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OPTIMIZATION OF SATELLITE LINK TO EARTH STATION USING SATTELLITE TOOL KIT (STK)

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Abstract- This proposed paper is related to Satellite Communication. In this paper the link budget analysis, access time to Leo Satellite and tradeoffs related to Satellite Transmitter, Satellite Receiver, onboard antennas, and Earth Stations parameter selection and Optimization will be simulated using Satellite Tool Kit (STK) Software. A scenario using STK will be developed for a satellite and it will be simulated for different Orbits and other Satellite and earth Station parameters. These Scenarios will be compared and trade-off analysis will be performed for optimized design of space to earth station link.

Index terms- Satellite Link, Satellite Tool Kit, Bit Error rate (BER), Link Budget.

I. INTRODUCTION

There are many types of satellites working in different orbit. Satellites need to send the data to the ground station. In recent years, the scientistis working on the small satellite's systems for the purpose of communication, navigation, scientific research and remote sensing for military and civilian purposes. Artificial Satellites are lower in weights and they are smaller in the sizes and they become more attractive because they have lower development costs and takes a shorter time to lead [1]. Some small satellites are usually under 500 Kg which is classified to their masses into different types like mini-satellite, microsatellite, nanosatellite, picosatelliteand femto-satellite. As shown in Table 1.

Type of Satellite	Mass
Mini Satellite	500-100 Kg
Micro Satellite	100-10 Kg
Nano-Satellite	10-1 Kg
Femto and Pico Satellite	< 1 Kg

Table 1.

There are various constraints of satellites due to size, power, and mass. In this way, new technologies of small satellites are working on the link budget analysis due to the gains and losses which are existing in the satellite transmitter when sending the data to the ground station through the medium is free space, cable, wave fiber, etc to the receiver in a telecommunication system. It makes attenuation of the transmitted signal due to propagation as well as the gains of antenna miscellaneous losses and feed line. Randomly it varies the Channel gains comparatively fading are taken into detail by calculating some margin which depends on the anticipated severity of its effect. The Communication link between earth and satellite is discovered to a lot of deterioration such as rain, noise, free space and atmospheric attenuations. It also faces the loss resulting in such as polarization and misalignment of the antenna. So, crucial design for possible attenuation scenarios since satellite deployed [2]. A communication satellite consists of two generic subsystems: payload subsystem and spacecraft subsystem (Elbert, B.R, pp.195-205, 2008). Payload subsystem holds the transponder equipment used for the reception and transmission of communication signals. This also provides the radio relay links between satellite and earth station. Most of communication satellites payload consist of twodistinct parts with well-defined [3]. The performance of uplink satellite communication system network receives the noise temperature and gain of the satellite.

II. LINK ANALYSIS

Link analysis of the satellite communication is basically to transmit the power and receive the power and shows the difference between to account for. Main transmission fundamentals are antenna gain, beam width, free space link, free-space path losses, temperature, and basic link of power exploited [4]. It accounts the attenuation of the transmitted signal due to propagation, it also antenna gains, feed line and miscellaneous losses. The link equation and flux density can be used for calculating the power received by an earth station from the satellite transponder with an output power P_t watts and driven losses less antenna gain G_t[4]. Equivalent Isotropic Radiated power (EIRP) measure the total power transmitted by satellite which includes the output power of transmitter and gain of antenna minus any losses from the wave guide.

$$\boldsymbol{\Psi M} = \frac{\boldsymbol{GPs}}{\boldsymbol{4\pi r^2}} \qquad (1)$$

From the start of calculation of power loss resulting from the growing of signal in the space is determined by the equation.

$$\text{FSL} = 20\log\left(\frac{4\pi r}{\lambda}\right) \qquad (2)$$

Atmospheric losses:

Losses occurin the earth's atmosphere which results in the absorption of atmospheric gases. The attenuation of specific frequencies up to 1000 GHz due to dry air and water vapor, which is evaluated most accurate at any value temperature, humidity and pressure by mean of summation of the individual resonance line form the oxygen and water vapor together with small additional factors for the non-resonant Debye spectrum of oxygen below 10 GHz, pressure-induced attenuation of nitrogen above 1000 GHz and continuum wet account for the excess water vapor absorption found experimentally [5].

*Losses due to Rain: A m*ain important factor of the losses with the frequency and rain rate require for Ku-Ka band links on the bad statistics of the rainfall. ITU-P. 618-5 designed the Earth-space communication links system effects considered is a non-ionized atmosphere for all frequencies, but there are some critical effects above 1 GHz and low elevation angles. Effect includes absorption, atmospheric gases, depolarization and scattering by hydrometeors (Which include water and ice droplets in perception, clouds, etc.) there is also another issue emission noise from absorbing media which are especially important for frequencies above 1 Ghz.

- Attenuation by atmospheric gases.
- Attenuation by clouds, rain, and other precipitation.
- Focusing and defocusing
- Antenna gain decreasing due to wave-front incoherence.
- Multipath and Scintillation effects
- Attenuation by dust storms and sand
- The contribution of these characteristics as frequency function, elevation angle, and geographic location.
- Elevation angles above 10°, only gaseous attenuation, rain attenuation and possibly scintillation will exceed few tenths of decibel, depending on the condition of propagation.

Antenna Mispointing Losses: The ideal situation is the Ground station and satellite antennas aligned for maximum gain (*Figure 2.1(a)*). We have a possible source for the off-axis loss one at the ground station and other is Satellite (*Figure 2.1(b)*).

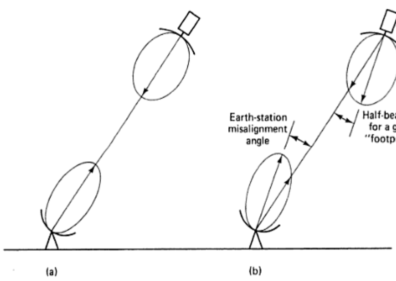

Figure 2

(*Figure Copied from Book Satellite Communication by McGrew*)

Polarization Losses: An electromagnetic wave polarization is the orientation of the electric field. If vector rotates with the time, then wave elliptically polarized.

Axial Ratio: The ratio of major axis to minor axis of polarization ellipse.

$$\text{Axial ratio} = 20_{Log}\left[\frac{E_{max}}{E_{max}}\right] \qquad (3)$$

Directivity is the measurement of concentration is maximum of radiation and easy of estimated time from the pattern:

$$\text{Directivity} = 10_{Log}\left[\frac{U_{max}}{U_o}\right]$$

On another hand, the gain is must measure and it is related to directivity.

Gain = directivity (ratio) X efficiency

Or

$$10_{Log}[directivity\ (ratio) \times efficiency]$$

There are various receivers for the demodulation or implementation losses new technology made new receivers for the loss ranging between 0.5 to 1 dB. There are always different components for active and passive between data antenna and transmitter. Losses are considered in link budget analysis losses between Satellite antenna and transmitter.

Ground Station G/T or figure of merit*:* The ratio of the antenna gain of the receiver G and the system temperature T. Total noise power includes the contribution of antenna and receiver. The gain of the system temperature must be referenced to the same point in the receiver system components. The G/T is an invariant that is independent reference point which calculated even it is gain and the system temperature at different points.

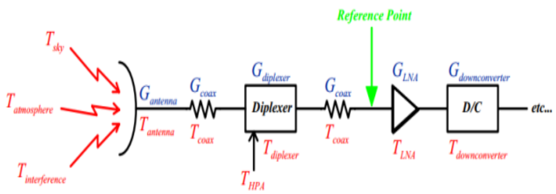

Figure 3

A measurement and performance of the satellite link is the ratio of carrier power to noise power at the input receiver and link budget calculation are concerned with this ratio. Probably the ratio is denoted by $\frac{C}{N}$ (or CNR), that is equivalent to P_r/P_n. In decibels,

$$\left[\frac{C}{N}\right] = [P_R] - [P_N] \qquad (4)$$

III. X-BAND LINK BUDGET ANALYSIS FOR IMAGIGN PAY LOAD LEO SATELLITE

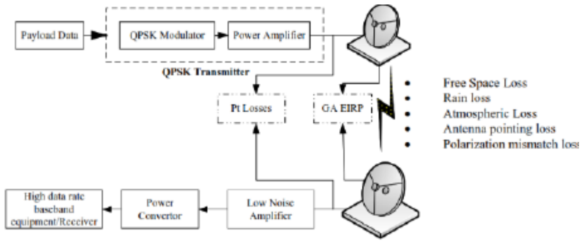

Figure 4. Satellite link

Initial Parameters of Satellite:

- Satellite Orbit of altitude = 700 km
- Slant rang at elevation ground Segment antenna = 2450 km
- Satellite Operating Frequency = 8.2 GHz
- Imaging data Rate + 10 Mbps

Wave length = $\frac{C}{f}$

Where $C = 3 * 10^8$

$F = 8.2 * 10^{-9}$

Therefore $\lambda = \frac{3*10^8}{8.2*10^{-9}}$

$\lambda = 0.0366$ Eq: (4.1)

Satellite Antenna gain at Edge of Coverage = 0 dB

Loss between satellite Antenna gain and QPSK Transmitter = 1 dB

QPSK Transmitter output Power:

Ptx = 3 dB ≈ 2W (Power Amplifier)

Required Bit Error Rate = 10^{-6}

Free Space Losses:

FSL = 20 log $\frac{4\pi R}{\lambda}$

FSL = 20 log $\frac{4\pi(2450000)}{0.0366}$ dB

FSL = 178.498 dB

Eq: (4.2)

Atmospheric Losses = 0.3 dB

Rain Attenuation Losses = 1.3 dB

Ground Segment Implementation loss = 1 dB.

Polarization Mismatch loss = 3 dB

Antenna Pointing Loss = 0.5 dB

Formula:

Total losses = FSL + Atmospheric Losses + Rain Attn Loss + Gs Imp Losses + Pol- Mismatch + Antenna pointing loss.

Total Losses = 178.498+0.3+1.3+1+3+0.5

Total Losses = 184.6 db Eq:(4.3)

Ground Station G/T = 31 dB/k

Boltzman Constant = -228.60 dBW/Hz.k

EIRP = Pt + Gt – Losses

EIRP = 3 + 0 – 1 dBw

EIRP = 2 dBw Eq: (4.4)

C/No = EIRP + G/T – Losses – Boltmzman Constant

Therefore:

C/No = 2 + 31 – 184.6 – (- 228.6) dB –Hz

C/No = 33 – 184.6 +228.6

C/No = 77 dB-Hz Eq: (4.5)

Threshold Eb/No for 10^{-6} BER = 10.5 dB

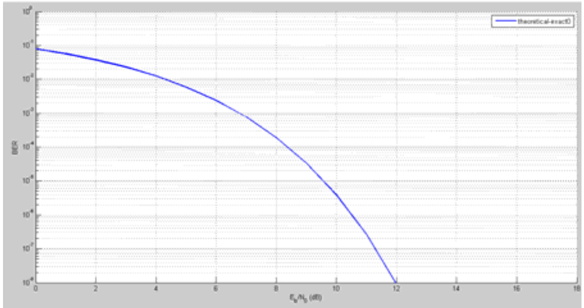

Figure 5. Bit Error Rate

Eb/No Calcutlation:

Formula: Eb/No = $\frac{C}{No}$ -Rb

Where Rb is Data Rate.

Eb/No = 77 – 10 log(10 Mbps)

Eb/No = 7 dB Eq: (4.6)

Calculation for Link Margin:

Link Margin = Calculated Eb/No – Threshold Eb/No

Link Margin = 7 – 10.5 dB

Link Margin = -3.5 dB Eq: (4.7)

Since link is negative and as per various standard like ESA, ECSS and NASA link margin should be in positive and ≥3dB. Therefore the link optimization is required.

There are two ways of link optimization:

1. Increase the transmitter power.
2. Using coding Scheme and get the use of channel coding gain.

Increasing transmitter power will require additional DC power for satellite transmitter and this will increase the size and capacity of the power subsystem and capacity will add few Kg mass in the satellite which will increase the launch cost of the satellite. Therefore the second approach of using channel coding scheme for optimization of the link between satellite and ground station is recommended. The only effect of using coding scheme is the increase in the bandwidth of the channel. Which has fewer cons than increasing transmit power of the satellite?

Coding gain of selected channel coding scheme

Channel Coding gain = 6.7 dB

Channel coding over head = 1.42 dB

Threshold Eb/No for 10^{-6} BER (coded) = Threshold uncoded Eb/No – Coding gain

Therefore:

Threshold Eb/No for 10^{-6} BER (coded) = 10.5 -6.7 dB

Threshold Eb/No for 10^{-6} BER (coded) = 3.8 dB Eq: (4.8)

Optimized Link Margin:

Link Margin = Calculated Eb/No – Threshold Eb/No (coded)

Link Margin = 7 – 3.8 dB

Link Margin = 3.2 dB Eq: (4.9)

The link margin for image data downlink of 10 Mbps with 10^{-6} BER is 3.2 dB. It is greater than 3 dB therefore the link is optimized and the data can be successfully downloaded to ground station with calculated BER of 10^{-6}.

IV. SIMULATIONS AND EXPERIMENTAL RESULTS

We had simulated with two methods, one is channel coding scheme and second is without channel coding scheme to know the best way of getting more data with short time and as much as data on day light. In day time, we had accessed to the sun light and we are generating power for satellite backup.

1. Without Channel Coding Scheme

Step 1. Create New Scenario.
Step 2. Set the Analysis Time Period
Step 3. Select the Environment from the RF and Check the use from rain model.
Step 4. Select the type ITU-R. 618-5.
Step 5. Check gaseous Absorption Model.
Step 6. Select ITU-R P.676-3, then Click apply and OK.
Step 7. Before proceeding the Next session save the EOB.

Creating Facility for EOB:

Step 1. Select Insert and Choose City From Database.
Step 2. Click Ok.

Insert Satellite in EOB:

Step 1. Insert a Satellite from the Object catalog and Select Orbit Wizard.
Step 2. Click next, Orbit Wizard window will appear, Select Sun Synchronous from the drop-down list.
Step 4. Select the Geometry definition and local time Node definition.
Step 5. Insert Receiver to the facility and type of Receiver Model is Simple Receiver.
Step 6. Set G/T value 31 dbw and set the frequency 8.2 GHz and the polarization type, then check the use rain model and click OK.

Insert Sensor in Satellite:

Insert sensor and set the pointing-type as target and then click facility to assign and then apply.

Insert the Transmitter to the Sensor:

Step 1. Click the sensor in the Object Browser and add a transmitter.
Step 2. Set the properties of Transmitter and also add details.
Step 3. Stet the Frequency 8.2 GHz and then Value EIRP 2 dbw then set the data rate 10 Mbps.
Step 4. Select Modulation type QPSK and set the Polarization to right Hand Circular.

Now we are going to add constraint in the facility receiver click right on the receiver and select properties and select Expand constraint then select comm. Then put the value Bit Error Rate Max 1e-006. Then set the elevation angle minimum 5 deg. Click apply and OK. Now link is established to the satellite. We have to compute the results. Then we have to click right option on the receiver tools select the Access tool compute results.

After then we will put the value of BER in receiver and open properties and expand the constraint, select the comm^ then select Max in Bit Error rate Option then select the Max 1e-006 and click apply and ok.

2. With Channel Coding Scheme

We have to put the values in channel coding gain of selected channel coding scheme in the Receiver to get maximum access time for our transmission.

Step 1. Select the Receiver properties and detail option.
Step 2. Select Pre-Demod to put the values.
Step 3. Select Add button to add values (dB).
Step 4. Click OK.

To get the result go to receiver properties tools and then select access option. Then in Associate Objects select the satellite then expand it and select sensor and then expand it and select the transmitter and press compute to get results.

Results without Channel Coding Scheme:
Access Time:

Acce		StartTime(UTCG)	StopTime(UTCG)	Duration (sec)
	1	13:41	22:54	553.06
	2	53:32	57:37	244.96
	3	12:15	19:17	421.93
	4	49:09	57:21	492.11
	5	22:57	23:32	35.3
	6	56:27	05:47	560.70
	7	53:39	03:09	570.21

Results with Channel Coding Scheme:
Access Time:

Access		StartTime(UTCG)	StopTime(UTCG)	Duration (sec)
	1	12:40.	23:52.0	671.412
	2	51:47.	59:19.2	451.443
	3	11:03.	20:31.2	567.396
	4	48:05.	58:28.8	622.869
	5	20:00.	26:25.5	384.608
	6	55:27.	06:44.4	676.948
	7	52:43.	04:08.7	684.888
	8	33:55.	38:50.3	294.917

CONCLUSION

As per the objective of the analysis there is a requirement of downloading 9000 Mbps payload data to the earth station while maintaining the data rate of

10 Mbps. This is possible only if the data downlink/access time is 15 minutes or higher. There is one more restriction on the transmission of the payload data; it should be downloaded in daytime that is in the presence of the sunlight. Therefore daylight passes must be considered.

The analysis results without using channel coding depicts that the total daytime access time is 13.3 minutes which is not sufficient to download 9000 Mbps payload data with 10 Mbps data downlink rate.

Therefore concatenated channel coding scheme was used in order to benefit from the coding gain which increased by the daytime access to 17 minutes which fulfills our data downlink time requirements with satisfactory link margins and BER.

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