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Performance Evaluation of Geostationary Satellites Operating in Sudan

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Abstract: *Wide areas such as remote and rural areas in the world suffer from poor or the absence of communication (phone and internet) services due to the lack or weak network coverage from telecommunications companies in these areas, and often the only possibility mean for an internet connection is the use of satellite-based link, this is why satellite communication services where developed to provide large ranges and capacities with the lowest cost , the aim of this paper is to assess two operating geostationary satellites in Sudan which are Nilesat 102 and Arabsat Badr-6 to evaluate their abilities to provide possible communication services such as mobile satellite services and VSAT technology based on coverage and communication links calculations using STK simulation program, the generated results showed acceptable coverage and link measurements to provide permanent and high quality services.*

Keywords: *Geostationary Satellites, Performance Evaluation, Communication Services, Coverage, Link Analysis*

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I. Introduction

Traditional Cellular and wired communication networks provide communication services to subscribers around the world but endure drawbacks in terms of limited network coverage in wide regions of these countries and the capacity of its networks which is affected by the number of users it can provide its services to without effecting the quality of service provided another critical factor is the cost of building new network infrastructure from cellular network facilities and wired lines in new areas to extend its service scope

Here comes the need for alternative service providers to solve this problem that takes into consideration the wide areas and the long roads in between that needs to be covered, satellite systems represent an important solution to provide communication services to mobile users in remote, low populated , emergency areas and vehicles due to their significant capabilities in terms of persistency, wide area coverage, and broadcast abilities [1].

Satellite communication systems are the outcome of research in the area of communications and space technologies whose aim is to achieve increasing geographical coverage and capacities with the lowest costs, the Second World War provoked the expansion of two different technologies which were missiles and microwaves. Scientists combined these two inventions to open up the era of satellite communications which complements the existing terrestrial networks built on radio networks and cables [2].

The space epoch started in 1957 with the release of the first artificial satellite Sputnik. In 1965 the first commercial geostationary satellite INTELSAT I initiated the long series of INTELSAT, in the same year the first Soviet communications satellite of the MOLNYA series was launched [3].

In general Satellite applications include communication services, Broadcast services, Remote Sensing, Global Positioning System (GPS), Meteorology & Earth Imaging and Radar systems. The satellite network consists of the space, earth and control segments which are satellites, ground gateways and network management stations relatively, they can provide international coverage and robust communication services during emergencies when ground infrastructure systems have been damaged, they are either one-way or two-way radio frequency (RF) transmission systems based on oscillators built in the satellites which operate in a wide frequency spectrum in the 1-30 GHz band. They differ from terrestrial systems in terms of the resources used, cost and transmission technologies and in how they are deployed and operated [4].

Satellite systems can be divided into fixed satellite services (FSS such as VSAT technology), broadcast satellite services (BSS such as Radio and TV) and mobile satellite services (MSS such as Thuraya).

The applications provided by satellite systems include TV and Radio broadcasting and voice and data transmissions for Internet services. Satellite communication systems have initially employed frequency bands of 1 to 4 GHz, which are L or S band. Due to saturation at these frequency low bands high frequency bands above 20 GHz such as Ka band which ranges from 27- 40 GHz have been increasingly utilized for their ability to provide stable broadband services, satellite networks can be used to provide services to mobile users known as the Mobile Satellite Services(MSS) to upgrade its services into 5G technology like the terrestrial networks which has achieved quick developments in recent years [3].

The aim of this study is to evaluate geostationary satellites operating in Sudan in this case Nilesat 102 and Arabsat Badr-6 test their coverage and link characteristics to come to a decision about their ability to present communication services including voice and data services in order to take advantage of their abilities to provide connectivity by possible mobile satellite services or VSAT technology deployment and other possible services for future development.

Satellite Communication Systems:

A communications satellite is an artificial satellite that receives and amplifies radio telecommunications signals via a transponder and creates a communication link between a source transmitter and a receiver at different places on earth, they are used for television, telephone, radio, internet, and military applications.

There are over 2000 communications satellites operating around the world, utilized by both private and government organizations [4], the following bock diagram shows the main parts of the Satellite communication system:

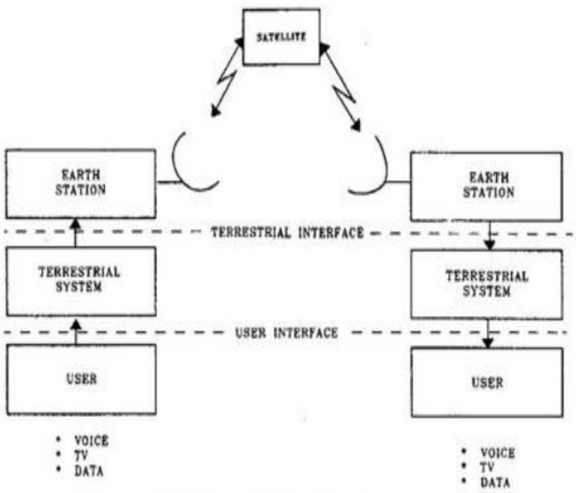


Figure 1 Satellite Communication System diagram [4]

Frequency bands and Regulations

Frequency bands are allocated at the World Radiocommunication Conferences (WRCs) and organized by the International Telecommunication Union Radiocommunication sector (ITU-R). Fixed Satellite services use high C and K frequency bands, mobile satellite services use lower L and S frequency bands that were assigned at the World Administrative Radio Conference (WARC) in 1992 which allows the use of small on board antennas due to lower signal attenuation and the less impact atmospheric effects have on them, but the requirements of broadband services and the limited amount of available L and S band frequencies (1-30 MHz) have pushed toward the use of Ku and Ka bands for Mobile Satellite Services. ITU-R has allocated parts of Ka frequency bands To both Mobile and Fixed Satellite Systems on a basic level in all regions (29.9–30GHz as an uplink frequency band for earth to space link and 20.1–21.3GHz as a downlink frequency band for space to earth link) and Ku band frequency portions to MSS on a secondary level in all regions (14–14.5GHz for uplink frequency spectrum and 10–12GHz for downlink frequency spectrum), Ku-based MSSs are available currently to provide broadband services for mobile transportation means such as trains, boats, planes, and cars but as a drawback Ku-band satellites, as opposed to L and S-band satellites, don`t provide good coverage overseas, because antenna spot-beams footprints are focused on land because Ku-band satellites are mainly planned for fixed users.[1].

The frequency bands and their applications can be categorized as follows:

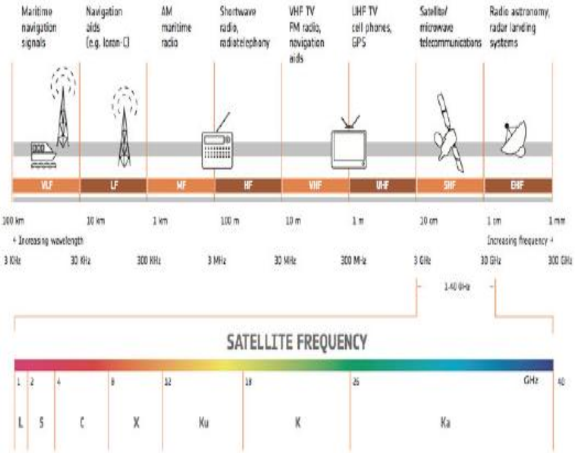


Figure 2 Radio frequency and satellite communication frequency bands [5]

Orbit Types

Generally satellite systems can be classified according to the altitude at which they are deployed and the types of services they provide. The satellite systems are categorized into three classes according to their altitude: low earth orbit LEO 200-2000 km, medium earth orbit MEO 2000-20000 km and geostationary orbit GEO 36000 km [4], from these classifications another categorization of satellite systems can be derived which are GEO Satellites and non Geo satellites [1].

A Geostationary satellite (GEO) is on the earth`s equator plane at a height of about 35 800 km, being at this altitude results in high signal propagation delay and attenuation. These satellites use S, L, Ku and Ka frequency bands.

Due to these reasons GEO satellites are more appropriate for fixed communication services, where large diameter antennas can be used in the earth station [1].

Non Geostationary (Non-GEO) satellites utilize two orbit types: Low Earth Orbit (LEO) which has a height between 200 and 1200 km of altitude, and Medium Earth Orbit (MEO), at a height between 1200 km and 35790 km of altitude [1,6].

Non Geostationary Satellites (Non GEO) satellites advantages are that they are closer to the earth that means having lower end to end latency and better link budget conditions but on the other hand non geostationary satellites need various satellites (a constellation) to cover a wide area or the entire earth, that means continual handover procedures are needed to switch over a connection from a terrestrial gateway, satellite antenna beam or a satellite to another [1].

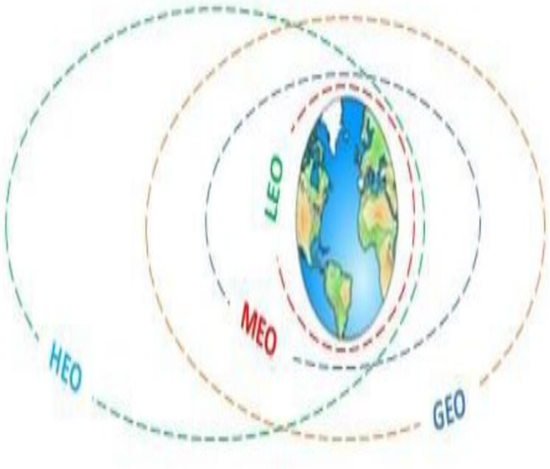


Figure 3 Satellite Orbit Types [4]

Table 1 Satellite Orbit Types [6]

ORBIT NAME	ORBIT INITIALS	ORBIT ALTITUDE (KM)
Low Earth Orbit	LEO	200-1200
Medium Earth Orbit	MEO	1200-35790
Geosynchronous Orbit	GSO	35790
Geostationary Orbit	GEO	35790
High Earth Orbit	HEO	Above 35790

II. Simulation Methodology

Satellite Tool Kit (STK) is an advanced software program developed by Analytical Graphics, Incorporated (AGI) that can be used to design satellite networks dynamically by defining different objects such as satellites, launch vehicles, missiles, earth stations, transmitters, receivers, antennas, transportation vehicles and other satellite systems components and by setting their parameters and attributes and thus the coverage and link characteristics can be calculated and evaluated [7].

In this paper a simulation scenario was created to simulate two geostationary communication satellites covering the Middle East and Africa regions to specifically compute and evaluate their coverage and link characteristics over Sudan.

STK has the capability of displaying the scenario in 2D and 3D graphs, the different calculated results are generated in the form of graphs and reports during a defined simulation time interval which is one day.

The Scenarios:

The scenario is the container of the inserted satellite communication system components.

The Satellite and Facility Objects:

The different components of the satellite segment and the earth segment were as follows [8]:

1. The Satellite:

There was several satellite types to choose from, in this case geostationary satellites were chosen because of the fact that they appear at a fixed point to the earth as their orbit period is close to earth acceleration period and hence the coverage will not suffer from area or time coverage gaps and the track of the satellite is reduced to a point on the equator [2], also for practical reason which is the existence of the services of these satellites in Sudan.

2. The Facility:

This is a fixed point on earth which is located in Khartoum through the latitude and longitude coordinates values and here represents a ground station.

3. Coverage Definition:

This object is an important part of the simulation which calculates the coverage and presents the results by adding the two satellites to it and by defining the coverage region by determining the minimum and maximum latitude and longitude of it which is Sudan in this scenario.

4. Figure of Merit

This is an object that is used for coverage calculation for a defined region by its coordinates and generates the results in terms of percentage of satisfaction for the coverage over the region and the space of the area being covered it can also compute the results of a chosen satisfaction criterion being met after entering a threshold at which satisfaction is achieved.

5. Antenna

There are different antenna models that can be selected and defined by changing their parameters, the chosen antenna model can either be embedded or linked, an embedded antenna is already built within the transmitter and receiver and any changes to them will not affect the antenna model, the linked antenna is an external antenna connected to the transmitter or the receiver and any change in its properties will change the object attached to it, the antenna is then placed on a sensor so it can receive sensor properties such as location and pointing.

6. Transmitter

The transmitter is the object transmitting the signal from the satellite to the ground station or any other object and vice versa and can have the characteristics, antenna and environment in which it operates modeled.

7. Receiver

The receiver is an object placed on the ground station or any other object that receives the signal from the satellite and vice versa where the characteristics, antenna and environment in which it operates can be modeled.

8. Sensor

The sensor is the object that models the field of view and other properties of a sensing device attached to the antenna or another object.

9. Chain

The chain is an object used to calculate and analyze the access from the satellite to a ground station in terms of the time period in which a satellite can see a target.

Coverage Scenario:

In this scenario the coverage and the utilized satellites were defined on the map as shown in the figure below:

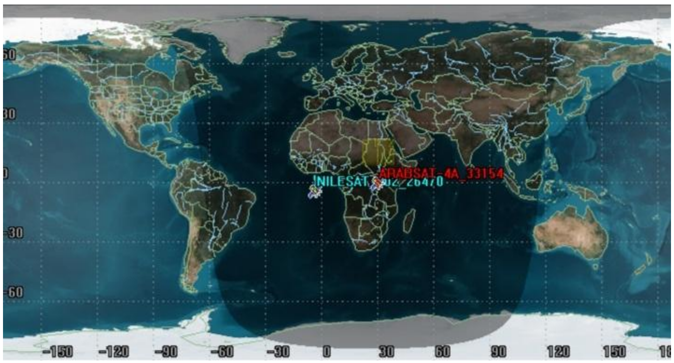


Figure 4 Coverage Map

The coordinates of Sudan where defined by the minimum and maximum latitude and longitude in the coverage definition object as shown in the table below:

Table 2 Sudan Coordinates:

Geographic Coordinates	Degree°	Cardinal Direction
Minimum Latitude	9.4	N
Maximum Latitude	21.76	N
Minimum Longitude	21.87	E
Maximum Longitude	38.6	E

Two Geostationary satellites were inserted from the default STK satellite library which were Nilesat 102 and Arabsat Badr-6, their parameters were stored by default including altitude, elevation angle, Rotation acceleration and other orbit attributes.

Their parameter definitions are shown in the tables below:

Table 3 Arabsat-Badr 6 Parameters:

Parameter	Info/Value
SSC Number	33154
Common Name	ARABSAT-4A
Official Name	BADR-6
Owner	Arab League Member States
Mission	Communication
Launch Date	2008/07/07
Apoapsis Altitude	35793 km
Periapsis Altitude	35780 km
Period	1436.1 min
Inclination	0.1°
Operational Status	Active

Table 4 Nilesat 102 Parameters:

Parameter	Info/Value
SSC Number	26470
Common Name	NILESAT 102

Official Name	NILESAT 102
Owner	Egypt
Mission	Communications
Launch Date	2000/08/17
Apoapsis Altitude	35813 km
Periapsis Altitude	35761 km
Period	1436.1 min
Inclination	0.4 deg
Operational Status	Active

Having the coverage region and satellites defined the coverage results were calculated where the coverage definition computes the results in terms of the percentage of access, gap duration and the figure of merit computes the percentage of satisfaction where condition of satisfaction where if at least two satellites covered the area it also calculates the total area that has been covered.

Communication Scenario:

In this scenario a ground station facility where located in Khartoum through its coordinates Latitude 15.5007° N, Longitude 32.5599° E) and within it two receivers, transmitters, sensors and antennas for each satellite were created with their specifications defined as shown in the following figure:

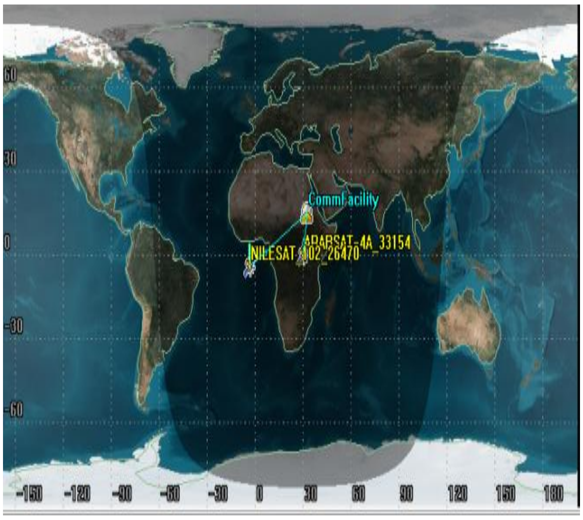


Figure 5 Communications Map

The earth station communication facility objects:

The receiver of the Arabsat Badr-6 satellite in the ground station was a complex receiver model that had a linked sensor and a Gaussian antenna attached to it with 4.2 GHz design frequency and 4 m diameter operating with c-band frequency from the satellite whereas the receiver of the Nilesat 102 satellite which was also a complex receiver linked to a sensor and a Gaussian antenna with 12.2 GHz design frequency and 1 m diameter operating with Ku-band frequency from the satellite.

The Satellite objects: Each satellite had a transmitter linked to an antenna and had the following options modeled:

Arabsat Badr-6

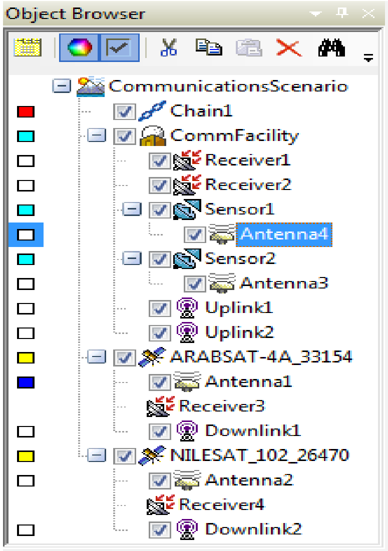
The design frequency was 4.2 GHz, the effective isotropic radiated power (EIRP) 40 dBW and the data rate was 4.995 Mb/s

The Azimuth (the rotation of the whole antenna around a vertical axis) was 269.35° and the Elevation (the angle between vertical plane and line pointing to the earth station) was -6.95°.

Nilesat 102

The design frequency was 12.2 GHz, the effective isotropic radiated power (EIRP) was 50.1 dBW and the data rate was 41.25 Mb/s.

The Azimuth was 254.45° and the Elevation was 28.02°.



Object Browser

- CommunicationsScenario
  - Chain1
  - CommFacility
    - Receiver1
    - Receiver2
    - Sensor1
      - Antenna4
    - Sensor2
      - Antenna3
    - Uplink1
    - Uplink2
  - ARABSAT-4A_33154
    - Antenna1
    - Receiver3
    - Downlink1
  - NILESAT_102_26470
    - Antenna2
    - Receiver4
    - Downlink2

Figure 6 Communication scenario objects

Having both the ground station`s and satellite`s objects defined the chain access which is the duration of the communication links and the bit error rate (BER) from each satellite to the ground station was calculated.

III. Results

1. The Coverage Results:

1.1. The coverage results from the coverage definition

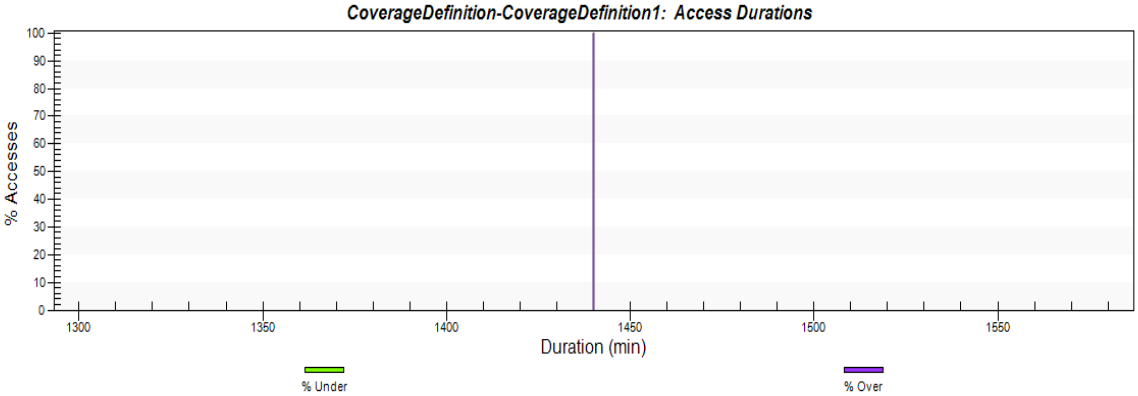


Figure 7 Access Duration

Table 5 Percent Satisfied

Satisfied Area Percentage	Area satisfied km^2
100.00	2462293.72

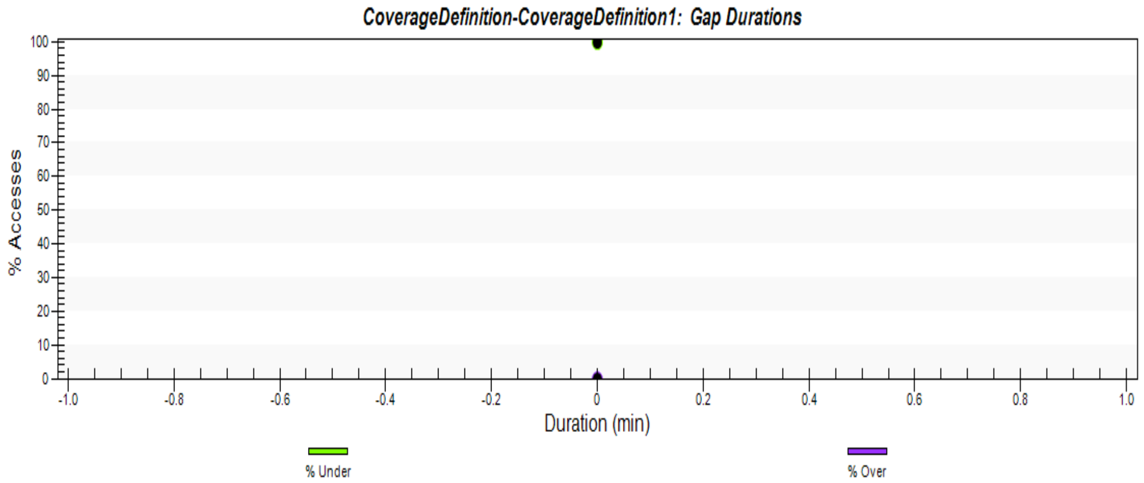


Figure 8 Gap Duration

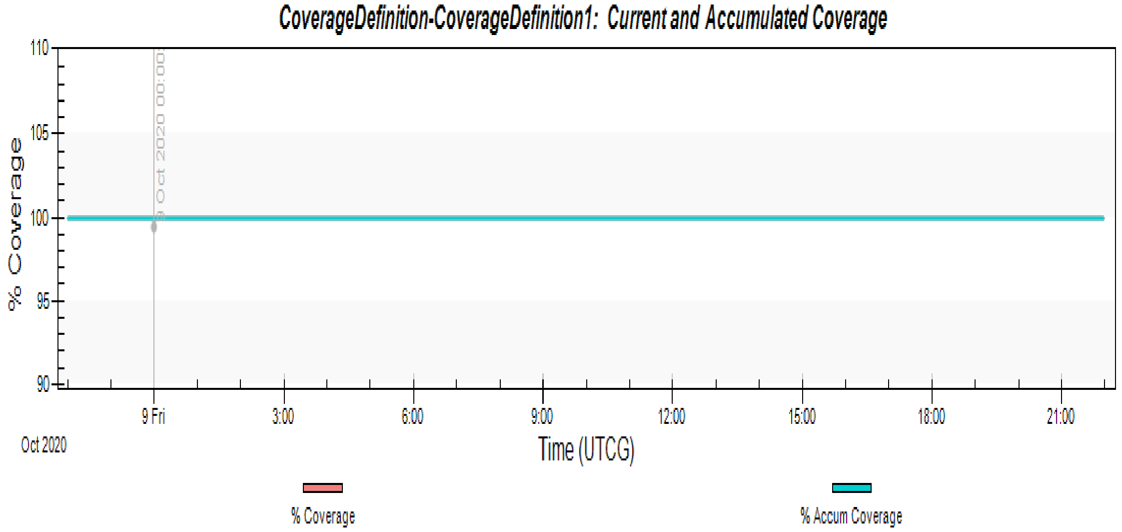


Figure 9 Current and Accumulated Coverage

1.2. The Coverage results from the Figure of Merit:

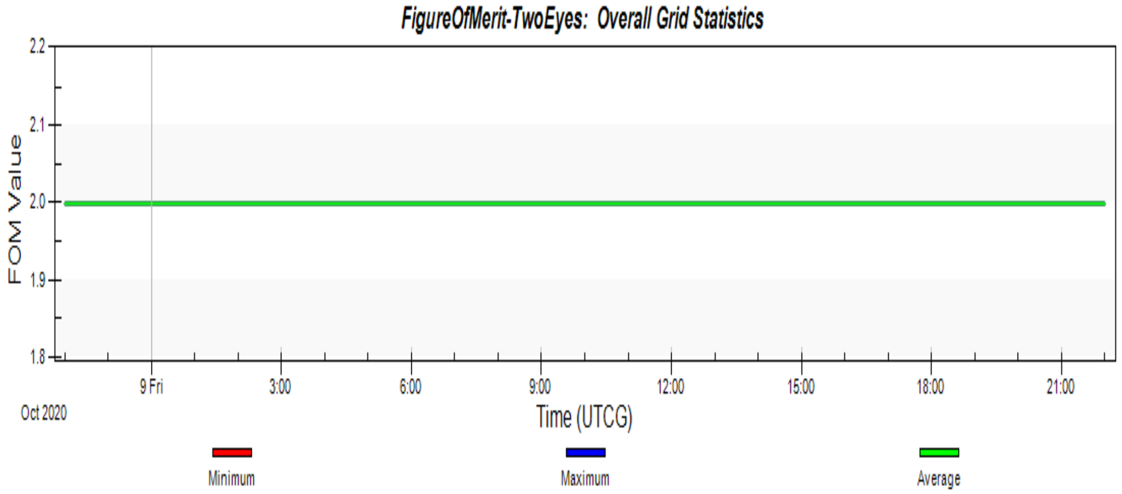


Figure 10 Overall Grid Statistics

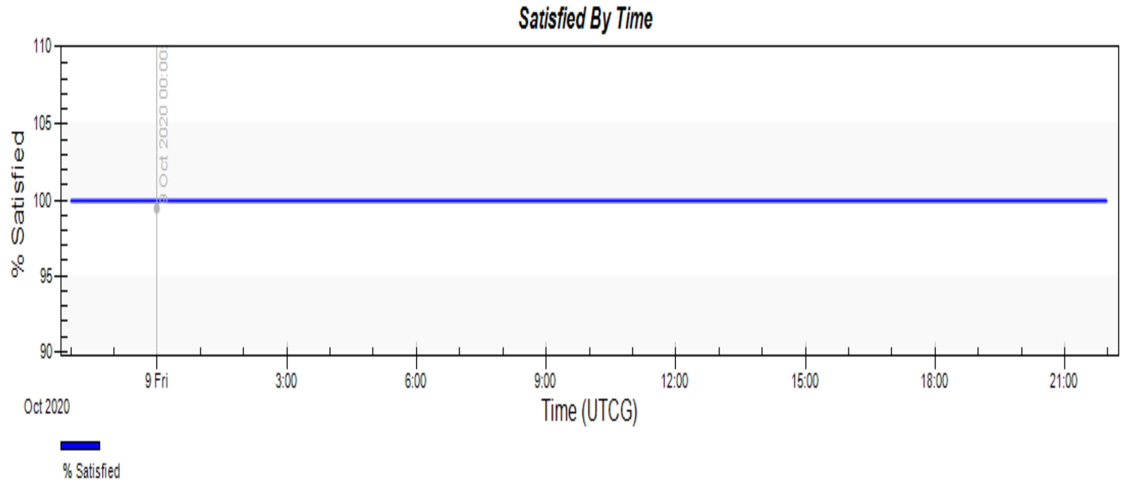


Figure 11 Satisfied by time

2. Communications Results:

2.1. Chain Access Results:

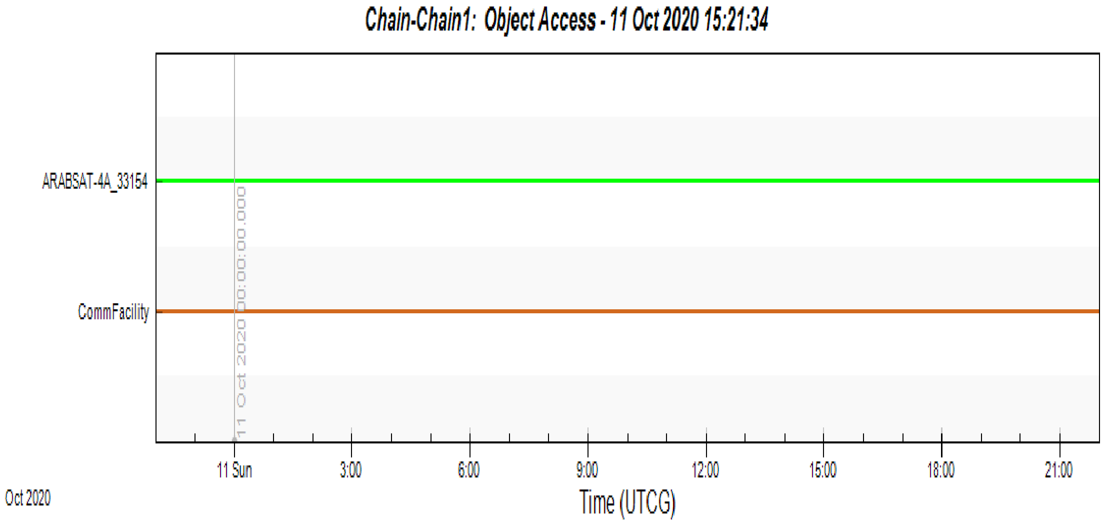


Figure 12 Arabsat Badr 6 Object Access

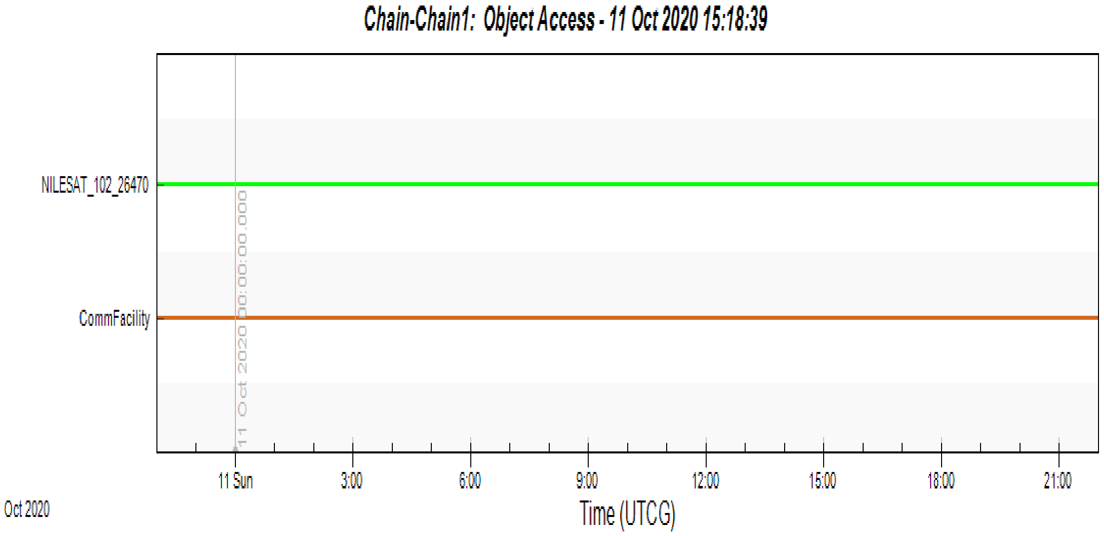


Figure 13 Nilesat 102 Object Access

2.2. Bit Error Rate Results:

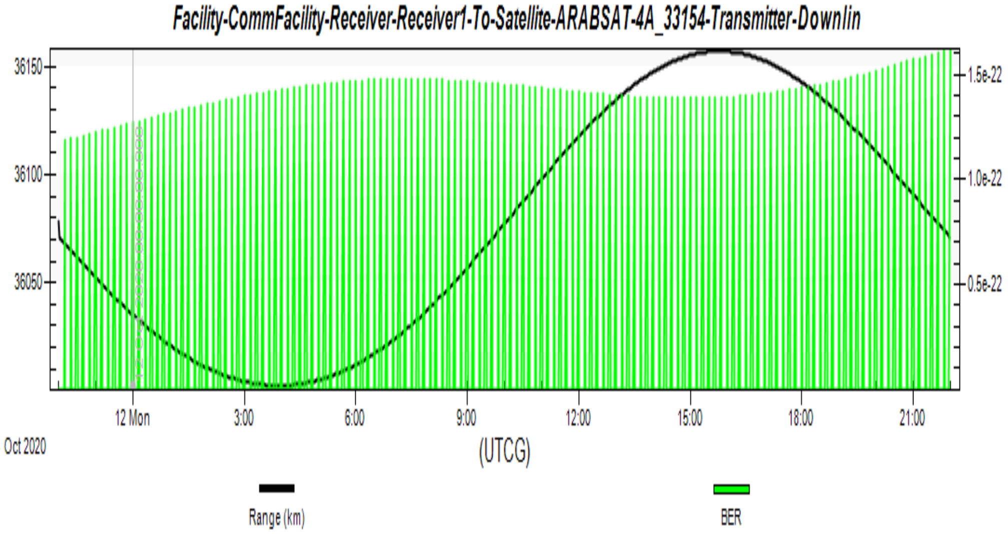


Figure 14 Arabsat Badr 6 downlink to receveir BER

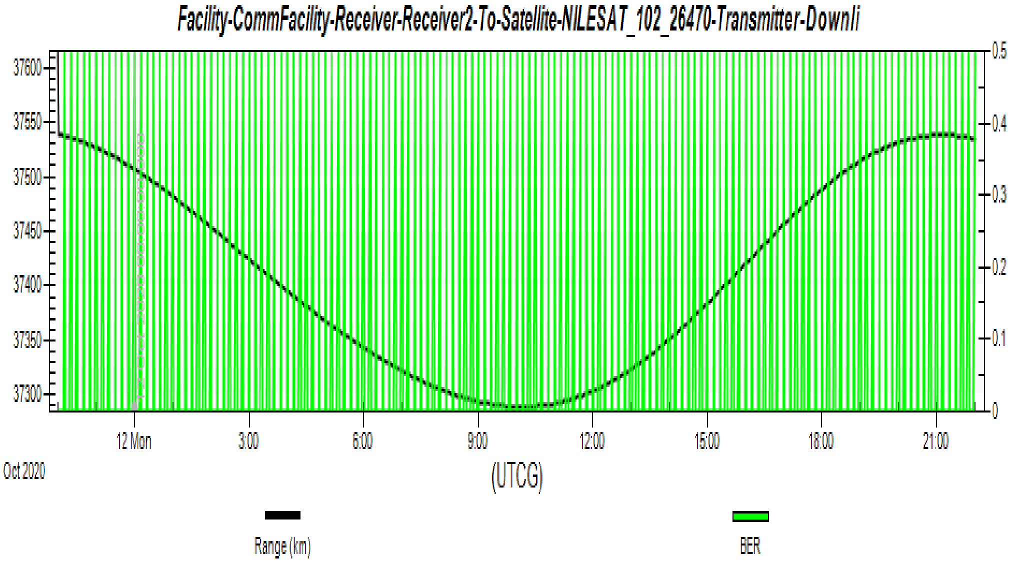


Figure 15 Nilesat 102 downlink to receveir BER

2.3. Signal/Noise Ratio (Eb/No Ratio)

Here Eb is the signal power (energy associated with every bit) and No is the noise power (noise spectral density)

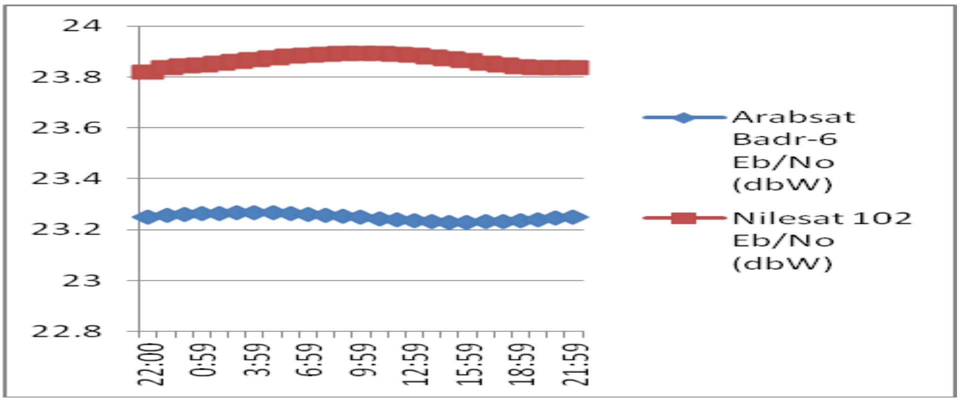


Figure 16 Eb/No Ratio

IV. Discussion

1. Coverage Results:

The two geosynchronous satellites coverage over Sudan remained 100% over entire operating time period achieving 100% satisfaction level with no coverage gap this shows the high capabilities of these satellites in providing communication services for this region in terms of time and area coverage results.

2. Link Analysis Results:

The connectivity of Nilesat 102 and Arabsat Badr 6 to the earth station using the chain measure maintained for 86400 seconds during the simulation period that means for 24 hours and indicates that these are permanent links over the operating cycle.

The BER was calculated in every minute from figure 10 the data rate in Arabsat Badr 6 was 4.9995 Mb/s that means there was 299.97 Mb was sent every minute and the BER was 1.5e that equals 1.5*10^-22 for each 299970000 bits sent every minute 0.0000000000000000000000015 bits had errors, this an extremely low BER representing the highest value of the BER during the simulation and it had lower values at the other durations.

For Nilesat 102 the data rate was 41.25 Mb/s that means there was 2475 Mb sent every minute, the BER was 0.5 bits in a minute at its highest that means for each 2475000000 bits sent every minute there was 5*10^-1 bits with errors approximately 1 bit and this was a constant BER value during the entire transmission period, this assures an accepted quality for digital voice and video. In the data reception process at the receiver we find that the bit error rate is not a parameter with notable effect, as the transmission can be made error free due to the retransmission protocols that are usually utilized between end to end user hosts, the bit error rate influences the number of required retransmissions, and therefore affects the delay [9].

The Eb/No is a dimensionless measurement of how strong the signal is where Eb is the energy per information bit and No the overall link noise power spectral density [9], the results show that Arabsat Badr-6 satellite had an Eb/No range (23.8-23.9) dbW and Nilesat 102 satellite to be (23.2-23.3) dbW throughout the simulation at their correspondent receivers at the earth station.

These results show the quality of the links to be acceptable which confirms that all the links are able to achieve permanent link requirements with acceptable quality.

V. Conclusion

Based on user experience of communication services in remote and under populated areas the network coverage provided by the operating service providers in Sudan is either weak or totally absent, here comes the need for an alternative solution for this problem which is represented in the practical and cost effective use of existing geostationary satellites operating in Sudan, in this article the performance of Nilesat 102 and Arabsat Badr-6 were evaluated to assess their abilities to be allocated for possible VSAT or Mobile Satellite Systems implementation, coverage and communication scenarios where created to test the coverage and link characteristics of both Arabsat Badr-6 and Nilesat 102 Geostationary Satellites which were in different orbits and operating with different frequency bands and the target area was Sudan.

According to the generated coverage and link simulation results which indicated that the coverage was 100% with no gabs for both satellites and the links of these satellites had very low BER and an Eb/No ratio at acceptable ranges with permanent object access from the satellites to the earth station through out the simulation it was verified that both of these satellites have robust, stable and continuous coverage and link connections with the earth segment placed in Khartoum with good quality and this confirms the high capabilities of these satellites to provide communication services in Sudan.

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