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The Influence of Non-Linear Amplification on COFDM Signals

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Abstract: *A 150 Mbit/s COFDM ATM based WLAN system using a non-linear 60 GHz indoor radio channel for transmission is investigated. The influence of the non-linear amplification of a solid-state modeled HPA on the mean error rate performance of various DQPSK-COFDM schemes is investigated. TURBO coding and classic convolutional coding are used to encode a high bit rate data stream, which carries asynchronous transfer mode (ATM) cells and signaling information. Mean bit error rates (BER) are shown versus mean signal to noise ratios (SNR) Eb/No. The influence of the non-linear HPA amplification is elaborated by degradation diagrams.*

1. Introduction

An increasing need for new communication services, like advanced multi-media, inherently need a high transmission data rate. The identified user requirements for future wireless local area network (WLAN) applications imply low cost high quality hardware, availability of all conventional LAN services, compatibility to the future fixed integrated broadband network, interface to other mobile systems.

In the framework of the 4-th European Research Program, under the ACTS section (Advanced Communications Technologies & Services), in the Project AC006 MEDIAN, a wireless customer premises network (WCPN) is developed. As a proof of the concept a system demonstrator will be designed. It is a 60 GHz ATM based WLAN, capable to carry up to 150 Mbit/s net data rate.

The inherent high free space attenuation, a large oxygen absorption, and the requirement to use a relatively high bandwidth make the 60 GHz band an attractive candidate for a WLAN system. The high attenuation gives the possibility to re-use the same frequency in a low distance making a frequency planning not necessary.

For simulations a typical 60 GHz impulse response of a potential environment using an omni-omni antenna assembly is used. It is obtained by complex wideband channel measurements. The simulation results shall be valid for uplink as well as for downlink, as an adaptive time division duplex (ATTD) scheme is considered. It is assumed that the transmission channel is reciprocal, because the same HPA will be used in both directions. The decision for an ATTD scheme is done mainly with the focus on the future ATM transmission. A packet switched network, such as ATM, gives a high grade of flexibility in transmission channel capacity and symmetry and therefore uses the network resources very effective. The asynchronous transfer mode formally introduced in 1988 [1] will be the backbone technology of future communication networks. The MEDIAN demonstrator will be designed to support up to 150 Mbit/s net data rate.

In order to minimize the destructive effects of the inter-symbol interference, caused by multiple reflections of the transmitted signal, the symbol duration of the signal to be transmitted in the case of orthogonal frequency division multiplexing (OFDM) can be made much larger than the time delay spread introduced by the multipath radio channel. This technique avoids the application of high speed equalization. In order to minimize OFDM inter-symbol interference in general a guard time between consecutive OFDM symbols is used. Because of the inherent intra-symbol interference of the OFDM scheme in the case of a multipath environment the mean bit error rate flattens at a certain value (about 10^{-3} in our special case). This behavior is typical for uncoded OFDM and therefore a channel coding scheme must be applied in order to achieve a better bit error rate performance. In this paper the coded OFDM (COFDM) with different kinds of coding schemes is investigated and results are commented.

The COFDM scheme is sensitive to non-linear transmission channels [2]-[4]. High power amplifier (HPA) are considered as the main source of such non-linear behavior. These devices usually work near to their saturation point in non-linear regions. The typical „real case" impulse response used in the simulations as well as a „solid state" modeled HPA gain curve are presented in Figure 2 and Figure 3, respectively. The influence of the HPA non-linear amplification on the BER performance of an COFDM system is investigated in [3]-[4] for the case of an AWGN transmission channel. In this paper simulation results are presented for a time-dispersive transmission channel.

2. System Description

The transmission system considered here consists of a data source, where source coding and packet generation are included, of the channel coding unit, where different coding schemes can be utilized, of the OFDM device, where signal mapping and inverse Fourier transform as well as guard time adding is processed, of the non-linear amplifier, where the signal is non-linear disturbed, of the channel device, where complex convolution with measured channel data is performed, and of an AWGN adding device.

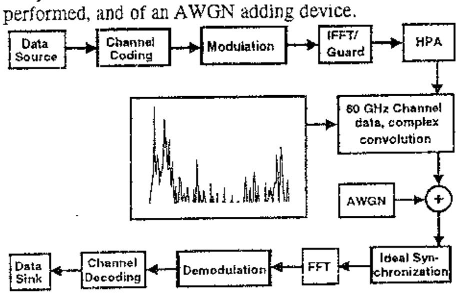

Figure 1: Transmission system.

The receiver assembly has the complementary structure. The transmission system is shown in *Figure 1*.

2.1 Transmitter

The transmitter consists of a high speed packet data source, a channel coding unit, a subcarrier modulation unit, an inverse fast Fourier transformation (IFFT) and guard time adding device and a high power amplifier. The D/A conversion and filtering of the complex signal as well as the I/Q-modulation and mixing steps are assumed to be performed ideal.

The data stream, provided by the source, consists of separate data packets containing ATM cells and additional overhead cells carrying signaling data for media access control (MAC) and synchronization. Each of the data packets has to be transmitted independently. Thus the burst length of the channel coding scheme has to be chosen so that 53 bytes of information are coded in one block. Classical convolutional coding with code rate R=0.5 (industrial standard), a shortened Reed-Solomon coding scheme with R=0.51, a parallel concatenation of two recursive systematic convolutional codes (TURBO code, [5]) with R=0.5 and a classical concatenated coding scheme with R=0.52 are utilized in this paper. Due to the burst transmission it is recommended to take advantage of using tail bits for codec resetting in the case of applying convolutional codes.

After coding the modulation device maps the coded bits to the Pi/4-QPSK symbols. The symbols are fed then to a 1024 points complex inverse Fourier transformation. Consecutive a guard time Tg=100ns is added to each computed OFDM symbol consisting of zero magnitude samples. The value of Tg is derived from channel measurements at 60 GHz using the formula $Tg \geq 2Td$, where Td is the delay spread of the transmission channel.

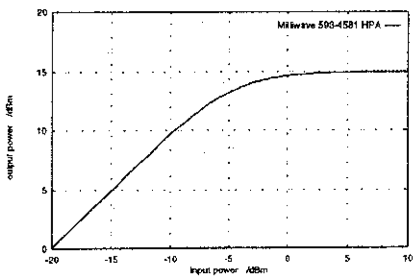

Figure 2: HPA amplification curve.

The high power amplifier is modeled as a solid-state HPA according to a data sheet, which is obtained from a commercially available 60 GHz HPA. The modeled power gain curve is shown in Figure 2. The 1dB compression point is at 12 dBm output power.

In order to meet the safety requirements regarding the electromagnetic exposure after the European pre-standard [7] and practical realization constrains, 12 dBm output power should not be exceeded if a horn antenna with 18 dB gain is used. This results in a safety distance of about 10 cm. Therefore an additional effort should be done to minimize the output power. In that case the output back off (OBO) is getting larger, making non-linear behavior less important, but on the other side the overall signal strength decreases. This leads to BER performance degradation. To find the trade-off different OBO values are considered for simulation purposes. The OBO is defined here as following:

$$OBO = -10 \cdot \log_{10}\left(\frac{\text{Pmeanout}}{\text{Psaturation}}\right), \qquad (1)$$

where Pmeanout is the mean output power of the amplifier and Psaturation is the saturation power of the amplifier. A solid state model [3] is used for modeling the 60 GHz HPA device from Milliwave. Due to the small output power required, there is no need to investigate TWT devices.

2.2 Transmission Channel

The channel describes the influences of the applied antenna configuration and the environmental geometry. It contains a transmitting antenna, the 60 GHz indoor radio channel, and a receiving antenna. Antennas were omni directional biconical-horn transmitting and receiving antennas, having about 5 dB gain (channel 1 in Figure 3), LOS condition is given. The time domain characterizations of two 60 GHz channels is shown in Figure 3. Channel 1 is influenced strongly by multipath propagation what results in deep fading notches in the frequency domain up to 20 dB. Therefore it is particularly interesting for further investigation. Channel 2 shows close to ideal behavior, the very low delay spread. The distance between transmitting and receiving antennas was 15 meter for channel 1 and 4 meter for channel 2.

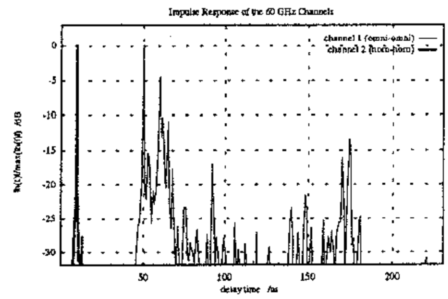

Figure 3: Impulse responses 1 and 2.

2.3 Receiver

Down conversion and filtering in the receiver are assumed to be performed with no frequency offset. The time synchronization, A/D conversion and guard time removal are assumed to be processed ideally. Afterwards a complex fast Fourier transformation with 1024 points is performed and the resulting signal is Pi/4QPSK demodulated. In the case of convolutional coding the demodulator provides soft inputs to the channel decoding device. The channel decoding is performed appropriate to the chosen coding scheme and the data bursts are delivered to the data sink. Each of the ATM cells is handled independently, in case of missing one cell the error is not spread and can be corrected using an automatic repeat request (ARQ) scheme of a higher layer function.

3. Simulations and Results

Inherent in uncoded OFDM a multipath reception results in an error floor due to the intra-symbol interference, which can not be removed without equalization. The recommended BER for packet data transmission using channel 1 can not be reached without coding. Therefore a channel coding scheme is applied, which codes across the subcarriers used for transmission of one data burst. In the simulations the OFDM symbol duration is 11.07 μs. In order to minimize the inter-symbol interference a guard time of 100 ns is used.

The classic convolutional coding scheme with rate 0.5 utilizes the industrial standard polynomials $G1=171_8$, $G2=133_8$ (K=7). To meet the packet data requirements the coder has to be reset after one information packet. This is achieved with 7 tail bits. The here used recently proposed TURBO code [5] has a memory of 4 and is described with the generator polynomial as published in [5]. For decoding of the TURBO code a soft-output Viterbi algorithm (SOVA) is applied. As in the case of classic convolutional coding the TURBO coder also needs to be reset by tail bits. This is difficult for both codecs, therefore only the first one is reset using 4 tail bits. The interleaver in the TURBO codec is a slightly modified block interleaver derived from a 22x22.

OFDM transmission in a multipath environment results in a burst error structure, if adjacent subcarriers are placed in the way, that their fading is well correlated. In the case of convolutional coding therefore an interleaver is used before transmission, so that the appropriate deinterleaver on the receiver side distributes the errors uniformly within the received data burst.

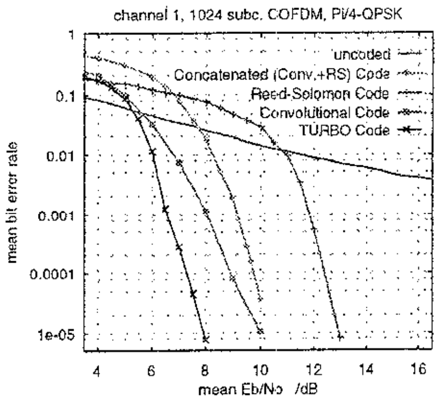

Figure 4: Mean BER vs. mean SNR with linear amplification.

The applied Reed-Solomon (RS) code is a shortened (255,199) code with 58 information symbols and a code rate of R=0.5. The concatenated code consists of a rate R=0.78 shortened (255,239) RS code and a rate R=2/3 classic convolutional code with K=7. Because of the overall code rate R=0.52 the achieved BER can be compared with the other applied coding schemes. Concatenation of a powerful convolutional code (R=0.5) and a long RS code is not possible because of the restricted block length.

The RS code, which is well suited for correction of burst errors, shows a poor BER performance for lower SNR values, because of the mainly random errors introduced by the AWGN, see Figure 4. For a SNR above 11 dB the drop off is significant. The TURBO code with 3 decoding iterations shows best results compared to all considered codes for the investigated BER range. However, a flattening out effect is expected for higher SNR's, which can be reduced by a sophisticated interleaver design [5].

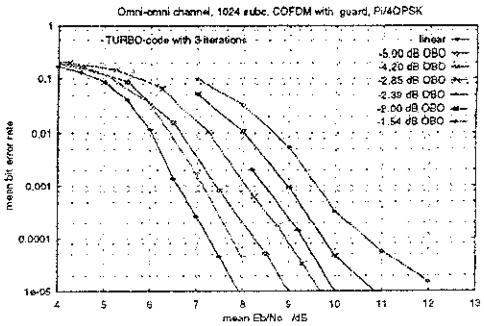

Figure 5: Mean BER vs. mean SNR with non-linear amplification and TURBO coding.

The classic convolutional code curve crosses the uncoded BER curve like the TURBO code at about 5 dB, but performs afterwards with the lowest slope of all considered codes (Figure 4). This code is not well suited to achieve a very low BER with a relative low SNR compared to the other codes. With concatenated coding a flattening effect is not expected. The slope of the BER curve is as strong as in case of RS coding and the absolute BER performance is about 2.5 dB better than the RS code at a BER of 1e-4. The advantage of the TURBO code compared to the other coding schemes is obviously. Better results are expected with an optimized TURBO-interleaver design .The TURBO code outperforms the other codes. Thus for further investigations mainly the TURBO code and the classical convolutional code for comparison are utilized. The influence of channel 1 with non-linear HPA is investigated, as a typical case of the future WLAN scenario.

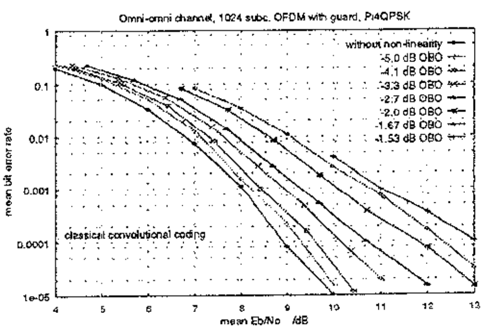

Figure 6: Mean BER vs. mean SNR with non-linear amplification and classic convolutional coding.

The results shown in Figure 5 are achieved using the TURBO coding scheme with 2.5 iterations and a solid state modeled 60 GHz amplifier. Using output back off values of 5 to 4 dB yields about one order of magnitude BER loss in the shown BER range. As the BER decreases, the BER loss increases. The signal magnitude degradation for higher magnitudes is expected to results in an error floor, which is lower for higher OBO. The comparison of Figure 7 and Figure 8 shows an advantage of the TURBO code compared to the classic convolutional code. For the same bit rate it requires about 1.5

dB less Eb/No ratio at 10^{-3} and the difference increases with lower BER values.

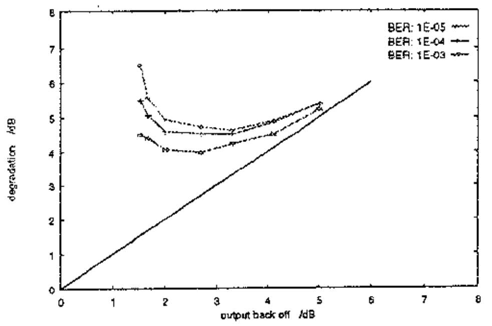

Figure 9: Total degradation vs. OBO with classic convolutional coding

Figure 10 and Figure 11 present the total degradation versus output back off for three bit error rates of 10^{-3}, 10^{-4} and 10^{-5}. The total degradation (TD) for a given BER is defined as:

$$TD = SNR_{(with\ non\text{-}linearity)} - SNR_{(without\ non\text{-}linearity)} + OBO \qquad (2)$$

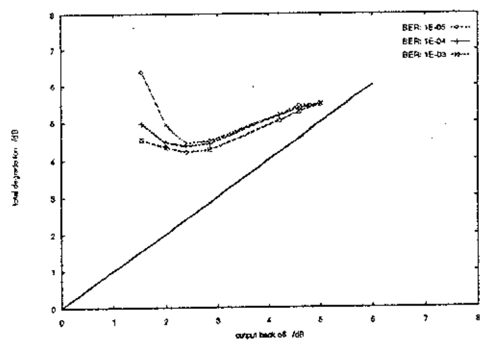

Figure 12: Total degradation vs. OBO with TURBO coding.

The optimal OBO having the minimal system degradation seems to be nearly the same for both codes at the BER of 10-3, having a value of about 2.5 dB. However, according to the figures it is obvious that the shift of the optimal OBO towards larger values if the reference BER decrease. For the practical point of view the simulation of the smaller BER (required for the communication system) are due to the CPU time lack is difficult. According to the expressed trend the optimum system OBO for the smaller BER should be placed at the higher values. The figures show that displacement of the optimum OBO towards higher values is more critical using classic convolutional code, which makes an utilization of TURBO code even more attractive.

4. Conclusions

Using wideband complex measurements of a 60 GHz radio channel and a solid state modeled 60 GHz high power amplifier, simulations are performed. Different coding schemes for ATM packet data transmission are compared with respect to their mean bit error rate performance. The optimum output back of the simulated system is discussed. TURBO codes are found to be more suited for the application compared to the other codes.

5. Acknowledgments

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