1 E_c/N_0 Target Investigation

Approaching the concept, we first explain what the E_c/N_0 actually means, though there is certainly room for misinterpretation.

1.1 Background for Sensitivity Calculations

In general it is not intuitive, how the energy per chip divided by the noise power spectral density relates to SNR. Actually the fact is that it does not, but we have to talk about *Carrier* to Noise Ratio (CNR, or some times the *Carrier to Interference and Noise Ratio* – CINR, in this case the interference is taken into account as well). However, the derivation from CNR to E_c/N_0 in linear domain is as follows:

$$CNR = \frac{P_{Rx}}{P_n} = \frac{P_{Rx}}{N_0 \cdot W} = \frac{P_{Rx} \cdot T_c}{N_0} = \frac{E_c}{N_0}. \tag{1}$$

The derivation starts from [W]/[W] and ends in [J]/[W/Hz] = [Ws]/[W/Hz] = [W/Hz]/[W/Hz], thus the unities agree.

1.2 Processing Gain

The difference between the CNR and SNR is that the SNR takes into account the processing gain (PG) and thus relates to bit energy divided by noise power spectral density E_b/N_0. The PG comes from spreading and coding. Multiple chips are *processed* to interpret the value of a single information bit. Hence the processing gain can be expressed as follows:

$$PG = 10\log(W / R_{info}), \tag{17}$$

Where W is the WCDMA chip rate, and R_{info} the information bitrate without any coding included.

1.3 Spreading Gain

Spreading gain should never be mixed with processing gain. Spreading gain is the gain introduced by signal despreading at the receiving end. The gain comes from coherent addition of SF chips per each bit, SF being the spreading factor. The exact relation between the spreading gain SG in decibels and the SF can be expressed as

$$SG = 10\log(W / R), \tag{18}$$

where R now denotes the user bitrate which includes the forward error correction (FEC) coding.

The whole concept of spreading gain is best clarified by a simple example: Let the chip amplitude be A_{chip}, and the noise sample amplitude be A_n correspondingly. Now, for each bit we make a coherent summation of SF chips, thus the bit amplitude A_{bit} and corresponding bit P_{bit} power are

$$A_{bit} = SF \cdot A_{chip} \Rightarrow P_{bit} = SF^2 \cdot A^2{}_{chip} = SF^2 \cdot P_{chip} \qquad (19)$$

On the other hand, the noise samples are uncorrelated, hence remembering that the **variance** of a random variable X being **sum of random variables** Y_i is the **sum of individual variances**, we can state that the total noise power contributing to a single bit $P_{n,bit}$ is SF times the noise power contributing to a chip. Now, combining this with (19) yields for the SNR e.g. E_b/N_0 in absolute units:

$$SNR = \frac{P_{bit}}{P_{n,bit}} = \frac{SF^2 \cdot P_{chip}}{SF \cdot P_n} = SF \cdot \frac{P_{chip}}{P_n} = SF \cdot CNR\,. \qquad (20)$$

1.4 Sensitivity

Understanding the concepts of E_b/N_0, E_c/N_0 and PG is essential in order to be able to determine the sensitivity levels e.g. required P_{Rx} for different bitrates, which indeed is a part of our overall goal. A typical approach for assessing the sensitivity for a given bitrate R and the WCDMA chip rate W is to assume a regular service specific E_b/N_0 target, of for example 4 dB, and calculate the required E_c/N_0 as follows:

$$\begin{aligned} E_c / N_0 &= E_b / N_0 - PG \\ &= 4\text{ dB} - 10\log\left(\frac{W}{R}\right). \end{aligned} \qquad (21)$$

In (21) the E_c/N_0 and E_b/N_0 are naturally in decibels as is the case with the PG as well. Now, for example for 0.2 Mbps we would have an E_c/N_0 requirement of

$$4\text{ dB} - 10\log\left(\frac{3.840\text{ Mcps}}{0.2\text{ Mbps}}\right) = -8.83\text{ dB} \qquad (22)$$

How does the E_c/N_0 relate to sensitivity then? It is simple, for a certain noise floor P_n [dBm] (including thermal noise and interference from other users), the WCDMA receiver sensitivity level is

$$P_n\,[\text{dBm}] - E_c/N_0\,[\text{dB}] \qquad (23)$$

The key thing to understand is that when discussing WCDMA, we have to differentiate between the carrier power and signal power. The carrier power may be way below the thermal noise level, but signal power has to be above. Otherwise the receiver would have to guess all the bits yielding a BER of 0.5!