Performance of OFDM and Comparable Single Carrier System in MEDIAN Demonstrator 60 GHz Channel

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Abstract: *Given the demonstrator line of sight (LOS) channel environment, this paper presents MEDIAN demonstrator physical layer performance predictions for selected OFDM and comparable single carrier transmission techniques. Among all nonlinearity influences, the main physical layer degradation is generally expected from the radio channel. With a high quality 60GHz LOS channel, a cell loss ratio (CLR) of 10^{-6} is predicted to be feasible in the MEDIAN demonstrator at about 10 - 11dB Eb/No.*

Introduction

The European ACTS project MEDIAN is about to realize a wireless ATM local area network (WATM-LAN) demonstrator for the 60 GHz frequency band as technological proof of concept for a new system approach. Whereas the future MEDIAN system will operate in a non-line of sight (NLOS) environment, the demonstrator was designed for pure line of sight (LOS) channel conditions. This is due to today's technology limitations in active 60GHz components (HPA power, LNA noise) which will be overcome within the next years before a potential market introduction of the system. As of today, a LOS channel environment is considered mandatory for a wideband 60GHz hardware implementation like the MEDIAN demonstrator.

Regardless of technology needs, it is always necessary to pay sufficient attention to the radio channel in portable/mobile applications. Different sources of physical layer (PHY) nonlinearities were evaluated within the project [e.g. 2]. As the most performance degrading nonlinearities following items are identified (in the order of importance):

a) Radio Channel
b) I/Q-mismatch (ADC/DAC, BB-filters, attenuators, I/Q-mod/demod)
c) RF-front-end high power amplifier (HPA) nonlinearity
d) RF-front-end mixer nonlinearity
e) ADC and other DSP clipping & quantisation effects
f) RF oscillator phase noise
g) Filter ripples & DAC-sinc-effect

Whereas all others were found to be 'manageable' with respect to PHY performance degradation, the major nonlinearity which has the potential to cause a residual error floor is and remains the radio channel. Under this background, chapter 1 extensively describes the MEDIAN demonstrator LOS radio channel including already manufactured directional antennas.

Then, chapters 2 and 3 are dedicated to the demonstrator physical layer performance. Chapter 2 illustrates MEDIAN demonstrator BER and CLR predictions on an 'as built' basis (real synchronisation, phase noise etc. included). Chapter 3 provides a comparison between the implemented OFDM and a comparable single carrier (SC) system under ideal conditions (ideal sync).

1. MEDIAN Demonstrator Channel Characterisation

Static impulse responses for the 60-62GHz channel were measured in a MEDIAN demonstrator typical environment with real demonstrator antennas at TU Dresden. Following potential demonstrator antennas were used:

Transmitter: wave guide fed lens antenna, gain 8dB
Receiver: standard horn antenna, gain 20dB

As the major outcome of this measurement campaign it is shown that the demonstrator channel behaves practically Gaussian like and is even better than a typical LOS multipath mobile radio indoor channel (see below). This is due to the strong directivity of the antenna combination lens-horn. With correct adjustment of the horn antenna, there were no reflections stronger than 35dB below the signal of the direct path in the whole room !

The arrangement of the antennas within the office is illustrated in Fig. 1. The office was filled with potential stationary reflectors like tables, chairs, instruments and heating radiators. The measured impulse responses are shown in Fig. 2 and Fig 3.

Fig. 1 60-62GHz demonstrator channel measurement configuration at TUD office 8x12x3.6m.

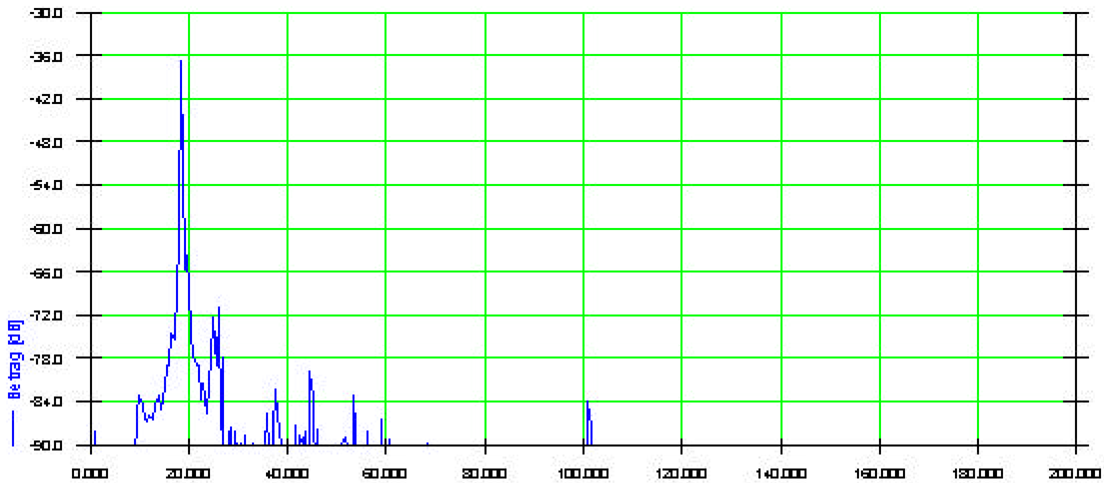

Fig. 2 Measured **typical** static impulse response for MEDIAN demonstrator channel (2GHz measurement bandwidth). Horn directed to Tx lens antenna. Distance horn-lens 5m. The channel looks **very Gaussian like** with one major peak, the small peak/reflection about 7ns after the main one could not even be resolved clearly with 200MHz measurement bandwidth.

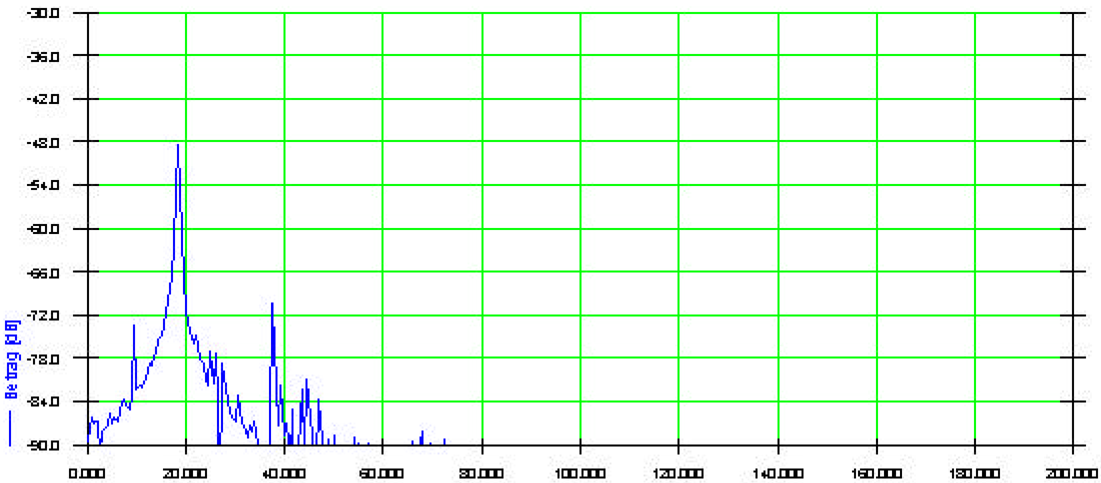

Fig. 3 Measured static impulse response for MEDIAN demonstrator channel (2GHz measurement bandwidth) where the Rx horn is directed 1.5m by the side of the Tx lens (horn antenna having a squint of 17° with distance horn-lens 5m). This channel is considered absolutely **worst case** for the MEDIAN demonstrator.

A simple static FIR based channel model described with Table 1 and Fig. 4 is derived from the worst case impulse response Fig. 3 for simulation purposes.

No.	τ [ns]	REAL	IMAG
1	0.00	-0.366881892	0.91643509
2	4.44	0.015706427	0.02554042
3	8.89	-0.035532684	0.004628134
4	13.33	0.028290878	0.020354526
5	17.78	-0.102209561	0.011829665
6	22.22	-0.040243954	0.045617301
7	26.67	0.036644023	0.0314888
8	31.11	-0.021956619	-0.001897402
9	35.56	-0.00064196	-0.042518852
10	40.00	-0.009151045	-0.00075171
11	44.45	0.002979981	-0.032858849
12	48.89	-0.018298903	0.002918891
13	53.33	-0.007793899	0.024905392
14	57.78	-0.001180239	0.031958403
15	62.22	-0.003118928	0.001202118

Table 1 Numerical values of worst case demonstrator generic impulse response (=FIR-filter coefficients for simulation).

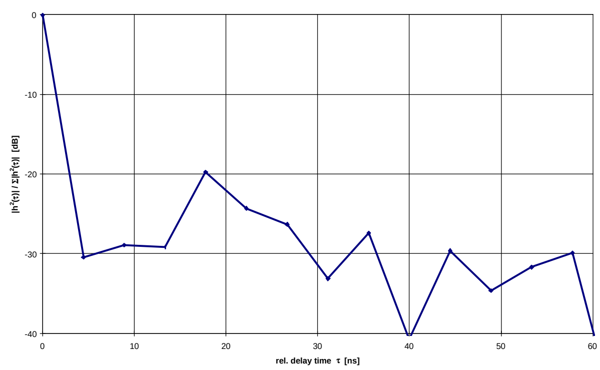

Fig. 4 Worst case demonstrator generic impulse response for simulation re-sampled with 225MHz (horn antenna having a squint of 17°).

From ‘empirical’ experience with the demonstrator antenna measurement system it is not expected that dynamic reflectors (moving people) significantly degrade the demonstrator channel characteristics as long as they are outside the direct LOS. Movement of measurement staff outside the direct link did not influence the static measurement results for the demonstrator lens-horn antenna combination, whereas results significantly changed with an omnidirectional type of PS-antenna (monopol).

The same conclusion can be drawn from dynamic channel measurements performed by Deutsche Telekom AG. There was no significant change in the dynamic frequency responses for omni-horn antenna configuration under pure LOS conditions. The nearly constant and flat range in the frequency responses indicate a typical Gaussian like and also time invariant channel in the omni-horn antenna case. Contrary, a typical multipath behavior is also reported for an omni-omni antenna configuration which will be used in the future MEDIAN system but not in the demonstrator. In summary, the MEDIAN demonstrator Gaussian like LOS channel is well described with present static channel model.

2. Demonstrator BER/CLR Simulations & Predictions

Uncoded and coded BER and CLR simulations were performed using the newly derived demonstrator typical channel model (see section 1). Following simulation parameters were used:

Sampling frequency:	225MHz
Coding:	RS(55,71)
OFDM-IFFT/FFT points:	512
Used OFDM subcarriers:	286 (276+2ref+8mac)
Preamble samples:	64
Postamble samples:	24
OFDM symbols in frame:	64
Subcarrier modulation:	DQPSK
Differential encoding:	Adjacent subcarriers, 2 reference carriers per symbol
Tx-Amplifier:	linear
Tx-filter:	none
Channel:	AWGN + Static worst case demonstrator model (see section 1)
Oscillator phase noise:	Farran-LO model
Oscillator frequency offset:	0.4 * subcarrier distance
Rx-filter:	none
Rx-DSP-Resolution:	infinite (floating point)
t-sync algorithm:	demonstrator acquisition & tracking α=1.0, β=0.001, χ=0.25, k=181
f-sync algorithm:	demonstrator acquisition & tracking
Subcarrier demodulation:	hard decision

In principle, these parameters match the demonstrator specifications. Specified time and frequency synchronisation algorithms and phase noise model are included. Uncoded BER and coded CLR are plotted in Fig. 5 and Fig. 6, respectively, as expected in the MEDIAN demonstrator physical layer.

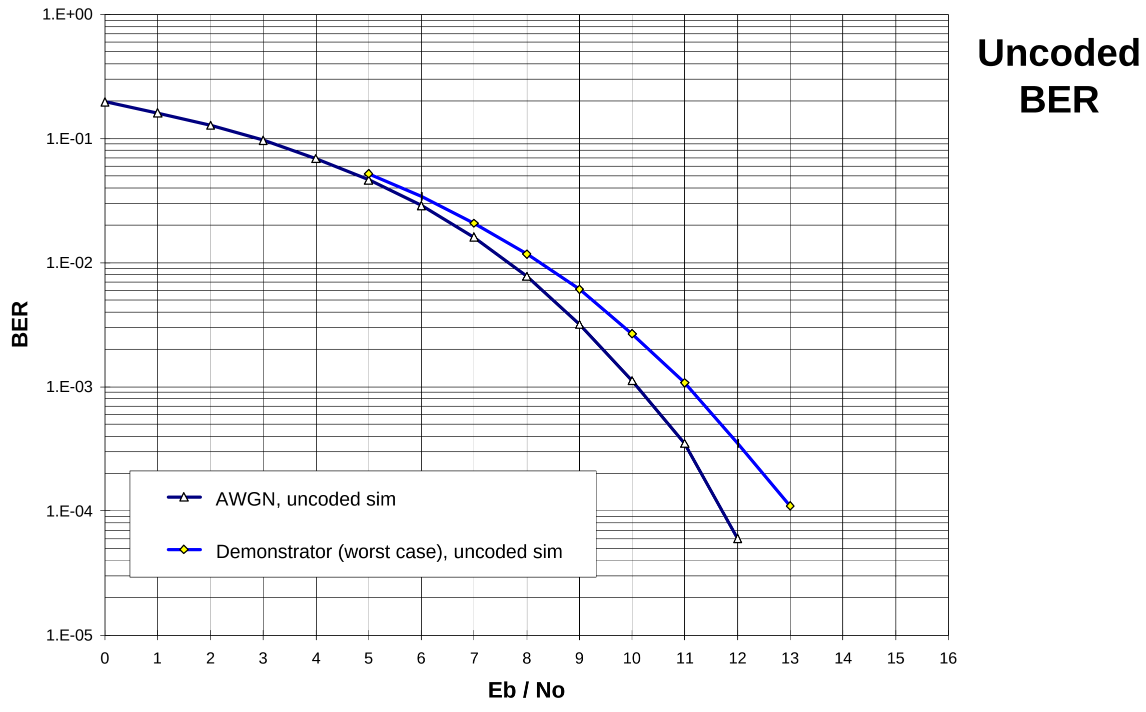

Fig. 5 Uncoded bit error rate of MEDIAN demonstrator configuration for AWGN and demonstrator worst case channel with working synchronisation. The demonstrator worst case BER is better than typical LOS and gives an absolutely upper performance bound. Typically, the demonstrator channel is AWGN like (see section 1).

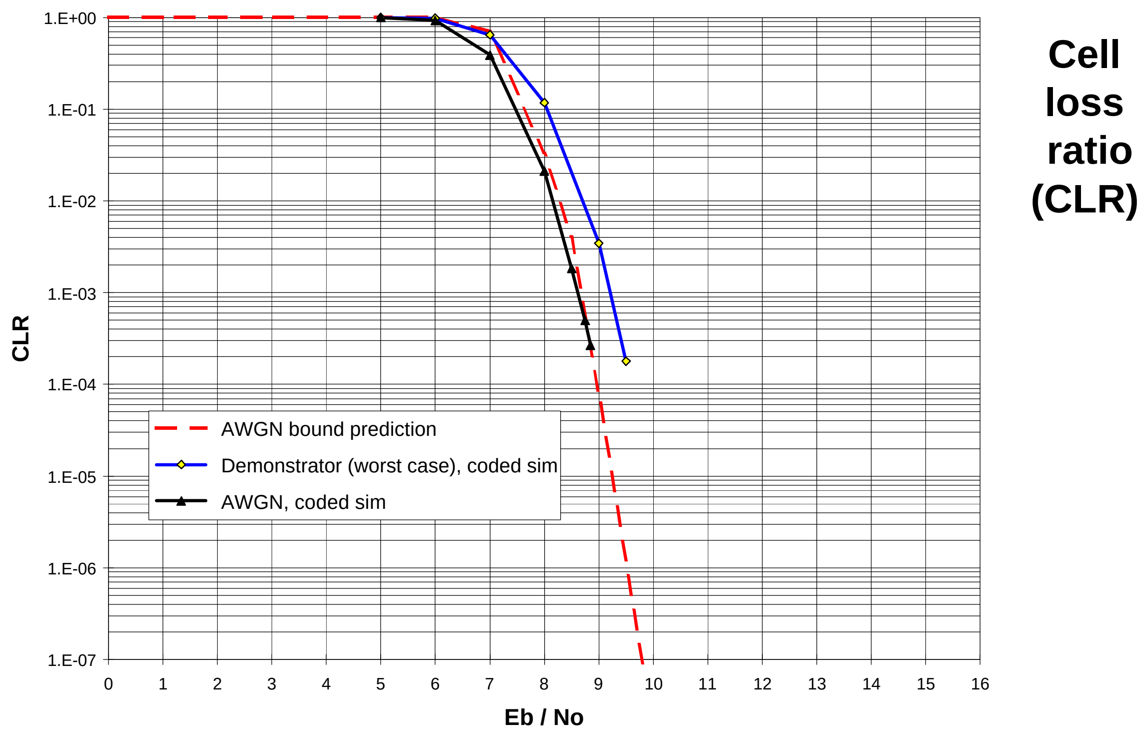

Fig. 6 (Coded PHY) cell loss ratio of MEDIAN demonstrator configuration for AWGN and demonstrator worst case channel with working synchronisation. Since the demonstrator channel is typically AWGN like, a theoretical CLR prediction (curve w/o markers) is expected to reliably represent the demonstrator performance.

The demonstrator CLR performance can be simulated down to a certain value only (here 10^{-4}). But, based on uncoded simulations and due to the fact that the MEDIAN demonstrator channel typically behaves Gaussian like (see section 1), the coded CLR can be predicted in AWGN using a closed form expression.

The simulated AWGN curve in Fig. 6 matches the predicted one in the region where samples could be obtained. The curve for the demonstrator worst case channel follows the AWGN one ‘pretty close’. We consider the demonstrator physical layer performance reliably predictable.

A CLR of 10^{-6} appears to be feasible in the MEDIAN demonstrator at about 10 - 11dB E_b/N_o.

A security margin of 4dB is added for all kind of unforeseeable hardware implementation losses and the value 15dB for required receiver E_b/N_o is used as input for the power budget calculation.

3. Comparison of Single Carrier and OFDM System

The purpose of this section is to compare the performances of a classical single carrier (SC) and an OFDM system for the uncoded DQPSK modulation in the MEDIAN demonstrator environment. The simulation parameters of the OFDM system are given in section 2. The SC system comprises a square-root cosine roll-off filter (roll-off = 0.5) in the transmitter as well as in the receiver. Moreover, the SC system uses an adaptive filter-type equalizer in the receiver. In this context, the transversal filter of the equalizer consists of 10 coefficients.

Fig. 7 shows some simulation results. The error curves are bounded by the curve of the pure AWGN channel of the SC system. The application of OFDM delivers a loss of about 0.5dB for a BER=10^{-4}. The LOS channel causes additional degradations in both, in the SC and in the OFDM system. It should be noticed that the SC system is more sensitive to the distortions of the channel than the OFDM system. Therefore, the receiver of the SC system uses an equalizer which reduces the channel distortions.

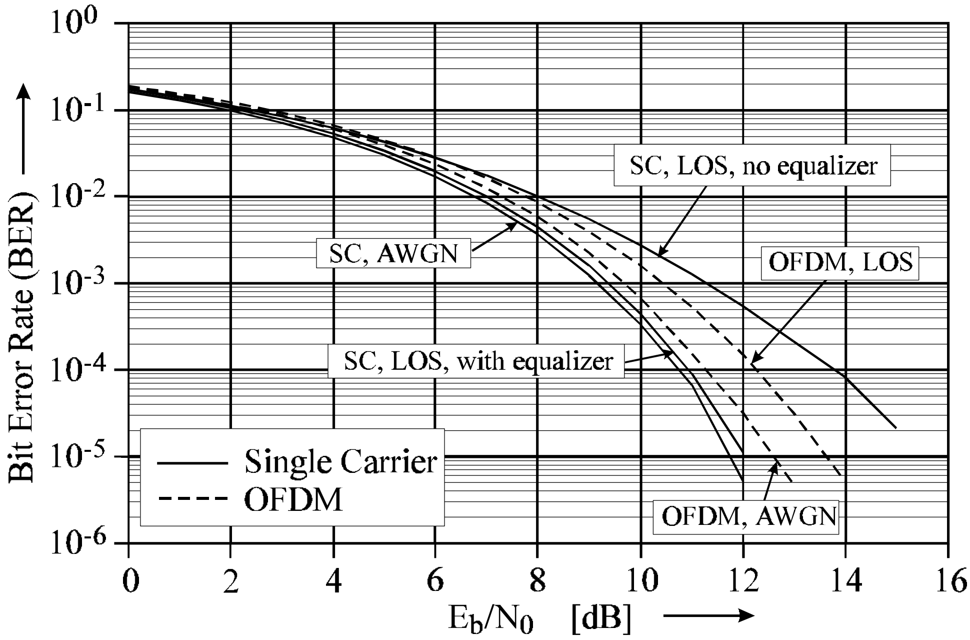

Fig. 7 Uncoded bit error rate for comparison of single carrier (SC) and OFDM system for AWGN and demonstrator worst case channel (LOS) for DQPSK under ideal synchronisation.

4. Conclusions

With above measurements and calculations it is predicted that we can assure a sufficiently reliable radio link in case of regular demonstrator use (adjusted antennas, no movement of PS, LOS guaranteed). In this case an average uncoded BER of 10^{-3} and an average (coded) CLR below 10^{-6} appear to be achievable with the demonstrator according to channel and hardware component measurement, simulation and analysis.

The key to this good radio link performance is the proper choice of the 60GHz antennas which were designed with high directivity for pure LOS. It shall be emphasised again that the LOS environment is applied to the MEDIAN demonstrator for 60GHz technology and power budget reasons only. A future system is envisaged to work under NLOS conditions with improved 60GHz components, where the advantages of OFDM vs. single carrier modulation become more visible.

References

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