S-72.2211 Mobile Communication Systems and Services

Exercise session 1 1.2.2008

Helka Määttänen

1 Link budget

A link budget analysis is a fairly straighforward way to determine the feasibility of any given system. It is also a good mean to understand the tradeoffs between costs and level of reliability for a communicantion link. In short, the link budget can be described as follows. The received signal power P_{rx} is equal to the transmitted signal power P_{tx} plus gains G, minus losses L, and it should be more than the sensitivity S of the receiver.

$$P_{rx} = P_{tx} + G - L \geq S \tag{1}$$

The gains refer often to the antenna gains and losses incude path loss and antenna feeder losses. The average radio path loss (in dB) as a function of the distance r is

$$L = L_o + 10\alpha \log_{10} r_{\text{km}},$$

where L_o is the loss at 1 km distance and α is the path loss exponent. Typical values for α are between 2 and 4, where 2 refers to propagation in free space and 4 for relatively lossy environment. In some indoor environments α may be between 4 and 6. In tunnels, a waveguide type of propagation may occur and α may drop below 2. For practical cases there are several approximating methods for the path loss such as Hata model, which has the general expression

$$L = L_o(f, h_{ms}) - 13.821 \log_{10}(h_{bs}) + (44.9 - 6.55 \log_{10}(h_{bs})) \log_{10}(r) \tag{2}$$

where f is the frequency of transmission in MHz, h_{ms} and h_{bs} are the heights of the mobile station and the base station, respectively, and r is the distance in km.

Hint: be carefull with the units when calculating path losses.

Tasks

1. Define dB, dBm, dBc and dBi.

Solution

All dBx describes a relation between a measured quantity and a reference quantity. For powers the reference to calculate dB is 1 W and for dBm the reference is 1mW. For example x W in dBm

$$X = 10 \log_{10}(\frac{xW}{0.001W})[dBm]$$

dBc compares power to carrier power. In telecommunications it indicates the relative levels of noise or sideband peak power. dBi compares to an (theorethic) isotrophic scatterer and is used to describe the directivity of an antenna.

2. Define sensitivity.

Solution

Sensitivity is the amount of received power necessary for the receiver to achieve a specific performance in terms of BER. Sensitivity can be expressed in Wats or in dBm. To see how to determine the sensitivity level we should look at the noise and signal powers at the receiver.

The single sided thermal noise spectral density N_t is

$$N_t = kT_0[W/Hz],$$

where k is Boltzmanns constant ($k = 1.38 \cdot 10^{-23}$) and T is the absolute temperature of the component. At $20°C$, $T_0 = 293K$ and $N_t = 4.04 \cdot 10^{-21}[W/Hz] = -174[dBm/Hz]$.

In addition to the thermal noise the receiver RF generates also noise. The amount of noise is conveniently described with the noise figure N_F that has typical values around 5-9dB.

$$N_0 = N_t N_F[W/Hz]$$

The receiver noise power N is measured over the signal sampling bandwidth B and is therefore

$$N = N_0 B[W].$$

This is also called the receiver noise floor. At the input of a receiver, before sampling of the signal, a carrier-to-noise power ratio can be measured and is defined as

$$\frac{C}{N} = \frac{P_{rx}}{N}$$

The signal is sampled at the sampling rate (or bandwidth) B which is not necessarely same as the symbol rate of the signal R_S. If it is higher it gives processing gain for the signal power at the receiver and SNR can be written as

$$SNR = \frac{P_{rx}B/R_S}{N}$$

However, when more samples of the signal is taken, more samples of the noise is taken as well and the signal-to noise-ratio does not depend on the sampling bandwidth.

$$SNR = \frac{P_{rx}B/R_S}{N_0 B} = \frac{P_{rx}/R_S}{N_0} = \frac{E_S}{N_0}$$

Thus, here the SNR is defined as symbol energy per noise density. As mentioned earlier, the sensitivity depends on the BER performance requirement. When we know the transmission specs, e.g. signal type (CDMA, OFDM..) receiver type (MMSE, ZF, SIC..) and the modulation, the $\left(\frac{E_S}{N_0}\right)_{min}$ requirement to achieve a certain BER level can be set. The minimum received signal power, the receiver sensitivity, is then the receiver noise floor - processing gain + the specific SNR requirement in dB

$$S = N - \frac{B}{R_s} + \left(\frac{E_S}{N_0}\right)_{min} [dBm] = N_0 R_s + \left(\frac{E_S}{N_0}\right)_{min} [dBm]$$

3. Preliminary measurements show that the average path loss L_p in dB including antenna feeder system losses and antenna gains can be modelled with

$$L_p = 130 + 10\log_{10}\left(r_{\text{km}}^{\alpha}\right) \tag{3}$$

where α is the path loss exponent.

a) Determine the required transmit power level to obtain a 5 km cell radius when the receiver sensitivity is -104 dBm and path loss exponent 3.2.

Solution

First calculate the loss term with the given formula.

$$L_p = 130 + 32\log_{10}(5) = 152.37dB$$

Transmitted power should be L_p above the receiver sensitivity.

$$P_{tx} = -104dBm + 152.37dB = 48.37dBm$$

b) Later it turns out that the path loss exponent is 3.5. What would the required transmit power level be to preserve the cell radius?

Solution

Keeping the cell radius constant calculate new loss term with a new α

$$L_p = 130 + 35\log_{10}(5) = 154.46\text{dB}$$

Transmitted power should be again L_p above the receiver sensitivity.

$$P_{tx} = -104\text{dBm} + 154.46\text{dB} = 50.46\text{dBm}$$

Transmitted power should be increased 2 dB in order to preserve the cell radius in this environment.

c) To which value is the cell radius reduced, if the transmit power remains unchanged?

Solution

Now we want to keep the transmitted power constant

$$\begin{aligned} P_{tx1} &= P_{tx2} \rightarrow \\ S + 130 + 32\log_{10}(5) &= S + 130 + 35\log_{10}(r) \rightarrow \\ 5^{32/35} &= 4.356\text{km} \end{aligned}$$

If the transmit power is preserved the change in path loss exponent means 644 m reduction in cell size.

4. How many times is the coverage area increased at 900 MHz carrier frequency in a city environment, when the base station antenna height is increased from 30 m to 200 m and all other system parameters remain constant?

With 30 m antenna height the cell radius is 2 km. The average path loss is assumed to follow the Hata model.

Solution

Now that the gain from the higher base station antenna is used to increase coverage the loss term should be kept constant.

$$L(h_{bs} = 30\text{m}) = \text{L}(\text{h}_{\text{bs}} = 200\text{m})$$

As the first term of hata model, $L_o = (f, h_{ms})$, is independent of the base station antenna height we have

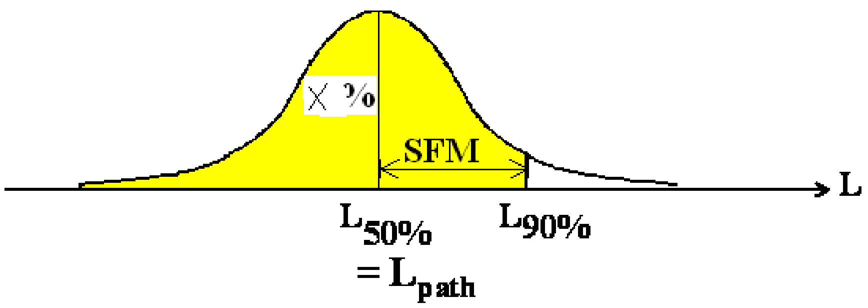

Figure 1: SFM from the log-normal distribution

$$\begin{aligned} -13.82\log_{10}(h_{bs1}) + (44.9 - 6.55\log_{10}(h_{bs1}))\log_{10}(d_1) &= \\ -13.82\log_{10}(h_{bs2}) + (44.9 - 6.55\log_{10}(h_{bs2}))\log_{10}(d_2) & \end{aligned}$$

with numbers

$$\begin{aligned} -9.8101 &= -318002 + 29.8283\log_{10}(d_2) \\ \log_{10}(d_2) &= \frac{21.9901}{29.8283} = 0.7372 \rightarrow \\ d_2 &= 5.4604 = 5.5\text{km} \end{aligned}$$

We are interested of the coverage area increase thus we calculate

$$\frac{A_2}{A_1} = \left(\frac{d_2}{d_1}\right)^2 = 7.45$$

2 Fade margin and time availability

The path loss discussed above is an *average* path loss which does not take into account any fading. One simple way to account for slow fading is to transmit more power. The extra amount of transmit power required to overcome the time dependent attenuation phenomena is referred to as fade margin. Slow fading is caused by for example by the shadowing effect, where a large obsticle such as hill or large building obscures the main signal path. Shadowing can be modelled as a log-normal process with a mean, that is the average path loss, and a standard deviation σ_{SF}. Thus, it means that if the fast fading is not considered, the received power follows this log-normal distribution.

The fraction of time that the received signal power, or signal–to–noise ratio, stays above some threshold γ_t is called the *time availability*. The fraction of time that received signal power stays below the threshold is called the *outage probability*.

The amount of the shadow or slow fade margin (SFM) depends on the desired reliability of the link. SFM can be calculated by using the standard deviation and the inverse Q-function (INVQ) depending on the fraction of time that the signal is allowed to be in outage, i.e. the outage probability P_o. See also figure 1.

$$SFM = INVQ(P_o)\sigma_{SF}$$

Tasks

5. The cell is first dimensioned for 50% coverage probability at the cell border. It means that 50% of time the received signal level is above the sensitivity level i.e. 50% of time the fade margin is large enough to cover the slow fade.

How much is the coverage area changed if the coverage probability target at the cell border is to 90%? Or to 99%? The path loss exponent α gets the values 3 and 5. Give the results as a table.

Solution

In logarithmic units the radio link budget can be given as

$$P_{tx} - S = G - L_p - SFM$$

where G includes all equioment gains and losses. If we want to increase the coverage probability i.e. the time the received signal level is sufficient to enable reception we need to increase the transmitted power or diminish the propagation losses. If all equipment parameters are unchanged, increasing the SFM means that the tolerated average path loss and thus the coverage area is degreased:

$$L_{p1} + SFM_1 = L_{p2} + SFM_2$$

or

$$L_o + 10\alpha \log_{10}(R_1) + SFM_1 = L_o + 10\alpha \log_{10}(R_2) + SFM_2$$

It follows that

$$10\alpha \log_{10}(R_2/R_1) = SFM_1 - SFM_2$$

Then express the ratio between areas before and after

$$\frac{A_2}{A_1} = \left(\frac{R_2}{R_1}\right)^2 = 10^{\frac{SFM_1 - SFM_2}{5\alpha}}$$

When the coverage probability target is 50%, 90% or 99% the fade margins become

$$\begin{aligned} 50\% &\rightarrow SFM = INVQ(0.5)\sigma_{SF} = 0 \cdot 6 = 0\text{dB} \\ 90\% &\rightarrow SFM = INVQ(0.1)\sigma_{SF} = 1.28 \cdot 6 = 7.68\text{dB} \\ 99\% &\rightarrow SFM = INVQ(0.01)\sigma_{SF} = 2.33 \cdot 6 = 13.98\text{dB} \end{aligned}$$

($Q(0) = 0.5$ and $Q(1.28) = 0.1$ and $Q(2.33) = 0.01$)

The 50% coverage probability target means that no fading margin is added and thus $SFM_1 = 0$. SFM_2 is either 7.68 dB or 13.98 dB depending on the requirement. Table below shows the results for the area decrease.

Coverage prob.	$SFM_1 - SFM_2$	$n = 3$	$n = 5$
90%	-7.68	0.3076	0.4929
99%	-13.98	0.1169	0.2759