Performance evaluation of 60 GHz WLAN antennas under realistic propagation conditions with human shadowing

Martin Jacob[1], *Anton de Graauw*[2], *Maristella Spella*[2], *Pablo Herrero*[3], *Sebastian Priebe*[1], *Joerg Schoebel*[3], and *Thomas Kürner*[1]

[1] Institut für Nachrichtentechnik, Technische Universität Braunschweig, Schleinitzstraße 22, 38106 Braunschweig, Germany, {jacob, priebe, kuerner}@ifn.ing.tu-bs.de

[2] NXP Semiconductors, 5656 AE Eindhoven, The Netherlands, {a.j.m.de.graauw, maristella.spella}@nxp.com

[3] Institut für Hochfrequenztechnik, Technische Universität Braunschweig, Schleinitzstraße 22, 38106 Braunschweig, Germany, j.schoebel@tu-bs.de, pablo.herrero@intel.com

(Pablo Herrero is now with Intel Mobile Communications, Am Campeon 7-12, 85579 Neubiberg, Germany)

Abstract

In this paper, the evaluation of different 60 GHz WLAN antenna designs is presented. Based on ray tracing and human blockage the radio propagation in a living room scenario is modeled. Then simulated 3D antenna patterns of conventional and smart antennas are linked to the radio channel data. The performance of the antennas is compared in terms of the coverage probability within the living room.

1 Introduction

The interest in the unlicensed 60 GHz frequency band ranging from 57 to 66 GHz for the use in wireless indoor communications is heavily growing. This becomes apparent since different groups have published their specifications (e.g. IEEE802.15.3c [1]) allowing for multi gigabit data transmission. It is commonly agreed that beamforming/-steering is an appropriate instrument to overcome the high free space attenuation in the mm-wave region (see e.g. [1]). In contrast to conventional systems, special importance must be paid to the antenna design process. The requirements of antennas are often defined focusing only on the maximum range of a wireless system. On the other hand, physical layer simulations, with the goal of determining the bit error rate (BER) performance of a system, are time consuming and often use statistical channel models . In this paper a different approach for the evaluation of antennas is presented. We combine deterministic channel modeling (ray tracing) including antenna characteristics with link budget calculations for modulation and coding schemes (MCS) of the IEEE802.15.3c standard [1]. Benefits of this method are, for example, that a misalignment of antennas is taken into account and that the deterministic channel model directly gives insight into the small-scale and large-scale propagation features. As a figure of merit, being more suitable than just the range of a system, we evaluate the coverage of a whole room in terms of achievable BERs. In the literature a few more advanced studies about the impact of antennas on 60 GHz can be found (e.g. [2, 3]). The advantage of our approach over these studies is that we also take into account human blockage, which is an important issue at such high frequencies [4].

2 Antennas and Ray Tracing

In the following, three different planar antennas as well as an ideal dipole, used as reference, will be analyzed. A full three-dimensional characterization of the antennas has been carried out using a commercial finite element based electromagnetic field simulation software. The antenna gain patterns are depicted in Fig. 1a and 1d. Here only the azimuth characteristics are shown, because the elevation characteristics have no major impact on the evaluation results. All antennas are vertically polarized. The first antenna is a planar dipole with ground plane reflector. The second antenna is a planar dipole array consisting of two single elements also with ground plane reflector. These antennas have a gain of 8.2 and 9.6 dBi. A half power beamwidth (HPBW) of 70° and 77° in the azimuth plane and 55° and 51° in the elevation plane have been determined. The third antenna is a planar 8x4 patch array with the capability of beamswitching in the azimuth plane. Here, four different beams can be selected by choosing a different feed port of a Rotman lens [5]. The single beams have a gain of 15 dBi and a HPBW of 19° in the horizontal and 17° in the vertical plane. Altogether the four beams lead to a virtual HPBW of 104° (see Fig. 1d). Please note that the gain within the virtual HPBW decreases by more than 3 dB at some angles. A detailed description of the antenna

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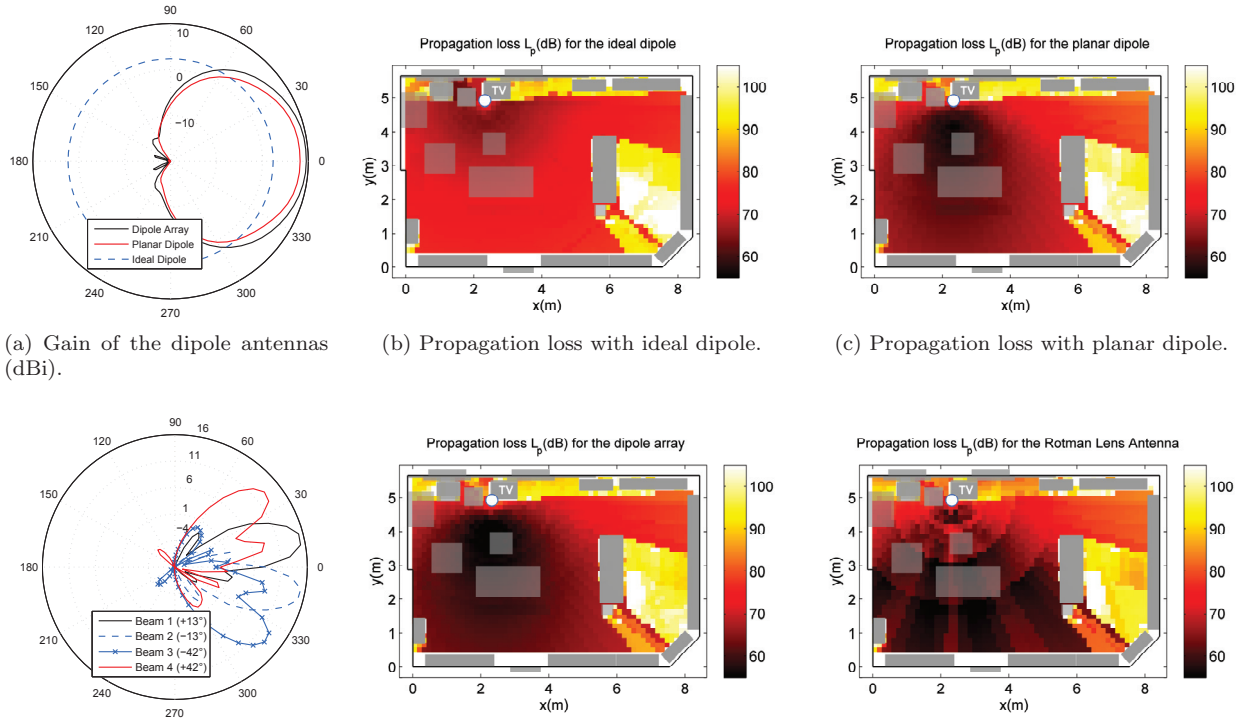


(a) Gain of the dipole antennas (dBi).

(b) Propagation loss with ideal dipole.

(c) Propagation loss with planar dipole.

(d) Gain of the Rotman lens antenna (dBi).

(e) Propagation loss with planar dipole array.

(f) Propagation loss with Rotman lens antenna.

Figure 1: Patterns of the analysed antennas in azimuth domain (a,d) and propagation loss maps for the different antennas (b,c,e,f).

geometries and designs is omitted here, because the focus of the paper lies on the performance evaluation methodology.

In order to analyze the coverage in a living room scenario ray tracing simulations have been performed. The receiver (for instance a TV set) has been kept fixed in space. Channel impulse responses (CIR) have been determined for $N = 2183$ different transmitter positions covering the whole room. All further calculations are performed considering the entire scenario. Both, the furnishing as well as all dimensions of the room can be found in Fig. 1. The polarization of the antennas as well as polarization changes during propagation are taken into account. The same antennas are used at both transmitter (TX) and receiver (RX). The TX antennas are located 0.9 m above the floor emulating devices connected to the TV, whereas the RX antenna is located at a height of 1.4 m. In the azimuth plane the RX antenna is directed to a fixed orientation into the room. The TX antennas point to the direction of the RX. To both antennas no elevation tilt is applied. For the Rotman lens antenna all 16 possible combinations of the four beams at Tx an Rx have been used in the ray tracing simulations. In addition to the scenario without human presence a human blockage is applied to the ray tracing results. In order to get a worst case estimation we have chosen a scenario where a person stands directly between TX an RX and hence blocks the LOS connection in any case, but also attenuates other clusters. The influence of the person on the CIR is modeled according to [4]. It is noteworthy to mention, that the term NLOS in the following explicitly corresponds to positions that are shadowed by furniture and not by a person.

3 Coverage Calculation

From the ray tracing CIRs, the propagation loss (L_p) averaged over the whole bandwidth of *channel 1*, defined in [1], and the Rician *k-factor* [6] have been extracted. This parameter is a measure for the multipath richness of the CIR. Propagation loss maps for all analyzed antennas can be found in Fig. 1. In case of the Rotman lens antenna the TX/RX beam combination with the lowest loss has been chosen. Here, the

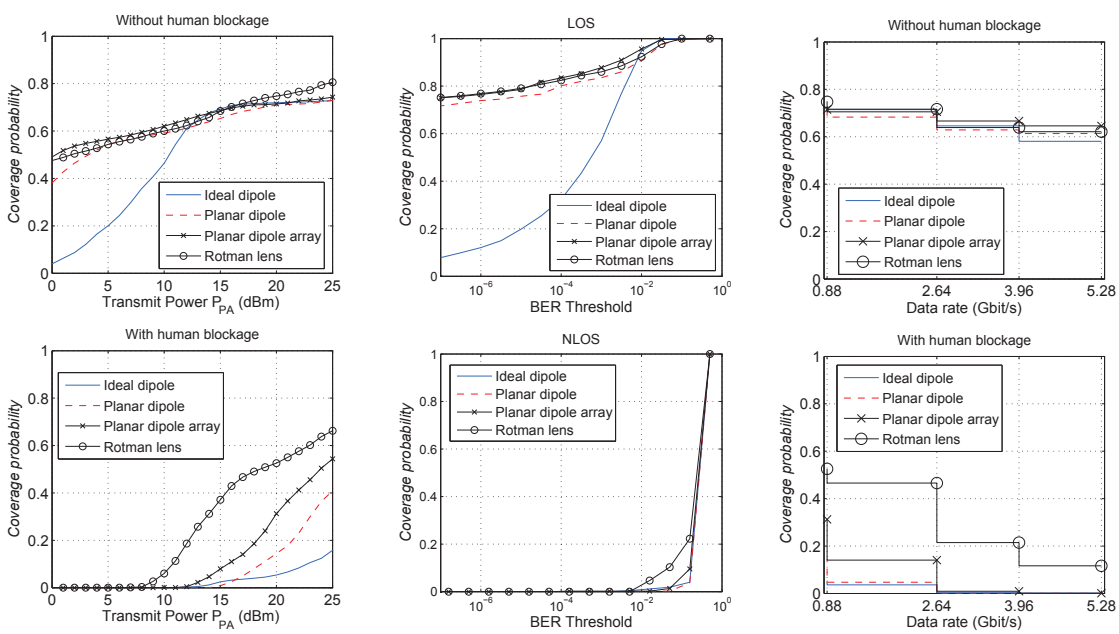
apparent unsteadiness in the propagation loss map can be traced back to the Rotman lens antenna patterns in the elevation plane. The relatively high losses of all antennas close to the TV can be attributed to the different heights of the TX and RX antennas and the fact that no down tilt has been used. From L_p the signal-to-noise-ratio (SNR) is calculated according to:

$$SNR\,[dB] = P_{PA}\,[dBm] - L_p\,[dB] - L_{RF}\,[dB] - NF\,[dB] - N\,[dBm]\,, \tag{1}$$

where P_{PA} is the output of the power amplifier at the transmitter, L_{RF} are losses in the RF front ends, NF is the receiver noise figure and N is the thermal noise power according to the channel bandwidth. The parameters L_{RF} and NF are kept fixed to values of 3 dB and 7 dB which is in line with a 45 nm CMOS process. The SNR and the *k-factor* are used to determine the BER for each TX position and the single-carrier-MCS *6, 8, 12* and *13* of the IEEE802.15.3c standard. These MCS employ BPSK, QPSK, 8-PSK and 16-QAM with LDPC-coding (code rates 1/2 or 3/4). In order to account for small-scale fading effects analytical expressions for the BER performance in fading channels have been used [6]. It is noteworthy to mention that the BER is always calculated without coding under two assumptions, *a)* a BER of 10^{-2} before error correction is sufficient to achieve a BER of 10^{-6} after error correction and *b)* intersymbol interferences do not occur. For the Rotman lens antenna an ideal beamswitching procedure is assumed, i.e. the TX/RX beam combination with the lowest BER is chosen. Depending on the *k-factor* and the MCS, the required SNR typically lies between 4 and 23 dB for a BER of 10^{-2} before any error correction [6]. The coverage probability p is defined as the ratio between the number of TX positions with a BER lower than the defined threshold and the number of all TX positions.

4 Evaluation Results

The coverage within the scenarios is analyzed by varying the transmit power P_{PA} as well as the BER threshold and by comparing the different MCS. In Fig. 2a the coverage is depicted as a function of output power. In this case P_{PA} is varied between 0 and 25 dBm for a BPSK modulation (MCS *6*). The upper



(a) Output power dependency with and without human blockage for MCS *6* and a BER threshold of 10^{-2}.

(b) Influence of BER threshold on coverage (MCS *6*) for LOS and NLOS situations without human blockage and a transmit power P_{PA} of 14 dBm.

(c) Coverage for different MCS (P_{PA} = 20 dBm, BER threshold: 10^{-2})

Figure 2: Results of the coverage evaluation.

limit of 25 dBm has been chosen, because this leads to the maximum allowed average EIRP for wireless 60 GHz systems assuming the gain of the Rotman lens antenna. In general, the coverage increases with increasing power. In the case without human blockage the coverage for the three planar antennas is similar. Nevertheless, at certain coverage values the dipole array or the Rotman lens antenna outperforms the other antennas by up to 5 dB. At power values above 12 dBm the ideal dipole behaves like the planar dipole array, whereas below this value the ideal dipole coverage decreases rapidly. This is due to the fact that in case of the ideal dipole, lower transmit powers lead to a smaller range because of the low antenna gain. For higher transmit powers there is no significant difference, since NLOS areas cannot be covered regardless of the antenna type for the reason of too high propagation losses. In the case with human blockage the coverage is generally lower than without, because the presence of a person can diminish the SNR by up to 30 dB and in addition leads to smaller *k-factors*. Both, aspects contribute to a higher bit error rate. From Fig. 2a it can be seen that up to a power of 8 dBm no coverage is possible at all. At higher powers a clear ranking according to the gain of the antennas is observed. Here, the Rotman lens antenna shows its strength of having a large virtual beamwidth paired with a high gain.

A similar behavior is observed when the LOS and NLOS coverage is investigated. Fig. 2b shows this comparison as a function of the BER threshold. In LOS situations, again a similar behavior of all planar antennas can be observed, whereas the ideal dipole shows worse performance for stricter BER requirements. At a reasonable threshold of 10^{-2} before error correction all antennas achieve a good performance covering between 90 and 95% of the room. In NLOS situations, all antennas have a very low coverage probability, proving that proper coding algorithms are mandatory at 60 GHz.

In Fig. 2c the coverage is compared for the different MCS and an output power of 20 dBm. In the case without human blockage a data rate of 880 Mbit/s is achieved in approximately 70% of the room. The coverage drops to 60% at a data rate of 5.28 Gbit/s. The difference between the antennas is 3% at maximum. In the case with human blockage the Rotman lens antenna again outperforms the other antennas, whereas the ranking is again according to the antenna gain.

5 Conclusion

In this paper, the coverage in a living room has been investigated. Regarding the analyzed planar antennas, an interesting result is that no significant difference can be observed in non-critical situations (no human blockage or LOS). However, in NLOS situations and the human blockage scenario the Rotman lens antenna shows its strength. The large (virtual) beamwidth and the high antenna gain make it possible to better cope with the human blockage than the other antennas. In addition, the slightly higher gain and larger HPBW of the array compared to the planar dipole manifests in the slightly better coverage results. The omnidirectional ideal dipole antenna also shows good performance under specific circumstances, which proves that omnidirectional modes, as proposed in the 60 GHz standards, are eligible.

6 References

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