Satellite Communications

Part IV-Lecture 3-Satellite Link Design

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Learning Objectives

- Solving calculations of Link Budget for various satellite systems

Design of Satellite Communication Links

- Based on two objectives
  - Meeting a minimum C/N ratio for a specified percentage of time
  - Carrying the maximum revenue earning traffic at minimum cost
- Art of good system design is to reach the best compromise of system parameters that meets the specification at the lowest cost
- Link budget is a tabular method of evaluating the received power and noise power in a radio link.
- It is impossible to design satellite link at the first attempt, so link budgets make the task easier because one a link budget has been established, it is easy to change any parameters and recalculate the result

Design of Satellite Communication Links

- Link budgets are usually calculated for a worst case when link will have lowest C/N
- Factors which contribute to a worst case scenario include:
  - An E/S located at edge of satellite coverage zone where the received signal is typically 3dB lower than in the center of the zone
  - Maximum path length from satellite to earth station
  - Low elevation angle at E/S giving highest atmospheric path attenuation
  - Maximum rain attenuation on link causing loss of received power aand an increase in receiving system noise temperature
- E/S antennas are assumed to pointed directly at the satellite(operate at their on-axis gain)
- If antenna is mispointed,a loss factor in included in link budget to account for reduction in antenna gain

Design of Satellite Communication Links

- Calculation of carrier to noise ratio in a satellite link is based on two equations for received signal power and receiver noise power.
- General Equation: $\mathbf{P_r = EIRP + G_r - L_p - L_a - L_{ta} - L_{ra}}$ **dBW**
  - L_p=path loss
  - L_a=attenuation in atmosphere
  - L_{ta}=losses associated with transmitting antenna
  - $L_{ra=}$losses associated with receiving antenna
- Receiving system noise power is given as $\mathbf{N = k + T_s + B_n}$ **dBW**
  - k=Boltzmann's constant(-228.6 dBW/K/Hz)
  - T_s=system noise temperature in dBK
  - B_n=noise bandwidth of receiver in dBHz
- Note: Because we are working in units of power, all decibel conversions are made as $10\log_{10}(T_s)$ or $10\log_{10}(B_n)$.The $20\log_{10}$ factor in path loss formula results from $(4\pi R/\lambda)^2$ term in path loss equation

Design of Satellite Communication Links

- We would first calculate the C/N ratio for a single radio link, either downlink or uplink
- Later it would be demonstrated to do evaluation of C/N for a complete satellite communication system e.g. In a two way satellite communication link there will be four separate links, each requiring a calculation of a C/N ratio.

Calculating C/N ratio for a Single Link

Design of Downlinks

- In previous lecture we went through the steps of calculating the C/N ratio for downlink in both clear sky and rain conditions
- All satellite communication links are affected by rain attenuation
- In 6/4 GHz band the effect of rain on the link is small
- In the 14/11 GHz(Ku) band and 30/20 GHz(Ka) band rain attenuation becomes significant
- Satellite links are designed to achieve reliabilities of 99.5 to 99.99%,averaged over a year
  - C/N ratio in the receiver will fall below minimum permissible value for proper operation of link for between 0.5 and 0.01% of the year. This is called link *outage*
- C band links are designed to have 99.99% reliability (52 mins outage)because rain attenuation rarely exceeds 1 or 2 dB
- Outage times of 0.1 to 0.5% of a year(8 to 40 hrs) are usually tolerated for Ka band links
- Allowable outage time also depends on type of traffic carried

Direct Broadcast TV Link Budget-Design of Downlink

- Calculate the downlink link budget for Ku band DBS-TV receiver when the transponder output power is 160W and the receiver is located on -3dB contour of the satellite antenna beam. The satellite antenna gain is 34.3dB and the receiving antenna gain is 33.5dB.The link is operational at 12.2GHz having path length of 38000km.Miscellaneous losses of 0.4dB for clear sky attenuation and 0.4dB for receiver antenna mispointing are allowed.

  At receiver antenna noise temperature is set at 35K in clear sky conditions and a 12GHz LNA with 110K noise temperature is used. The system uses QPSK implementation whereby a QPSK signal with a symbol rate 20Msps is assumed. The threshold C/N value is set at 8.6dB.What link margin is achieved when the above parameters are used.

Direct Broadcast TV Link Budget Example 4.5.1 of Book (pg 123)

- Suppose that there is 3dB rain attenuation in the downlink path of the DBS-TV system under consideration from previous slide. Assuming 100% coupling between sky noise temperature and antenna temperature, calculate the new $(C/N)_{dn\ rain}$?
- Note: Do not confuse yourself with the way this example is done in book. Follow the procedure taught in class

Design of Uplink

- The uplink design is **EASIER** than the downlink design in many cases:
  - An accurately specified carrier power must be presented at the satellite transponder
  - Use of higher power transmitters at E/S's is possible
  - VSAT's and Satellite telephone systems however have low transmit powers
- Satellite transponder is a quasi-linear (very nearly linear)amplifier and the received carrier level determines the output level
- The HPA in transponder must be run with a back-off to avoid IM products appearing at output.
- Amount of power to be backed off is determined by the uplink carrier power received at the spacecraft
  - Develop self understanding about the Output back off in amplifiers and it impact in satellite communication link. It is part of your Simulation Exercise assignment

Design of Uplink

- E/S transmitter power is set by the power level required at the input of the transponder. This can be done in one of two ways
  - Achieving a specific flux density at the satellite
  - Achieving a specific power level at the input of the transponder→ This way adopted as it helps finding the uplink C/N ratio

Design of Uplink

- **Finding $(C/N)_{up}$:**
  - It is the C/N ratio in the transponder measured in noise bandwidth B_n of the band-pass filter in the IF stage of the earth station receiver for which the uplink signal is intended. It is important that the uplink C/N ratio be calculated in the bandwidth of the receiver and NOT the bandwidth of the transponder
  - Noise power at the transponder input is N_{xp} W where $\mathbf{N_{xp}=k+T_{xp}+B_n}$
  - Power received at the input of transponder is $\mathbf{P_{xp}= P_t+G_t+G_r-L_p-L_{up}}$
    - Where $P_t G_t$ is the uplink earth station EIRP, G_r is the satellite antenna gain, L_p is the path loss, L_{up} accounts for all uplink losses other than path loss
  - Value of $(C/N)_{up}$ at the LNA input of satellite receiver is given by

    $C/N= P_{xp}-N_{xp}$

Design of Uplink

- **Finding the Earth Station Transmitter Output Power, P_t**
  - When C/N ratio is specified/known, the required transmit power at the earth station can be found from the equation just seen in previous slide
  - It can also be calculated from the output power of the transponder and the transponder gain when these parameters are known.

    $$\mathbf{P_{rxp} = P_{sat} - G_{xp} - BO_o}$$

    where P_{sat} is the saturated power of the transponder in dBW, G_{xp} is the gain of the transponder in dB, BO_o is the output back off in dB

    Use this value in $\mathbf{P_{rxp} = P_t + G_t + G_r - L_p - L_{up}}$ to find $\mathbf{P_t}$

Design of Uplink

Article 4.6,Example 4.6.1 pg 127

- A transponder of a Ku-band satellite has a linear gain of 127 dB and a nominal output power at saturation of 5 W.The satellite's 14 Hz receiving antenna has a gain of 26 dB on axis, and the beam covers western Europe.

  Calculate the power output of an uplink transmitter that gives an output power of 1W from the satellite transponder at a frequency of 14.45GHz when the earth station antenna has a gain of 50 dB and there is a 1.5dB loss in the waveguide run between the transmitter and the antenna. Assume that the atmosphere introduces a loss of 0.5 dB under clear sky conditions and that the earth station is located on -2dB contour of the satellite's receiving antenna

Design of Uplink

Article 4.6,Example 4.6.1 pg 127

- The input power required by the transponder is simply the output power minus the transponder gain:

$$\mathbf{P_{in}=0dBW-127dB=-127dBW}$$

The uplink power budget is given by link equation:

$$\mathbf{P_r=EIRP+\ G_r-L_p-L_{wg}-L_{at}-L_{pointing}}$$

Rearranging and putting proper losses:

$$\mathbf{P_t=P_r-G_t-G_r+L_p+L_{wg}+L_{at}+L_{pointing}}$$

$$\mathbf{P_t=-127-50\ -26+207.2+1.5+0.5+2.0\ dBW}$$

$$\mathbf{P_t=7.2\ dBW\ or\ 5.2\ W}$$

Uplink Design

Article 4.6,Example 4.6.1 pg 127

- If rain in the path causes attenuation of 7 dB for 0.01% of the year, what output power rating is required for the transmitter to guarantee that a 1-W output can be obtained from satellite transponder for 99.99% of the year

Solution: If we provide extra 7dB of output power to compensate for fading on the path due to rain, the transmitter output power will be:

$$\mathbf{P_t=7.2+7=14.2dBW\ or\ 26.3\ W}$$

Uplink Power Control (UPC)

- UPC can used to combat uplink rain attenuation
- The transmitting earth station monitors a beacon signal from the satellite, and watches for reduction in power indicating rain fading on the downlink
- Automatic monitoring and control of transmitted uplink power is used in uplink E/S's to maintain the uplink C/N ratio in the satellite transponder during the periods of rain attenuation

Instructions for Paper

- Weightage 25 %
- Syllabus:
  - Chapter 1 –Wireless Communication, Andrea Goldsmith Book
  - Chapter 1 and 2-Rappaport Book
  - Chapter 1 to 4 (Inclusive till design of Uplink, Article 4.6)-Satellite Communication)
  - Communication Terminology concepts
  - Multiple Access Concepts
- Objective +Subjective Part
  - Objective: MCQs +Short Questions/Answers
  - Subjective: Questions with general theory+Numericals

Instructions for Paper

- Formulas to be given:
  - Formulas to calculate gain,G
  - $L_p=(4\pi R/\lambda)^2$

θ_{3dB}=75 λ/D degrees

For antennas with **η_A=60%** :

$G=33{,}000/(\theta_{3dB})^2$

$$a = \frac{p}{1-e^2} \quad \text{and} \quad b = a\left(1-e^2\right)^{1/2}$$

where $p = \dfrac{h^2}{\mu}$ and h is the magnitude of the angular momentum

p = width of ellipse at focus = $a(1-e^2)$

$$\upsilon = \sqrt{Gm_e\left(\frac{2}{r}-\frac{1}{a}\right)}$$

$$e=[(a^2-b^2)/a^2]^{1/2}$$

Exercise Question 1

- A C-band station has an antenna with a transponder gain of 54dB.The transmitter output power is set to 100 W at a frequency of 6.100 GHz. The signal is received by a satellite at a distance of 37,500 km by an antenna with a gain of 26 dB.The signal is then routed to a transponder with a noise bandwidth of 36 MHz, and a gain of 110dB
  - Calculate the path loss at 6.1 GHz
  - Calculate power at the output port of the satellite antenna
  - Calculate the noise power at the transponder input,in dBW,in a bandwidth of 36MHz
  - Calculate the C/N ratio,in dB,in the transponder
  - Calculate the carrier power,in dBW and in W,at the transponder output

Exercise Question 2

- The satellite antenna in Problem 1 transmits at a frequency of 3875 GHz to an earth station at a distance of 39,000km.The antenna has a 6˚ E-W beam width and a 3˚N-S beam width. The receiving earth station has an antenna with a gain of 52 dB and a system noise temperature of 100 K and is located at the edge of the coverage zone of the satellite antenna (Assume antenna gain is 3dB lower than in the center of the beam).Assume transponder carrier power is 10 W at the input port of the transmit antenna of the satellite
  - Calculate gain of the satellite antenna
  - Calculate carrier power received by earth station
  - Calculate noise power of earth station is 36 MHz bandwidth
  - Hence find C/N for the earth station