ETSI EP BRAN#4
London,
9-12 September 1997

WG3 Temporary document 62
23 September 1997
page 1

Source: Lucent Technologies

Richard van Nee, Wireless Networking an Mobile Computing Research, Bell Laboratories

E-mail: vannee@lucent.com

Jan Boer, Wireless Communications and Networking Division

E-mail: janboer@lucent.com

Title: **SCALEABLE OFDM RADIO PARAMETERS**

Agenda item:

Document for:

Decision	
Discussion	**X**
Information	**X**

Introduction

This document describes the scaleability characteristics of OFDM radio technology. It is expected that the fast growing market of radio network access with all kind of requirements and applications will demand for low cost, high performance radio technology. This can only be achieved if the radio is build up out of common building blocks that do not have to be (re)designed for each new application area with its own requirements in terms of bandwidth, data rate, delay spread tolerance, error rate or velocity requirements. In stead the common blocks are scaled to the specific needs without changing the hardware.

The OFDM radio technology gives a excellent opportunity to design such a scaleable radio. It is the intention of this document to discuss the scaleable parameters of OFDM and show examples of sets of parameters that cam be applicable to ETSI BRAN.

Overview of scaleable parameters

The scaleable parameters of OFDM that will be discussed are the (I)FFT size or the number of subcarriers, the guard time, the clock rate, the coding rate and the constellation size. All these parameters influence the characteristics of the OFDM system in terms of rate, bandwidth, delay spread or interference tolerance, power requirements, noise performance or the link budget.

FFT size / Number of subcarriers

OFDM deals with delay spread by transmitting the data in parallel, over a large number of narrowband channels, called *carriers*. Each of the carriers can be modulated independently. The symbol rate of each of the narrow band carriers is dimensioned to signal at a rate slow enough to prevent ISI. If we narrow the carrier spacing, the symbol duration increases, and so does the delay spread tolerance. To retain the same bit rate we must increase the number of carriers.

The number of carriers is increased at the expense of a slight increase in hardware complexity. The circuitry most commonly used for parallelizing (at the transmitter) and serializing (at the receiver) the data is a Fast Fourier Transform function. The FFT has the attractive property that it is a standard block, whose operation is well-understood. Optimized hardware solutions exists, the computational complexity of which is $\frac{1}{2}\cdot N\cdot \log_2 N$, *butterflies* where N is the number of carriers. Each butterfly consists of 4 multiplications and 6 additions of 2 real numbers. We specify processing requirements in Mbutterflies per second (Mbf/s).

Now, to double the delay spread tolerance, one has to double the symbol duration, and therefore —to retain the same bit rate—also double the number of carriers. Hardware complexity now grows from $N\cdot\log_2 N$, to $2N\cdot\log_2 2N$, i.e. with a factor of somewhat more than 2. However, since the symbol duration is twice as long, there's double the time to do the calculations, so the processing requirements increase by a factor of somewhat more than 1, even though we can handle double the delay spread. The table below lists the increase in processing requirements when going from N to 2N carriers. Note that we take N to be a power of 2, since a 2^n -point FFT has the most practical implementation.

N	processing power increase to double delay spread tolerance
32	20%
64	17%

128	14%
256	13%
512	11%
1024	10%

Guard time

Apart from the number of subcarriers, it is essential that a guard time is introduced between the OFDM symbols to overcome delay spread. The receiver FFT has to comprehend full periods of the subcarriers. Because of the delay spread (echo’s) only a part of the subcarrier can fall in the FFT’s window, with the result that the energy of one carrier leaks into another. The guard time makes it possible to perform the FFT over the correct period in the time signal. In this guard time period no information is being sent, so the guard time is pure overhead. The guard time has to be at least twice the delayspread to be effective. In order to get a guard time overhead of less than 20%, the symbol duration (inclusive the guard time) has to be at least 5 times the guard time.

Clock rate

Doubling the clock rate doubles the bit rate. However also the bandwidth will be doubled as the processing requirement. On the other hand, a chip designed for high rates can also be applied at lower rates in other applications and with lower bandwidth.

Coding rate

Coding is essential in OFDM to cope with frequency selective fading channels, where the power and hence the error probability may widely fluctuate among the different subcarriers. By coding and interleaving across the subcarriers, the bit error rate is determined by the average signal-to-noise ratio, rather than by the worst case signal-to-noise ratio of subcarriers in deep fades. Further, coding is important to relax the link budget by providing a certain coding gain, and also to increase the capacity by tolerating a higher level of cochannel interference.

There are different ways to do coding such as convolutional codes or block coding. The coding rate determines the actual bit rate.

Constellation size

Each subcarrier can be modulated independently. The raw data rate is directly dependent on the modulation method chosen. Candidates are QPSK, 16-QAM or 64-QAM. The constallation size influences the BER and thus the link budget.

Cyclic extensions and Windowing

Starting at time $t=t_s$, an OFDM symbol is defined as:

$$rc(t - t_s) \cdot \sum_{i=0}^{N} \exp\left[j\left(2\pi f_i \, (t - t_s - T_{prefix})\right)\right]$$

rc(t) is the raised cosine pulse shaping function.

The signal is written here in complex notation, where the real and imaginary parts correspond to the in-phase and quadrature signals in the ASIC.

The OFDM signal is generated as follows: first, the N_u data symbols are padded with zeros to get N input samples which are used to calculate an IFFT. Then, the last T_{prefix} samples of the IFFT output are inserted at the start of the OFDM symbol, and the first $T_{postfix}$ samples are appended at the end. The OFDM symbol is then multiplied by a raised cosine window *rc(t)* to reduce the power of out-of-band subcarriers. The OFDM symbol is then added to the output of the previous OFDM symbol with a delay of T_s, such that there is an overlap region of b T_s, where b is the roll-off factor the raised cosine window. The time structure of OFDM symbols is depicted in figure 1.

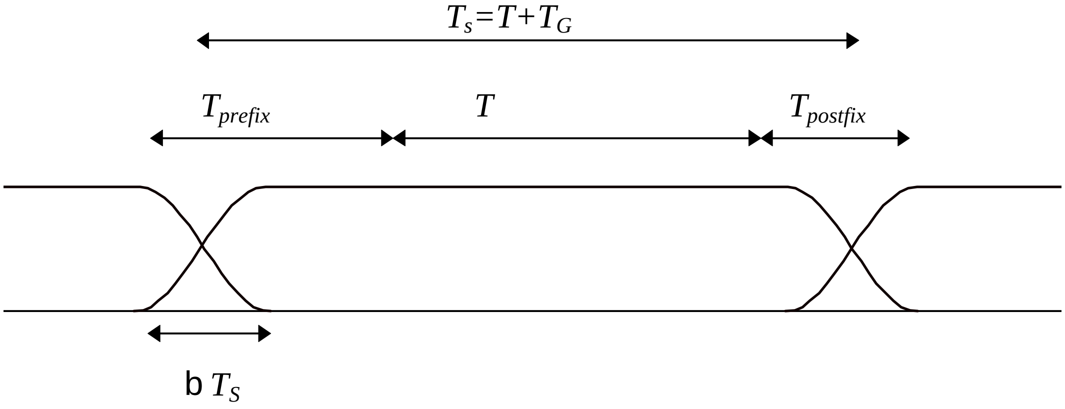

Figure 1: OFDM cyclic extension and windowing. T_s *= symbol time,* T *= FFT time,* T_G *= guard time,* T_{prefix} *= pre-guard interval,* $T_{postfix}$ *= post-guard interval,* b *= roll-off factor.*

The length of the cyclic extension is scaleable and directly influences the guard interval and thus the delay spread tolerance.

The way of windowing also has its influence on the spectrum shaping of the OFDM signal.

Examples of scaleability

In the following examples, practical OFDM parameters are calculated for different delay spreads. Also listed is the number of butterflies that have to be calculated per second. One butterfly consists of a complex multiplication plus two complex additions.

For the first example we have added some performance figures

Example 1

Indoor : 200 ns delay spread (warehouse)

Bandwidth = 23.5294 MHz (HiperLAN I channel spacing)

Take 25% excess bandwidth for oversampling at transmitter : 29.41175 MHz

FFT size = 64 : FFT time = 64/29.41175E6 = 2.176 µs

At least 400 ns of guard time; the number of prefix and postfix samples is 12 (note that consecutive symbols overlap): Symbol time = 2.584 µs (76/29.41175E6)

Modulation: 16 QAM

Number of carriers used for data : $64 \cdot 0.8 - 8 \cong 43$ (factor 0.8 because of the 25% oversampling and 2 times 4 carriers used at the edges of the spectrum for spectrum shaping(-30dB))

Raw data rate: $4 \cdot 43 / 2.584E{-6} = 66.56$ Mbps

Data rate with ½ rate coding : 33.28 Mbps

Other rates:

16-QAM with rate ¾ coding: rate $\cong 4 \cdot 0.75 \cdot 43 / 2.584E{-6} = 49.92$ Mbps

QPSK with rate ¾ coding: rate $\cong 2 \cdot 0.75 \cdot 43 / 2.584E{-6} = 24.96$ Mbps

QPSK with rate ½ coding: rate $\cong 2 \cdot 0.5 \cdot 43 / 2.584E{-6} = 16.64$ Mbps

Number of Butterflies per second: $74\cdot10^6$

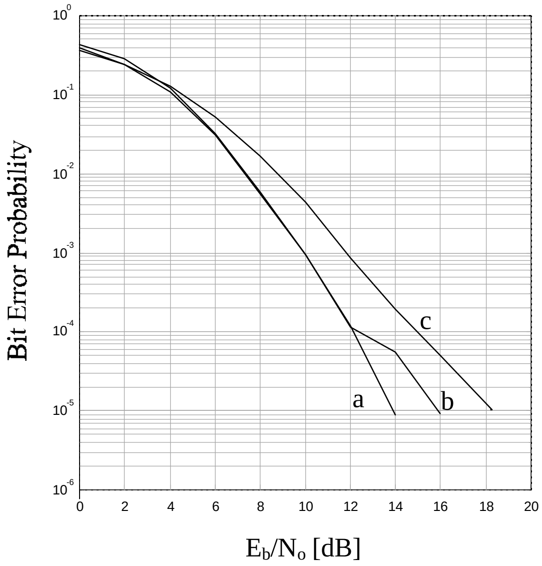

Figure 2: BER versus mean E_b/N_o for Rayleigh fading with delay spreads of a) 100, b) 200, c) 50 ns (exponentially decaying power dely profile). OFDM with 48 data subcarriers is used, with an FFT size of 64. The symbol duration is 2.576 µs, including 400 ns of guard time. Rate ½ convolutional coding and QPSK is used with coherent detection, using 4 training symbols. Results are averaged over 4000 different channels.

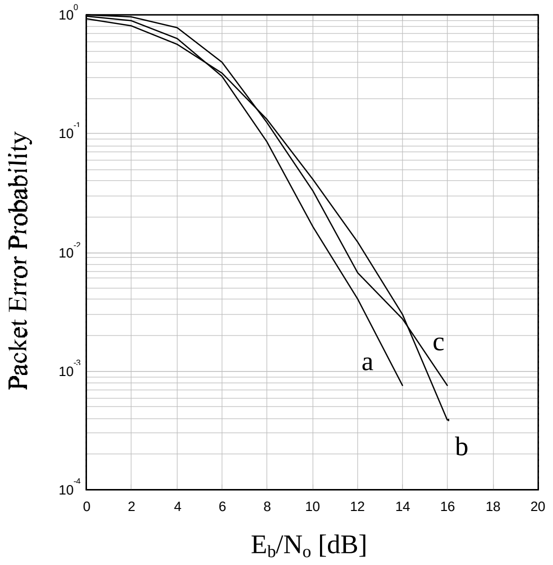

Figure 3: Packet error ratio versus E_b/N_o for the same conditions as for figure 1. Packet size is 1024 bits.

Delay spread is a) 100, b) 50, c) 200 ns.

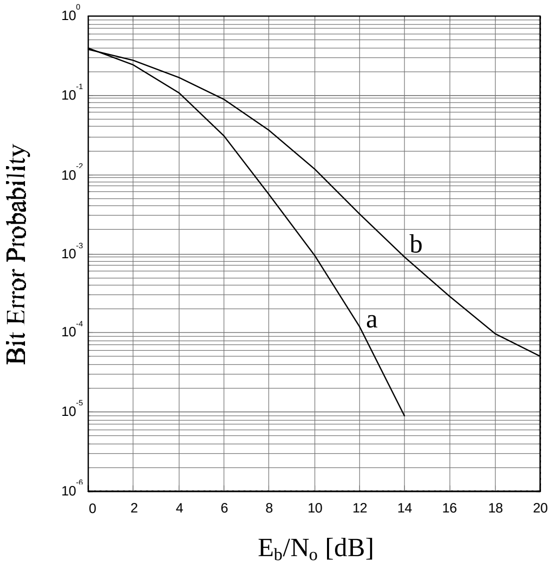

Figure 4: BER versus E_b/N_o for a) rate ½ coding and b) rate ¾ coding. Delay spread is 100 ns

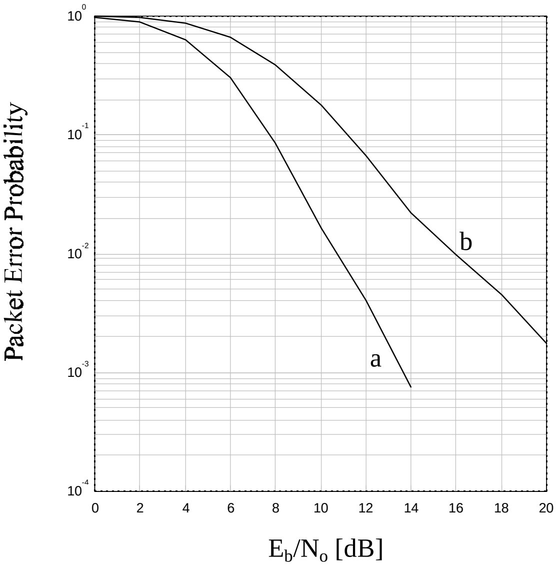

Figure 5: Packet error ratio versus E_b/N_o for ½ rate and ¾ rate coding. Packet size is 1024 bits. Delay spread is 100 ns.

Example 2:

Indoor/outdoor : 500 ns delay spread (large factory hall or outdoor with directional antennas with small beamwidth)

Bandwidth = 23.5294 MHz (HiperLAN channel spacing)

Take 25% excess bandwidth for oversampling at transmitter : 29.41175 MHz

FFT size = 128 : FFT time = 128/29.41175E6 = 4.352 μs

At least 1 μs of guard time : Symbol time = 5.372 μs (158/29.41175E6)

Modulation: 16 QAM

Number of carriers used for data : $128 \cdot 0.8 - 16 \cong 86$

Raw data rate: $4 \cdot 86 / 5.372\text{E-}6 \cong 64.04$ Mbps

Data rate with ½ rate coding : 32.02 Mbps

Number of Butterflies per second: $83 \cdot 10^6$

Example 3:

Fixed wireless : Bandwidth = 24 MHz, delay spread is 2 μs

Take 25% excess bandwidth for oversampling at transmitter : 30 MHz

FFT size = 512 : FFT time = 512/30E6 = 17.067 μs

At least 4 μs of guard time : Symbol time = 21.333 μs (640/30E6)

Modulation: 64 QAM (16 QAM)

Number of carriers used for data : $512 \cdot 0.8 - 64 = 345$

Raw data rate: $6 \cdot 345 / 21.333\text{E-}6 \cong$ 97.03 (64.68) Mbps

Data rate with ½ rate coding : 48.52 (32.34) Mbps

Number of Butterflies per second: $108 \cdot 10^6$

Other options:

Variable guard times to support large delay spreads without increasing FFT

For example, use parameters for 500 ns delay spread.

If larger delay spread is detected, increase guard time to 2 or even 4 μs. This increases delay spread tolerance at cost of slightly increased power loss of 1.7 and 2.9 dB, respectively. At the same time, the bit rate compared to the case of 1 μs guard time decreases by a factor of 0.84 and 0.64, respectively.

Rate reduction by reducing the number of carriers

If the rate has to be reduced without reducing the spectral efficiency, a simple approach is to reduce the number of subcarriers used to transmit data, without changing the FFT size or clock frequency. This has the advantage of:

- Minimum changes in hardware

- No need for different IF filters, since bandwidth scaling is done by FFT

- Possibility of OFDMA; simultaneous users in the same band

The disadvantage is:

- FFT/IFFT run at full rate, so more power consumption.

Conclusion

As the examples given above show, ODFM is well suited to provide a flexible implementation that can be used in a variety of environments. The examples given are not intended as a proposal for specification but as a basis to begin specification.

Choosing OFDM allow the minimising the number of different implementations needed to meet a wide range of user demands. This, in turn, supports the BRAN project's objective of "low cost" implementations.

At the same time, OFDM appears well suited to clever implementations so that a measure of competitive advantage - a major motivation towards technological innovation - is maintained even though key parameters are fixed by the standard.