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Physical layer simulation results for IEEE 802.15.3c with different channel models

M. Liso Nicolás, M. Jacob, and T. Kürner

Institut für Nachrichtentechnik, Technische Universität Braunschweig, Braunschweig, Germany

Abstract. This paper investigates the performance of the 60 GHz IEEE 802.15.3c physical layer (PHY) specification in terms of bit error rate (BER) against signal to noise ratio. Two PHY modes of the standard have been implemented and simulated, i.e., Single Carrier and High Speed Interface. The first mode uses single carrier (SC) block transmission and the second mode uses orthogonal frequency division multiplexing (OFDM). One of the main issues in the new 60 GHz standards is multipath propagation, which plays an important role in the link quality. Thus, we have tested the PHY with the IEEE standard channel model, ray tracing simulations and real 60 GHz measurements.

1 Introduction

During the last years, wireless communication systems using the 60 GHz frequency band have attracted much attention. This unlicensed band, ranging from 57 to 66 GHz, is usually divided into four 2-GHz channels, and aims to satisfy the need for increasingly higher data rates required by new wireless multimedia applications. Given the high free space losses and attenuation through building materials at the millimetre-wave 60 GHz spectrum, only short-range indoor applications are considered.

Four different specifications for WLAN/WPAN applications using the 60 GHz band have already been issued: IEEE 802.15.3c by IEEE 802.15 Task Group 3c (TG3c) (TG3c Standard, 2009), ECMA-387 (ECMA-387, 2008), Wireless HD (Wireless HD, 2010) and WiGig (WiGig, 2010). Moreover, the IEEE 802.11 Task Group ad (TGad) has recently released a first draft (TGad Draft, 2009).

In order to evaluate the system performance of different 60 GHz standards, we have developed a simulation environment in MATLAB/Simulink. In a first step, we have implemented the PHY of the IEEE 802.15.3c (TG3c) specification. This standard includes three different physical layer designs, with both SC and OFDM modes.

An extensive work has been done on channel modelling in TG3c, since the propagation of the signal through 60 GHz wireless channels was not accurately described when the standardisation started. Hence, we have included this channel model in our simulation environment. Moreover, we have also evaluated different PHY modes with channel impulse responses (CIR) coming from 60 GHz channel measurements and ray tracing simulations.

This paper is organised as follows: in Sect. 2 we present a general view of the TG3c standard. In Sect. 3 we give an explanation of the 60 GHz channel modelling. In the next section we explain the simulation environment and the parameters we have used. In Sect. 5 the results from the simulation are presented and evaluated. Finally, Sect. 6 concludes this paper.

2 802.15.3c overview

In 2009, the TG3c working group finished the standardisation process, releasing the IEEE 802.15.3c PHY specification for millimetre wave communications. It includes three different PHY modes: Single Carrier (SC PHY), High Speed Interface PHY (HSI PHY) and Audio/Visual PHY (AV PHY). In our research, we have focused on HSI and SC PHY.

SC PHY is thought for line-of-sight (LOS) and non-line-of-sight (NLOS) and is able to work with and without equalisation. This PHY mode consists of 14 different modulation and coding schemes (MCS), with data rates of up to 5.3 Gbps. It utilises Reed-Solomon (RS) and low-density parity-check (LDPC) codes, whereas in the paper only MCSs with LDPC are considered.

Correspondence to: M. Liso Nicolás
(liso@ifn.ing.tu-bs.de)

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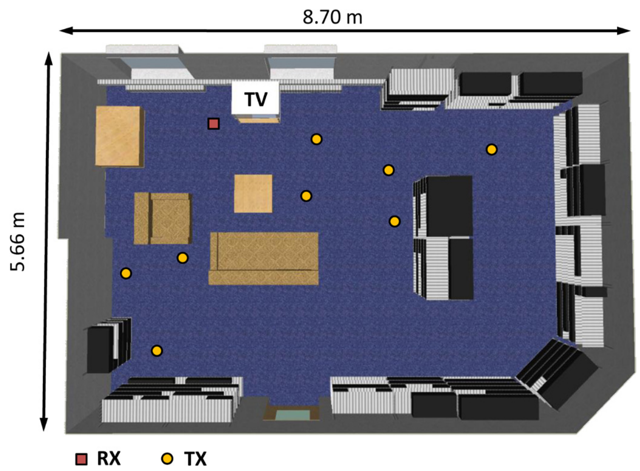

Fig. 1. Living room scenario with Rx/Tx positions.

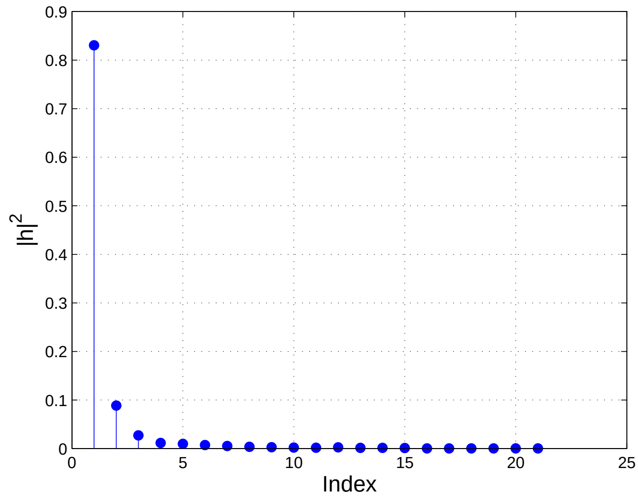

Fig. 2. CIR obtained from 60 GHz channel measurement.

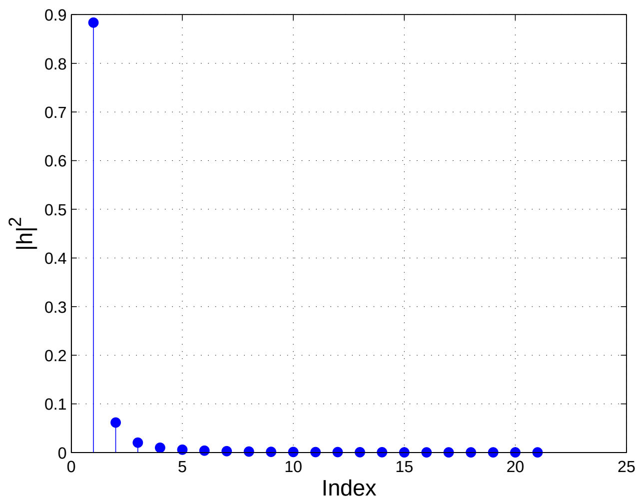

Fig. 3. CIR obtained from ray tracing simulation.

On the other hand, HSI PHY is conceived for NLOS and utilises OFDM. It includes 12 MCSs, with a maximum data rate equal to 5.8 Gbps, and uses only LDPC.

The fact that a single carrier physical layer could outperform a multicarrier scheme in presence of multipath is a new topic that has been addressed at the 60 GHz standardisation. The result of the comparison depends on several factors like RF impairments, channel coding and multipath characteristics. A good overview of SC in mm-wave wireless networks can be found in Kato et al. (2009) and Funada et al. (2009), and a comparison between SC and OFDM in Hoffmann et al. (2009).

3 Channel modelling

Multipath propagation in millimetre-wave indoor communications poses a considerable problem, since it can dramatically degrade the link quality. Therefore, special attention has to be paid to this issue.

The TG3c developed a 60 GHz channel model that covers typical environments for the planned use cases like residential, office, library, desktop and kiosk scenarios. In order to implement a model that fits the reality as much as possible, the TG3c utilised real 60 GHz channel measurements as base for its work. Thus, CIRs are built with a combination of a two-ray channel model and an extension of the Saleh-Valenzuela (SV) model (Saleh and Valenzuela, 1987) to the angular domain (TG3c Channel Modelling, 2007). Hence, TG3c proposed a statistical channel model dependent on the temporal and spatial domain, where the signals arrive at the receiver first in a LOS component (calculated with a two-ray model), and then in groups called clusters (modified SV model). This 60 GHz channel model was included in our simulation environment, so that we can evaluate the system performance in different scenarios with different modulation and coding schemes.

In addition, wideband channel measurements have been performed in a living room (Jacob and Kürner, 2009a, b). All measurements were conducted in frequency domain. The channel impulse responses were then calculated via inverse Fourier transform. The measurement setup consists of an Agilent E8361A vector network analyzer with external transmitting and receiving test heads. For the measurements we used circular horn antennas with a half-power beam width (HPBW) of approximately 20° at receiver and transmitter. Figure 1 shows a schematic of the living room where the measurements were performed. During the measurements the receiver position was kept fixed near a television set. The transfer functions were then measured at different positions in the room. As it can be seen, there is always line of sight between both antennas.

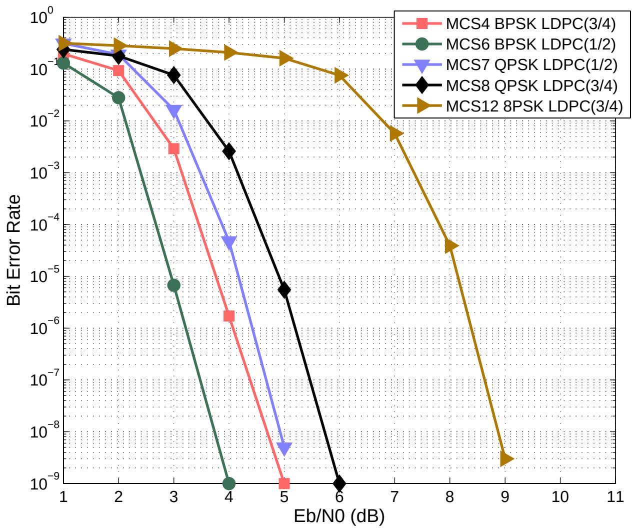

Fig. 4. BER against Eb/N0 for AWGN channel and SC PHY.

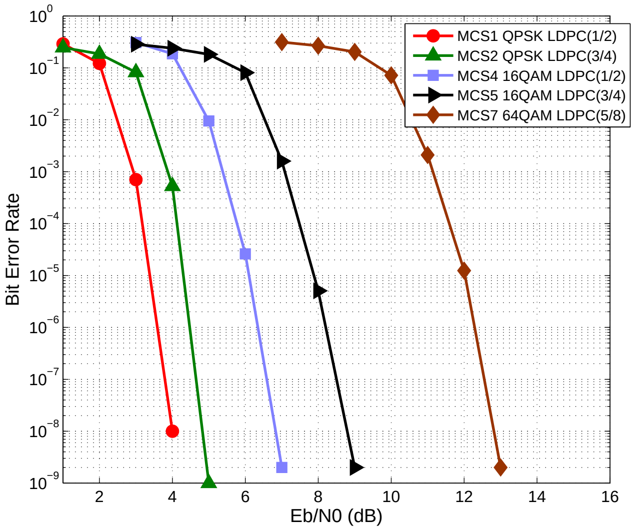

Fig. 5. BER against Eb/N0 for AWGN channel and HSI PHY.

Given this setup, a ray tracing tool (Kürner and Jacob, 2009) was used to model the wave propagation deterministically by using a 3-D model of the living room (see Fig. 1). For the modelling of the dielectric properties of fitment, walls etc. material parameters from literature have been used (BROADWAY, 2002). The 3-D antenna pattern of the horn antennas has been modelled by analytical expressions (Green, 2006).

Hence, real measurements, deterministic and statistical channel models are included in our work.

4 Simulation parameters

For our simulations we have considered SC and HSI PHYs. Tables 1 and 2 summarise the MCSs included in our work.

Table 1. Single Carrier PHY MCSs parameters.

MCS	Bit rate (Mbps)	Channel coding
4	1320	LDPC(672,504), $R=3/4$
6	880	LDPC(672,336), $R=1/2$
7	1760	LDPC(672,336), $R=1/2$
8	2640	LDPC(672,504), $R=3/4$
12	3960	LDPC(672,504), $R=3/4$

Table 2. High Speed Interface PHY MCSs parameters.

MCS	Bit rate (Mbps)	Channel coding
1	1540	LDPC(672,336), $R=1/2$
2	2310	LDPC(672,504), $R=3/4$
4	3080	LDPC(672,336), $R=1/2$
5	4620	LDPC(672,504), $R=3/4$
7	5775	LDPC(672,504), $R=3/4$

First, we evaluate the performance of SC and HSI using an AWGN channel. Then, we assess the goodness of SC PHY in a LOS environment. For this case, we have implemented single carrier frequency domain equalisation (SC-FDE) with zero forzing (ZF) as explained in Lei and Huang (2009) and Lei et al. (2008) using a guard interval of 64 samples. This guard length should be enough to cope with the multipath propagation present in the selected LOS scenario. For the channel estimation, Golay sequences (Golay, 1961) are used in time domain to estimate the channel.

For the TG3c channel model, we concentrate our work on the TG3c 1.3 channel model, where LOS in a residential environment is considered, since it is the model that most resembles the measurement scenario. The transmitting antenna HPBW is fixed to 30° and the receiving antenna to 20°. Eight different channel realisations where simulated for different values of signal to noise ratio and five modulation and coding schemes.

In case of the channel data from the channel measurements and the ray tracing simulations, the channel impulse responses according to the positions in Fig. 1 have been used. As for the TG3c simulation, eight CIRs obtained in the measurement campaign were utilised, as well as eight CIRs from the ray tracing simulation of the corresponding measured points. As an example, Figs. 2 and 3 show two CIRs obtained by measurement and ray tracing for one point in the room. The shape of the CIRs is due to the hight directivity of the antennas, the existence of line-of-sight and the short distance between transmitter and receiver.

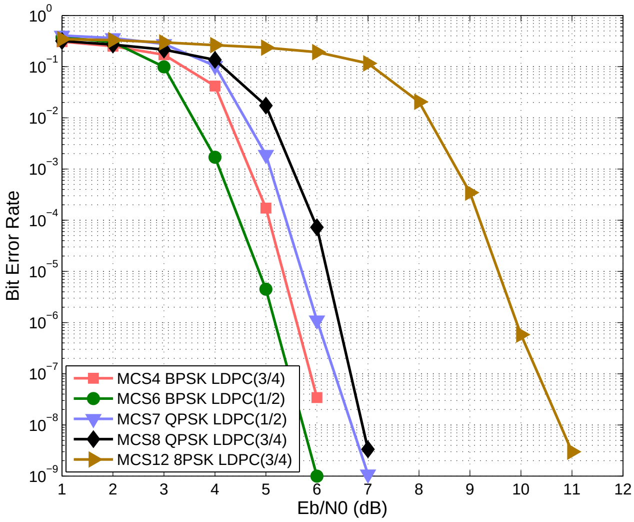

Fig. 6. BER against Eb/N0 for 60 GHz channel measurements and SC PHY.

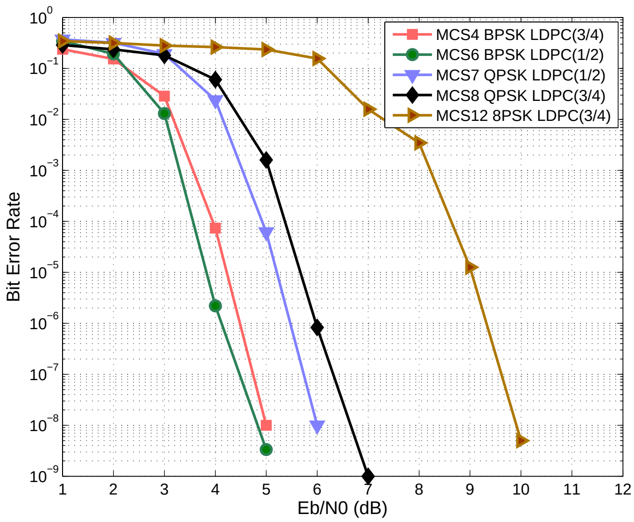

Fig. 7. BER against Eb/N0 for ray tracing simulation with SC PHY.

5 Simulation results

Figures 4 and 5 show the bit error rate obtained for different values of the relation energy per bit to spectral noise density (Eb/N0) for SC and HSI in case of AWGN channel. In case of perfect channel estimation and equalisation, the results of the simulation with 60 GHz channel realisations should resemble these figures. At both figures can be seen that, for the same modulationorder, by decreasing the code rate from 3/4 to 1/2 a gain of up to 1 dB is achieved.

After the simulation with the multipath channels, the BER values due to the best six of the eight CIRs where averaged. The results of the averaging are presented in Figs. 6, 7 and 8, which illustrate the BER obtained for the 60 GHz measurements, ray tracing and TG3c model. It is shown that a degradation of up to 2 dB is obtained when compared with the AWGN channel. This is partly caused by the ZF equalisation method, which on the one hand removes inter symbol interference in the received signal due to multipath, and on the other hand elevates the Gaussian noise after the equaliser. Besides, the time domain channel estimation performs quite well, so that its contribution to the degradation is very small. Moreover, the shift to the right in the curves of Figs. 6–8 when compared with Fig. 4 is also caused by the reduction of the spectrum efficiency introduced by the guard interval necessary for the channel equalisation.

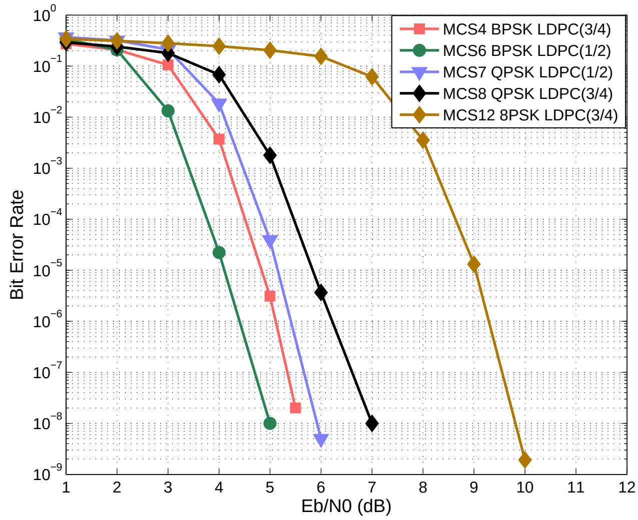

Fig. 8. BER against Eb/N0 for TG3c CM1.3 with SC PHY.

Figure 9 shows the values of Eb/N0 required to reach a BER below 10^{-7}. This value was selected because it is a good compromise between the different requirements in terms of quality of service in the planned use cases. Comparing the channel models (TG3c, Ray Tracing, Measurements), slight differences can be found. For the difference between TG3c and the other two data sets this can be explained by the fact that the scenarios and the used antennas are similar but of course not identical. The best results in terms of BER are obtained for the TG3c channel model, and the worst for the 60 GHz channel measurements. Nevertheless, the values obtained by the simulations with the multipath channels are very similar to each other, with differences below 1.1 dB. For the selected threshold (BER below 10^{-7}) a maximum data rate of up to 3.47 Gbps (MCS 12) can be achieved for Eb/N0 values better than 11.3 dB. Besides this, the figures illustrate that the gain obtained by reducing the code rate for a fixed modulation order is smaller than in the case of an AWGN channel.

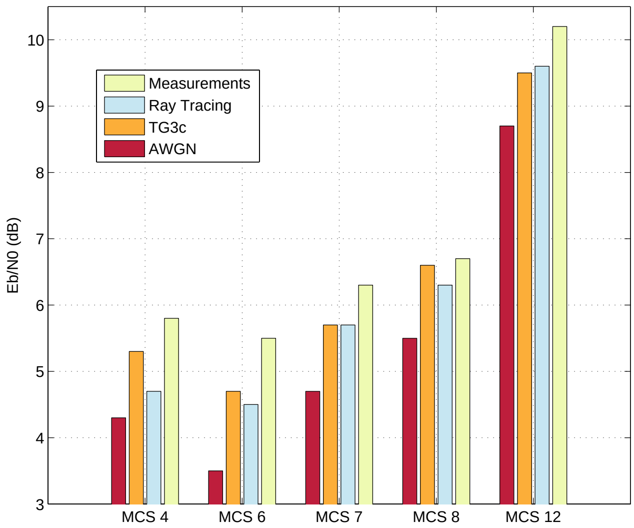

Fig. 9. Eb/N0 values (dB) for BER below 10^{-7}.

6 Conclusions

We have presented and evaluated two different physical layer modes of the IEEE 802.15.3c standard. This has been done first for an AWGN channel, and second with different kinds of channel impulse responses obtained from measurements and statistical and deterministic models.

Our simulations show that when an AWGN channel is considered, which would be the case with perfect channel estimation and equalisation, HSI and SC PHY performance is similar. For the other three channels included, SC PHY with SC-FDE presents a good overall performance, and allows multigigabit wireless communication with reasonable values of signal to noise ratio.

In future work, we will improve the channel equalisation method and we will include NLOS propagation. For this case, we will implement a beam forming algorithm, and will evaluate its impact on the system performance.

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