ZEIT4225 Satellite Communications

Assignment: Link Budget Analysis

Due Date: February 4, 2018

Question 1

A satellite communications channel between a fixed Earth station and a transportable Earth station via a geostationary satellite is required. There are two different transportable Earth stations available. Perform a link budget analysis of the communications channel, in both the upstream and downstream directions, for each transportable Earth station, to determine which Earth station will provide the highest E_b/N_0 ratio in both directions. (upstream refers to transmitting from the transportable Earth station to the fixed Earth station)

The specifications for the geostationary satellite are:

Uplink Frequency (GHz)	30.5
Satellite Longitude (°)	78 E
Receiver Noise Figure	2.4
Environmental Temperature (K)	300
Antenna Diameter (m)	0.6
Antenna Efficiency (%)	60
Feeder Loss (dB)	0.5
Atmospheric Loss (dB)	6
Transmitter Power (W)	5
Downlink Frequency (GHz)	20.5
RF Bandwidth (MHz)	60
Filter roll-off	0.25
Modulation Scheme	QPSK

The specifications for the two available transportable Earth stations are:

	Earth Station A	**Earth Station B**
Transmitter Power (W)	30	50
Antenna Diameter (m)	1.2	0.6
Efficiency (%)	60	65
Feeder Loss (dB)	1	1
Receiver Noise Figure	2.8	2.6
Environmental Temperature (K)	20	20
Longitude (°)	68 E	68 E
Latitude (°)	34 N	34 N

The specifications for the fixed Earth station are:

Transmitter Power (W)	500
Antenna Diameter (m)	10
Efficiency (%)	55
Feeder Loss (dB)	2
Receiver Noise Figure	2
Environmental Temperature (K)	20
Longitude (°)	149 E
Latitude (°)	35 S

For each pair of satellite links that are analysed complete the following table and include it in your report:

	Uplink	**Downlink**
Transmitter Power (W)		
Transmitter Power (dBW)		
Transmitter Antenna Diameter (m)		
Frequency (GHz)		
Transmitter Efficiency (%)		
Wavelength (m)		
Transmitter Antenna Gain (dB)		
Transmitter Feeder Loss (dB)		
Transmitter EIRP (dB)		
Earth Station Longitude (°)		
Earth Station Latitude (°)		
Satellite Longitude (°)		
Central Angle (°)		
Slant Range (km)		
Free Space Loss (dB)		
Atmospheric Loss (dB)		
Carrier Power Density (dBW)		
Receiver Noise Figure		
Receiver Environmental Temperature (K)		
Equivalent Noise Temperature (K)		
Receiver Antenna Diameter (m)		
Receiver Efficiency (%)		
Receiver Antenna Gain (dB)		
Receiver G/T_e (dBK^{-1})		
Receiver Feeder Loss (dB)		
C/N_0 (dB)		
RF Bandwidth (MHz)		
Spectral Efficiency (bits/s/Hz)		

Filter Roll-off Factor		
Maximum bit-rate (Mbit/s)		
E_b/N_0 (dB)		

It is also recommended that any spreadsheets or matlab code used to calculate the solutions be submitted in a separate file.

Question 2

A satellite phone service is required to operate anywhere in Australia. Two satellite systems are available to provide this service. The first system uses a geostationary satellite and the second uses a constellation of low Earth orbit (LEO) satellites.

For the LEO constellation, the satellites operate as a repeater to create a communications channel between a satellite phone and a fixed Earth station. The minimum E_b/N_0 ratio for the links between the LEO satellites and the fixed Earth stations is 30 dB. The minimum elevation angle from a satellite phone to a satellite is 40^o.

The longitude of the geostationary satellite is 98^o E which also operates as a repeater between a satellite phone and a fixed Earth station. The minimum E_b/N_0 ratio for the links between the geostationary satellite and the fixed Earth station is 30 dB. The longest slant range from the geostationary satellite to a point on the Australian continent will occur at Tasman Island in Tasmania which is located at 43.25^o S and 148^o E.

Perform a link budget analysis, in both the upstream and downstream directions, between a satellite phone located at Tasman Island and the geostationary satellite and also between this satellite phone and a LEO satellite at an elevation angle of 40^o. Which satellite system provides the highest E_b/N_0 ratio in both directions?

The specifications for the geostationary satellite are:

Uplink Frequency (GHz)	1.65
Satellite Longitude (°)	98 E
Receiver Noise Figure	2.0
Environmental Temperature (K)	300
Antenna Diameter (m)	15
Antenna Efficiency (%)	50
Feeder Loss (dB)	4
Atmospheric Loss (dB)	6
Transmitter Power (mW)	200
Downlink Frequency (GHz)	1.55
RF Bandwidth (kHz)	10
Filter roll-off	0.2
Modulation Scheme	BPSK

The specifications for the LEO satellites are:

Uplink Frequency (GHz)	1.625
Minimum Satellite Elevation (°)	40
Receiver Noise Figure	2.1
Environmental Temperature (K)	300
Orbital Height (km)	1400
Antenna Gain (dB)	8
Feeder Loss (dB)	4

Atmospheric Loss (dB)	0.1
Transmitter Power (W)	0.5
Downlink Frequency (GHz)	2.49
RF Bandwidth (kHz)	10
Filter roll-off	0.2
Modulation Scheme	BPSK

The specifications for the satellite phone are:

Transmitter Power (W)	1
Antenna Gain (dB)	0
Feeder Loss (dB)	4
Receiver Noise Figure	4
Environmental Temperature (K)	20
Longitude (°)	148 E
Latitude (°)	43.25 S

For each pair of satellite links that are analysed complete a table similar to the table for Question 1 and include it in your report:

Question 3

A satellite communications channel for a broadcast digital television service uses 8-PSK modulation and has a bandwidth of 60 MHz and a filter roll-off factor of 0.3. A convolutional channel coder will be used to prepare the data for transmission over the satellite channel. Find the maximum data rate for the channel if a BER of 1×10^{-6} is required. The downlink has a C/N_0 ratio of 92 dB and the E_b/N_0 ratio for the uplink is 30 dB.

The coding gain of the convolutional coder at different code rates is:

Convolutional Code Rate	7/8	3/4	1/2
Coding Gain (dB)	3	3.5	4

Complete the following table and include it in your report:

	Convolutional Code Rate		
	7/8	3/4	1/2
Maximum Data Rate (Mbit/s)			
Equivalent Downstream E_b/N_0 (dB)			
Downstream Bit Error Rate			

Coding Gain

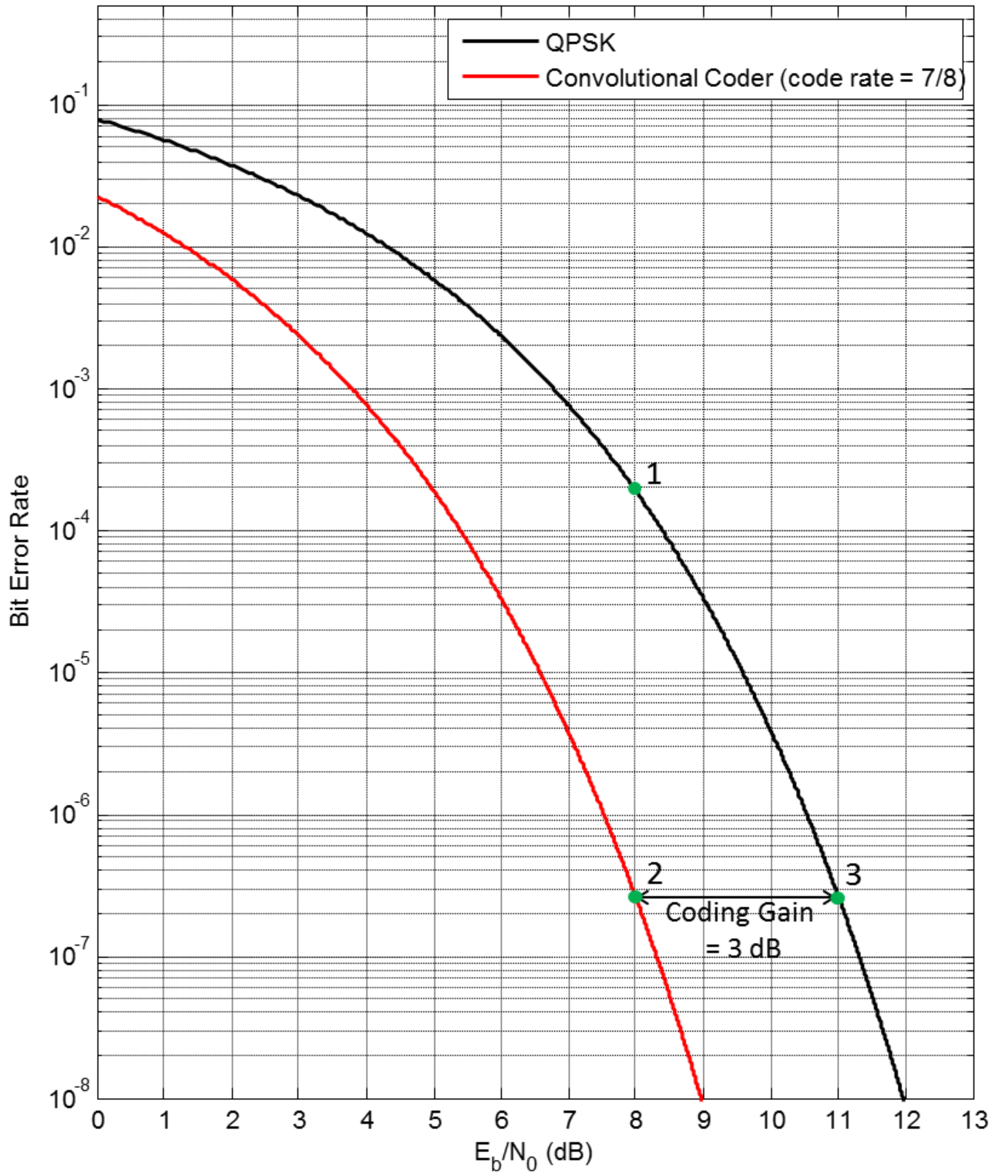
The waterfall diagram below shows the relationship between bit error rate (BER) and E_b/N_0. A BER of 1×10^{-6} means 1 error for every million bits transmitted so the smaller the BER the better the quality of the received signal. E_b/N_0 (energy per bit over noise power density) is a measure of the "quality" of the channel and is independent of the modulation scheme used (i.e. the number of bits per symbol for PSK modulation) and the bandwidth of the channel (so you can compare two channels that have different bandwidths). The larger the E_b/N_0 value the better the quality of the channel.

The diagram below shows the waterfall diagram for a signal transmitted using QPSK with no channel coding applied to the signal and a signal transmitted using QPSK with channel coding applied to the signal before it is transmitted. The channel coder used is a convolutional coder with a code rate of 7/8. This means that for every eight bits transmitted, 7 bits will be from the original data signal and 1 bit is a redundancy bit that can be used to detect and correct errors at the receiver.

Now consider a channel with an E_b/N_0 of 8 dB. If no channel coding is applied to the transmitted signal, the BER for the transmitted signal will be 2×10^{-4} or 1 error in every 5,000 bits transmitted (point 1 in the diagram below). If this is an unacceptably high error rate for the type of signal that is being transmitted then channel coding can be used to reduce the BER. If the convolutional coder with a code rate of 7/8 is applied to the signal before it is transmitted, then the waterfall diagram below shows that the BER will be reduced to approximately 2.6×10^{-7} or 1 error in every 3.85 million bits transmitted (point 2 in the diagram below). Note that the E_b/N_0 of the channel has not changed. It is the channel coding that has reduced the bit error rate at the receiver and the price paid for this improved error rate is a reduction in the *data* rate that can be transmitted to 7/8 of the maximum *bit* rate for the channel.

When describing the improvement in BER provided by the various forms of channel coding, the term used is the coding gain. The coding gain is the difference in E_b/N_0 required to produce the same BER for the coded and uncoded signals. The diagram below shows that the coding gain for the convolutional coder is 3dB.

The coding gain provides a convenient method for determining the expected BER for a signal that is transmitted after channel coding has been applied. First find the E_b/N_0 of the channel and then add the coding gain of the convolutional coder to this E_b/N_0. The resulting *equivalent* E_b/N_0 can then be used in the standard formulas for finding the BER given a particular modulation scheme (QPSK, 8-PSK etc.). The diagram below shows that applying the standard formula for QPSK using an E_b/N_0 of 8+3=11 dB (point 3 on the diagram below) will produce the same BER as the waterfall diagram of the channel coder at 8 dB. When using this method it is not necessary to know the waterfall diagram of the channel coder. If the coding gain is known, the standard formulas for BER can be used.



Question 4

A satellite communications channel for a broadcast digital television service is required to provide a data rate of 20 Mbit/s with a bit error rate of less than 1×10^{-9}. The channel uses QPSK modulation and has a bandwidth of 20 MHz and a filter roll-off factor of 0.5. A convolutional channel coder will be used to prepare the data for transmission over the satellite channel. Find the minimum carrier-to-noise ratio (C/N) for the satellite downlink that will be required to provide this service. The minimum E_b/N_0 ratio for the uplink is 30 dB.

The coding gain of the convolutional coder at different code rates is:

Convolutional Code Rate	7/8	3/4	1/2
Coding Gain (dB)	3	3.5	4

Complete a table similar to the table in Question 3 and include it in your report.