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Static and Dynamic Millimeter-Wave Channel Measurements at 60 GHz in a Conference Room

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***Abstract*—In this work, we present an empirical study of the characteristics of the radio channel at 60 GHz for an indoor environment. The measurement campaign is conducted in a conference room scenario and the propagation properties are evaluated and analysed. The wideband channel sounding equipment is utilized in the channel evaluation. First, the static measurement results are presented for various transmitter positions in the conference room. Moreover, we present the measurement results of the channel impulse response for the case when there are several people randomly moving in the room. It is well known, that human blockage can severely attenuate the signal and, hence, the strongest reflected paths can be used for communication. The analysis of the path loss is presented for the dynamically changing environment.**

***Index Terms*—millimeter-wave, 60 GHz, indoor radio communication.**

I. Introduction

Since the first wireless systems appeared about 100 years ago, the data rates have dramatically increased. The rapid increase of mobile data transfer and appearance of new devices such as smartphones and tablets create increasing demands for the system designers. Deployment of wireless networks operating at millimeter-wave (mm-wave) frequencies is one of the promising solutions to support multi- Gbit/s communications. The unlicensed frequency range in the 60 GHz frequency band provides a growing interest from academia and industry for the allocation of the immense data rate communication systems in indoor environments [1], [2]. One application example that require high data rate transmission in indoor environment is uncompressed high-quality video streaming. These communication systems are expected to provide more than 1 Gbit/s data rate at the distances up to 10 m. However, to optimize the allocation of the receiver and transmitter positions, radio wave propagation modeling is required. Traditionally, propagation models are based on labor-intensive measurements.

Radio channel measurements and modeling calibrated by the measured channel properties is essential for the effective planning of the wireless local area networks (WLAN). Currently, there is an extensive amount of the research works related to the studies of the channel properties at millimeter-wave frequencies [3], [4], and especially at 60 GHz [5], [6], [7], [8], [9]. For example, in [10] an overview of the characterization 60 GHz radio channels for different environments is presented. However, conference room configuration with the transceivers located around the table was not studied. It is also necessary to study a human blockage effect on the radio communication performance. This influence can be crucial for the mm-wave radio links. There are studies of the human blockage models [11] and some measurement campaigns were conducted [12], [13]. In [12], the authors study propagation specifics in a residential area. In [13] and [14], the authors present measuremen results of the possible signal attenuation by the human body. In this work, we try to examine the effect of the several people moving in a conference room on the radio channel properties. A conference room is one of the typical scenarios for high data rate network deployment. In a real case, there can be a walking person who can disturb the mm-wave link. By the obtained measurement results, we show that several of the strongest reflected paths can be used to maintain the link connection. In order to achieve this beam steering/beam switching antennas or antenna arrays can be used (e.g. [15]). The results retrieved from this work can be utilized for the future ray tracing simulations of the dynamically changing environment.

The paper is organized as follows: Section II briefly describes the channel sounding equipment and the measurement scenario. In Section III static measurements are analysed in order to provide a baseline of channel characteristics in an empty office. Section IV includes the results and analysis of the measurement results for the case when several people are randomly walking in the room. Finally, Section V provides the conclusions.

II. Setup Description

The measurement system includes a vector network analyzer (VNA), a signal generator, up- and down-converters and omnidirectional antennas on the transmitter (Tx) and receiver (Rx) sides. The detailed description of the measurement equipment can be found in [5]. The main difference between the setup in [5] and this work is that bi-conical omnidirectional antennas were used at both the Rx and Tx sides in the measurements presented. Two types of measurements are realized: 1) static measurements and 2) dynamic measurements with people moving in the room. During both measurements the Rx position was fixed on the tripod in the corner of the conference

Fig. 1. Photograph of the conference room environment.

Fig. 2. Measured distances between the Rx and Tx versus Tx position.

room. A photograph of the conference room environment is shown in Fig. 1. The room size is approximately 6.1 x 8.6 m^2. There is a table in the middle of the room and chairs around the table. The walls are made mainly from the brick and wood material. The distance dependence between the Rx and Tx for the different Tx positions is presented in Fig. 2. The shortest link distance is measured at Tx position 15 and it is 0.7 m. The longest distance separation between the Rx and Tx is 6 m and limited by the size of the room.

A. Static Channel Measurements

The power delay profile (PDP) was measured for 17 different positions of the Tx placed on the table (Fig. 1). For each Tx location 100 samples were recorded for averaging to improve the measurement dynamic range. Measurements were performed at 61 to 65 GHz frequency band with 4 GHz bandwidth. These measurements give the amplitudes and delays of the most significant propagation paths with good delay resolution and large dynamic range. The results can be, e.g., utilized as a calibration data for the ray tracing simulations and also as a reference for the dynamic measurements, when people are moving in the room.

B. Dynamic Channel Measurements

In addition to the static measurements, described in the previous section, the dynamic measurements were performed

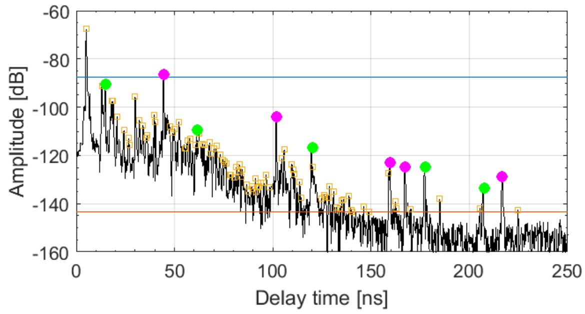

Fig. 3. Example of the power delay profile for the Tx position №13 with the tracked peaks.

for the 3 Tx positions, i.e. Tx13, Tx16, and Tx17 (Fig. 2). During these measurements, three people were randomly walking in the room, while approximately 250 samples of the PDP characteristic were recorded over a few minutes. The aim of this measurement set is estimation of the dynamic human blockage effect on the radio link and verification of the reflections which can support stable communication.

III. Static Measurement Results (Empty Office)

The measurement results for an empty conference room are presented in this section. First, we are going to analyze PDP characteristics for some of the Tx positions. In Fig. 3, an example of the PDP characteristic with tracked peaks is presented for the Tx position №13. For this position, the LOS path length is 2.2 m. Some peaks are highlighted with the markers and the dependence of the peak amplitude versus travelled distance for the Tx positions №9-14 is presented in Fig. 5. It can be observed that there is only a small deviation of each peak value with the increasing LOS link distance.

In Table I, the path loss (PL) model parameters, delay spread (DS), and K-factor mean and standard deviation values are presented for the 17 Tx positions. These parameters are calculated with a dynamic range of 20 dB from the peak. K-factor is calculated as the power ratio of the direct LOS path and the total power in all the other paths. Normally K-factor is modeled with a simple log-normal distribution. If the K-factor is modeled with a similar link distance dependent model as PL it would be

$$K = -21 \cdot \log_{10}(d/1m) + 19. \tag{1}$$

The K-factor has strong link distance dependence and it is about 20 dB at very short distances and goes down to about 0 dB for the longest measured links distances. This has the effect that the communication link more severely affect when the LOS path is blocked with the shorter link distance, as we see in Section IV.

IV. Dynamic Measurement Results (Randomly Walking People)

At 60 GHz the blockage attenuation of the signal is relatively high and the presence of the human body between the Rx

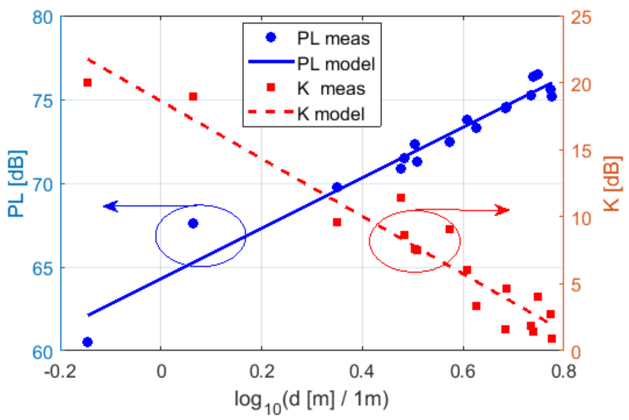

Fig. 4. The link dependency of the Path Loss and K-Factor.

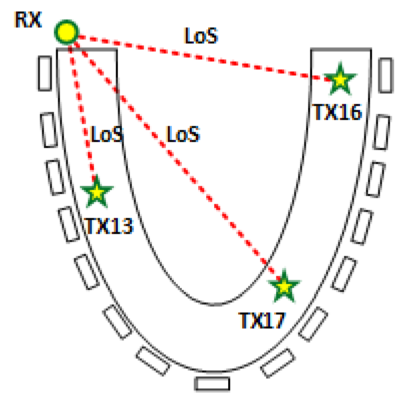

Fig. 6. Scematic top view of the conference room with the Tx locations №13, №16, and №17 used in the dynamic measurements. In locations 16 and 17 also the direct LOS path was occasionally blocked by a human.

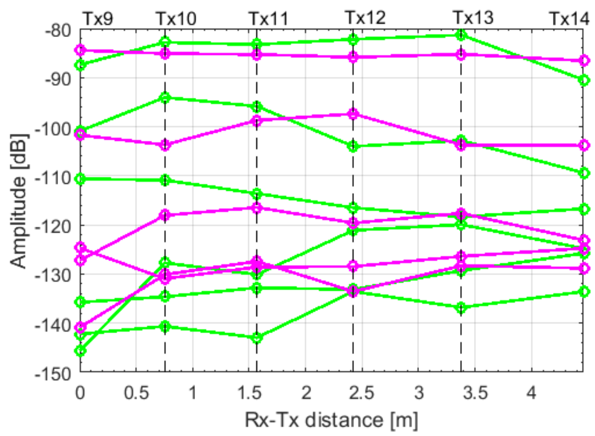

Fig. 5. Amplitudes of the detected dominant paths.

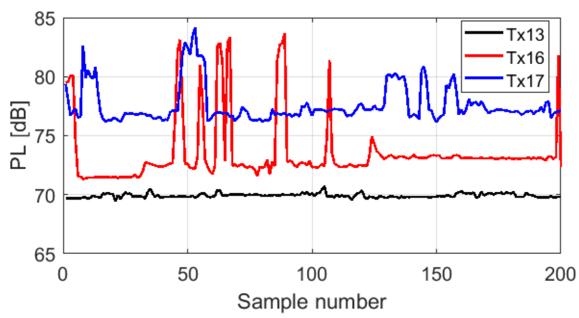

Fig. 7. The path loss variation versus the Tx position.

TABLE I
CHANNEL PARAMETERS FROM THE 17 STATIC MEASUREMENTS. PATH LOSS MODEL, DELAY SPREAD, K-FACTOR MEAN (μ), AND STANDARD DEVIATION (σ).

parameter		value
$PL(dB) = 10 \cdot A \cdot \log_{10}(d/1m) + B$	A	1.5
	B	64
DS [ns]	μ_{DS}	6
	σ_{DS}	2
K [dB]	μ_K	7
	σ_K	6

and Tx can be crucial for stable high data rate communication link.

For the Tx locations №13, №16 and №17 (Fig. 6) the dynamic measurements of the CIR were performed. During these measurements 3 people were randomly walking around the conference room while roughly 250 measurement samples were recorded over a few minutes. It is obvious that there is no human blockage of the direct LOS signal for the Tx position №13. However, the blockage is present for the positions №16 and №17. Fig. 7 presents the path loss diversity versus Tx positions №13, №16 and №17 for the dynamically changing scenario. It is visible, that for the position №13 the path loss almost stays at the level of 70 dB during the whole measurement. It is noticeable, that the path between the Rx and Tx located at the postion №16 was disturbed more often by the people walking around the room due to the explicit location. The link Rx-Tx17 is not affected as much as previously described location №16. It can be noticed, that the LOS signal is decreased more than 25 dB when the human blocks the radio link. This value corresponds to the results obtained in [13] and [14].

Fig. 8 presents the PDP characteristic for the Tx position №13, while the Fig. 9 shows the comparison of LOS signal level and the strongest found paths. The distance separation of the Rx and Tx is 3 m for this position. If a randomly walking person crosses the direct LOS path the power level is reduced significantly. Nevertheless, there is a reflected signal which can compensate the power loss and can be used for the communication. The drop in the received amplitude can be greatly reduced if the strongest path can be chosen in a dynamic channel with people moving. It can be seen that the power level decreases by about 12 dB if the strongest reflected multipath component and about 30 dB if only the LOS path is used. However, sometimes both the direct LOS path and the reflections from the wall are blocked. For the most of the cases the first reflection with the delay of 11 ns compensates the human blockage of the LOS path. Only for one of the cases, i.e., for the sample 90, the second reflection appeared

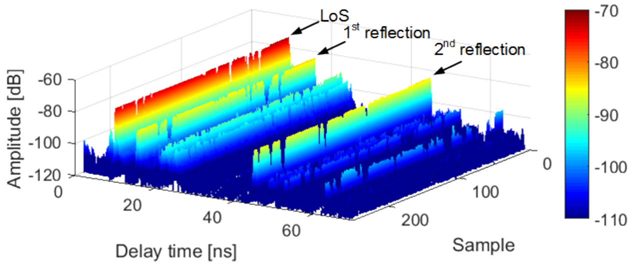

Fig. 8. Power delay profile profile as a function of measurement time (approximately 250 samples) at the Tx location №16.

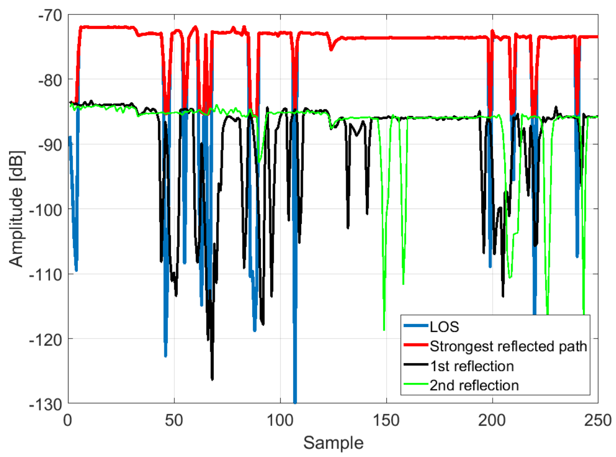

Fig. 9. Amplitude of the direct LOS path and amplitude of the strongest available path in Tx position №16.

to be stronger than LOS and 1st reflected path.

In Fig. 10, the PDP for the Tx position 17 is presented. Fig. 11 displays the LOS signal and the strongest detected reflected signal. For this Tx location, there are several strong reflections almost of the same level due to the similar distances from the Tx to the walls where the reflections take place. The distance between the Rx and Tx is 5.5 m. The rst reection is 12 dB, the second 5 dB, and the third one is 7 dB weaker than the LOS path. In comparison with the Tx position 16, in this case the reflected paths are used more often because the LOS and distances via reflections are almost equal. The usage of the strongest reflected path can help to maintain the communication and minimize the losses.

V. Conclusion

In this paper, the static measurement results for a conference room scenario are presented. The analysis of the received results is provided. In addition, the measurements were performed for the realistic case when there are several people are walking in the room. The results show which reflected signal can be used in the communication. This can be an important information for the planning the mm-wave base station locations inside the room and give an estimation of the necessary antenna configurations.

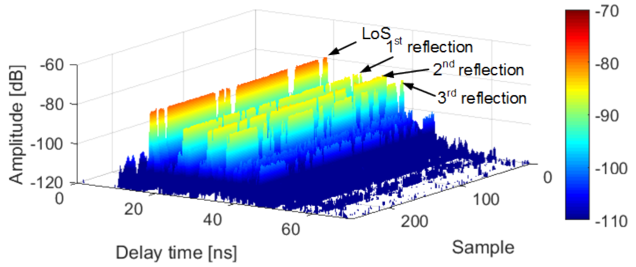

Fig. 10. Power delay profile profile as a function of measurement time (approximately 250 samples) at the Tx location №17.

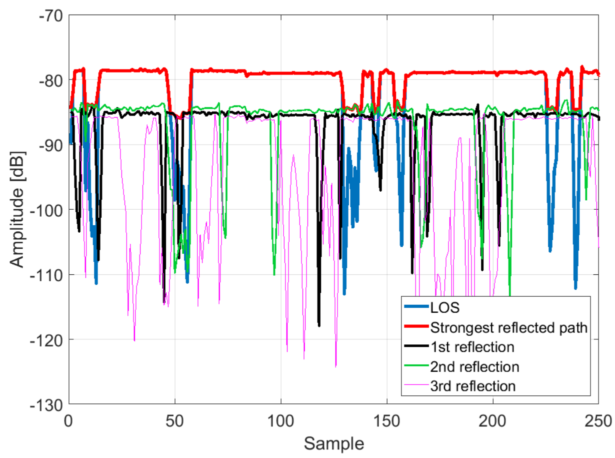

Fig. 11. Amplitude of the direct LOS path and amplitude of the strongest available path in Tx position №17.

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References

[1] "8802-11:2012/amd.3:-2014 - ISO/IEC/IEEE International Standard for Information technology–Telecommunications and information exchange between systems–Local and metropolitan area networks–Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 3: Enhancements for Very High Throughput in the 60 GHz band (adoption of IEEE Std 802.11ad-2012)," March 2014.

[2] Y. Ghasempour, C. da Silva, C. Cordeiro, and E. Knightly, "Ieee 802.11ay: Next-generation 60 GHz communication for 100 gbps Wi-Fi," *to appear in IEEE Communications Magazine*, 2017.

[3] G. Maccartney, T. Rappaport, S. Sun, and S. Deng, "Indoor office wideband millimeter-wave propagation measurements and channel models at 28 and 73 GHz for ultra-dense 5G wireless networks," *IEEE Access*, vol. 3, pp. 2388–2424, October 2015.

[4] S. Salous, V. Degli-Esposti, F. Fuschini, R. Thomä, K. Haneda, J.-M. Garcia-Pardo, J. Garcia, D. Gaillot, M. Nekovee, and S. Hur, "Millimeter-wave propgation. characterization and modeling toward fifth-generation systems," *IEEE Antennas and Propagation Magazine*, vol. 58, pp. 115–127, December 2016.

[5] J. Vehmas, J. Järveläinen, S. Nguyen, R. Naderpour, and K. Haneda, "Millimeter-wave channel characterization at helsinki airport in the 15, 28, and 60 GHz bands," in *IEEE 84th Vehicular Technology Conference (VTC-Fall)*, September 2016.

[6] J. Järveläinen, K. Haneda, and A. Karttunen, "Propagation channel simulations at 60 GHz using point cloud data," *IEEE Transactions on Antennas and Propagation*, vol. 64, pp. 4457–4467, October 2016.

[7] V. Semkin, M. Jacob, T. Kürner, A. Bisognin, F. Ferrero, C. Luxey, and A. Räisänen, "Estimation of optimum antenna configurations supported by realistic propagation models at 60 GHz," in *The 8th European Conference on Antennas and Propagation (EuCAP2014)*, (The Hague, Netherlands), pp. 3434–3438, April 2014.

[8] A. Maltsev, R. Maslennikov, A. Sevastyanov, A. Khoryaev, and A. Lomayev, "Experimental investigations of 60 GHz wlan systems in office environments," *IEEE Journal on Selected Areas in Communications*, vol. 58, pp. 1488–1499, JuneOctober 2009.

[9] X. Wu, C.-X. Wang, J. Sun, J. Huang, R. Feng, Y. Yang, and X. Ge, "60-GHz millimeter-wave channel measurements and modeling for indoor office environments," *IEEE Transactions on Antennas and Propagation*, vol. 65, pp. 1912–1924, April 2017.

[10] P. Smulders, "Statistical characterization of 60-GHz indoor radio channels," *IEEE Transactions on Antennas and Propagation*, vol. 57, pp. 2820–2829, October 2009.

[11] M. Jacob, S. Priebe, A. Maltsev, A. Lomayev, V. Erceg, and T. Kürner, "A ray tracing based stochastic human blockage model for the IEEE 802.11ad 60 GHz channel model," in *The 5th European Conference on Antennas and Propagation (EuCAP2011)*, (Rome, Italy), pp. 3084–3088, April 2011.

[12] S. Collonge, G. Zaharia, and G. Zein, "Wideband and dynamic characterization of the 60 GHz indoor radio propagation future home wlan architectures," *Annals of Telecommunications - annales des t ?el ?ecommunications*, vol. 58, no. 3-4, pp. 417–447, 2003.

[13] M. Jacob, C. Mbianke, and T. Kürner, "A ray tracing based stochastic human blockage model for the IEEE 802.11ad 60 GHz channel model," in *IEEE 14th International symposium on Consumer Electronics (ISCE)*, pp. 3084–3088, July 2010.

[14] M. Peter, M. Wisotzki, M. Raceala-Motoc, W. Keusgen, R. Felbecker, M. Jacob, S. Priebe, and T. Kürner, "Analyzing human body shadowing at 60 GHz: Systematic wideband MIMO measurements and modeling approaches," in *The 6th European Conference on Antennas and Propagation (EuCAP2012)*, (Prague, Czech Republic), April 2012.

[15] V. Semkin, F. Ferrero, A. Bisognin, J. Ala-Laurinaho, C. Luxey, F. Devillers, and A. Räisänen, "Beam switching conformal antenna array for mm-wave communications," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 28–31, April 2016.