An overview of OFDM and Related Techniques Towards Development of Future Wireless Multimedia Communications

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Abstract

In the future wireless broadband communication systems demands on data rates will exceed several Mbps. Consequently the delay time of the delayed waves will typically become greater than the duration of one symbol and delay spreads handling by traditional adaptive equalization will not be an easy task.

OFDM (Orthogonal Frequency Division Multiplexing) is a spectrum efficient kind of multi-carrier transmission. Using OFDM-techniques makes it possible to reduce the effects of multi-path fading and thus complex equalizers at the receiver side can be avoided.

The principles, technology and limits of OFDM will be introduced and discussed. Special attention will be given to SNR-problems and to the synchronization in time and frequency at the receiver.

OFDM is a strong candidate for the future generation of wireless communications. The performance of an OFDM-based system is limited by the system speed and the synchronization-ability but also by the given antenna concept. Thus the required future communication performance is not obtained only by improvements of the OFDM-concept but also by advanced diversity techniques and adaptive antenna technology.

Introduction

The rapid increase in voice, image and data communication over the internet and wireless by mobile telephony calls for heavy research and development to define the next generation of communication systems where the traditional fixed nets, the internet and the mobile nets will merge together to form a wireless broadband communication system. Figure 1 depicts the future universal wireless information society [1], [2], [4].

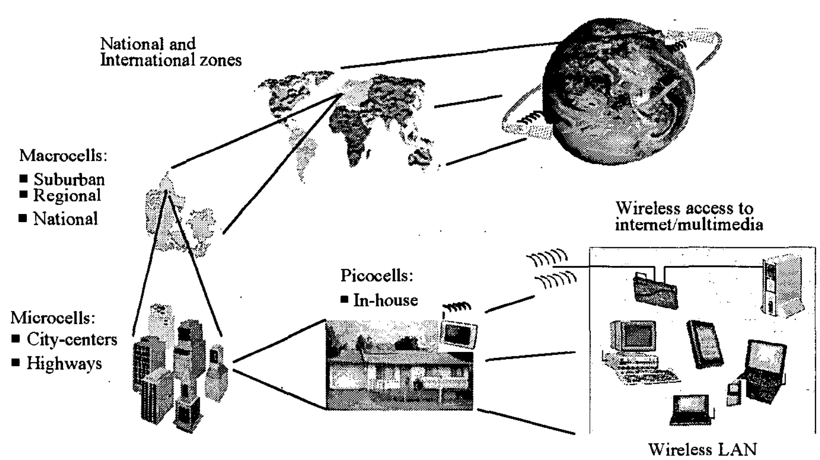

Figure 1: A set-up for the future universal wireless information society

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Numerous considerations are needed on all levels to assure sufficient bandwidth for all end-users. The demands on data rates will exceed several Mbps, which means the delay time of the delayed waves will become greater than 1 symbol time. Adaptive equalization at the receiver is possible but not easy owing to the practical difficulties in equalization at very high data rates with (portable) low-cost hardware. OFDM offers a possibility of reducing the multipath-fading effects by parallel data transmission in an orthogonal frequency division multiplexing setup and hereby making the complex equalizers unnecessary [1], [2].

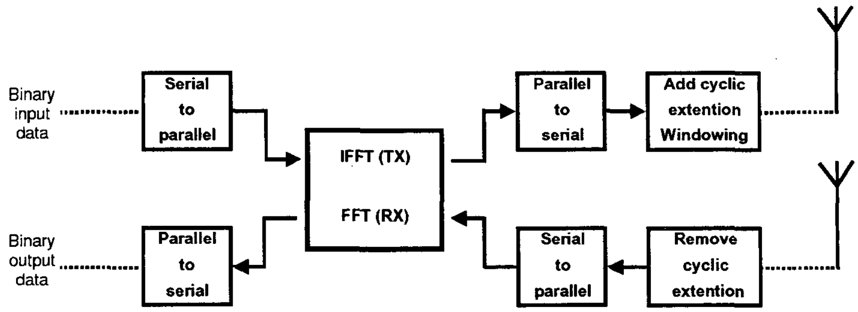

Figure 2: Simplex in an OFDM-based transceiver system

OFDM Basics

OFDM is a spectrum efficient kind of multicarrier transmission (Figure 2) where a single datastream is transmitted over a number of linear independent sub-carriers for which the frequency spacing is reciprocal to the symbol period i.e. at the centerfrequency of each channel there will be no crosstalk from other channels. The IDFT (inverse discrete Fourier transform) and DFT are respectively used for the modulation and demodulation and replace in an efficient manner the banks of I/Q-modulators and demodulators, that would otherwise be required.

Before the IDFT-modulation the original binary input data is encoded by a forward error correction code and thereafter interleaved and mapped onto QAM-values. On the receiver side the signal samples are demodulated by DFT and the resulting sequences are then demapped, deinterleaved and finally decoded to get the binary output data. The symbol timing and the frequency offset have to be determined on the receiver side.

To preserve the orthogonality of the sub-carriers and the independence of subsequent OFDM symbols a cyclic guard interval is introduced. The guard interval is established as a copy of the last part of the OFDM symbol and the duration T_{guard} is just made larger than the maximum excess delay of the radio channel. The guard interval is transmitted just before the effective part of the symbol that means the demodulation by DFT at the receiver side will not be initiated before after T_{guard} and only for the original effective symbol time T_x in which the received signal can be considered as a stationary part of the cyclic convolution of the transmitted OFDM symbol by the channel impulse response.

After the stationary part a roll-off region (transition period) is needed before the next symbol is introduced. The forming of the OFDM-symbol by output-samples from the IDFT (for the period $T_x \quad T_{guard}$) introduces side-lobe effects by the rectangular windowing. Smoother windowing, for instance by a raised cosine window, is introduced by inserting extra samples before the guard interval and after the effective symbol time (the roll-off period). The total symbol time is then given by: $T_s \quad T_x \quad T_{guard} \quad T_w$ (Figure 3).

The choices of the various OFDM parameters are fundamentally based on the requirements on bandwidth, bit rate and delay spread. The delay spread directly dictates the $T_{guard} \quad T_w$. Depending on the coding and QAM modulation (the sensitivity to ICI and ISI) $T_{guard} \quad T_w$ should be about two to four times the RMS-value of the delay spread. To minimize the SNR-loss caused by the "wasted time" $T_{guard} \quad T_w$, it is desirable to have a long effective symbol time T_s compared to

T_{guard} T_w, but the choice of T_x is not free because a larger symbol time means more and less spaced sub-carriers and consequently more sensitivity to phase noise and frequency offset, a larger implementation complexity and an increased peak-to-average power ratio [1], [5].

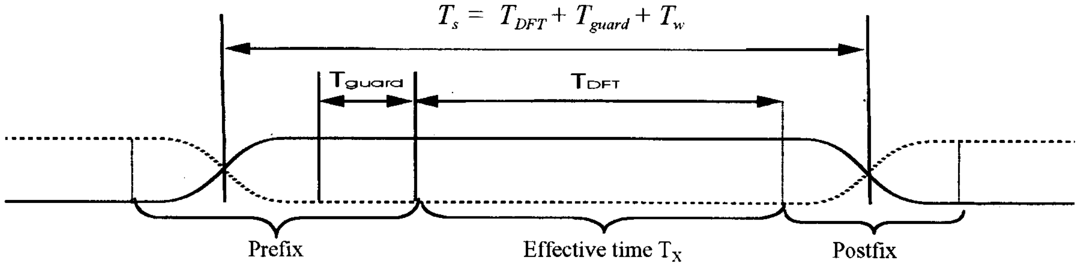

Figure 3: OFDM cyclic extension and windowing at the transmitter

Example
We want to design a system with the following requirements:

- Bit rate: 75 Mbps
- Tolerable delay spread: 250 ns (RMS)
- Bandwidth: 50 MHz

According to the previous recommendations 1 µs will be a safe value for T_{guard} T_w. By choosing T_x six times larger the loss caused by T_{guard} T_w will be less than 1 dB. The sub-carrier spacing is 1/(6-1)µs. 200 kHz. To achieve 50 Mbps each OFDM symbol has to carry 75 Mb/s x 6 µs 450 bits. With for instance 16 QAM with rate coding we get 2 bits per symbol per sub-carrier, that means we need 225 sub-carriers to get the required 450 bits per symbol. 225 sub-carriers covers 225 x 200 45 MHz. An efficient 256 point radix-4 IFFT/FFT can be used, leaving 21 sub-carriers for zero-padding i.e. getting reduced aliasing by oversampling.

FFT-complexity
A main reason to use OFDM is its ability to deal with large delay spreads with a relatively little increase in implementation complexity. The FFT-complexity grows only a bit faster than linear with the bandwidth delay spread product. In a single-carrier system, an equalizer is necessary when the delay spread is larger than about 10% of the symbol duration, and equalization is the dominant complexity factor. Doubling of the bit rate - by doubling the bandwidth with the delay spread tolerances unchanged require a doubling of the equalizer tabs and the sampling rate i.e. the equalizer complexity grows quadratic with the bandwidth.

Synchronization
An important issue is synchronization in time and in frequency. The OFDM sub-carriers are only perfectly orthogonal if the transmitter and the receiver use exactly the same frequency. One adjacent problem is that due to phase noise the frequency of a practical oscillator is never perfectly constant. Frequency offsets and phase noise causes ICI. OFDM is relatively more robust toward timing offsets. ICI (due to timing offsets) and ISI only occur when the DFT interval extends over the given symbol boundaries. Time and frequency synchronization can be established by means of the cyclic extension in the prefix and the postfix period. Alternatively it is possible to use special OFDM training symbols for which the data content is known to the receiver or to introduce coherent detection by channel estimation just after the demodulation [1], [2], [3], [5].

Forward correction coding
Another important matter is the varying SNR for different carriers, i.e., a large peak-to-average power ratio for all carriers causing a poor SNR for some carriers, especially in case of low sub-carrier spacing. After demodulation on the receiver side the bit error rate (BER) for the resulting bit-stream is irreducible. In case of a fading channel it is therefore necessary to introduce forward

correction coding (FEC) on the in-coming and out-coming data-stream (transmitter/receiver). Eventually the signal and noise for individual channels can be estimated and fed as channel state information (CSI) for the FEC decoder on the receiver side. In case of selective fading channels in an OFDM system it is relatively easy in the frequency domain to separate noisy information from the clean part and hereby obtain an advantage by use of the information in connection with error correction coding [1], [3].

IEEE standards

The present IEEE 802.11a standard is based on 64 sub-carriers (IFFT/FFT-points) and mainly focused at in-door wireless LAN's. The work in the IEEE 802.16 standard committee is focused on standards for wireless MAN's. The standards shall provide broadband-wireless-access standards similar to the DOCSIS standards for cable modems. The IEEE 802.16 standard will specify two kinds of OFDM systems identified as *OFDM* and *OFDMA* respectively. *OFDM* is focused at less demanding applications, i.e. short distances and indoor. It is based on 256-point IFFT/FFT and simultaneously transmission of all sub-carriers. Down-stream data is time-division multiplexed (TDM) and the upstream time frame is time-division multiple access (TDMA).

OFDMA (Orthogonal Frequency Division Multiplexing Access) aims at outdoor broadband wireless access including various challenging NLOS scenarios. OFDMA normally use more carriers (i.e. is based on 2048 or 4096 IFFT/FFT) which are divided into sub-channels. The sub-channels are used in downstream for separating the data into logical streams with different modulation, coding and amplitude, to address subscribers with different channel characteristics. In upstream the sub-channels are used for multiple access. The individual sub-channel consist of a subset of carriers from the total set of sub-carriers. In order to reduce frequency selective fading, all sub-channels are composed of sub-carriers along the whole channel spectrum [3].

Conclusions

The OFDM advantages are clear. Due to the continuous development in communication electronics it is to be expected that limits due to restrictions in system speed and system complexity will decrease. Therefore it will be possible to take maximum advantage of the OFDM-principle in the future - partially by improving methods for symbol timing and frequency synchronization as well as sample detection/decision making. Thus, OFDMA technique is a strong candidate for future NLOS broadband wireless access solutions.

The fundamental preconditions concerning the multipath propagation and the excess delay of the radio channel are still to be observed in the future. Therefore the development of new methods for enhancing the performance and extending the wireless range including diversity techniques and adaptive antennas are of great importance.

Future wireless multimedia communication systems will be designed mainly from user perspectives that will provide enhanced flexibility, adaptability and interworking seamless service provision for asymmetric data services, inhomogeneous traffic distribution and heterogeneous networks with a suitable radio access scheme. The future radio access scheme is expected to be a hybrid scheme based on OFDM-techniques and advanced antenna concepts [1]-[5].

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