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(Link Budget of GEO Satellite (Nile Sat) at Ku-band Frequency) Case of study Tripoli and Sebha

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Abstract The link communication between satellite and the Earth Station is exposed to a lot of impairments such as noise, rain and atmospheric attenuations. The successful implementation of satellite communications need to the efficient system design to ensure robust air links for the communications signals. However, the quality of satellite signals are subject to degradation through the atmosphere due to atmospheric impairments. It is therefore crucial to design for all possible attenuation cenarios before the satellites is deployed. The performance indicator "Link budget" is a tabular method of calculating satellite communication system parameters. Link Budget used to estimate the effectiveness and reliability of the link in satellite communication. The link budget is the compilation of all gains and losses in the satellite communication link. This paper presents the fundamentals of a satellite link budget analysis of GEO satellite (Nile Sat) to accounting of atmospheric attenuation, signal strength and predict the quality of signal received at the ground station during the atmospheric conditions in Tripoli and Sebha using actual climatic parameters. Evaluation of the satellite link performance also presents. The performance of the satellite link is evaluated in terms of carrier to noise ratios, bit energy-to-noise ratios, bit error rate and link margin.

Keywords: Link budget, GEO, Downlink , EIRP, Propagation Losses, attenuation.

ميزانية الوصلة للقمر الصناعي GEO (النايل سات) بتردد Ku-band حالة الدراسة طرابلس وسبها

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الملخص تتعرض وصلة الاتصال بين القمر الصناعي والمحطة الأرضية لكثير من المعوقات مثل الضوضاء والأمطار والتوهين الجوي. السبب وراء التنفيذ الناجح للاتصالات بالأقمار الصناعية هو تصميم النظام الفعال لضمان وجود روابط جوية قوية لإشارات الاتصالات. ومع ذلك ، فإن جودة هذه الإشارات عرضة للتدهور عبر الغلاف الجوي بسبب عيوب الغلاف الجوي. لذلك من الضروري تجميع التوهين المحتمل علي إشارة القمر الصناعي. مؤشر الأداء "ميزانية الوصلة" هي طريقة مجدولة لحساب معاملات نظام الاتصالات. تستخدم ميزانية الوصلة لتقدير فعالية و موثوقية الوصلة في الاتصالات بالأقمار الصناعية. ميزانية الوصلة هي تجميع جميع المكاسب والخسائر في وصلة الاتصالات بالأقمار الصناعية . تعرض هذه الورقة أساسيات تحليل ميزانية وصلة القمر الصناعي GEO (النايل سات) لحساب التوهين الجوي للإشارة وقوة الإشارة والتنبؤ بجودة الإشارة المستقبلة في المحطة الأرضية أثناء الظروف الجوية في طرابلس وسبها باستخدام بيانات مناخية فعلية. .يتم تقييم أداء وصلة القمر الصناعي باستخدام المعاملات: نسبة الموجة الحاملة إلى الضوضاء ونسب الطاقة إلى الضوضاء ومعدل الخطأ في البتات وهامش الارتباط.

الكلمات المفتاحية: ميزانية الوصلة، المدار المتزامن، الوصلة الهابطة، قدرة القمر المرسلة، فقد الانتشار، التوهين.

Introduction

Satellite communication systems have become an essential part of the world's largest telecommunication infrastructure, serving millions of people with telephone, data and video service. GEO satellite stay above a fixed point on the surface by orbiting the equatorial plane of the Earth at a speed matching the Earth's rotation. Because they stay above a fixed spot on the surface, they provide a constant vigil for the atmospheric. The ability to communicate depends on the strength of the signal . An accounting of signal strength and its quality is an important part of system design and is known as a "link budget". The calculation of the link budget is a very important step in the design and analysis phase of any satellite in order to ensure the proper functioning of the satellite communications. Transmission of signals over a satellite communication link requires Line ofSight (LoS) communication. Satellite communication specialists, radio and broadcast engineers are in the business of determining the factors required for optimal link availability and quality of performance. These factors can be divided into two broad categories; the conduit factors and the content factors. The conduit factors include: earth-space and space-earth path (uplink and downlink), effects on signal propagation, quality of earth station equipments, and the impact of the propagation medium in the frequency band of interest, et cetera. The content factors deal mainly with the type of message transmitted and the devices involved in its transformation from one form to another for suitability for transmission over a microwave medium. It is for these reasons that a proper engineering methodology is required to guarantee timely deployment and effective and efficient exploitation of satellite communication applications and devices[1-2]. This paper aims to analyse the satellite links and make the calculation of the link budget and evaluates the link performance and predicts the different types of propagation losses as well as combining them together to determine the overall impact on satellite links. Actual climatic parameters[3] used to accounting of signal atmospheric attenuation at the ground station subject to the atmospheric conditions in Tripoli and Sebha.

Satellite Link Analysis

Link analysis basically relates to accounte the transmit power and the receive power and shows in detail how the difference between these two. To this end the fundamental elements of the satellite communications Radio Frequency (RF) or free space link are employed. Basic transmission parameters, such as antenna gain, free space loss, and the basic link power equation are exploited. The concept of system noise and how it is quantified on the RF link is then developed, and parameters such as noise power, noise temperature, noise figure and figure of merit are defined. The carrier to noise ratio, bit energy to noise ratio and bit error rate related parameters used to define communications link design and performance are developed based on the basic link and system noise parameters introduced earlier [2,4].

Link Budget

A link budget is a method of calculating and evaluate the performance of a communication link by taking into account all gains and losses that affect the signal along the path. The calculation of link budget involves calculation of many parameters such as effective isotropic radiated power (EIRP), free space loss (FSL), carrier to noise ratio, receiver sensitivity ,energy per bit noise density ratio, bit error rate, link margin and propagation losses. Link budgets are used to design communications systems from the earliest stages of the design and are updated throughout the design process[4-5].

Received Power

Received power is one of the most important factors for having a reliable radio communication link . The received power is given by Friis radio link formula as[4]:

$$P_r = EIRP - G_r - FSL - other\ losses \qquad (1)$$

Where EIRP is Equivalent Isotropic Radiated Power from satellite, G_r is the receiver antenna gain .

Receiver Sensitivity

Receive sensitivity is the threshold of the received signal power that required at the receiver. Receive sensitivity dependent on the noise figure and required carrier to noise ratio of the system. System noise comprises of the low noise amplifier (LNA) generated noise and associated noises in terms of noise temperature contributes the overall noise along with elevation angle of the antenna system above horizon. The required carrier to noise ratio is dependent on the modulation technique and code rate. Typically, the higher the data rate of the system, the more bandwidth is needed. This means the receiver must capture more signal, which means more noise is captured. The minimum required power (sensitivity P_{min}[dBw]) can be calculated from the minimal required receiver noise input power (P_n[dBw]) and carrier to noise ratio (C/N) [4]:

$$P_{min} = P_n + C/N \qquad (2)$$

$$P_n = F + 10log_{10}(kT_0B)$$

where, F is the receiver noise figure , K is Boltzmann's constant (1.38.10–23 Ws/K), T_0 is the absolute temperature (290K) and B the receiver noise bandwidth [Hz].

Link Margin

The link margin is obtained by comparing the expected received signal strength to the receiver sensitivity or threshold. The link margin is a measure of how much margin there is in the satellite communications link between the operating point(satellite) and the receiver [6]. The link margin required for the link budget calculations is usually given at the edge of the coverage area to achieve certain C/N at the receiver. The link margin can be calculated using [4]:

$$Link\ margin = EIRP - (\text{path losses}) + G_r - P_{min} \qquad (3)$$

Radio Propagation Losses

The transmission of a satellite signal occurs almost in a free space conditions (more than 97% of a slant path in case of geostationary satellite). The problem of receiving a radio frequency signal, between two antennas separated by atmosphere, is in principle simple, but in practice is complicated. The frequency band and the weather conditions play the important role in satellite communication networks. Wave propagation in high frequency region is mainly surface and sky whereas above it the propagation is primarily space waves. During radio propagation electromagnetic waves suffer several atmospheric effects that results in power loss and these effects are: Reflection and refraction, diffraction and scattering. These effects results in the large scale or small scale fading in accordance with the size of the object compared to the wavelength. In case of satellite based system the main losses are categorized are[7]:

Free-Space Loss (FSL)

Loss in free space is a function of frequency squared plus distance between satellite and earth station squared plus a constant, using kilometers (km) for distance and megahertz (MHz) for frequency[4]

$$FSL = 32.45 + 20 \times \log(D) + 20\ \log(f) \qquad (4)$$

Atmospheric Losses

Atmosphere loss can be categorized as attenuation or absorption where absorption signal energy. The problems become acute for systems operating in the bands above 10 GHz, where radio links can be adversely affected by atmospheric gases (primarily oxygen and water vapor), rain, clouds and scintillation. These conditions, when present alone or in combination on the Earth-space radio link, can cause uncontrolled variations in signal amplitude, phase and polarization which results in reduction in the quality of analog transmissions and an increase in the bit error rate of digital transmission[8] .

- **Attenuation Due to Atmospheric Gaseous**

The principal interaction mechanism between the radio waves and gaseous constituents is molecular absorption from molecules. Attenuation by atmospheric gaseous depends on frequency, elevation angle, altitude above sea level and humidity . The gaseous attenuation measured in dB is expressed as below[9]:

$$A_{Gaseous} = \frac{A_0 + A_w}{\sin\theta} \quad (5)$$

Where A_0 is oxygen attenuation, A_w is water vapor , θ is elevation angle .

- **Cloud Attenuation**

The liquid water content of cloud also causes absorption and scattering of electromagnetic energy especially for frequencies above 10 GHz, but with less intensity than that of rain . Cloud attenuation can specific by[9] :

$$A_{cloud} = \gamma_{cloud}\left(\frac{LWC}{\sin\theta}\right) \quad (6)$$

Where γ_{cloud} is cloud specific attenuation coefficient , LWC is liquid water content .

- **Rain Attenuation**

Rain droplets absorb and scatter the signal energy and cause its power level to attenuate to a value depending on the size, amount, and shape of the droplets that the signal passes through as well as the rain rate .Rain usually occurs at different heights above sea level depending on a region on the earth. The rain attenuation measured in dB is expressed below[7-9-10]:

$$A_{rain} = A_{0.01}\left(\frac{p}{0.01}\right)^{-[0.655+0.033\ln(p)-0.045\ln(A_{0.01})-\beta(1-p)sin\theta]} \quad (7)$$

Where $A_{0.01}$ rain attenuation at 0.01% of time, p is the percentage of probability.

- **Scintillation**

Scintillation happens when signals travels through this turbulent mixing atmosphere, it will experience alternation and scattering. The scintillation fade depth can be calculating by [11]:

$$A_s = a(p).\sigma \quad (8)$$

where a(p) is the time percentage factor for time percentage, σ standard deviation of the signal amplitude.

Noise Power

Noise temperature provides a way of determining how much thermal noise active and passive devices generate in the receiving system. The most important source of noise in receiver is thermal noise in the pre-amplification stage. The noise power is given by the Nyquist equation as[12]:

$$N = k T_s B_n \quad (9)$$

Where T_S is receiving system noise temperature; k – Boltzman constant = 1.39 x 10-23 J/K = - 228.6 dBw/K/Hz; Bn – Noise bandwidth in which the temperature is measured in Hz.

Link Performance

The quality of signals received by the satellite and that retransmitted and received by the receiving earth station are important if successful information transfer via the satellite is to be achieved. Within constraints of transmitter power and information channel bandwidth, a communication system must be designed to meet certain minimum performance standards. The most important performance standard is bit error probability carrier to noise ratio, the bit energy per noise density ratio in the information channel, which carries the signals in a format in which they are delivered to the end users[13].

Carrier to noise ratio C\N:

C/N is a key parameter which defines the performance of satellite communications link The carrier power (C) and the noise power in the earth station receiver (N) can be represented as[4-12]:

$$C/N = EIRP - (\text{path losses} + \text{attenuation}) + \text{Ground Station } G/T + 228.6 \quad (10)$$

Energy Per Bit to Noise Density

The energy-per-bit to noise density ratio is the most frequently used parameter to describe digital communications link performance and one of them is used to know how the link responds within an acceptable range of errors and how strong the signal is respect to the noise, energy per noise density ratio E_b / N_o in the information channel, which carries the signal in the form in which it is delivered to the user(s). The energy-per-bit to noise density ratio given by[5]:

$$E_b/N_0\,(dB) = EIRP + G_r - (\text{path losses} + \text{attenuation}) - N_0 - 10\log(R_b) \quad (11)$$

Bit Error Probability

Bit Error Probability P_e is the indicator of quality in a digital radio link and is defined as the likelihood that a bit sent over the link will be received incorrectly. P_e occurs because a symbol error occurs, the link noise produce spurious in the stream causing that the decision circuitry cannot identify the original sent data. Using differential modulation one error in one symbol will produce that the next symbol be misinterpreted and as a consequence, the number of bit error could be more than the number of bits per symbol. As thermal noise increase, symbol rate also increase. for minimum probability of error (N_0 is the noise energy per bit)[4]:

$$P_e = \frac{1}{2}\,\text{erfc}\sqrt{\frac{E_b}{N_0}} \quad (12)$$

Figure of Merit

The quality or efficiency of the receiver portions of a satellite communications link is often specified by a figure of merit which defined as the ratio of receiver antenna gain to the receiver system noise temperature, figure of merit is given by[14]:

$$M = \left(\frac{G}{T}\right) = G_r - 10\log(T_S) \quad (13)$$

Satellite Down Link Budget Methodology

The link budget determines the power requirements, link availability, bit error rate, as well as atmospheric attenuations. It simplifies C/N ratio calculations. The down link budget calculated for a ku-band frequency connection using a GEO satellite (Nile sat) with 60 cm earth station antenna diameter. Actual climatic data were adopted form (timeanddate.com) for Tripoli and Sebha. The climatic data are : temperature, relative humidity, pressure and rainfall rate. These data used to calculate atmospheric attenuations. Link budgets are calculated for clear sky and non clear sky. The link budget calculations is usually given at the edge of the coverage area to achieve certain C /N at the receiver. It provides account of all the gains and losses from transmitter to receiver via medium .It is calculated by taking into account the various losses as shown below:

For clear sky

Sum of all losses = FSL + gaseous attenuation + scintillation fade depth

For non clear sky

Sum of all losses = FSL + gaseous attenuation + scintillation fade depth +cloud attenuation + rain attenuation

The link budget methodology for satellite communication link can be summarized into the following steps:

Step 1: Frequency band
Step2: Determination of satellite parameters
Step 3: Earth station parameter determination
Step 4: Propagation condition determination.
Step 5: Calculate free space loss
Step 6: Calculate atmospheric attenuations
Step 7: Calculate the received power
Step 8: Calculate receiver sensitivity
Step 9: Calculate C/N
Step10: Calculate E_b/N_0
Step11: Calculate figure of merit
Step12: Calculate the bit error rate
Step13:Determine Link Margin

Results and Discussion

Link budget is calculated for clear sky (Table 1) and a worst-case(non clear sky) shows in Table 2. Due to the large area of Libya, the distances between the satellite and earth stations are different so the losses are different. The results showed that the FSL in Sebha is the lowest and that is because the signal passes less distance. The atmospheric attenuations showed the various effects of local weather conditions on the propagation of radiowave signals. The results also showed that the rain attenuation has the largest effects among other atmospheric phenomena, followed by scintillation fade depth, cloud attenuation, gases attenuation. Atmospheric attenuations causes decrease in the received signal. The highest values of atmospheric attenuation is in Tripoli. The reason behind that is high values of surface humidity which is the main contributor to absorption of signal's radiation power, additionally the attenuation increases with decreasing the elevation angle. It can be seen from Table 1 and Table 2 that the required margin is achieved in both location by antenna diameter 60 cm. The results confirm that C/N and E_b/N_o depend on transmitting power. The improvement on the signal quality indicators C/N, E_b/N_o and P_e could be achieved by the receiving antenna gain. Sebha is less affected by all propagation impairments but the satellite signal is the weakest comparing with Tripoli. The results showed that the rain attenuation effect causes decrease in the received signal. The rain attenuation of horizontally polarized electromagnetic waves is greater than the attenuation of vertically polarized electromagnetic waves. The signal quality, which indicated by C/N , E_b/N_o decrease at heavy rain events, this condition corresponds to high P_e. The results also show that the performance of the ground station figure of merit does not depend on location.

Table 1: Link Budget for GEO Satellite(Nile Sat) in Clear Sky

Parameters	Unit	Tripoli	Sebha
Downlink frequency	GHz	12.322	12.322
Elevation angle	degree	51.712	57.629
Earth station antenna Gain	dBi	35.18	35.18
EIRP[15]	dBW	50	48
Satellite position[15]		7^0 W	
Distance	Km	36986.108	36653.217
FSL	dB	205.6161	205.5376
Gaseous attenuation	dB	0.18785	0.13561
Scintillation fade depth	dB	0.83366	0.62838
Received power	dBm	-91.45	-93.11
Receiver sensitivity ,code rate 1/2	dBm	-102	-102
T_S system noise temperature[16]	K	108.27	108.27
C/N ratio in receiver	dB/K	14.06	12.40
E_b/N_0	dB	8.12	6.466
G/T	dB/K	14.83	14.83
P_e		8.80×10^{-5}	2.13×10^{-4}
Link Margin	dB	10.5	8.88

Table 2: Link Budget for GEO Satellite(Nile Sat) in Clear Sky

Parameters	Unit	Tripoli	Sebha
Downlink frequency	GHz	12.322	12.322
Elevation angle	degree	51.712	57.629
Earth station antenna Gain	dBi	35.18	35.18
EIRP[15]	dBw	50	48
Satellite position[15]		7^0 W	
Distance	Km	36986.10	36653.217
FSL	dB	205.6161	205.5376
Gaseous attenuation	dB	0.18632	0.13211
scintillation fade depth	dB	0.83336	0.62814
Cloud attenuation	dB	0.0264	0.0245
System noise temperature[16]	K	108.27	108.27
Horizontal polarization			
Rain attenuation	dB	3.9363	1.972
Received power	dBm	-94.98	-94.8
C/N	dB	10.54	10.67
E_b/N_0	dB	4.59	4.73
G/T	dB/K	14.83	14.83
P_e		5.1×10^{-4}	5×10^{-4}
Link Margin	dB	7.0	7.1
Vertical polarization			
Rain attenuation	dB	3.681	1.939
Received power	dBm	-94.729	-94.81
C/N	dB	10.79	10.70
E_b/N_0	dB	4.854	4.767
G/T	dB/K	14.83	14.83
P_e		0.00050	0.00053
Link Margin	dB	7.271	7.184

Conclusion

Several of factors have to be taken into consideration in the analysis of satellite link. We have presented the most important of these factors. Link budget and various losses mechanism associated with as well as propagation path statistics is detailed in this paper. Case of GEO satellite (Nile sat) are taken for studying various propagation effects, accounting of signal strength in Tripoli and Sebha using actual climatic parameters. We have summarized in the link budget the most necessary points for achieving a robust satellite link with desired characteristics. This paper will help in quick integration and expansion of telecommunication services in Libya. Also useful for satellite system designer to accurately predict the atmospheric impairments that may affect the channel, and identifying signal quality performance with error rates during different weather conditions. This paper also will help radio engineers to predict the link margin easily.

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