Link Budget Calculations and Final Review

Link Budgets

- a link budget is the most important tool for system-level design of wireless systems
- it's a "budget" similar to an accountant's budget: the sum of gains and losses in various parts of the system has to result in satisfactory performance (typically output SNR or BER)
- the link budget includes all gains (and losses) from baseband input to baseband output
- since values are gains/losses it is more convenient to add values expressed in dB instead of multiplying and dividing

Gains Included

- the following are the basic quantities included in a link budget:
  - transmitter output power
  - transmit antenna gain
  - path loss
  - receive antenna gain
  - receiver noise power
  - link margin
- depending on the type of wireless system, other factors may need to be taken into account (e.g. interference) and these may involve other calculations
- during the system design phase many system design options will need to be considered, each of which affects one or more of the above gains/losses
- the difference between the required SIR/SNR and what the link budget predicts is the "margin"
- the objective of the system design phase is to "close the link" (end up with a positive margin) with the lowest (dollar) cost
- link budgets are usually prepared with a spreadsheet so that system design options can be explored

Variations on the Basic Link Budget

- the basic link budget shown above is seldom enough to capture all of the parameters of a real system
- usually require different link budgets for forward and reverse channel
- may also need to prepare different link budgets for different modulation schemes or rates, types of users (portable, mobile, fixed), etc.
- some values may only be characterized statistically (e.g. path loss). In this case the mean value plus an additional value for the desired percentage coverage or the desired availability (e.g. BER less than 10^{-2} over 90% of the service area) is used
- in some cases other parameters (e.g. bit rate) can be varied so as to "close" the link; these values must then also be included in the link budget

Typical Link Budget Elements

- transmitter output power: cost will be affected by transmitter output power and power amplifier efficiency. Battery consumption may limit the maximum output power and safety considerations may limit the EIRP.
- transmitter feedline losses: low-loss cable or waveguides are more expensive
- transmit antenna gain: higher-gain antennas are more expensive and may not be practical for portable or mobile users

- path loss: this may be fixed (e.g. a geostationary satellite) or may be a system design parameter (e.g. cell size). For free-space systems we can use the Friis equation, for land-mobile applications we can use statistical models such as Hata-Okumura
- other propagation losses: these effects may need to be considered in some applications
  - log-normal shadowing (land-mobile)
  - diffraction losses (obstructed paths)
  - atmospheric absorption (at high frequencies)
  - outdoor-to-indoor loss (base outside, user indoor)
- receiver antenna gain: same gain/cost considerations and with transmitter antenna. in some cases using a higher-gain receiving antenna will also reduce interference
- receiver noise figure: lower noise figure is more expensive. Many systems are interference-limited (the performance is limited by the interference power which is much greater than the thermal noise power) so this may not be an issue. For other systems designs using a low-noise figure LNA (low noise amplifier) is the lowest-cost way of closing the link and the cost of the LNA may be a significant part of the system cost
- receiver noise bandwidth: this will depend on the signal bandwidth which in turn depends on the data rate and modulation scheme
- coding gains: a system using FEC may include coding gain in the link budget
- implementation losses: some link budgets include an implementation loss to account for distortion, intermodulation, phase noise and other degradation introduced by real receivers and transmitters

Sample Link Budget (Geostationary TV Broadcast)

- increasing the transmit power or antenna gain (on the satellite) is relatively expensive, so the receiving antenna has more gain and low-noise-figure LNAs are used instead of higher transmitter power

transmitter power output	43	dBm (20 W)
transmit antenna gain	20	dB
frequency	4	GHZ
wavelength	7.5	cm
path distance	42,164	km
free-space path loss	197	dB
receiver antenna gain	45	dB
feedline loss	1	dB
received signal power	-90	dBm
kT	-174	(dBm/Hz)
receiver noise bandwidth	67	dB-Hz (5 MHz)
receiver noise figure	1	dB
received noise power	-106	dBm
IF SNR	16	dB

Sample Link Budget (Cellular System)

- figure 1 shows a link budget taken from the GSM specification
- there are separate link budgets for forward and reverse links
- the end result of this particular link budget is the maximum cell radius for a certain fraction of coverage since the other parameters are considered to be fixed
- the GSM system was designed to be interference-limited in small cells and noise limited in large cells and a 3 dB interference degradation margin is included in this particular example

Review of Post-Midterm Material

- the final exam will cover all of the material on the mid-term exam plus all of the material covered in the lectures since then
- you should be able to:
- Multiple Access Techniques
  - differentiate between FDMA, TDMA and CDMA multiple-access systems
  - compare (state advantages and disadvantages) of these MA schemes
  - compare FH-SS and DS-SS
  - compare SDMA with other MA schemes
- Wireless Networks
  - identify the functions of the PSTN and MSC in completing a cellular telephone call
  - explain differences between packet- and circuit-switched networks
  - explain difference between Aloha and slotted Aloha packet radio systems
  - use the terminology used in wireless networks
- Wireless Standards
  - identify the most important characteristics of GSM and IS-95 systems
- Link Budgets
  - write up a link budget and compute a link margin based on specifications of system components
  - use a link budget to decide between alternatives system designs to arrive at a lowest-cost solution

Annex A.4: Example of RF-budget for GSM 900 Class4 (peak power 2 W) in a small cell

Propagation over land in urban and rural areas				
Receiving end: TX :		BTS MS	MS BTS	Eq. (dB)
Noise figure(multicoupl.input)	dB	8	10	A
Multipath profile		TU50	TU50	
Ec/No min. fading	dB	8	8	B
RX RF-input sensitivity	dBm	-104	-102	C=A+B+W-174
Interference degrad. margin	dB	3	3	D (W=54.3 dBHz)
Cable loss + connector	dB	2	0	E
RX-antenna gain	dBi	16	0	F
Diversity gain	dB	3	0	F1
Isotropic power, 50 % Ps	dBm	-118	-99	G=C+D+E-F-F1
Lognormal margin 50 % ->75 % Ps	dB	5	5	H
Isotropic power, 75 % Ps	dBm	-113	-94	I=G+H
Field Strength 75 % Ps		24	43	J=I+137 at 900 MHz
Transmitting end: RX:		MS BTS	BTS MS	Eq. (dB)
TX PA output peak power	W	-	12.6	
(mean power over burst)	dBm	-	41	K
Isolator + combiner + filter	dB	-	3	L
RF Peak power,(ant.connector)	dBm	33	38	M=K-L
1)	W	2	6.3	
Cable loss + connector	dB	0	2	N
TX-antenna gain	dBi	0	16	O
Peak EIRP	W	2	158	
	dBm	33	52	P=M-N+O
Isotropic path loss,50 % Ps 2)	dB	148	148	Q=P-G-3
Isotropic path loss, 75 % Ps	dB	143	143	R=P-I-3
Range km - 75 % Ps				
Urban, out of doors		1.86		
Urban, indoors		0.75		

1) The MS peak power is defined as:

a) If the radio has an antenna connector, it shall be measured into a 50 Ohm resistive load.
b) If the radio has an integral antenna, a reference antenna with 0 dBi gain shall be assumed.

2) 3 dB of the path loss is assumed to be due to antenna/body loss.

Figure 1: Sample GSM link budget