BANDWIDTH IN WCDMA SYSTEMS

Standards precisely specify a system, but they are rarely enjoyably read. The most important concepts are clarified here.

BANDWIDTH IN UMTS WCDMA

The process of spreading and de-spreading information signal over a certain bandwidth is shown in Fig. 1 below.

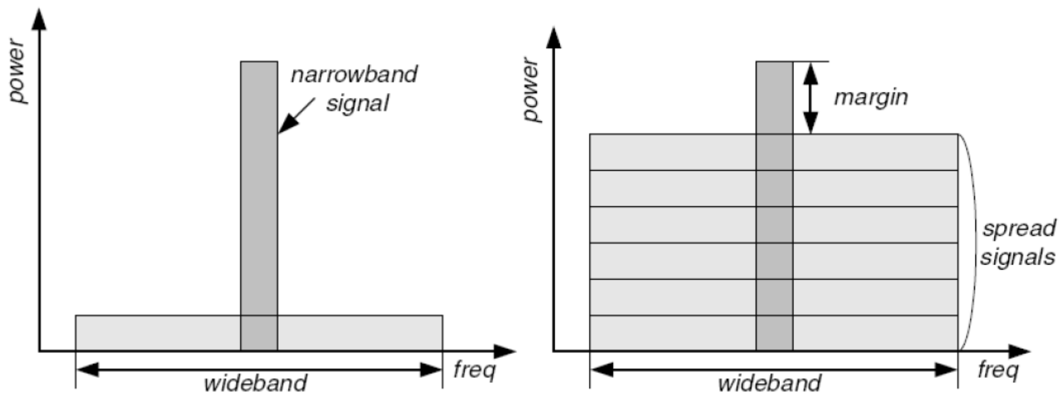

Figure 1: Process of spreading and de-spreading a narrow-band information signal over a wider channel bandwidth.

The process of spreading the narrow-band signal is also known as 'chipping', and it is done by multiplying the information sequence by the chip sequence. This is illustrated, in the time domain, in Fig. 2.

In frequency domain, data is the vertical narrow-band signal shown on the left-hand side of Fig. 1, while the spread signal is shown by the horizontal wide-band signal on the left-hand side of Fig. 1. The spreading code from Fig. 2 is not shown in Fig. 1.

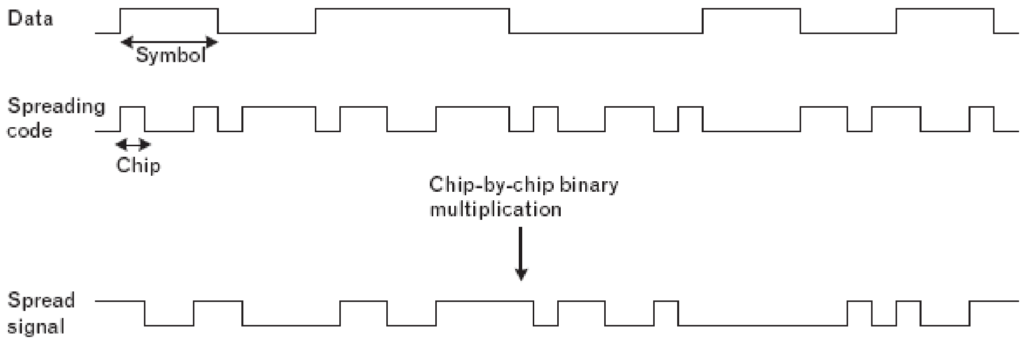

Figure 2: Multiplication of the data stream
with the spreading code results in the spread signal.

'Symbol' in Fig. 2 refers to a collection of bits, which are the result and a function of the modulation format.

Both the data sequence and the spreading sequence in Fig. 2 will have a certain rate, expressed in bit/second. Data rate depends on user demand as well as on the type of payload content. The rate of the spreading sequence (chip rate) is a function of the system. The chip rate (even though in principle just a mathematically predetermined sequence of ones and zeroes, with a bit/second rate), is measured in chip/second, rather than bit/second.

The final spread-spectrum bandwidth of the (spread) signal, given its data rate, is determined by the chip rate. If the chip rate is slow, the resulting bandwidth is small, and vice versa.

The following formula can be used to determine the bandwidth of the spread signal:

$$BW = R_c(1+\alpha)$$

where R_c is the chip rate. If the chipping rate is given in Mchip/s, the resulting bandwidth is in MHz. In the above equation, α is the rolloff factor of the raised cosine pulse, and it will be discussed in more detail later on. For now, it is sufficient to know that a typical value is $\alpha = 0.22$. Therefore, the resulting spread-spectrum bandwidth is some 20 % ($100 \cdot \alpha$ %) larger than the chipping rate.

Historically, a chipping rate of 4.096 Mchip/s was envisaged for WCDMA systems. [1, page 519] This translates into a spread-spectrum bandwidth of 4.99712 MHz which, for practical purposes, is always rounded up to 5 MHz.

Therefore, the nominal UMTS WCDMA channel bandwidth, for historical reasons, was set to 5 MHz.

Later on, the envisaged chipping rate was changed to 3.84 Mchip/s, thus resulting in a spread-spectrum bandwidth of 4.7 MHz, according to the above formula.

The 3GPP specification TS25104-820, Section 5.4.1, "Channel spacing," deals with spacing rather than channel bandwidth:

The nominal channel spacing is 5 MHz, but this can be adjusted to optimise performance in a particular deployment scenario.

In the same 3GPP specification, Section 6.6.1 ("Occupied bandwidth") states:

The occupied bandwidth is the width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage β/2 of the total mean transmitted power. See also ITU-R Recommendation SM.328. The value of β/2 shall be taken as 0,5%.

Furthermore, Section 6.6.1.1 ("Minimum requirement," regarding above) states:

The occupied channel bandwidth shall be less than 5 MHz based on a chip rate of 3.84 Mcps.

Section 6.6.1 effectively says that the bandwidth is defined as the sub-band of the 5 MHz frequency band that contains 99% of the total emitted power.

There are other chipping rates commonly used in 3GPP WCDMA systems. They are, most notably: 1.28 Mchip/s, and 7.68 Mchip/s. They are not directly related to Mesaplexx work on UMTS900.

WCDMA PROCESSING GAIN

The ratio between the chip rate and the data rate is called the spreading factor. Spreading factor equal to 1 means that the data rate is equal to the chip rate, and thus that no spreading occurs at all. In reality, the chip rate is higher than the data rate. In UMTS WCDMA, a chipping rate of between 4 and 512 is selected.

Closely related to the above, the processing gain is the ratio of the spread bandwidth to the de-spread bandwidth, usually expressed in dB.

Since the bandwidth and the data rate are closely related in spread-spectrum systems, the processing gain can be expressed as:

$$G_p = 10 \cdot \log\left(\frac{R_c}{R_d}\right)$$

where R_c is the chip rate, while R_d is the data rate. For example, voice data rate of 12.2 kbps, spread by 3.84 Mchip/s, results in the processing gain of 25 dB.

The processing gain indicates the resilience of spread-spectrum systems to noise. It is effectively the benefit of using spread spectrum systems. In link budgets, the processing gain is used to offset losses, such as the propagation loss.

Given a fixed R_c, we see that the higher the R_d (eg high download speeds), the processing gain is smaller. This means that the connection is more prone to errors.

WHERE DOES 3.84 MCHIP/S COME FROM?

The chip rate in the 3GPP standard TS25104-820, Section 6.8 ("Transmit modulation"):

Transmit modulation is specified in three parts, Frequency Error, Error Vector Magnitude and Peak Code Domain Error. These specifications are made with reference to a theoretical modulated waveform. The theoretical modulated waveform is created by modulating a carrier at the assigned carrier frequency using the same data as was used to generate the measured waveform. The chip modulation rate for the theoretical waveform shall be exactly 3.84 Mcps. The code powers of the theoretical waveform shall be the same as the measured waveform, rather than the nominal code powers used to generate the test signal.

RAISED-COSINE DIGITAL FILTERING

Raised-cosine digital filtering is used in many 3GPP specifications. In digital communications, pulse (digital bit) shaping is used to make the transmitted signal better suit the characteristics of the communication channel used. Pulse shaping is effectively a filtering process, through which the bandwidth is limited (and thus the transmitted spectrum effectively determined). This occurs at the baseband (digital) stage, before the analogue RF stage.

Raised-cosine pulse shaping filters are used in UMTS WCDMA systems. Section 6.8.1 of TS25104-820 ("Transmit pulse shape filter") states:

The transmit pulse-shaping filter is a root-raised cosine (RRC) with roll-off α=0.22 in the frequency domain. The impulse response of the chip impulse filter $RC_0(t)$ is

$$RC_0(t) = \frac{\sin\left(\pi \frac{t}{T_C}(1-\alpha)\right) + 4\alpha \frac{t}{T_C}\cos\left(\pi \frac{t}{T_C}(1+\alpha)\right)}{\pi \frac{t}{T_C}\left(1-\left(4\alpha \frac{t}{T_C}\right)^2\right)}$$

where the roll-off factor α = 0.22.

This is where factor α = 0.22, used in determining the spread-spectrum bandwidth, comes from. Different raised-cosine filter responses, with different rolloff factors (denoted by β in the figure) are shown in Fig. 3.

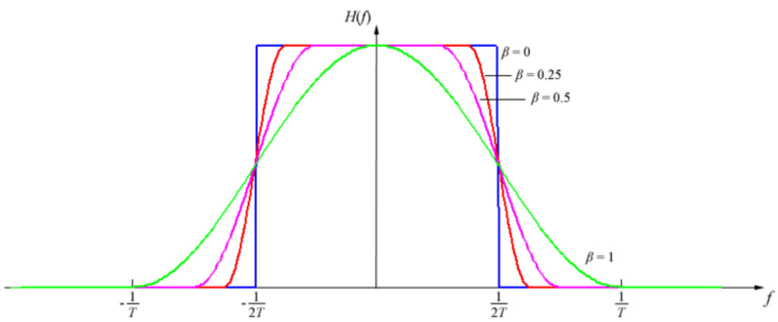

Figure 3: The effect of different rolloff factors
on the shape of the raised-cosine filter (β in the figure is the same as α in the text).

WHAT IS THE FILTER BANDWIDTH THEN?

The 3GPP standard specifies many details, but still leaves the important questions unanswered, for example: what should the RF filter bandwidth be then?

Given a chip rate of 3.84 Mchip/s and α = 0.22, we get a total bandwidth of 4.685 MHz, within the nominal 5 MHz channel separation. However, the bandwidth (if defined in a typical RF sense) of the raised-cosine digital filter is (with α = 0.22) smaller than the chipping bandwidth (defined by α = β = 0.22 in Fig. 1).

The intermediate point between these two values is the definition which defines the bandwidth as the frequency range within the 5 MHz block which contains 99% of the total transmitted power.

Therefore, in practice, the actual bandwidth depends on the quality of the operator’s transmitter equipment. If the equipment (dealing with digital signal processing, spreading, modulation, power amplification) works well, the resulting emitted signal will not suffer from nonlinear effects, but will fit into the smallest bandwidth possible. If, on the other hand, the equipment is not working well, the signal will occupy a larger bandwidth.

It is also worthwhile noticing that the performance of transmitter equipment at around 2 GHz (where most UMTS systems are currently operating) is very likely to be different than the operation of transmitter equipment at 900 MHz.

In one of their product notes, Agilent demonstrate several WCDMA measurements. They show measured occupied bandwidth of a WCDMA signal as shown in Fig. 4.

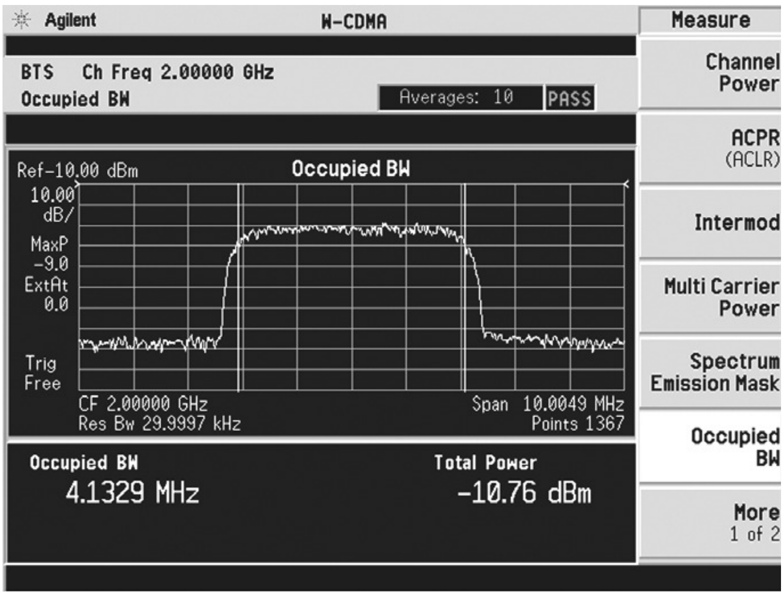

Figure 4: A demonstration how an operator could make their UMTS WCDMA bandwidth be 4.2 MHz wide (the bandwidth to contain 99% of the power).

BIBLIOGRAPHY

[1] Andreas F. Molisch: “Wireless Communications,” John Wiley & Sons, 2005.

VERSION INFORMATION

Version 1 (03 OCT 2008): First release.