain

EIRP is often expressed in decibels relative to 1 watt, or dBW. Let P_t be in Watts then;

$$EIRP = [P_T] + [G_T] \text{ dBW} \quad (2.7)$$

If the transmitter feeder loss & antenna pointing loss is taken in to account :

$$EIRP_T = 10 \log(T_{PC}) - T_{FL} + G_T - T_{PL} \text{ (dBW)} \quad (2.8)$$

Where

T_{PC} : Transmit power per carrier is the power given to the antenna at the Earth station to radiate power.

T_{FL} : Transmitter feeder loss are the losses which occur in the connection between the transmitting antenna and the transmitter

proper. Such losses will occur in the connecting wave-guides, filters and couplers.

T_{PL} : Antenna pointing loss, when a satellite link is established, the ideal situation is to have the earth station and satellite antennas aligned for maximum gain. There are two possible sources of off axis loss , one at the satellite and one at the earth station . The off axis loss at the satellite is taken into account by designing the link for operation on actual satellite antenna contour. The off axis losses at the earth station is referred to as the antenna pointing loss. Antenna pointing losses are usually only a few tenths of a decibel.

The traveling tube amplifier in a satellite transponder exhibits power output saturation. The flux density required in the receiving antenna to produce saturation of the TWTA is termed the saturation flux density (FDs) which can be expressed as :

$$FDs = EIRP_T - U_{RA} - 162.2 \text{ (dB /Sq m)} \quad (2.9)$$

Where

U_{RA} : Up link rain attenuation (dB), Rain fall results in attenuation of radio waves by scattering , and by absorption , of energy from the wave. Rain attenuation increases with increasing frequency and is worse at Ku band compared to C band. Studies have shown that the rain attenuation for horizontal polarization is considerably greater than for vertical polarization.

Power rating of ground transmitter (P_{GT}) can be expressed as shown in equation 2.10 :

$$P_{GT} = 10^{\left(\frac{(10 \log(N_C * T_{PC}) + A_{BO})}{10}\right)} \quad (2.10)$$

Where

P_{GT} : Power rating of ground transmitter is the power delivered by the ground transmitter.

N_C : Number of Carriers, by frequency multiplexing scheme any number of carriers can be transmitted through an antenna.

A_{BO} : Amplifier back off, to reduce inter-modulation distortion, the operating point of the TWT must be shifted to the linear portion of the curve, the reduction in input power being referred as input back off. When multiple carriers present, the power around saturation, for any carrier, is somewhat less than the achieved with single carrier operation. The input back-off is the difference in decibels between the carrier input at the operating point, and saturation input that would be required for single carrier operation.

5. Calculation of Uplink Carrier to Noise Ratio

In communications, the carrier-to-noise ratio, often written CNR or C/N, is a measure of the received carrier strength relative to the strength of the received noise.

Carrier to noise ratio of uplink is given as :

$$\begin{aligned} [C/No]_U &= [EIRP]_U + [G/T]_U - [losses]_U + 228.6 \\ &= EIRP_T - (U_{PL} + U_{RA}) + \text{Satellite } G/T + 228.6 \text{ (dB)} \end{aligned} \quad (2.11)$$

Where

$[C/No]_U$: Uplink Carrier to noise ratio which is the uplink of a satellite circuit is the link in which the earth station is transmitting the signal and the satellite is receiving it .

$[G/T]_U$: Ratio of gain of the Transmitted antenna to the thermal noise temperature of the Transmitted antenna.

Satellite G/T : Ratio of gain of the satellite to the thermal noise temperature of the satellite . G/T ratio indicates figure of merit. G/T ratio depends on the satellite components.

6. Calculation of Satellite Operating Down Link EIRP

Satellite operating down link EIRP ($EIRP_D$) can be calculated as follows:

$$EIRP_D(dB W) = SFD + ((Saturated EIRP - O_{BF}) - (FD_S - I_{BF})) \quad (2.12)$$

Where

SFD : Satellite operating flux density.

I_{BF} : input back-off is the difference in decibels between the carrier input at the operating point, and saturation input that would be required for single carrier operation.

O_{BF} : Output back-off, where input back-off is employed corresponding output back off must be allowed for the satellite EIRP.

7. Calculation of Satellite Operating Band Width

To calculate the satellite operating bandwidth the effective input data rate (E_{DR}) (kbps) needs to be calculated. It can be calculated by the formulas :

$$E_{DR} = \frac{DR(kbps)}{(1+Link\ over\ head\ factor/100)} \quad (2.13)$$

Where

DR : Input data rate (Kb/s) is the number of actual message signals per second.

Link overhead factor (% Worst case) : It represents additional transmitting delay between message bits to avoid collision or inter-symbol interference of message bits.

The transmission rate T_R is calculated using equation 2.14:

$$T_R = \frac{DR}{FEC} \quad (2.14)$$

The satellite operating bandwidth (BW_S) can be calculated as follow:

$$BW_S = \left(\frac{T_R}{Bits\ per\ symbol} \right) * 1.4 \quad (2.15)$$

Where

Bits/Symbol (m) : It is defined as the number of symbols transmitted by the transmitter per bit.

8. Calculation of Downlink Path Loss

The downlink loss D_{PL} can be found from the following equation :

$$D_{PL} = 10 \log \left(\frac{4\pi dC}{D_f} \right)^2 dB \quad (2.16)$$

where

d : is the distance between satellite & ground station

D_f : is the frequency of the down link wave

C : is the velocity of the light = 3×10^8 m/Sec

9. Calculation of Receiver Antenna Gain

The isotropic power gain of the antenna, G_R , is defined as the power density in the maximum direction, denoted here by P_D , to the power density archived by a 100% efficient isotropic radiator as shown in equation 2.17.

Thus

$$G_R = \frac{P_D}{(P_T/4\pi)} \quad (2.17)$$

where

P_T : is the total power radiated.

P_D : power density

$$G_R = 10 \log\left(\frac{\pi^2 D_R^2 \eta_R}{(3/D_f)^2}\right) d \quad (2.18)$$

Where

D_R : is the receiving antenna diameter

η_R : is the Rx antenna efficiency, it is the ratio of input power to the radiated power of the antenna. It has a value between 0.55 to 0.73.

10. Calculation of Receiver G/T

The Receiver G/T is the Figure of merit at the receiver antenna. To be calculated the system noise temperature should be calculated first as expressed in equation 2.19 :

$$S_{NT}(k) = A_{NT} + AR_{NT} + LNA_{NT} \quad (2.19)$$

Where

N_T : System noise temperature (k) is the sum of all noise temperatures at the receiving antenna

A_{NT} : Antenna noise temperature is the sum of all noise sources at the antenna.

AR_{NT} : Increase in Antenna noise due to rain, Rain affects the antenna noise temperature. It increases the antenna noise temperature.

LNA_{NT} : LNA noise temperature, LNA means Low Noise Amplifier. LNA noise temperature means noise temperature of LNA.

Using system noise temperature receiver G/T can be calculated as expressed in equation 2.20 :

$$[G/T]_R (dB/K) = G_R - 10 \log(S_{NT}) \quad (2.20)$$

Where

G_R : Receiver Antenna gain.

11. Calculation Carrier to Noise Ratio

To calculate the Total C/No the downlink C/No is needed to be calculated as well as uplink C/No. Downlink $[C/No]_D$ is expressed in the 2.21 equation as follow :

$$[C/No]_D (dB Hz) = EIRP_S - D_{PL} - D_{RA} - R_{PL} + [G/T]_R + 228.6 \quad (2.21)$$

Where

$EIRP_S$: Satellite operating EIRP.

D_{RA} : Down link rain attenuation

R_{PL} : Receiver antenna pointing loss, Antenna pointing losses are usually a few tenths of a decibel.

Then the overall C/No is needed;

$$\left[\frac{C}{N_0} \right]_T (dB Hz) = -10 * \log(10^{-\left[\frac{C}{N_0} \right]_U} + 10^{-\left[\frac{C}{N_0} \right]_D}) \quad (2.22)$$

Over all C/No (dB Hz): It is the sum of carrier to noise ratio at the down link and carrier to noise ratio at the uplink. It is the effective C/N ratio of the total link of the system (Transmitter & receiver).

Then available Eb/No has to be calculated as follow :

Available Eb/No = Over all downlink (C/No) / Input data rate

Available Eb/No (dB) = [C/No]_D (dB) - DR (dB)

$$Available \left[\frac{E_b}{N_0} \right] (dB) = [C/No]_D (dB) - 10 \log (DR \text{ in } KB * 10^3) \quad (2.23)$$

12. High Power Amplifier Calculation

To calculate total HPA, the earth station EIRP required per carrier has to be calculated first as shown in equation 2.24.

$$EIRP_{EC} (dBm) = SFD - Gsq + FSL - I_{BOC} \quad (2.24)$$

Where

$EIRP_{EC}$: Earth Station EIRP required per carrier

SFD : Saturated Flux Density of satellite

G_{sq} : Conductance of square microstrip

FSL : Free Space Loss

I_{BOC} : Input Back-off per carrier

Then HPA power per carrier has to be calculated as shown in equation 2.25.

$$HPA_C (dBw) = EIRP_{EC} - G_T + T_{FL} \quad (2.25)$$

Where

HPA_C : HPA Power per carrier

G_T : Tx antenna gain

Adding 1dB to equation 2.25 will give us HPA power per carrier with 1dB back-off as shown in equation 2.26.

$$HPA_{one} (dBw) = 1 + HPA_C \quad (2.26)$$

Where

HPA_{one} : HPA power per carrier with 1dB back off

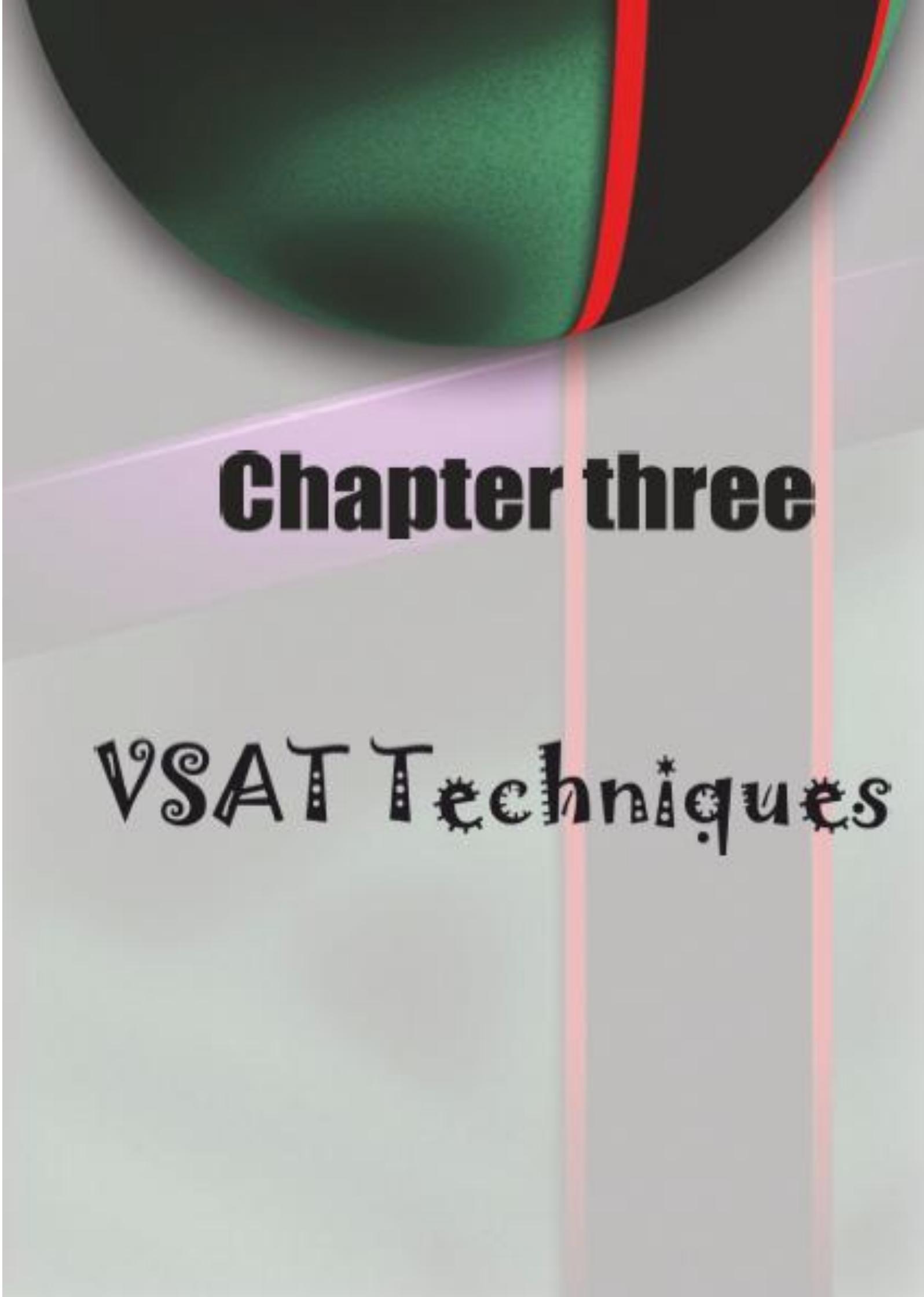
Now the Total HPA power can be calculated as shown in equation 2.27.

$$HPA_T (dBw) = HPA_C + CH_N \quad (2.27)$$

Where

HPA_T : Total HPA power

CH_N : required number of channels



Chapter three

VSAT Techniques

3.1 Introduction

Traditionally, the satellite is a radio relay station that receives, amplifies and redirects analog and digital signals contained within a carrier frequency. These signals contain data, voice, and video communications. VSAT systems can be configured for bi-directional or receive-only operation. In bi-directional operation, the dish both sends (uplinks) and receives (downlinks) the information for use in LANs[8].

3.2 VSAT Network Configurations

VSATs are connected by radio frequency (RF) links via a satellite as illustrated in Figure 3.1.

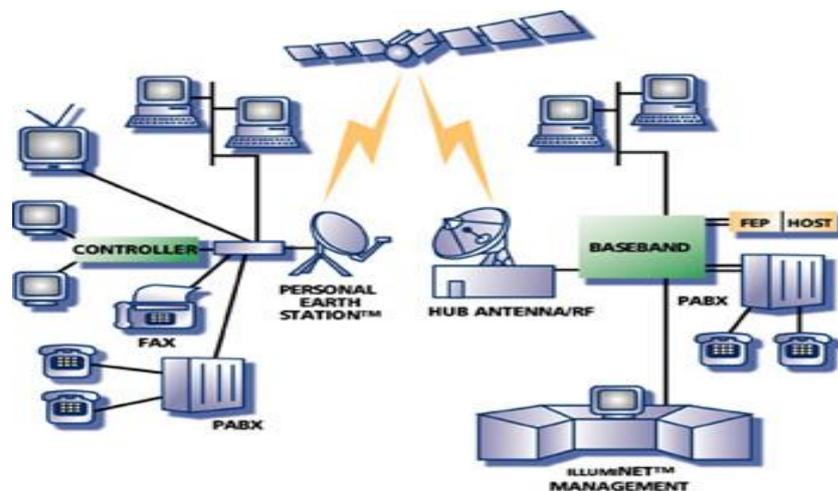


Figure 3.1: Trunking Stations to VSATs

The overall link from station to station is sometimes called hop it consists of an uplink and a downlink as shown in Figure 3.2. A radio frequency link is a modulated carrier conveying information. Basically the satellite receives the uplinked carriers from the transmitting earth stations within the field of view of its receiving antenna. It amplifies those carriers, translates their frequency to a lower band in order to avoid possible output/input interference. It then transmits the amplified carriers to the stations located within the field of view of its transmitting antenna.

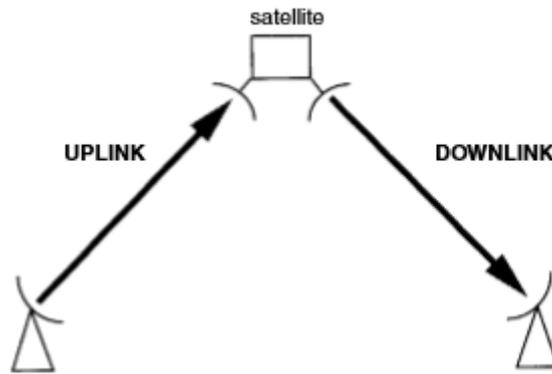


Figure 3.2 : Definition of uplink and downlink

Present VSAT networks use geostationary satellites, which are satellites orbiting in the equatorial plane of the earth at an altitude above the earth surface of 35 786 km. The orbit period at this altitude is equal to that of the rotation of the earth. As the satellite moves in its circular orbit in the same direction as the earth rotates, the satellite appears from any station on the ground as a fixed relay in the sky. Figure 3.3 illustrates this geometry. It should be noted that the distance from an earth station to the geostationary satellite induces a radio frequency carrier power attenuation of typically 200 dB on both uplink and downlink, and a propagation delay from earth station to earth station (hop delay) of about 0.25 s.

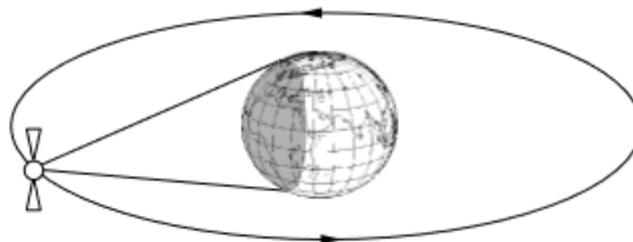


Figure 3.3: Geostationary satellite

As a result of its apparent fixed position in the sky, the satellite can be used 24 hours a day as a permanent relay for the uplinked radio frequency carriers. Those carriers are down linked to all earth stations visible from the satellite (shaded area on the earth in Figure 3.3). Due to

its fixed position in the sky, there is no need for tracking the satellite. This simplifies the VSAT equipment and installation[9].

3.3 VSAT Satellite Network Topology

There are three types of VSAT network topologies; star, mesh, and hybrid.

In star topology, each VSAT terminal transmits and receives only to the hub as shown in Figure 3.4-A. This does not preclude the VSAT terminals from communicating among them, because VSAT-to-VSAT communication can be routed via the hub using a double satellite hop. The majority of VSAT networks use star topology because the large antenna gain at the hub optimizes the use of the space segment and minimizes the size of the VSAT terminal. The drawback of star topology is that the delay for VSAT to VSAT communication doubles in comparison to single hop transmission[1].

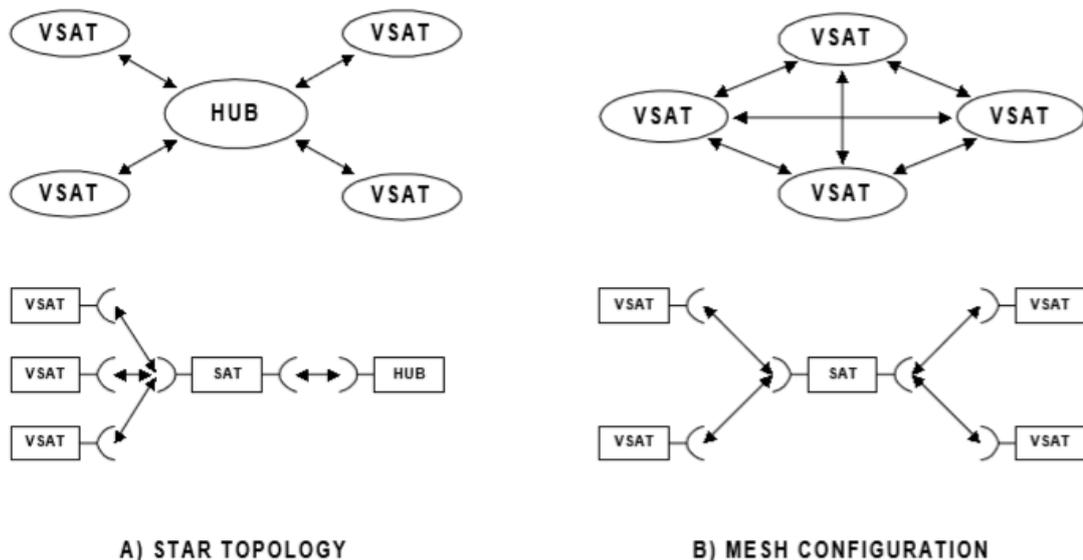


Figure 3.4 : Commonly Used VSAT Topologies

Mesh topology shown in Figure 3.4-B allows all terminals to communicate with each other directly. A hub must control the

communication set up and tear down process, but need not be involved in carrying traffic. Sometimes, a VSAT terminal is equipped with the network management and control equipment, and the network is said to operate hublessly. Because each VSAT must have sufficient power and receive sensitivity (G/T) to communicate with every other VSAT, mesh topology requires larger antennas and SSPAs (Solid State Power Amplifiers) than star topology. Mesh technologies are well suited for applications such as voice that cannot tolerate delay[5].

Hybrid topology allows a group of VSAT terminals to communicate in mesh topology while others communicate only in star topology. This topology is useful for networks in which certain terminals have larger traffic demand between themselves than the other terminals. The terminals with higher traffic demand can be accommodated in mesh to reduce the expense of extra equipment at the hub, and satellite resources required for a double hop. The rest of the network can communicate with any of these larger terminals or each other via a star topology[1].

3.4 VSAT Multiple Access Techniques

A satellite link can relay signals from a single earth station. These signals must be separated to avoid interfering with each other. This separation to share the bandwidth is called multiple access. The most common forms of multiple access are:

1. Single Channel Per Carrier (SCPC)

Single Channel per Carrier (SCPC) is a satellite transmission system that employs a separate carrier for each channel; as opposed to frequency division multiplexing that combines many channels on a single carrier as shown in Figure 3.5.

The primary advantage of SCPC is that the architecture allows full connectivity between sites in the network. Additionally, SCPC allows incremental usage of the satellite transponder and therefore allows a flexible expansion of the network.

There are, however, several disadvantages in SCPC when compared with the other techniques. For example in SCPC system, each channel requires a separate satellite modem at each earth station. This results in an incremental cost in ground equipment and has to be considered based on the number of circuits required at each site[8].

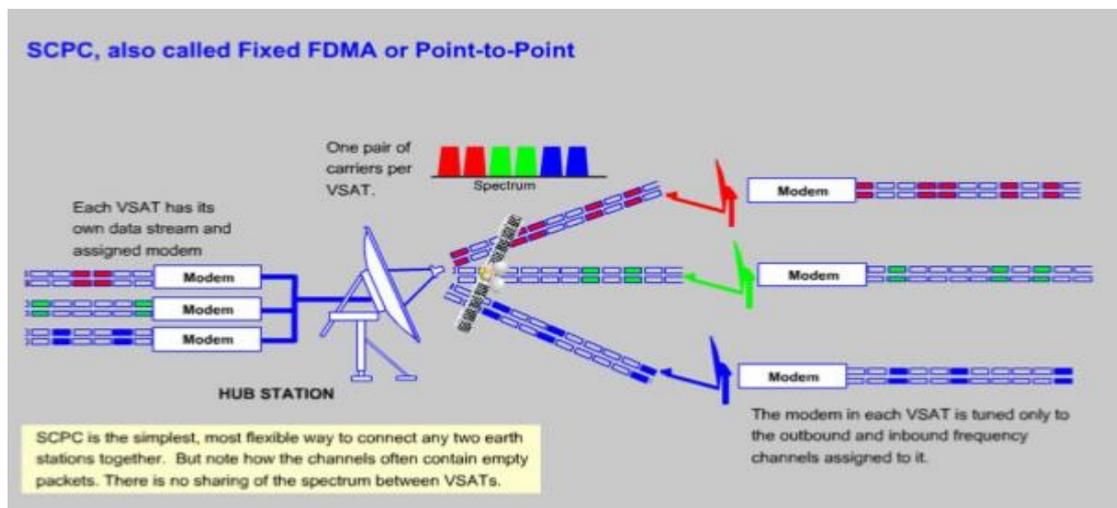


Figure 3.5 : SCPC Technology

In simple terms this is nothing but lease lines in the sky (as illustrated before in Figure 3.2). SCPC Channels can be either Pre Assigned Multiple Access (PAMA) or Demand Assigned Multiple Access (DAMA).

PAMA: in this access method the bandwidth is assigned permanently to the two VSATs terminals to communicate to each other. This assigned bandwidth will be available to the VSAT's on a permanently basis. This link can either be a symmetric and asymmetric link. It is nothing but a point to point connectivity[10].

The PAMA service interconnects high data traffic sites within an organization. It is a cost-effective alternative to terrestrial leased lines, providing high reliability links to support mission critical applications.

DAMA: This scheme is very similar to a telephone connection. Whenever, there is a need to talk to someone, a number is dialed. The call lands at the telephone exchange, and the telephone exchange connects the person to the dialed number. The role of the telephone exchange is to connect to the desired number. This is exactly how a DAMA network operates. The HUB plays the role of a telephone exchange, between any two VSAT's. The DAMA service addresses point to point voice, fax, and data communication requirements of remote sites. It provides a cost effective and reliable solution to business having a high internal voice/ fax communication requirements. Additionally it enables organizations with operations in remote areas, to establish a reliable communications network[11].

2. Time Division Multiple Access

The TDMA network operates in a Star topology. All the remote VSATs communicate to the central hub station, on a Time Division Multiple Access Modes. At the hub the signal is re-transmitted to the destination VSAT using TDM technology after amplification. The Access mechanism of TDMA operates on a technology called Slotted Aloha. All the remote VSAT's contend for a time divisional slot to transmit their packets to the Hub. The channel used by the remotes to communicate to the Hub is called the Return Link. Each of these return channels operates at a maximum of 128 Kbps. The Hub communicates to all the destination remotes using the TDM technology.

The communication channel from the Hub to the remote is also called the Outbound or Outlink. It operates at 256 Kbps. In TDM/TDMA the

implementation topology is a Hub & Spoke architecture here all the remote sites communicate to the central site via the HUB. The Hub is connected to the central site on an SCPC connection.

TDM is used for the “outbound” traffic. Hundreds or thousands of VSATs listen to the same outbound carrier signal. TDM is illustrated in Figure 3.6[12].

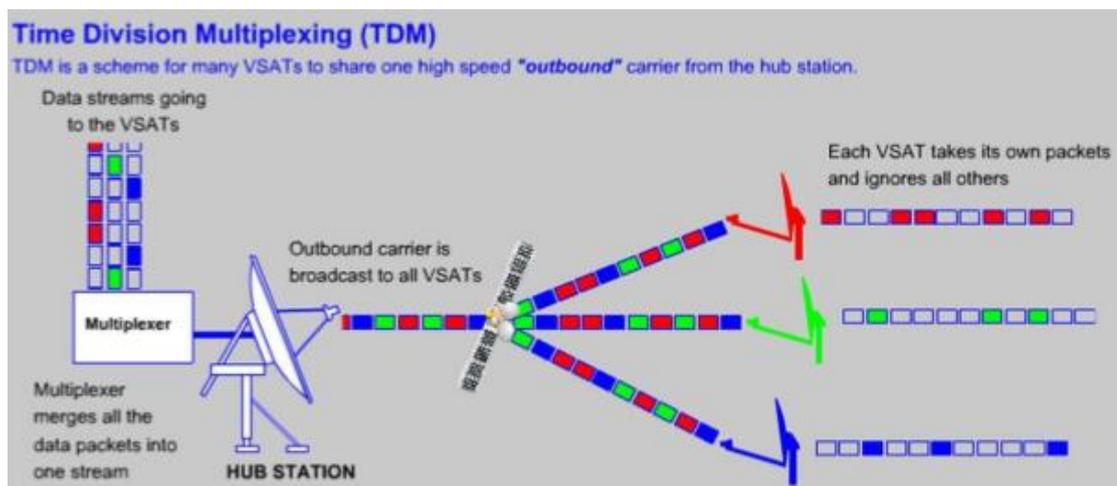


Figure 3.6 : TDM Scheme

3. Carrier in Carrier (CnC)

Space segment costs are typically the most significant operating expense for any satellite-based service, having a direct impact on the viability and profitability of the service. A satellite transponder having finite resources in terms of bandwidth and power, the transponder leasing costs are determined by bandwidth and power used. For optimal utilization, a satellite circuit should be designed to use similar share of transponder bandwidth and transponder power.

Once the satellite and earth station parameters are fixed, the traditional approach to balancing a satellite circuit involves trade-off between modulation and coding. A lower order modulation requires less transponder power while using more bandwidth. Conversely, higher

order modulation reduces the required bandwidth, but at a significant increase in power[2].

Comtech EF Data has added a new dimension to satellite communication optimization – Carrier-in-Carrier (CnC). This innovative technology provides a significant improvement in bandwidth and power utilization, beyond what is possible with forward error correction (FEC) and modulation alone, allowing users to achieve unprecedented savings. When combined with advanced Modulation and FEC, it allows for multi dimensional optimization[4];

- Reducing Operating Expenses(OPEX)
 - e.g. : Occupied Bandwidth & Transponder Power.
- Reducing Capital expenditures(CAPEX)
 - e.g. : Block-Up Converter/ High Power Amplifier (BUC/HPA) Size and/or Antenna Size.
- Increasing throughput without using additional transponder resources.
- Increasing link availability (margin) without using additional transponder resources.
- A combination of any of the above to meet different objectives.

Traditional full-duplex links utilize frequency division multiplexing to allow communications in two directions. This requires allocating two frequency bands – one for each direction (A and B). These standard carriers must occupy non-overlapping spectral segments with no more than one carrier in the same space.

Carrier-in-Carrier uses a signal processing algorithm that allows both the forward and reverse carriers of a full duplex link to share the same segment of transponder bandwidth, using adaptive cancellation.

CnC allows the two carriers to reside on the same center frequency, a practice that is disastrous for normal carriers. When carriers share common bandwidth, up to 50% savings in transponder utilization is possible[11].

3.5 Carrier in Carrier VS Single Carrier Per Channel

Figure 3.7 illustrates a conventional, full duplex satellite link where two carriers are placed in non-overlapping channels. Figure 3.8 shows the same link using the modulator equipped with the Carrier-in-Carrier option. Note that only 50% of the bandwidth is being used, as both carriers are now occupying the same bandwidth[4].

The transponder downlinks the composite signal containing both carriers on the same band to the modem which then translates the signal to near baseband where it can be filtered (decimated) and then processed as a complex envelope signal. The modem then suppresses the version of the near end carrier on the downlink side and then passes the desired carrier.

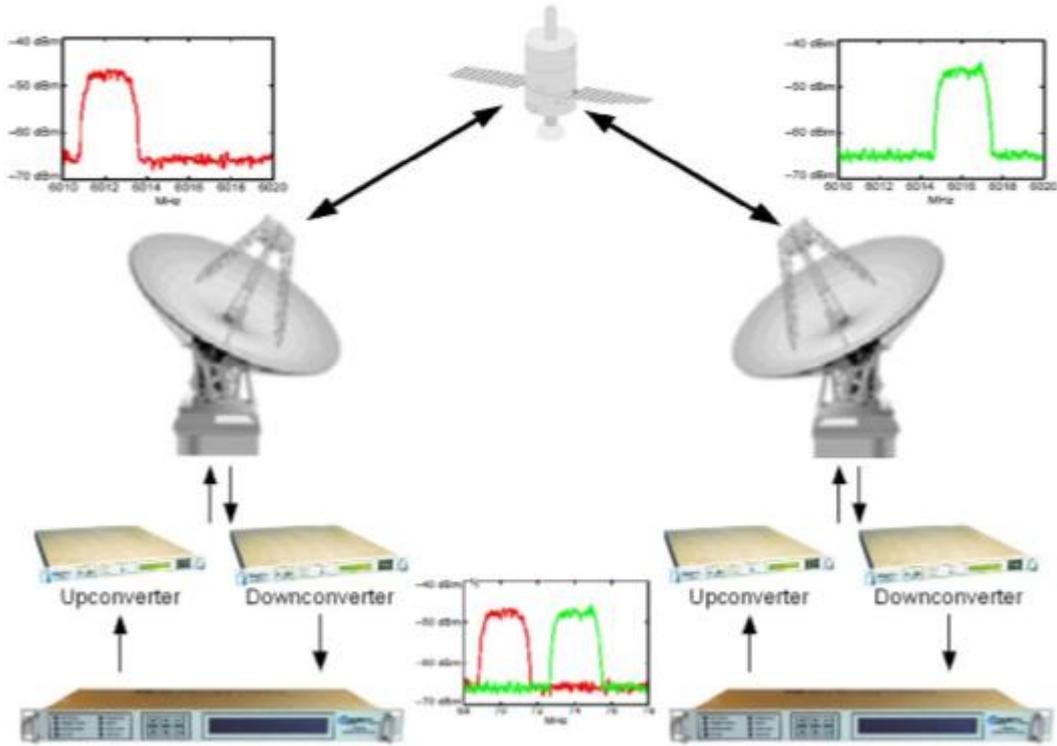


Figure 3.7 : Conventional FDMA Link

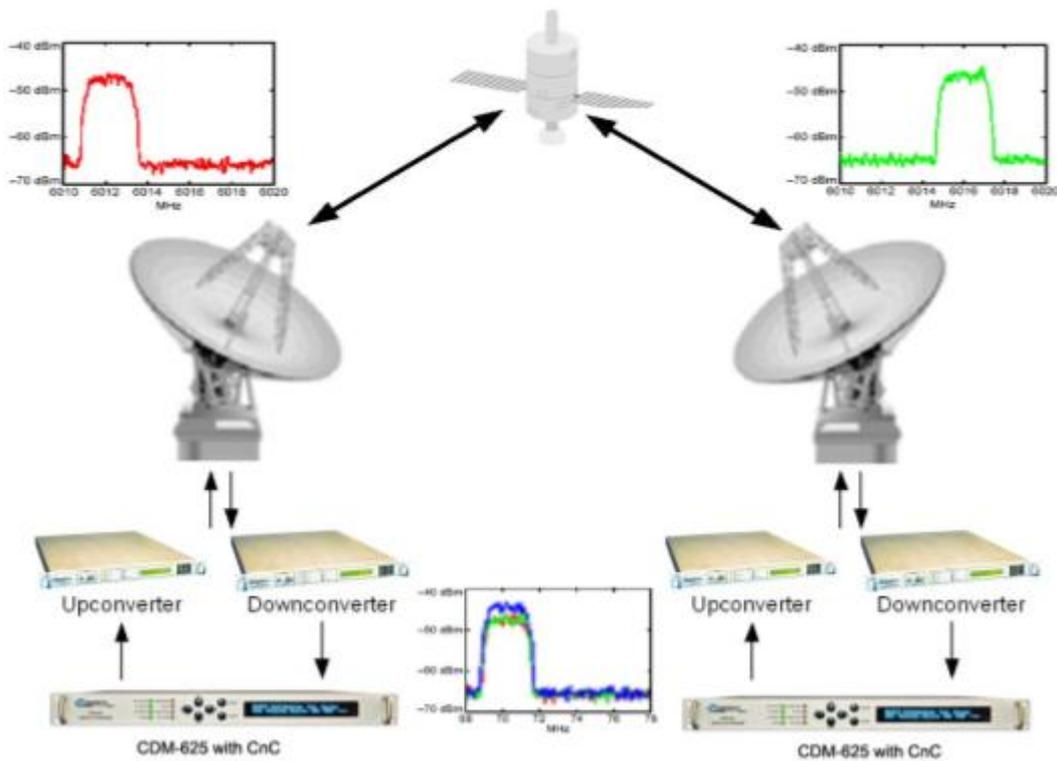


Figure 3.8 : Same Link Using a CnC modem

To further illustrate, without Carrier-in-Carrier, the two carriers in a typical full duplex satellite link are adjacent to each other as shown in Figure 3.9. With Carrier-in-Carrier, only the composite signal is visible when observed on a spectrum analyzer. Carrier 1 and Carrier 2, shown here for reference only, are overlapping, thus sharing the same spectrum[4].

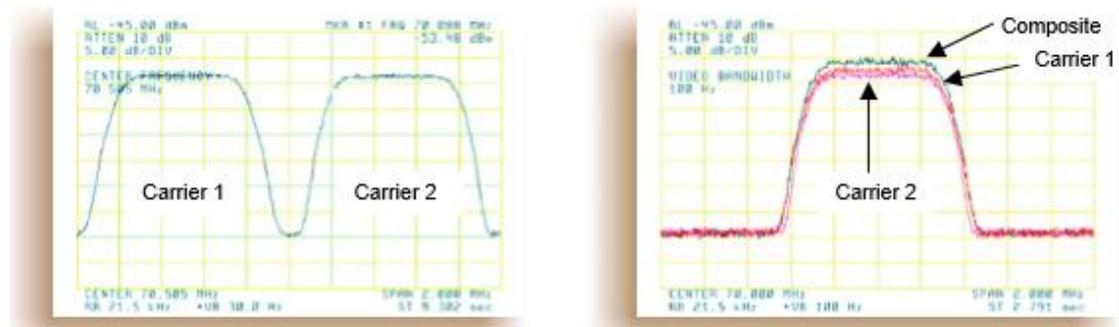


Figure 3.9 : Duplex Link Optimization

Carrier-in-Carrier is complementary to all advances in modern technology, including advanced FEC and modulation techniques. As these technologies approach theoretical limits of power and bandwidth efficiencies, Carrier-in-Carrier utilizing advanced signal processing techniques provides a new dimension in bandwidth and power efficiency.

As Carrier-in-Carrier allows equivalent spectral efficiency using a lower order Modulation and/or FEC Code, it can simultaneously reduce CAPEX by allowing the use of a smaller BUC/HPA (Block-Up Converter/ High Power Amplifier) and/or antenna.[2]

As Carrier-in-Carrier can be used to save transponder bandwidth and/or transponder power it has been successfully deployed in bandwidth-limited as well as power-limited scenarios.

3.6 Carrier in Carrier Block Diagram

Figure 3.10 shows a simplified conceptual block diagram of CnC processing. The two ends of the link are denoted 'A' and 'B' and the uplink and downlink are shown below:

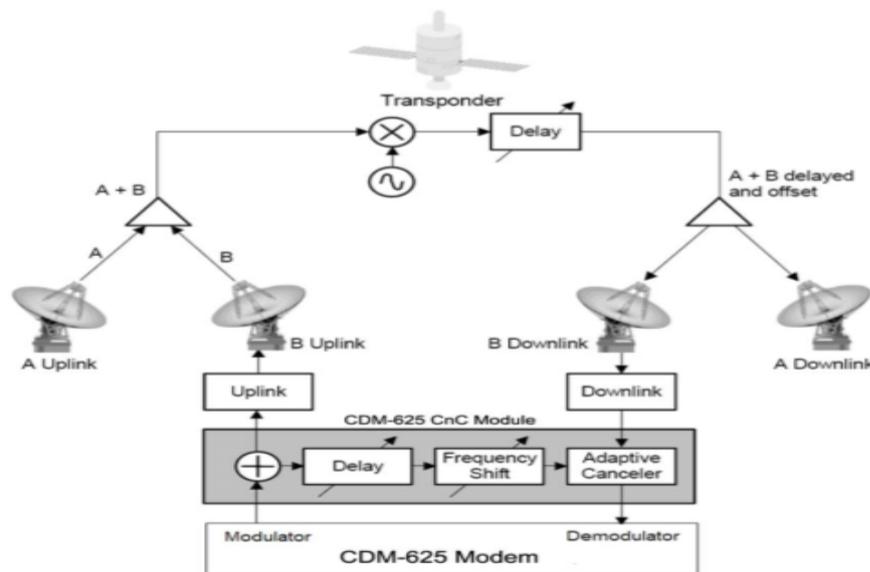


Figure 3.10 : Conceptual CnC Block Diagram

CnC is a technique in which two satellite communication signals are transmitted on the same channel signal. The greatest benefit of this technique is the savings of bandwidth[7].

To demodulate the mixed downlink signal, digital signal processing is used to cancel one of the two signals in the receiver, resulting in recovery of the second signal. Two steps for cancelling the first signal: In the first step the first signal is known a priori by the receiver, perhaps from a paired transmitter at the receiver's location in a two-way communications system. In the second step, the two uplink signals differ significantly in power levels resulting in a high-power (HP) signal and a low-power (LP) signal. The difference in power levels allows the HP signal to be demodulated directly by the receiver. If the LP signal desired, then after demodulating the HP signal, the receiver can re-

modulate that signal to create an inverted replica to cancel the original downlinked HP signal. This action results in the LP signal which can then be demodulated directly[4].

This performance is achieved through advanced signal processing algorithms that provide superior cancellation while tracking and compensating for the following common link impairments:

- 1) Time varying delay: In addition to the static delays of the electronics and the round-trip delay associated with propagation to the satellite and back, there is a time-varying component due to movement of the satellite. The CnC module tracks and compensates for this variation.
- 2) Frequency offset and drift: Common sources are satellite Doppler shift, up and down converter frequency uncertainties, and other drift associated with the electronics in the modem itself. The CnC module tracks and compensates for this frequency offset and drift.
- 3) Atmospheric effects: Fading and scintillation can affect amplitude, phase, and spectral composition of the signal and the degree to which it correlates with the original signal. The CnC module tracks and compensates for these atmospheric related impairments.
- 4) Link Asymmetries: Various asymmetries in the forward and return link can produce differences in the relative power of the two received signal components. These can be both deterministic (static) or random (and time varying). An example of the former would be the differences resulting from antenna size/gain variations between the two ends of the link. An example of the latter would be transient power differences due to different levels of atmospheric fading in the uplinks. CnC compensates for the asymmetries, up to a certain extent.

3.7 Carrier in Carrier Cancellation Process

In a traditional full duplex satellite connection between two sites, separate satellite channels are allocated for each direction. If both directions transmit on the same channel, each side would normally find it impossible to extract the desired signal from the aggregate due to interference originating from its local modulator as shown in Figure 3.11. However, since this interference is produced locally, it is possible to estimate and remove its influence prior to demodulation of the data transmitted from the remote location[2].

Carrier-in-Carrier achieves state-of-the-art performance by combining the latest signal processing technology. It continually estimates and tracks all parametric differences between the local uplink signal and its image within the downlink. Through advanced adaptive filtering and phase locked loop implementations, it dynamically compensates for these differences by appropriately adjusting the delay, frequency, phase and amplitude of the sampled uplink signal. The result is excellent cancellation performance[4].

For the Carrier-in-Carrier cancellation, it is necessary to provide each demodulator with a copy of its local modulator's output.

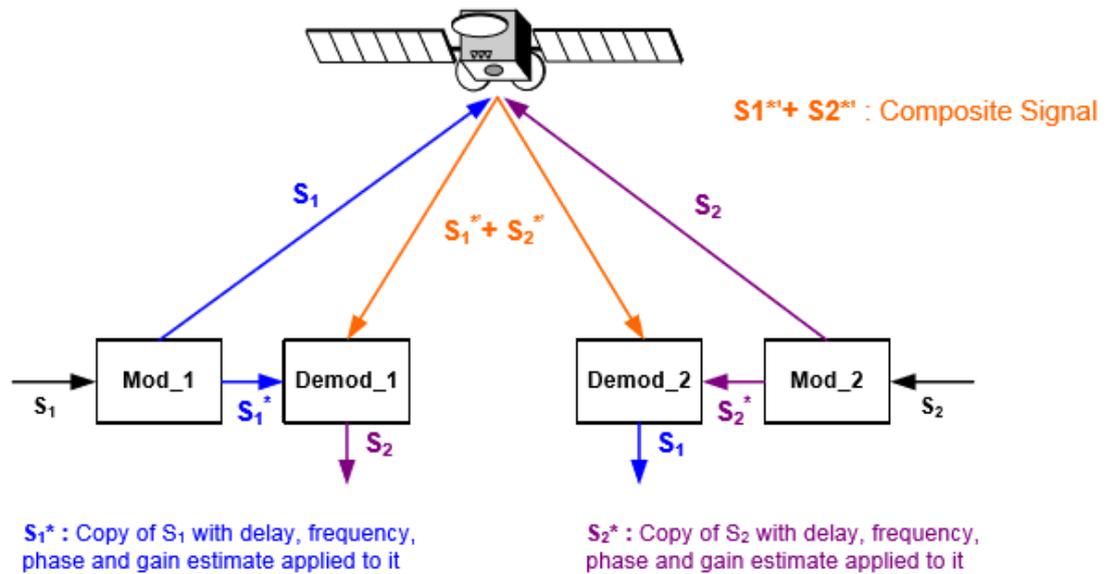


Figure 3.11 : Carrier-in-Carrier Signals

For round trip delay estimation, a search algorithm is utilized that correlates the received satellite signal to a stored copy of the local modulator's transmitted signal. The interference cancellation algorithm uses the composite signal and the local copy of S_1 to estimate the necessary parameters of scaling (complex gain/phase), delay offset and frequency offset. The algorithm continuously tracks changes in these parameters as they are generally time-varying in a satellite link[4].

The resulting estimate of the unwanted interfering signal is then subtracted from the composite signal. In practical applications, the estimate of the unwanted signal can be extremely accurate. Unwanted interfering signal suppression of 30 dB or more has been achieved in commercial products with minimal degradation of the demodulator performance. Figure 3.12 shows the cancellation process of CnC[2].

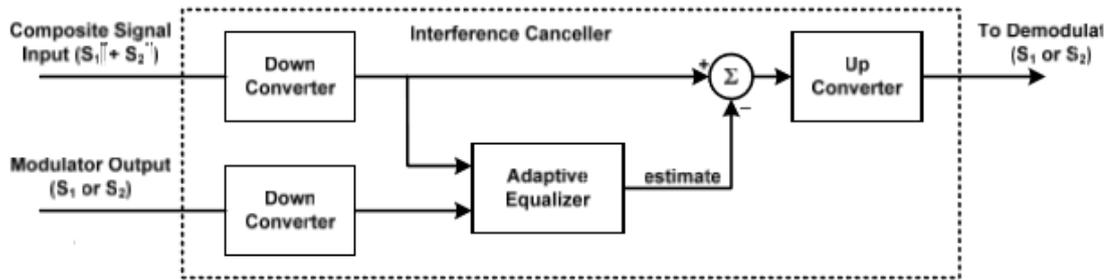


Figure 3.12 : Carrier-in-Carrier cancellation process Block Diagram

A CnC communication system is shown in Figure 3.13. There are two terminals communicating peer to peer, together with a satellite transponder satisfying the following requirements[9]:

- In a CnC communication system, the two terminals, or satellite stations, use the same communication resources for uplink and downlink, respectively.
- That means, both terminals transmit signals in the same frequency band, time slot and CDMA code space, sharing the same uplink channel, and both terminals share the same downlink channel.

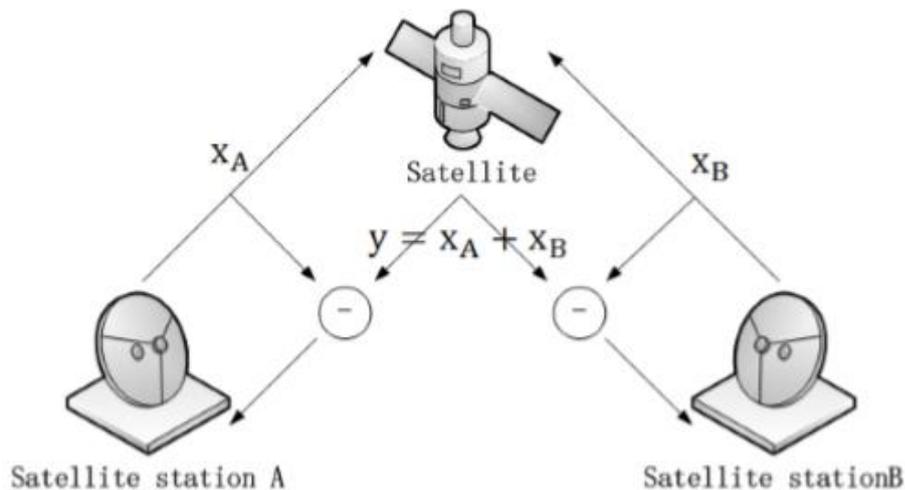


Figure 3.13 : CnC Communication System

The CnC operates as follows:

Terminal (satellite station) A and B generate data symbol sequences to be transmitted, denoted as s_A and s_B , where :

$$s = \{s_0, s_1, s_2, \dots, s_n, \dots\} \quad (3.1)$$

Data symbol sequences are modulated using shaping filters g_A and g_B , respectively, and modulated signals x_A and x_B are transmitted to the satellite transponder.

$$x(t) = a_0 + \sum_{n=0}^{\infty} s_n g(t - nT) \quad (3.2)$$

where T denotes the sampling period.

The satellite transponder amplifies both signals respectively and transmits their sum using the downlink channel in a broadcast method (Both terminals share the same downlink channel). Denoting α_A and α_B as the propagation fading factor after satellite transponder's amplification, τ_A and τ_B as the propagation delay, signal received by one terminal, or a third party receiver, can be expressed as :

$$y(t) = \alpha_A x_A(t - \tau_A) + \alpha_B x_B(t - \tau_B) + n(t) \quad (3.3)$$

where $n(t)$ is additive Gaussian white noise.

The terminal estimates the amplification (fading) factor $\hat{\alpha}$ and propagation delay $\hat{\tau}$ of the signal it transmits, and suppresses the estimated signal from received signal.

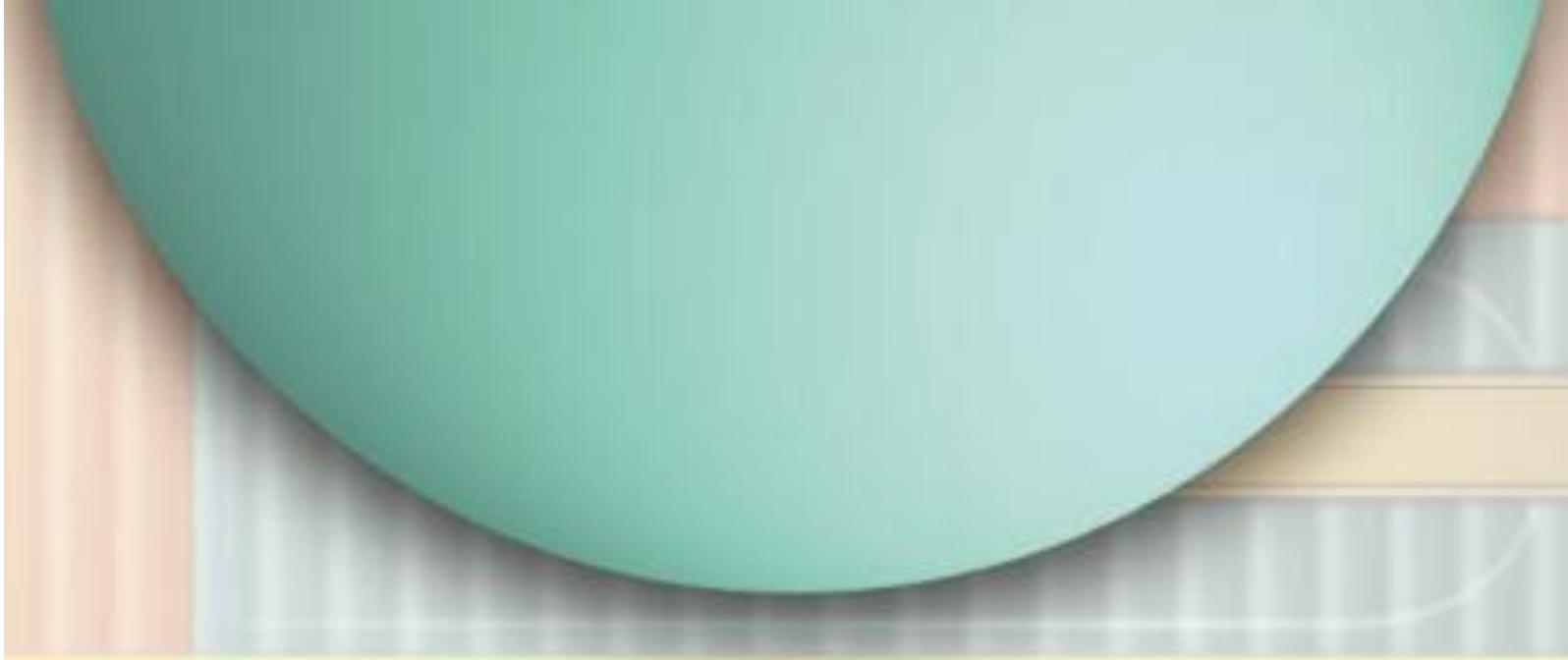
Taking terminal A as example, it can extract the signal transmitted by its communicating peer terminal B as follow:

$$\hat{x}_B(t) = y(t) - \hat{\alpha}_A x_A(t - \hat{\tau}_A) = \alpha_B x_B(t - \tau_B) + (\alpha_A x_A(t - \tau_A) - \hat{\alpha}_A x_A(t - \hat{\tau}_A)) + n(t) \quad (3.4)$$

When $\hat{\alpha}_A \approx \alpha_A$ and $\hat{\tau}_A \approx \tau_A$, then

$$\hat{x}_B(t) \approx \alpha_B x_B(t - \tau_B) + n(t) \quad (3.5)$$

s_B can then be demodulated and decoded using original methods. From the description of CnC, it can be concluded that CnC calls for half resources for two-way peer to peer communication. If parameter (fading factor and propagation delay) is estimated accurately, no performance loss is introduced. When the parameter estimation is not that accurate, $(\alpha_A x_A(t - \tau_A) - \hat{\alpha}_A x_A(t - \hat{\tau}_A))$ can be regarded as additive noise, and the system suffers from a power gain loss[9].



Chapter Four

Simulation & Results

4.1 Introduction

In this chapter two parts will be discussed; the CnC link budget and the CnC spectrum utilization. In the CnC link budget the power needed for each carrier to be transmitted will be calculated and the comparison between traditional SCPC and CnC in bandwidth utilization will be provided using Graphical User Interface (GUI). In the CnC spectrum utilization a practical evaluation will be carried out to compare the performance of the CnC with the SCPC technique.

4.2 Carrier in Carrier Link budget

The first step in designing a satellite network is to analyze the satellite link budget. The link budget determines; the size of the antennae to be used, the Solid State Power Amplifiers (SSPAs) or the Traveling Wave Tube Amplifiers (TWTAs) or the High Power Amplifier (HPA) for power requirements, the link availability and bit error rate, and in general, the overall customer satisfaction.

What a link budget actually involves is a relatively simple addition and subtraction of gains and losses within an RF link. When these gains and losses of the various components are determined and summed, the result is an estimation of the end-to-end system performance in real world. To get an accurate answer, factors such as the uplink power amplifier gain and noise factors, transmit antenna gain, slant angles and corresponding atmospheric loss over distance, satellite transponder noise levels and power gains, receive antenna and amplifier gains and noise factors, cable losses, adjacent satellite interference levels, and climatic attenuation factors must be taken into account. Figure 4.1 shows the data parameters needed in calculating the link budget. It consists of; the information data, data carrier, satellite data, earth station data and the attenuation data.

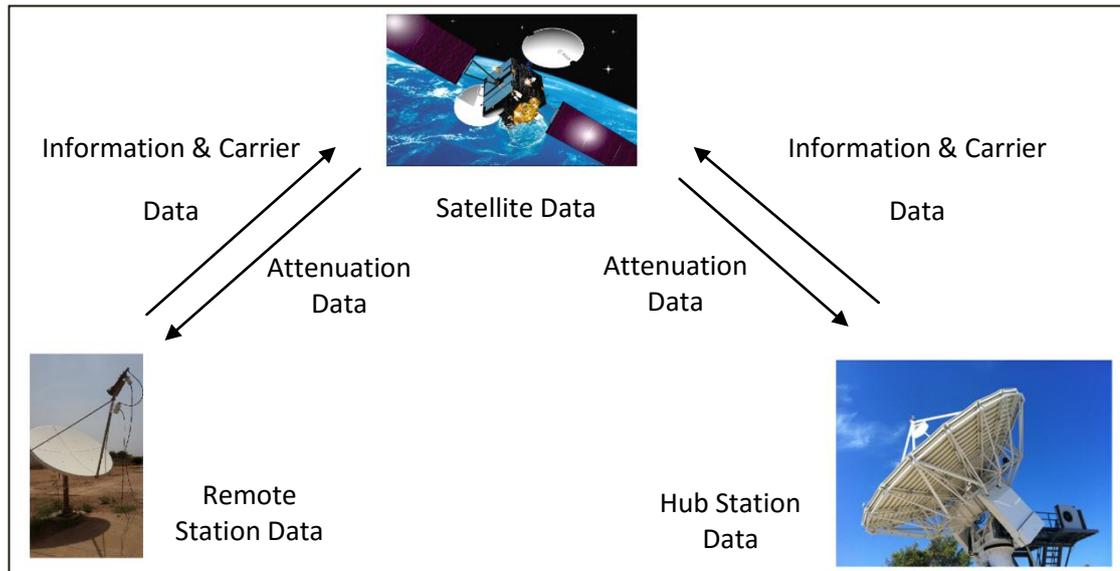


Figure 4.1 : Link Budget Data Parameters

1. Information Data

It contains the data specification that the user has to send through the satellite. Table 4.1 shows the different parameters needed.

Table 4.1: Information Data

Information Data	
Parameter	Value
Information Rate I	2048 Kbps
RS Coding	YES
RS coding Ratio	<u>1.0896</u>
FEC Code Rate	3/4
Type of Modulation	QPSK
Modulation Factor	2.0
Demod BW Product	1.30
BER Threshold	1.00E-07

Eb/No Required	5.80 dB
Eb/No Margin/System Margin	1 dB

2. Carrier Data

It contains the frequency range or the band type that the satellite deals with for the uplink and the downlink. Arabsat Satellite Badr-6 has been considered in this thesis with the frequency range shown in Figure 4.2, 4.3.

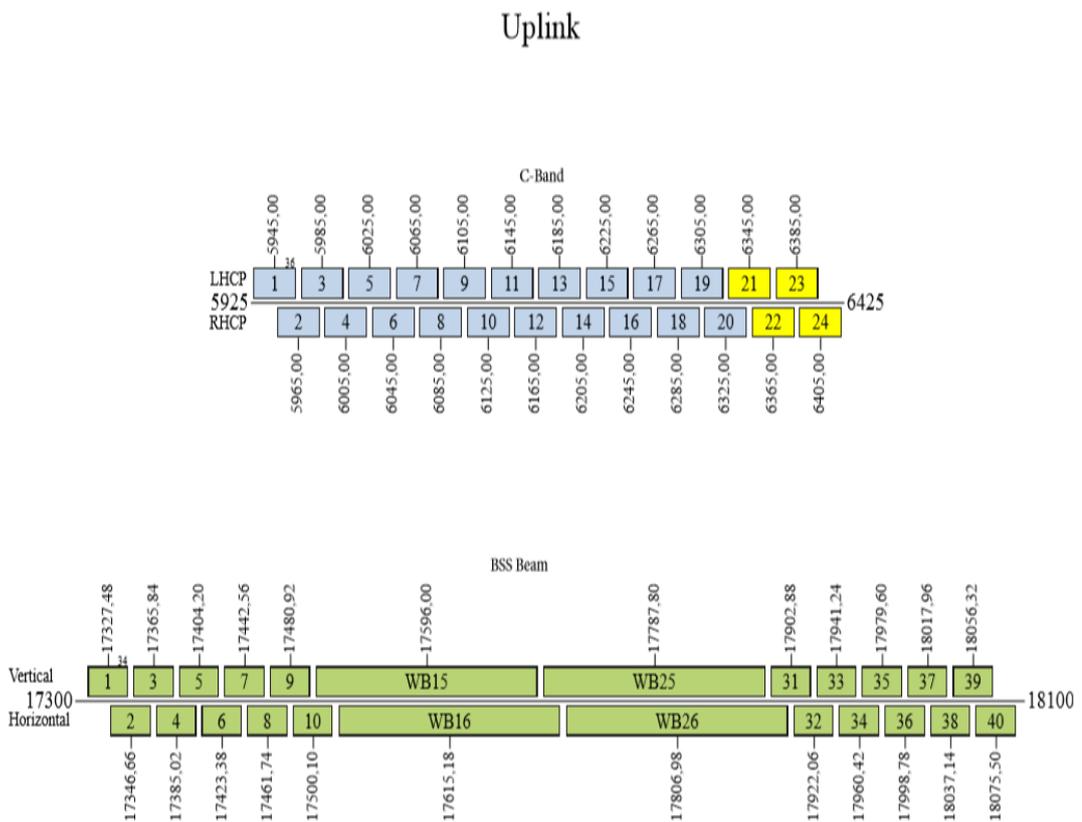


Figure 4.2: Badr-6 Uplink Frequency Range

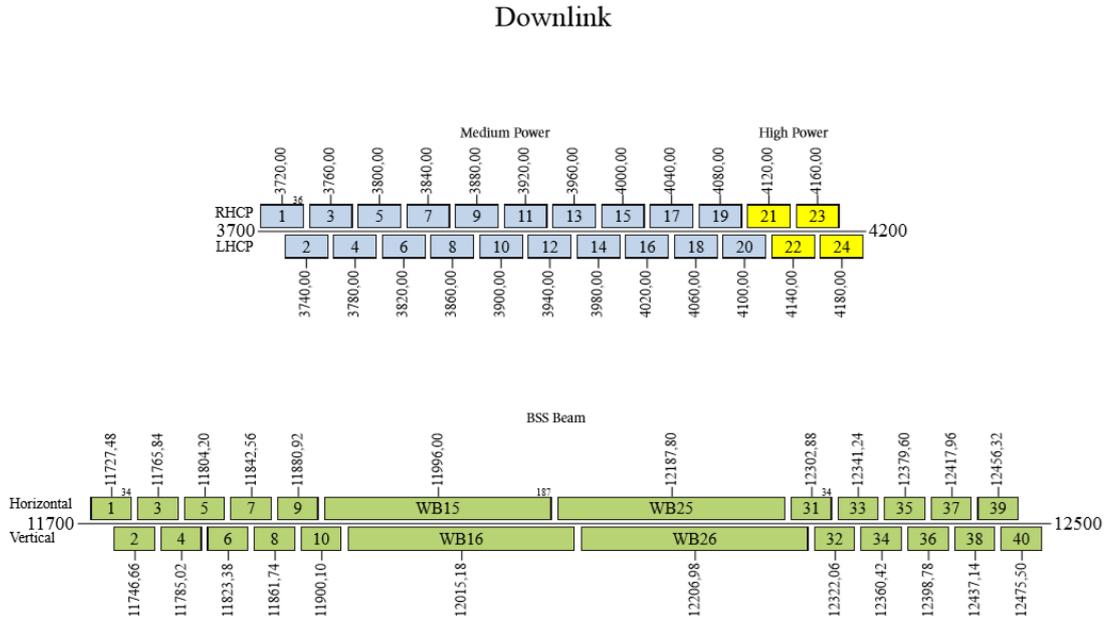


Figure 4.3: Badr-6 Downlink Frequency Range

3. Satellite Data

Satellite data contains the data needed regarding the satellite used. Table 4.2 provides the different parameters of the Arabsat Badr-6

Table 4.2: Satellite Data

Satellite Data		Arabsat Badr-6
Parameter	Value	Unit
Longitude	26.00	deg
Saturation Flux Density	-90.00	dBw/m ²
G/T satellite	-2.00	dB/K
Saturation EIRP	40.00	dBw
Transponder Bandwidth	36.00	MHz
Input Backoff	10.00	dB
Output Backoff	4.50	dB

4. Earth Station Data

Its contains the coordinates of the Hub Earth Station and the Remote Earth Station as described in Table 4.3 and Table 4.4.

Hub Earth Station

Table 4.3: Hub Earth Station Data

Earth Station Data		Hub
Parameter	Value	Unit
Tx Earth Station Diameter	11.2	m
Rx Earth Station Longitude	32.62	deg
Rx Earth Station Latitude	15.62	deg

Remote Earth Station

Table 4.4: Remote Earth Station Data

Earth Station Data		Remote
Parameter	Value	Unit
Rx Earth Station Diameter	3.8	m
LNA Noise Temperature	90	K
Receive Antenna Noise Temperature	40	K
Rx Earth Station Longitude	32.62	deg
Rx Earth Station Latitude	15.62	deg

5. Attenuation Data

It consist of the parameters that attenuate the transmitted signal either in the free space or in the passive components as shown in Table 4.5.

Table 4.5: Attenuation Data

Attenuation Data		
Parameter	Value	Unit
Tx Antenna Feeder Loss	0.5	dB
Tx Antenna Pointing Loss	0.3	dB
Tx Connectors Loss	0.6	dB
Tx Cable Loss	1.5	dB/25m
Uplink Rain Margin	4.0	dB
Rx Antenna Pointing Loss	0.3	dB
Rx Connectors Loss	0.6	dB
Rx Cable Loss	1.5	dB/25m
Downlink Rain Margin	4.0	dB

4.2.1 Graphical User Interface Design

MATLAB software was used to design a GUI that calculates the CnC link budget. The menu driven interactive GUI includes both the uplink and the downlink simulation for the Link Budget calculation. Figure 4.4 shows the main interface of the VSAT Link budget.

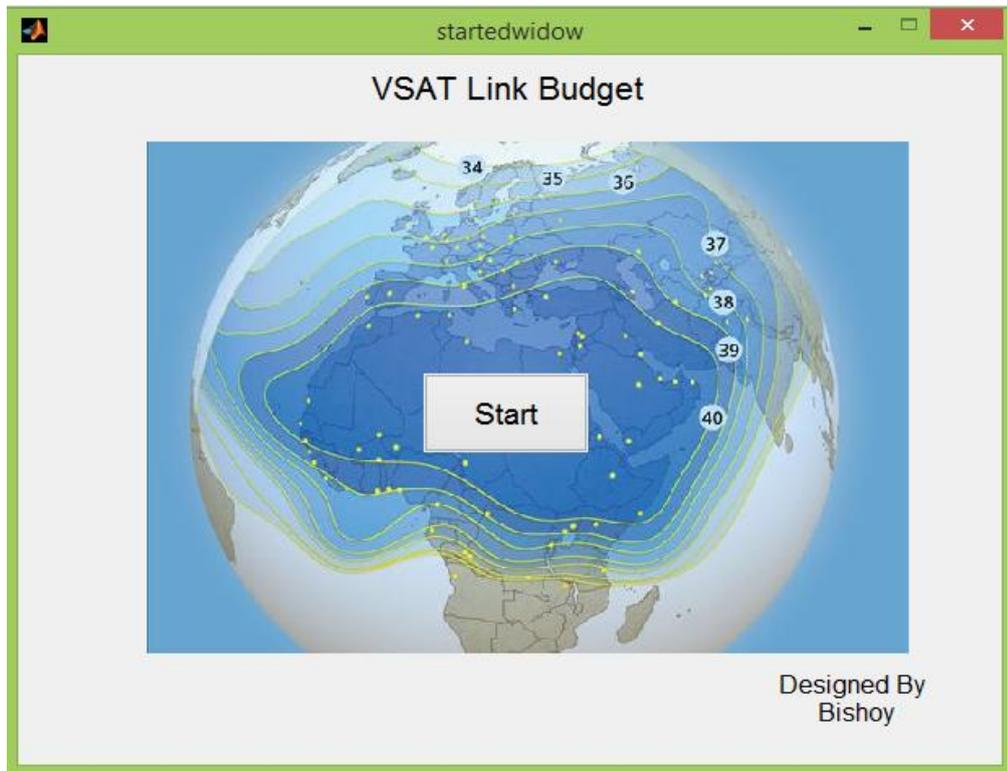


Figure 4.4: Main interface

By pressing the **Start** push button, the window shown in Figure 4.5 appears where the user is asked to enter the parameters of the data to be transmitted. Depending on the data entered, the Information Rate, the Noise Band Width (BW), the C/N Required and the Carrier Spacing are calculated and displayed to the user.

The screenshot shows a software window titled "data" with a standard Windows-style title bar. Inside the window, there is a section titled "Information Data" which contains the following parameters and controls:

- Data Rate:** An empty text input field followed by the unit "Kbps".
- RS Coding Rate:** An empty text input field.
- FEC Code Rate:** An empty text input field.
- Modulation:** A dropdown menu currently showing "BPSK".
- Eb/No required:** An empty text input field followed by the unit "dB".
- Eb/No Margin:** An empty text input field followed by the unit "dB".
- Carrier Spacing Factor:** An empty text input field.
- Uplink Frequency:** An empty text input field followed by the unit "MHz".
- Downlink Frequency:** An empty text input field followed by the unit "MHz".
- Calculate Information Rate:** A button followed by an empty text input field and the unit "dB".
- Calculate Noise BW:** A button followed by an empty text input field and the unit "dB Hz".
- Calculate C/N Required:** A button followed by an empty text input field and the unit "dB".
- Calculate Carrier Spacing:** A button followed by an empty text input field and the unit "KHz".

A "Next" button is located at the bottom right corner of the window.

Figure 4.5 : Information Data window

The different parameters required by the user are;

- **Data Rate:** the different data rates that can be used are 128, 256, 512 1024 Kbps.
- **Reed Solomon (RS) coding rate** is a fixed value equal to 1.0896.
- **FEC Code Rate** can be 1/2, 3/4, 7/8, 0.78,..
- **Modulation Technique:** the different modulation techniques that can be used are BPSK, QPSK, 8PSK, 8QAM and 16QAM.
- **Eb/No required** normally more than Margin with 2dB.
- **Eb/No Margin** is the minimum Eb/No with acceptable BER.
- **Carrier Spacing Factor**, is a factor that measure the space between carrier mostly its equal 5% of the transmitted carrier BW in CnC.

- Uplink Frequency: is the uplink frequency for c-band in the range (5925 – 6425 MHz).
- Downlink Frequency: is the downlink frequency for c-band in the range (3700 – 4200 MHz).

Pressing the Next push button opens the window shown in Figure 4.6. In this window the user has to enter both the satellite parameters and the Earth Station Data. Depending on the data entered, the transmitted Antenna gain, Received Antenna Gain, System Noise Temperature and the G/T Earth Station are calculated and displayed to the user.

The screenshot shows a software window titled 'satdata' with two main sections: 'Satellite Data' and 'Earth Station Data'. Each section contains several input fields with units and a 'Next' button at the bottom right.

Section	Parameter	Unit
Satellite Data	Satellite Longitude	Degree
	Saturation Flux Density	dBw/m ²
	G/T Satellite	dB/K
	Saturation EIRP	dBw
	Transponder Bandwidth	MHz
	Input Backoff	dB
	Output Backoff	dB
Earth Station Data	Tx Earth Station Diameter	m
	Tx Antenna Efficiency	
	Rx Earth Station Diameter	m
	Rx Antenna Efficiency	
	Tx Antenna Gain	dB
	Rx Antenna Gain	dB
	LNA Noise Temperature	K
	Receive Antenna Noise Temperature	K
System Noise Temperature	K	
G/T Earth Station	dB/K	

Figure 4.6: Satellite and Earth Stations Data Window

The satellite data parameters are obtained from the satellite datasheet:

- Saturation Flux Density is equal to -90.0 dBw/m^2 in Badr6.
- Satellite Longitude is between $0-360^\circ$
- G/T Satellite is the noise temperature of the satellite and is equal to -2.0 dB/K in Badr6.
- Saturation EIRP is equal to 40.0 dBw in Badr6.

- Transponder Bandwidth usually is equal 36 MHz for c-band.
- Input Backoff is fixed value equal to 10 dB.
- Output Backoff is usually less than Input Backoff with 5.5dB.

The Earth Stations (Hub and Remote) parameters are :

- Transmitted Earth Station Diameter: is the diameter of the transmitted earth station antenna in the range of 2.4 to 11.2m.
- The Transmitted and Received Antenna Efficiency is in the range of 0.55-0.75.
- Received Earth Station Diameter: is the diameter of the received earth station antenna in the range of 1.2 to 3.8m.
- Low Noise Amplifier (LNA) Noise Temperature is a fixed value depend on LNA material equal to 90 K.
- Received Antenna Noise Temperature is a fixed value depend on antenna material equal to 40 K.

The user then press the Next button to open the coordinate window shown in Figure 4.7. This window contains the Earth Stations coordinate data. The window provides the user with the following data; the transmitting earth station distance from the satellite, the transmitting earth station Azimuth, the transmitting earth station elevation, the receiving earth station distance from the satellite, the receiving earth station azimuth and the receiving earth station elevation.

The screenshot shows a software window titled "coordinate" with a standard Windows-style title bar (minimize, maximize, close buttons). The main content area is titled "Earth stations and Satellite Coordinates" and contains a form with two columns: "Tx" and "Rx". Each column has five input fields with labels and units: "Tx Earth Station Longitude" (Degree), "Tx Earth Station Latitude" (Degree), "Tx Earth Station Distance" (Km), "Tx Earth Station Azimuth" (Degree), and "Tx Earth Station Elevation" (Degree). The "Rx" column has identical fields: "Rx Earth Station Longitude" (Degree), "Rx Earth Station Latitude" (Degree), "Rx Earth Station Distance" (Km), "Rx Earth Station Azimuth" (Degree), and "Rx Earth Station Elevation" (Degree). A "Next" button is located at the bottom right of the form.

Figure 4.7 : Earth Station Coordinates Data Window

Using a compass, the user can enter the Earth Stations coordinates data which are :

- Transmitting Earth Station Longitude is in range between $0-360^{\circ}$.
- Transmitting Earth Station Latitude is in range between $0-180^{\circ}$.
- Receiving Earth Station Longitude is in range between $0-360^{\circ}$.
- Receiving Earth Station Latitude is in range between $0-180^{\circ}$.

Then the uplink and downlink losses are calculated from Figure 4.8.

The screenshot shows a window titled "losses" with a light gray background and an orange border. Inside, there are two main sections: "Uplink Losses" and "Downlink Losses". Each section contains several input fields with "dB" units. Below these sections are four more input fields: "Carrier/Interference Ratio", "Total Uplink Losses", "Total Downlink Losses", "Uplink Free Space Loss", and "Downlink Free Space Loss". A "Next" button is positioned at the bottom right of the window.

Figure 4.8 : Losses Data Window

The losses are either from the equipment where the user can get its value from the equipment's manual or from the nature in free space; the losses are :

- Transmitting Antenna Feeder Loss is about 0.5 dB.
- The Transmitting and receiving Earth Station Contour Loss is a very small value and the user can discard it or put it equal to zero.
- IFL Cable Loss and connector loss in both the transmitting Earth Station and the receiving earth station is about 1.5dB/10 m and each connector can make about 0.3dB losses.
- The Transmitting Antenna Pointing Loss and the receiving antenna pointing loss depend on how accurate the antenna has been installed and is about 0.3 dB for good installation.
- Uplink and downlink Atmospheric Loss is less affecting on c-band, in normal weather it can be discarded.

- Uplink rain margin and the downlink rain margin is less affecting on c-band frequency. It is equal to 0 if there is no rain or can reach 4 dB if there is heavy rain.
- Carrier to Interference Ratio is fixed value about 20 dB.

The user then press the Next button to open the CNR window as shown in Figure 4.9. The CNR window calculates the number of channels, the Carrier to Noise Ratio of both the uplink and downlink and the HPA using the parameters in the previous windows.

The screenshot shows a window titled "CNR" with a sub-header "C/N and HPA Calculation". Inside the window, there are several input fields and buttons:

- "Calculate No. of Channels" with an empty text box.
- "Calculate C/N Uplink" with an empty text box and "dB" to its right.
- "Calculate C/N Downlink" with an empty text box and "dB" to its right.
- "Calculate C/N Total" with an empty text box and "dB" to its right.
- "Nature of Channel" with an empty text box.
- "HPA Power per Carrier" with two empty text boxes, the top one labeled "dBW" and the bottom one labeled "W".

Figure 4.9 : CNR Window

4.3 Practical Analysis of Carrier in Carrier Technology

In this section, a practical analysis is carried out on the devices provided by Sudasat. Sudasat is one of the biggest VSAT companies in the Middle-east and north of Africa. The analysis compares the existing technique SCPC with the new technique CnC in terms of bandwidth utilization. The devices used to perform the analysis are:

1. Um Haraz Hub

A 11.2 m Antenna is used as a Hub Antenna in Um Haraz Station as shown in Figure 4.10.



Figure 4.10: 11.2 m Antenna Hub

This antenna can move automatically searching for the beacon frequency of the satellite. Because it is a hub antenna and it is required to carry many channels, it will need a large SSPAs (one for each polarization) as well as a large LNBs. These are connected to the hub antenna through a waveguide.

To complete the analysis a Comtech modem had been used as shown in figure 4.11. Two modem were used, one to work as a hub modem and the other as a remote modem.



Figure 4.11 : Hub modem-Comtech CDM625A

2. Remote Site

A 2.4 m remote antenna shown in figure 4.12 was used at the remote site.



Figure 4.12 : 2.4 m Remote Antenna

The same model of modem was used at the remote site as shown in figure 4.13.



Figure 4.13 : Hub modem-Comtech CDM625A

4.4 Results and Discussions

This section provides both the simulation and the practical analysis of the CnC compared to SCPC.

4.4.1 Carrier in Carrier Link Budget Results

Figure 4.14 shows the data entered into the information data parameters window and the results obtained.

Parameter	Value	Unit
Data Rate	2048	Kbps
RS Coding Rate	1.0896	
FEC Code Rate	3/4	
Modulation	QPSK	
Eb/No required	6.1	dB
Eb/No Margin	2	dB
Carrier Spacing Factor	1.05	
Uplink Frequency	6133.5	MHz
Downlink Frequency	3908.5	MHz
Calculate Information Rate	63.1133	dB
Calculate Noise BW	61.937	dB Hz
Calculate C/N Required	9.27635	dB
Calculate Carrier Spacing	1640.15	KHz

Figure 4.14 : Information Data window filled with parameters

- Information rate = 63.1133 dB. The information rate is directly proportional to the data rate. If the data rate decrease then the information rate will decrease.
- Noise BW = 61.937 dB Hz. Noise BW is directly proportional to the data rate, RS coding rate and carrier spacing factor; and inversly proportional to FEC code rate and the modulation factor.

- C/N required =9.2764 dB. C/N is directly proportional to the E_b/N_0 required, E_b/N_0 margin, and the information rate. It is inversely proportional to the noise bandwidth.
- Carrier Spacing =1640.15 KHz. It is the bandwidth utilization of the channel (Carrier) which is directly proportional to the noise BW and the carrier spacing factor.

After entering the different parameters, CNR and HPA is calculated as shown in figure 4.15.

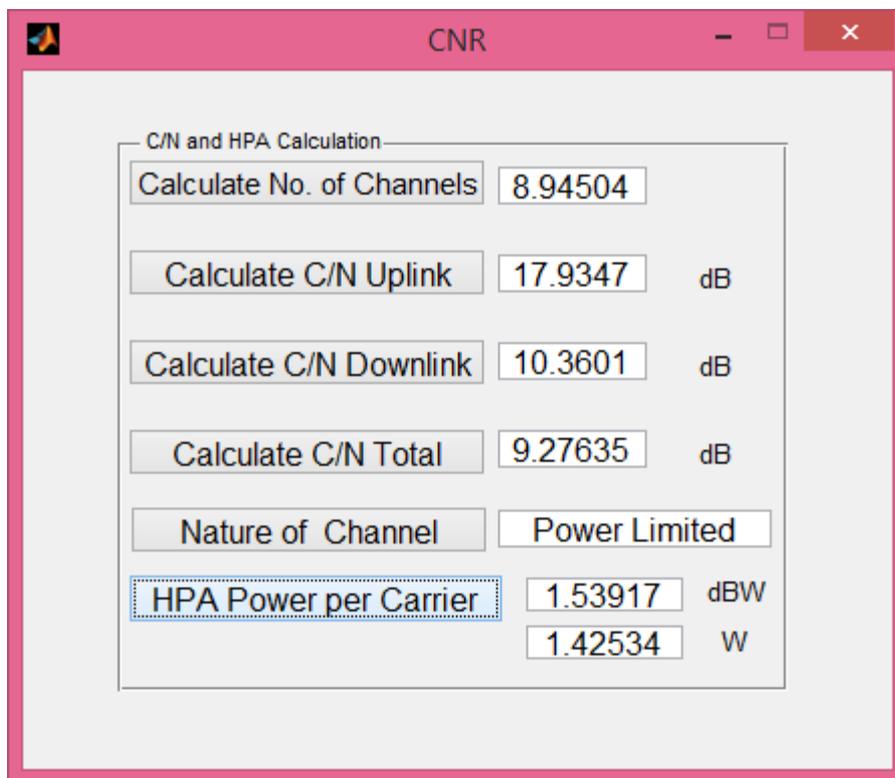


Figure 4.15 : Calculating Carrier to Noise Ratio and HPA in CNR window

- No. of channels = 8.94504, about 9 maximum channels can be transmitted from the transponder with the same data rate 2048. Number of channels is directly proportional to the C/I ratio; and inversely proportional to the data rate and the C/N ratio required increase.

- The C/N Uplink and downlink is inversely proportional to the No. of channels.
- The C/N Total = 9.2764 dB, is directly proportional to the C/N uplink, C/N downlink, and C/I ratio.
- Nature of channel; when it is "power limited" that is means a low modulation technique and CnC technique is highly recommended and when its "Bandwidth limited" a high modulation technique is recommended to save more BW.
- The Tx antenna gain (large antenna diameter) and the satellite antenna gain increases. It increases as the total uplink loss, uplink free space loss, and Tx antenna feeder loss increase

Figure 4.16 shows the relation between the BW and data rate using different modulation techniques.

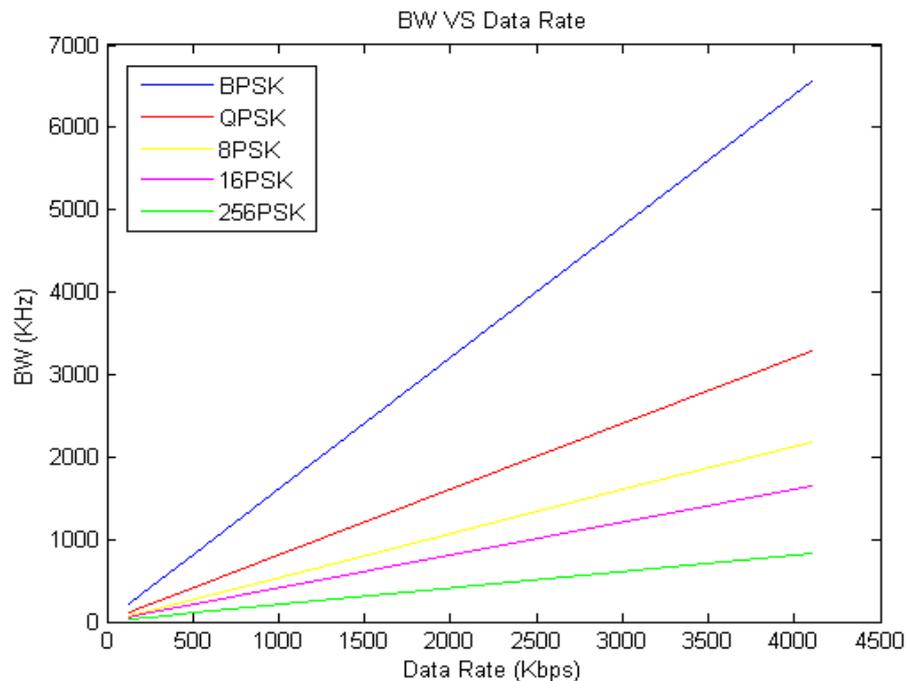


Figure 4.16 : BW vs Data Rate With Different Modulation Factors

Figure 4.16 shows that the BW decreases as the modulation factor increases. Using 256PSK modulation will save about 7 times of the BW when using BPSK modulation for the same data rate.

Figure 4.17 shows the BW utilized when using both the CnC and the SCPC under different data rates and QPSK modulation. The figure shows that the CnC BW utilization is about 50 % of the SCPC BW utilization.

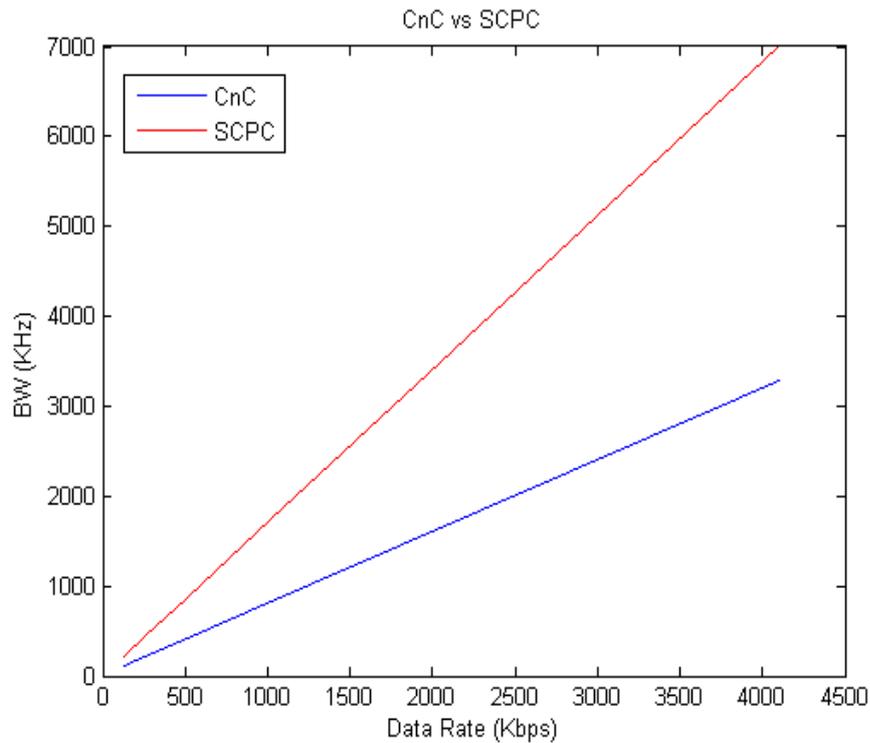


Figure 4.17 : CnC vs SCPC

4.4.2 Practical Analysis Procedure

In this part a practical analysis was carried out to compare the spectrum utilization of both the CnC and the SCPC.

1. Single Carrier Per Channel Analysis

The testing parameters needed for SCPC analysis are shown in Table 4.6.

Table 4.6: SCPC Data Parameter

Customer & Location	#E1	BW (MHz)	Uplink Carrier C.F	Downlink Carrier C.F	TX HUB LO4900 (MHz)	RX HUB & Remote (MHz)	EbNo THRESHOLD	MODULATION
SCPC Hub Carrier	1	0.95	6132.03	3907.03	1232.03	1242.97	6.1	SCPC VerFEC 8QAM 0.78
SCPC Remote Carrier	1	0.95	6132.97	3907.97	1232.97	1242.03	6.1	SCPC VerFEC 8QAM 0.78

SCPC site installation procedures are as follow;

A) For any new installation the Modem should be configured locally using the front panel and the above parameters should be entered to the Hub modem and the Remote modem. The Tx carrier for both modems should be off.

B) The Tx carrier of the hub modem is switched on and the power is increased as shown in figure 4.17a until the remote modem receive a carrier with about 8.1 dB which is more than threshold with 2 dB as shown in figure 4.17b.

C) The carrier is then seen on the Spectrum Analyzer as shown in figure 4.17c.



Figure 4.17a : Hub modem power adjustment

The power that can be transmitted from the modem is in the range -40dBm to -17dBm. -17dBm is the highest power that can be transmitted through the modem, more than -17dBm the BUC will go into saturation. Figure 4.17a shows the power at the hub modem = -29.5 dBm which is not high because the diameter of the transmitted antenna is 11.2m.

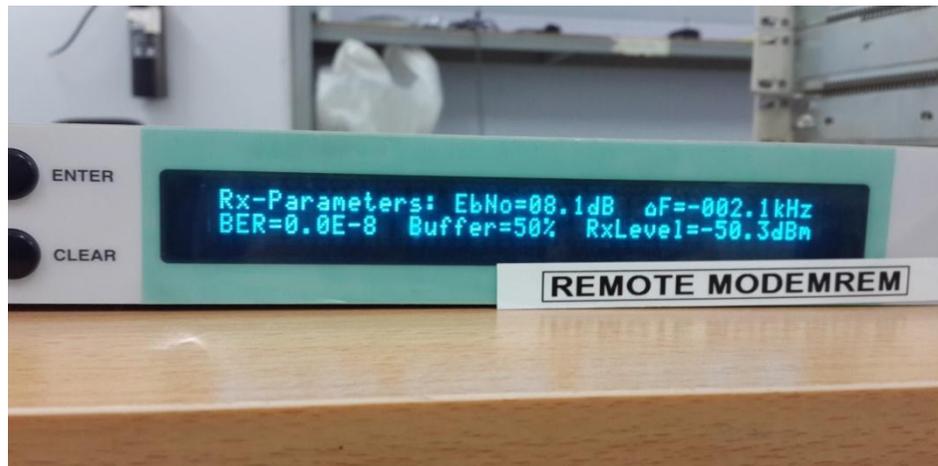


Figure 4.17b : Received Eb/No at remote site

Figure 4.17b show the Eb/No received by the remote modem which is 8.1 dB with an acceptable BER of 10^{-8} . If the Eb/No is less than 6.1(Eb/No Margin) then the BER will become less than 10^{-6} which is not an acceptable rate.

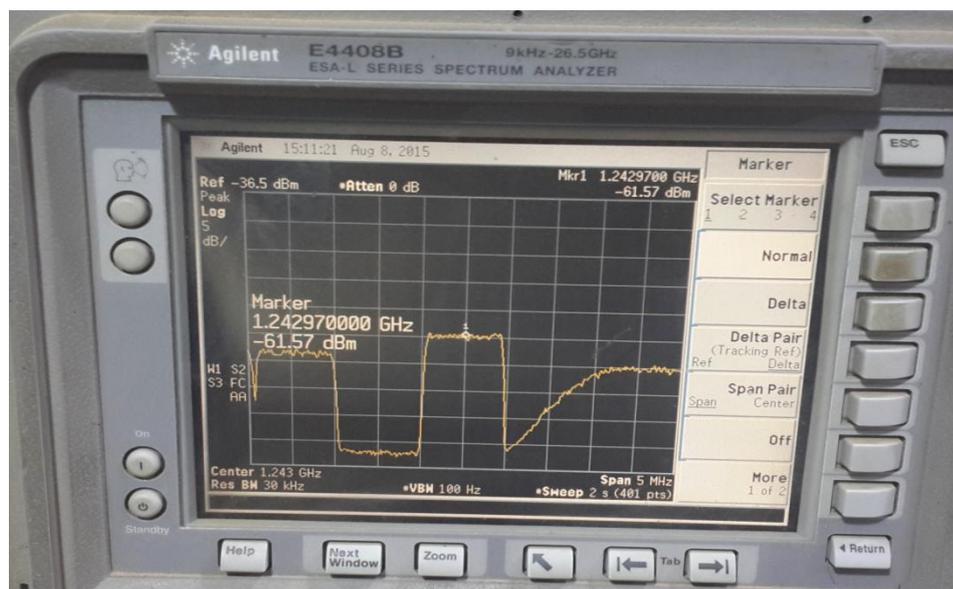


Figure 4.17c : Hub Tx Carrier with 5MHz span

Figure 4.17c, shows the spectrum of the received carrier which is 1.24297 MHz for the uplink. As the Spectrum span a 5MHz, the BW of the received carrier is measured which is about 1MHz.

D) The hub's Tx carrier is switched off.

E) The Tx carrier of the remote modem is switch on and the power is increased as in figure 4.18a until the hub modem receives a carrier of 8.1 dB which is more than threshold with 2 dB as shown in figure 4.18b.

F) The carrier is then seen on the Spectrum Analyzer as shown in figure 4.18c.

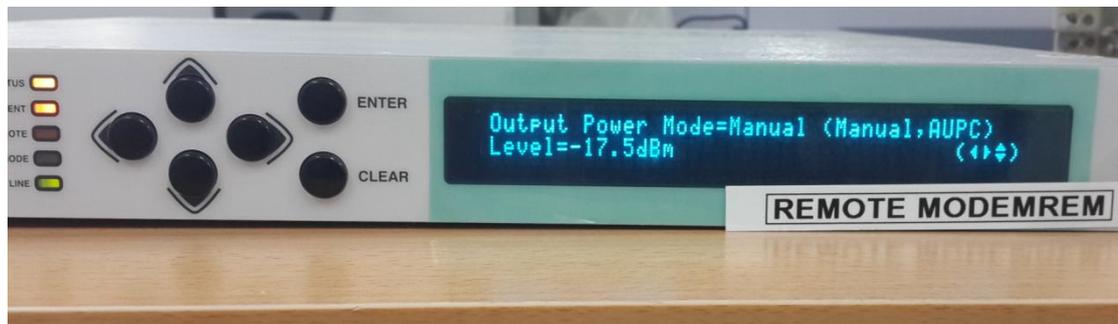


Figure 4.18a : Remote modem power adjustment

The power that can be transmitted from the modem is in the range -40dBm to -17dBm. -17dBm is the highest power that can be transmitted through the modem, more than -17dBm the BUC will go into saturation. Figure 4.18a shows the power at the Remote modem = -17.5 dBm which is very high because the diameter of the transmitted antenna is 2.4m.

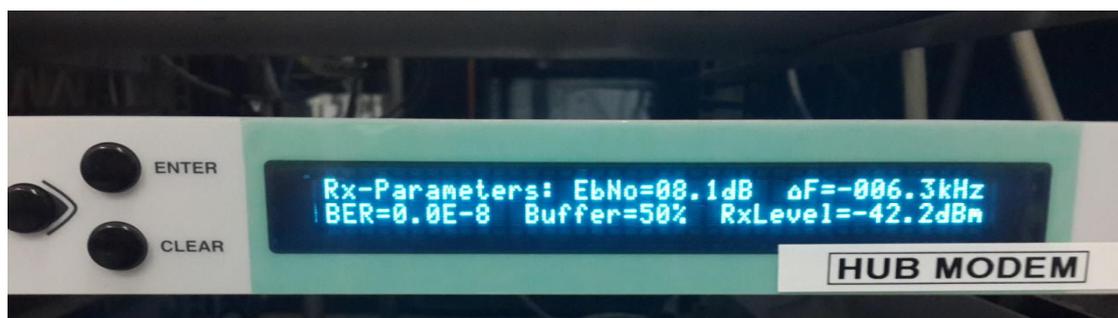


Figure 4.18b : Received Eb/No at hub site

Figure 4.18b show the E_b/N_0 received by the remote modem which is 8.1 dB with an acceptable BER of 10^{-8} . If the E_b/N_0 is less than 6.1(E_b/N_0 Margin) then the BER will become less than 10^{-6} which is not an acceptable rate.

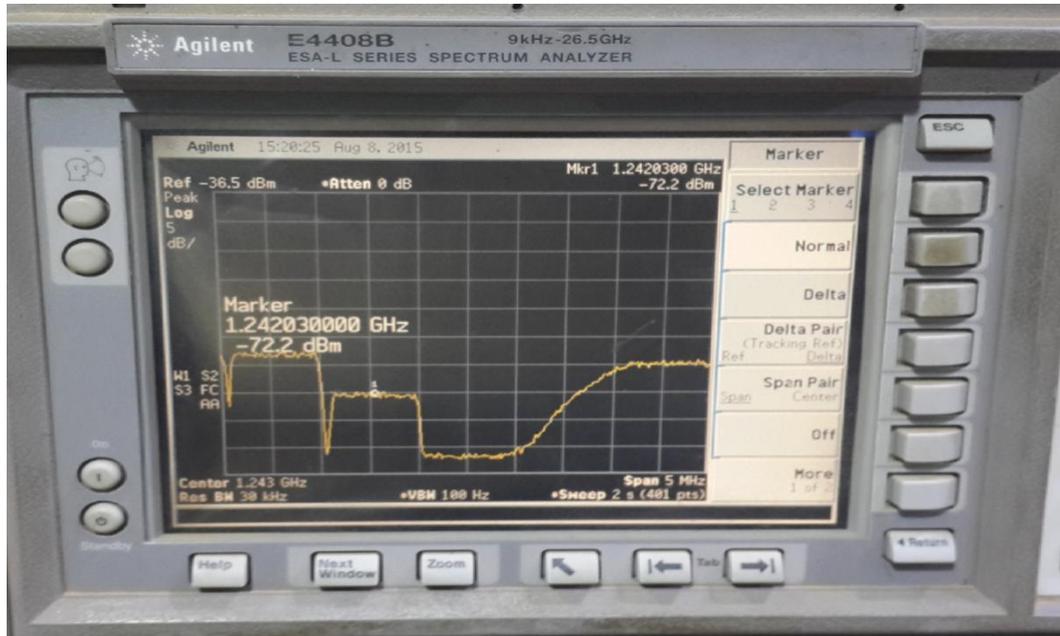


Figure 4.18c : Remote Tx Carrier with 5MHz span

Figure 4.18c, shows the spectrum of the received carrier which is 1.24203 MHz for the uplink. As the Spectrum span a 5MHz, the BW of the received carrier is measured which is about 1MHz.

G) Now the connectivity is ready. The Tx carrier of the hub is switch on as shown in Figure 4.19.

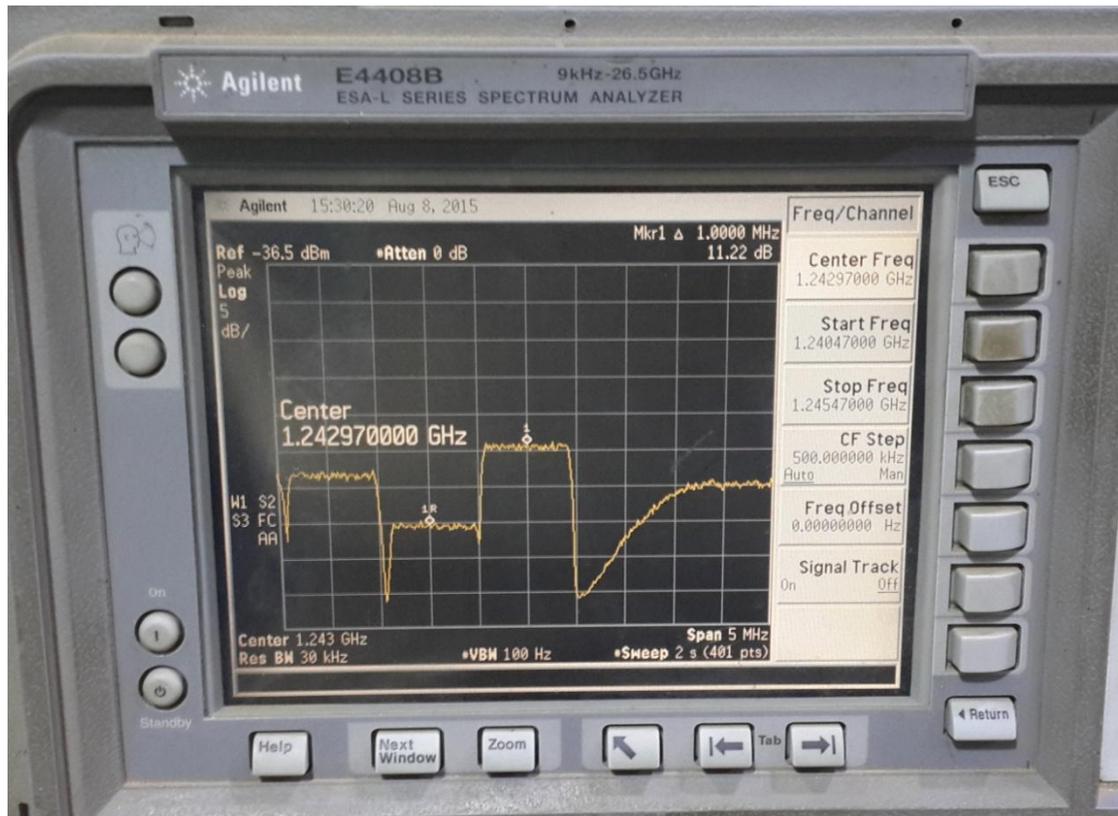


Figure 4.19 : SCPC spectrum utilization

Figure 4.19 shows that the hub carrier power is more than the remote carrier, this is because the hub antenna is bigger than the remote antenna.

SCPC carriers in spectrum take 2MHz from the transponder, 1MHz for the uplink and 1MHz for the down link.

2. Carrier in Carrier Analysis

The testing parameters needed for CnC analysis shown in Table 4.7.

Table 4.7 : CnC data parameter

Customer & Location	#E1	BW (MHz)	Uplink Carrier C.F	Downlink Carrier C.F	TX HUB LO4900 (MHz)	RX HUB & Remote (MHz)	EbNo THRESHOLD	MODULATION
CnC Hub Carrier	1	0.95	6132.5	3907.5	1232.5	1242.5	6.1	CnC VerFEC 8QAM 0.78
CnC Remote Carrier	1	0.95	6132.5	3907.5	1232.5	1242.5	6.1	CnC VerFEC 8QAM 0.78

CnC site installation procedures are as follow;

- A) The steps from A-F shown in the SCPC analysis are repeated.
- B) After switching on the Tx carrier of both sites; the CnC option from the front panel of both modems is switch on.
- C) The carrier will be shown in the spectrum as in figure 4.20.

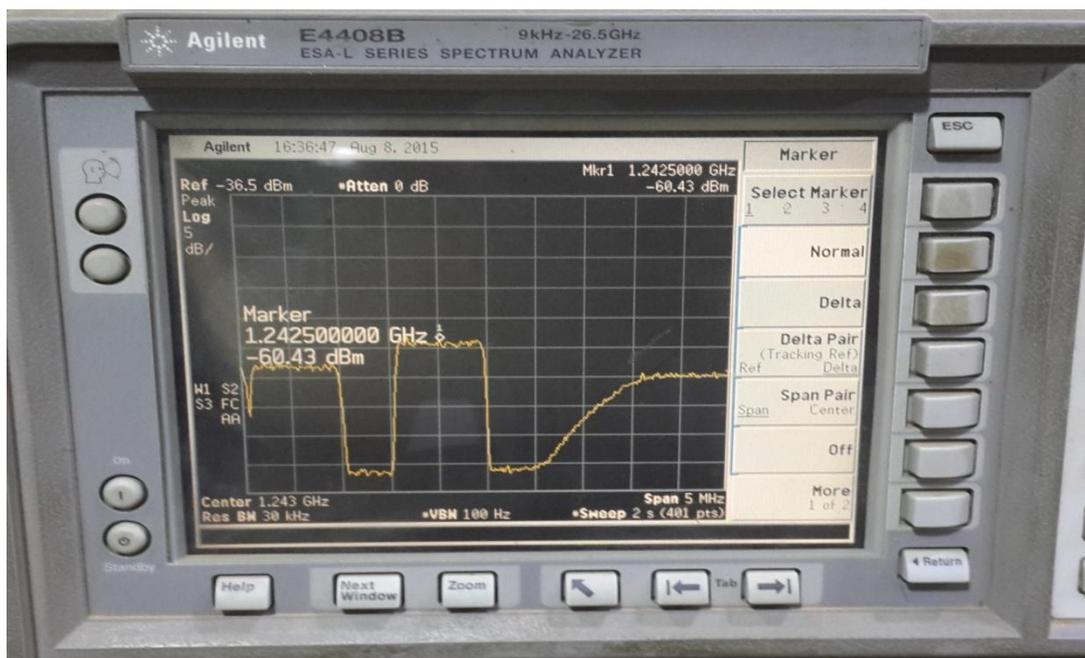


Figure 4.20 : CnC spectrum utilization

Figure 4.20 shows the uplink and the downlink carrier having a value of 1.2425 GHz, which means that both the uplink and downlink carriers use the same spectrum 1 MHz from the transponder.

Comparing figure 4.19 (SCPC spectrum utilization) and figure 4.20 (CnC spectrum utilization), show that the CnC use only about 50% of the spectrum that the SCPC uses.

CnC allows satellite users to achieve spectral efficiencies (bps/Hz) that cannot be achieved with modulation and FEC alone. Table 4.8 illustrates how the CnC, when used with 16-QAM, approaches the bandwidth efficiency of 256-QAM (8bps/Hz).

Table 4.8 : CnC vs SCPC in Spectrum Efficiency

Modulation and Code Rate	Spectral Efficiency (bps/Hz)	
	TraditionalSCPC	Carrier-in-Carrier
BPSK 1/2	0.50	1.00
QPSK 1/2	1.00	2.00
QPSK 2/3	1.33	2.67
QPSK 3/4	1.50	3.00
QPSK 7/8	1.75	3.50
8-QAM 2/3	2.00	4.00
8-QAM 3/4	2.25	4.50
8-QAM 7/8	2.63	5.25
16-QAM 3/4	3.00	6.00
16-QAM 7/8	3.50	7.00

Table 4.8 shows that CnC allows equivalent spectral efficiency using a lower order modulation and/or FEC Code Rate; CAPEX is therefore reduced by allowing the use of a smaller BUC/HPA and/or antenna. The table also shows that the CnC can be used to save transponder bandwidth and/or transponder power, it can be successfully deployed in bandwidth-limited as well as power-limited scenarios.



Chapter five

Conclusion & Recommendation

5.1 Conclusion

Satellite with VSAT systems come with characteristics of a dynamic flexibility, dependability, low cost, easy to use, and a direct link up to the user through a local station. VSAT satellites work on GEO orbit in which they appear fixed. To ensure proper coverage in a particular location, a Link Budget calculation is needed. It is used to determine the maximum distance at which a transmitter and receiver can successfully operate.

Traditional full-duplex links (SCPC) utilize frequency division multiplexing to allow communications in two directions. This requires allocating two frequency bands – one for each direction. VSAT spectrum is limited and it is shared by all the regions in the world, for that, saving spectrum is desirable. CnC is one of various techniques that the satellite industry is using to help reduce bandwidth costs for customers and improve network performance.

In this thesis Matlab software was used to design a graphical user interface to calculate the BW utilized by the CnC technique and compare it with the SCPC traditional technique. A practical evaluation also carried out to compare the performance of both techniques. The results from both the simulation and the practical analysis showed that the CnC uses 50% of the BW used by the SCPC.

5.2 Recommendations

A lot of work has been done in this thesis but still there is room for more improvement;

- In this thesis the CnC link budget was calculated using simulation. The implementation of the physical modem by using FPGA technique in embedded system is recommended.
- In this thesis the GUI was designed to test the performance of different parameters such as power per carrier, BW, data rate, and modulation factor. It is recommended that other parameters such as BER, carrier interferers, antenna diameter to be taken into consideration.
- In this thesis the study was about Carrier in Carrier which means carrying one two single carriers in same BW. Studying about Multi Carrier Per Channel (MCPC), which is using the same BW for inbound (transmitted single carrier) and outbound (receiving multi carriers) is recommended.

Appendix

Graphical User Interface Code for Carrier in Carrier Link Budget

The GUI Code for CnC link budget has been done in MATLAB Program. The code has 6 m-files integrating together as follow:

1. startedwindow.m

```
% --- Outputs from this function are returned to the command
line.
function varargout = startedwindow_OutputFcn(hObject,
eventdata, handles)
% varargout  cell array for returning output args (see
VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see
GUIDATA)
% Get default command line output from handles structure
varargout{1} = handles.output;
imshow('G:\Satellite Communication\arabsat-badr-6-c-band-
downlink.jpg')
% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton1 (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see
GUIDATA)
run data;
%%% <http://www.mathworks.com MathWorks> '
```

2. data.m

```

function pushbutton1_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton1 (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see
GUIDATA)
global DR RSCR FEC MOD EBNR EBNM CSF UF DF ID1
DR=str2num (get(handles.DR, 'string'));
RSCR=str2num (get(handles.RSCR, 'string'));
FEC=str2num (get(handles.FEC, 'string'))
MOD = get(handles.MOD, 'Value'); %get currently selected option
from menu
if MOD == 1
    MOD=1;
elseif MOD == 2
    MOD=2;
elseif MOD == 3
    MOD=3;
elseif MOD == 4
    MOD=3;
elseif MOD == 5
    MOD=4;
end
MOD=MOD
EBNR=str2num (get(handles.EBNR, 'string'));
EBNM=str2num (get(handles.EBNM, 'string'));
CSF=str2num (get(handles.CSF, 'string'));
UF=str2num (get(handles.UF, 'string'));
DF=str2num (get(handles.DF, 'string'));
ID1=10*log10 (DR*1000);
set(handles.ans1, 'string', ID1);
global DR RSCR FEC MOD NBW1 NBW CSF
NBW=DR*RSCR*CSF/FEC/MOD
NBW1=10*log10 (NBW*1000)
set(handles.ans2, 'string', NBW1);
global EBNR EBNM ID1 NBW1 CNR1_dB
CNR1_dB=EBNR+EBNM+ID1-NBW1

```

```

set(handles.ans3, 'string', CNR1_dB);
global CSF NBW
CS=CSF*NBW
set(handles.ans4, 'string', CS);
run satdata;

```

3. satdata.m

```

global SL UF DF SNT RAG GTES GTS IBO SFD SEIRP OBO TB TAG
SL=str2num (get(handles.SL, 'string'));
SFD=str2num (get(handles.SFD, 'string'));
GTS=str2num (get(handles.GTS, 'string'));
SEIRP=str2num (get(handles.SEIRP, 'string'));
TB=str2num (get(handles.TB, 'string'));
IBO=str2num (get(handles.IBO, 'string'));
OBO=str2num (get(handles.OBO, 'string'));
TESd=str2num (get(handles.TESd, 'string'));
TAE=str2num (get(handles.TAE, 'string'));
RESd=str2num (get(handles.RESd, 'string'))
RAE=str2num (get(handles.RAE1, 'string'))
LNAN=str2num (get(handles.LNAN, 'string'));
RANT=str2num (get(handles.RANT, 'string'));
DF=DF
TAG=10*log10 (TAE*(10.472*UF*TESd/1000)^2);
RAG=10*log10 (RAE*(10.472*DF*RESd/1000)^2);
SNT=LNAN+RANT;
GTES=RAG-10*log10 (SNT);
set(handles.ans1, 'string', TAG);
global RAG
set(handles.ans2, 'string', RAG)
global SNT
set(handles.ans3, 'string', SNT);
global GTES
set(handles.ans4, 'string', GTES);
% --- Executes on button press in nexttocoordinate.
function nexttocoordinate_Callback(hObject, eventdata,
handles)
% hObject    handle to nexttocoordinate (see GCBO)

```

```
% eventdata reserved - to be defined in a future version of
MATLAB
% handles structure with handles and user data (see
GUIDATA)
run coordinate;
```

4. coordinate.m

```
% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject handle to pushbutton1 (see GCBO)
% eventdata reserved - to be defined in a future version of
MATLAB
% handles structure with handles and user data (see
GUIDATA)
global TEL TESA SL TESD
TESLG=str2num (get(handles.TESLG,'string'));
TESLA=str2num (get(handles.TESLA,'string'));
TESD=(42164.2-6378.155)*sqrt(1+0.42*(1-
cos(TESLA*3.14159/180)*cos(abs(SL-TESLG)*3.14159/180)))
if TESLG<SL
    TESA=180-180*atan(tan( abs(SL-
TESLG)*3.14159/180)/sin(TESLA*3.14159/180))/3.14159;
else
    TESA=180+180*atan(tan( abs(SL-
TESLG)*3.14159/180)/sin(TESLA*3.14159/180))/3.14159;
end
TEL=(atan((42164.2-6378.155*cos(TESLA*3.14159/180)*cos(abs(SL-
TESLG)*3.14159/180))/(6378.155*sin(acos(cos(TESLA*3.14159/180)
*cos(abs(SL-TESLG)*3.14159/180)))) - acos(
cos(TESLA*3.14159/180)*cos(abs(SL-
TESLG)*3.14159/180)))*180/3.14159
set(handles.ans1,'string',TESD);
global TESA
set(handles.ans2,'string',TESA);
global TEL
set(handles.ans3,'string',TEL);
```

```

global SL REL RESA RESD
RESLG=str2num (get(handles.RESLG,'string'))
RESLA=str2num (get(handles.RESLA,'string'))
RESD=(42164.2-6378.155)*sqrt(1+0.42*(1-
cos(RESLA*3.14159/180)*cos(abs(SL-RESLG)*3.14159/180)))
if RESLG<SL
    RESA=180-180*atan(tan( abs(SL-
RESLG)*3.14159/180)/sin(RESLA*3.14159/180))/3.14159;
else
    RESA=180+180*atan(tan( abs(SL-
RESLG)*3.14159/180)/sin(RESLA*3.14159/180))/3.14159;
end
REL=(atand((42164.2-6378.155*cosd(RESLA)*cosd(abs(SL-
RESLG))))/(6378.155*sind(acosd(cosd(RESLA)*cosd(abs(SL-
RESLG)))))) - acosd(cosd(RESLA)*cosd(abs(SL-RESLG)))
set(handles.ans4,'string',RESD);
global RESA
set(handles.ans5,'string',RESA);
global REL
set(handles.ans6,'string',REL);
% --- Executes on button press in nexttolosses.
function nexttolosses_Callback(hObject, eventdata, handles)
% hObject    handle to nexttolosses (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see
GUIDATA)
run losses;

```

5. losses.m

```

% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton1 (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see
GUIDATA)

```

```

global TDL UF DF TESD UFSL RESD DFSL CIR_dB TUL TFL
TFL=str2num (get(handles.TFL, 'string'));
TECL=str2num (get(handles.TECL, 'string'));
TIFL=str2num (get(handles.TIFL, 'string'));
TCL=str2num (get(handles.TCL, 'string'));
TAPL=str2num (get(handles.TAPL, 'string'));
UAL=str2num (get(handles.UAL, 'string'));
URM=str2num (get(handles.URM, 'string'));
RECL=str2num (get(handles.RECL, 'string'));
RIFL=str2num (get(handles.RIFL, 'string'));
RCL=str2num (get(handles.RCL, 'string'));
RAPL=str2num (get(handles.RAPL, 'string'));
DAL=str2num (get(handles.DAL, 'string'));
DRM=str2num (get(handles.DRM, 'string'));
CIR_dB=str2num (get(handles.CIR_dB, 'string'))
TUL=TECL+TIFL+TCL+TAPL+UAL+URM;
TDL=RECL+RIFL+RCL+RAPL+DAL+DRM;
set(handles.ans1, 'string', TUL);
UFSL=10*log10((4*3.14159*TESD*1000*UF*1000000/299700000)^2)
DFSL=10*log10((4*3.14159*RESD*1000*DF*1000000/299700000)^2)
global TDL
set(handles.ans2, 'string', TDL)
global UFSL
set(handles.ans3, 'string', UFSL);
global DFSL
set(handles.ans4, 'string', DFSL);
% --- Executes on button press in pushbutton6.
function pushbutton6_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton6 (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see
GUIDATA)
run CNR;

```

6. CNR.m

```

% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton1 (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see
GUIDATA)
global UF GTS NBW1 IBO SFD SEIRP TDL DFSL GTES OBO K2_dB
CNR1_dB CIR_dB NOC CNRU_dB CNRD_dB CNRT_dB TB PBW GSQ IBOC
NOC_dB
GSQ=10*log10(4*pi*(UF*1000000/299700000)^2);
K1_dB=SFD-GSQ+GTS-(-228.6)-NBW1-IBO;
K1=10^(K1_dB/10);
K2_dB=SEIRP-TDL-DFSL+GTES-(-228.60)-NBW1-OBO;
K2=10^(K2_dB/10);
CNR1=10^(CNR1_dB/10);
CIR=10^(CIR_dB/10);
NOC=((1/CNR1)-(1/CIR))/((1/K1)+(1/K2));
NOC_dB=10*log10(NOC);
CNRU_dB=K1_dB-NOC_dB;
CNRU=10^(CNRU_dB/10);
CNRD_dB=K2_dB-NOC_dB;
CNRD=10^(CNRD_dB/10);
CNRT=1/(1/CNRU+1/CNRD+1/CIR);
CNRT_dB=10*log10(CNRT);
MSEIRP_dBW=SEIRP-OBO;
MSEIRP=10^(MSEIRP_dBW/10);
SEIRPC_dBW=SEIRP-OBO-NOC_dB;
SEIRPC=10^(SEIRPC_dBW/10);
SEIRPCpercent=SEIRPC*100/MSEIRP;
OBOC=SEIRP-SEIRPC_dBW;
IBOC=OBOC+IBO-OBO;
PBW=SEIRPCpercent*(TB*1000)/100
global K2_dB
set(handles.ans2, 'string', K2_dB);

```

```

global UF GTS NBW1 IBO SFD SEIRP TDL DFSL GTES OBO K2_dB
CNR1_dB CIR_dB NOC_dB CNRU_dB CNRD_dB CNRT_dB TB PBW GSQ IBOC
NOC
GSQ=10*log10(4*pi*(UF*1000000/299700000)^2);
K1_dB=SFD-GSQ+GTS-(-228.6)-NBW1-IBO;
K1=10^(K1_dB/10);
K2_dB=SEIRP-TDL-DFSL+GTES-(-228.60)-NBW1-OBO;
K2=10^(K2_dB/10);
CNR1=10^(CNR1_dB/10);
CIR=10^(CIR_dB/10);
NOC=((1/CNR1)-(1/CIR))/((1/K1)+(1/K2));
NOC_dB=10*log10(NOC);
CNRU_dB=K1_dB-NOC_dB;
CNRU=10^(CNRU_dB/10);
CNRD_dB=K2_dB-NOC_dB;
CNRD=10^(CNRD_dB/10);
CNRT=1/(1/CNRU+1/CNRD+1/CIR);
CNRT_dB=10*log10(CNRT);
MSEIRP_dBW=SEIRP-OBO;
MSEIRP=10^(MSEIRP_dBW/10);
SEIRPC_dBW=SEIRP-OBO-NOC_dB;
SEIRPC=10^(SEIRPC_dBW/10);
SEIRPCpercent=SEIRPC*100/MSEIRP;
OBOC=SEIRP-SEIRPC_dBW;
IBOC=OBOC+IBO-OBO;
PBW=SEIRPCpercent*(TB*1000)/100
set(handles.ans3,'string',NOC);
global CNRU_dB
set(handles.ans4,'string',CNRU_dB);
global CNRD_dB
set(handles.ans5,'string',CNRD_dB);
lobal CNRT_dB
set(handles.ans6,'string',CNRT_dB);
global PBW NBW
if NBW>PBW
set(handles.ans7,'string','Bandwidth Limited');
else
set(handles.ans7,'string','Power Limited');

```

```
end
global SFD GSQ TUL UFSL IBOC TAG TFL HPACdB1 HPACdB1_dB
HPAC_dB HPAC THPA_dB THPA
ESEIRPC=SFD-GSQ+TUL+UFSL-IBOC
HPAC_dB=ESEIRPC-TAG+TFL
HPAC=10^(HPAC_dB/10)
set(handles.ans8,'string',HPAC_dB);
set(handles.ans9,'string',HPAC);
```