

S. Ranvier, M. Kmec, R. Herrmann, J. Kivinen, J. Koivunen, R. S. Thomä, and P. Vainikainen. 2005. Mm-wave wideband MIMO channel sounding. In: Proceedings of the XXVIIIth General Assembly of the International Union of Radio Science (URSI GA 2005). New Delhi, India. 23-29 October 2005, Paper 01644.

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MM-WAVE WIDEBAND MIMO CHANNEL SOUNDING

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I. INTRODUCTION

The use of wideband 60 GHz radio propagation channel will allow high data rates in future communication systems [1]. E.g., the 57...64 GHz frequency band will allow Gbit data rates for short-range wireless access. Indeed this frequency range offers huge bandwidths and, due to the oxygen absorption, improves frequency reuse in cellular networks compared to lower frequencies. Furthermore, array signal processing is a promising approach to enhance the link performance. Fortunately enough, antenna arrays are small at mm-wave frequencies so that large MIMO (Multiple Input Multiple Output) systems with high capacity could be realized in a small volume like the corner of a laptop, PDA or mobile phone. The adaptive antenna array gain can be used to enhance the link gain and to reduce interference. Missing line-of-sight can be mitigated by directing beams towards the strongest available multipaths or by submitting a variety of links toward widely distributed infrastructure antennas.

The achievable capacity of MIMO systems is defined by the availability of parallel propagation channels in multipath environment. Therefore, the performance prediction of mm-wave mobile radio links requires thorough investigation of the time-varying and directional propagation characteristics

Most of the solutions for characterizing the radio channel in the 60 GHz band with adequate bandwidth are based on vector network analyzers, where the characterization of the channel is slow, limiting the possibilities to perform multi-channel measurements required for MIMO. Most real-time measurement results reported in the literature suffer from a too small bandwidth. E.g., a bandwidth of 400 MHz corresponds to spatial resolution of only 0.75 m, which is not enough to resolve propagation occurring in a typical indoor environment.

In section, II we introduce the measurement setup. The measurement campaign and the results are presented in section III and IV respectively. Section V concludes this paper.

II. MEASUREMENT SETUP

The measurement set up shown in Fig. 1 is a combination of two sub-systems: an ultra-wideband (UWB) sounder developed in the Electronic Measurement Research Lab of Ilmenau University of Technology and a mm-wave MIMO system developed in the Radio Laboratory of Helsinki University of Technology consisting in frequency converters and virtual antenna arrays.

The ultra wide band sounder uses direct sequence waveform with broadband real-time sampling, which enables fast measurements. This sounder, partly based on a custom specific SiGe chip hardware, has an inherent MIMO capability. Its bandwidth extends from 3.5 to 10.5 GHz. During this measurement campaign, which was mainly performed to proof that our measurement system is working properly, the maximum delay range was only 73 ns due to the short pseudo-noise code length. Since that time, the code length has been changed so that the maximum delay range is now 585 ns. The duration of one chip of the code is 143 ps and thus the nominal delay resolution is 43 mm. This sounder is described in detail in another paper [2]. In practice, the up and down converters (see below) limit the signal bandwidth, which makes the delay resolution somewhat poorer.

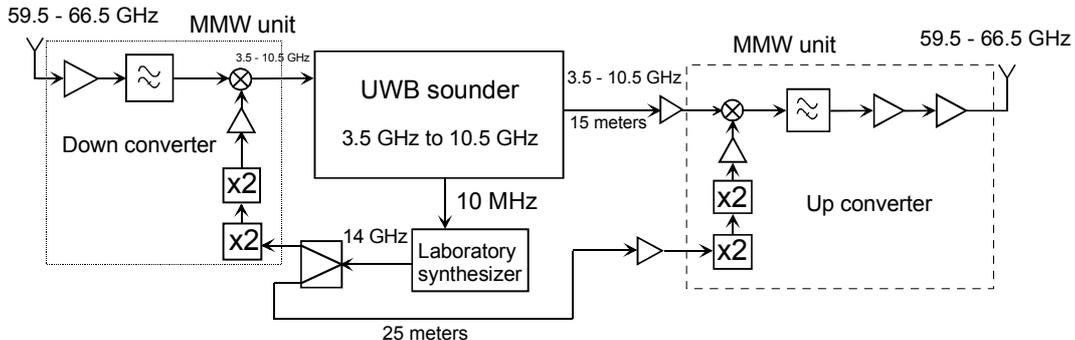


Fig.1. Combination of the sounder and the frequency converters

The up and down converters use the same 14 GHz LO (local oscillator). The optimum output power of the up converter is +17 dBm at 61 GHz, which enables NLOS (non line of sight) measurements. These up and down converters are small enough so that we can move them with our scanners to create virtual antenna arrays. A full description of the frequency converters can be found in [3].

To create MIMO antenna arrays, we use virtual antenna arrays, as in [4]: there is one antenna for the transmitter and one antenna for the receiver. We move the antennas and the up/down converters with fast and accurate scanners (see Fig. 2). Then, we get an array of elements at TX and RX as shown Fig. 3. The advantages of using virtual antenna arrays are: good link budget, relatively low complexity compared to use of switches and freedom in the choice of the antenna array configurations.



Fig.2. Picture of the transmitter (up converter and antenna) on the scanner.

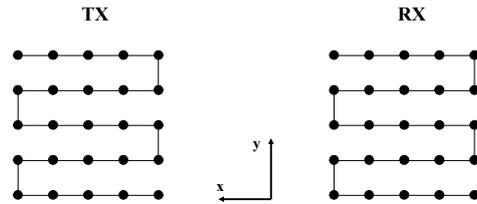


Fig. 3a. Antenna array configuration (25x25).

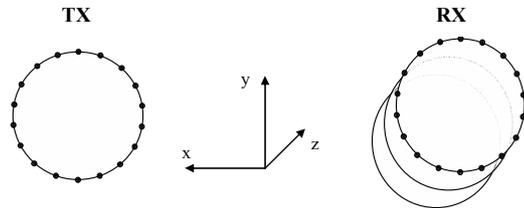


Fig. 3b. Antenna array configuration (18x54).

The antenna arrays are either full squares with 5x5 “virtual antennas” by side (25 elements) as depicted in Fig. 3a or a circle with 18 elements uniformly distributed at TX and a cylinder composed from 3 identical circles at RX, as depicted in Fig. 3b. Therefore we get a 25x25 channel matrix (25 positions at TX and 25 positions at RX = 625 channels) or a 18x54 channel matrix (18 positions at TX and 54 positions at RX = 972 channels). For both configurations, the spacing between two adjacent elements is $0.4 \lambda_{\min}$ (=1.8 mm). The scanners at TX and RX are manufactured by PI (Physik Instrumente GmbH). The resolution is $0.1 \mu\text{m}$ and the repeatability $1 \mu\text{m}$. Then, the location accuracy is $2.22 \cdot 10^{-4} \lambda$ (= 0.08 degrees of the phase) at 66.5 GHz. The virtual antenna arrays are controlled by a computer which trigs the sounder based on the position of the antennas on the arrays.

We used 2 identical omni-directional biconical antennas at the transmitter and the receiver. The HPBW (half power bandwidth) is 11° in the elevation plane, and the gain of each antenna is 5 dBi. For all the measurements, the antennas were positioned 1.5 meter above the floor level.

Because of the 15 m cable between the output of the sounder and the up converter, we restricted our measurement range in 15 m. Nevertheless, within this area we can get significant data, and we are able to characterize propagation channels in LOS and NLOS cases. Anyway, the distance between communication devices in the future radio systems in the 60 GHz frequency range will not be very large.

III. MEASUREMENTS

The most critical point when creating virtual antenna arrays is the duration of the measurement. The first problem is the phase drift between the transmitter and the receiver. The second one is that the channel must be static during the measurement. As the wavelength is about 5 mm, even the breathing of a person in the channel under test can dramatically affect the results. For this reason, we performed all the measurements when the measurement area was empty (with nobody inside).

The phase continuity is a major concern when defining the direction of arrival [5]. Therefore, we checked the phase drift of the whole system in order to determine the maximum time we can measure. This measurement shows that after a sufficient time (about 30 minutes) the temperature of the system is quite stable, and the phase drift is less than 1 degree per hour. Practically, the maximum time of measurement was not restricted by the phase drift. Then, in order to have a better accuracy, we slowed down our scanners and stopped 1 second between two points on the array in order to decrease the amplitude of the oscillations when the scanners start and stop. The

time to measure the 25x25 channel matrix was 14 minutes, and the respective time for the 18x54 channel matrix 22 minutes.

We performed LOS (line of sight) and NLOS (non line of sight) measurements in order to demonstrate the wide possibility of measurements our system allows. All measurements were performed with both the square (25x25) and circular (18x54) matrix configurations.

In the LOS configuration we made measurements with a reflector, with an obstacle and without the obstacle. In all these cases, the measurements were performed in a room containing many electronic devices and the distance between the antenna arrays was 5.03 m (Fig. 5). The distance between the elements on the array was $0.4\lambda_{\min}$ (1.8 mm) in order to reduce the level of the spurious responses in DOD and DOA estimations. The reflector was a rectangular sheet of metal (40 cm x 40 cm) placed at equal distance of the TX and RX, see Fig. 5. The obstacle was a square absorber (50 cm x 50 cm) placed 1.05 m away from the RX, in the direction of the TX (obstructed LOS), see Fig. 5.

In the NLOS measurements the receiver was kept in a room, while the transmitter was moved to 15 different positions in a corridor (Fig. 5).

IV. RESULTS

The power delay profile (PDP) plotted in Fig. 6 from LOS measurement reveals that there are at least 10 multipath components. The SNR (signal to noise ratio) is more than 30 dB. Because of the short code length, there are inter-code interferences that we can see, for example, on Fig. 6: there is one peak before the LOS path.

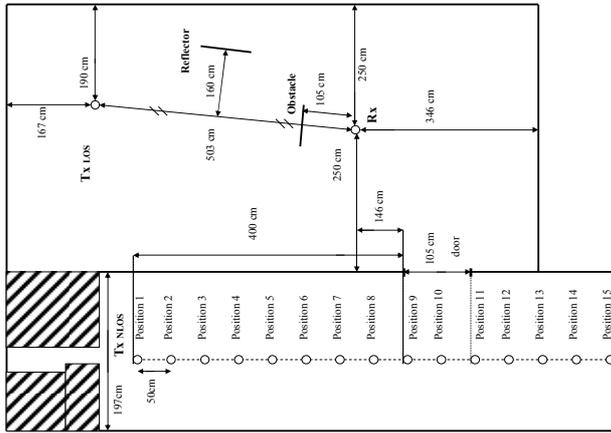


Fig. 5. Measurement location.

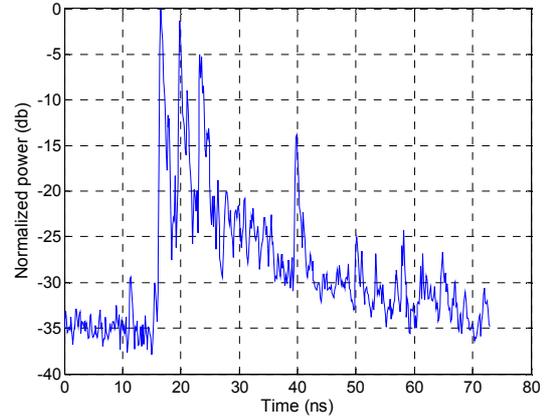


Fig. 6. Power delay profile from a LOS measurement, averaged over 625 channels. (antenna array depicted in Fig. 3a)

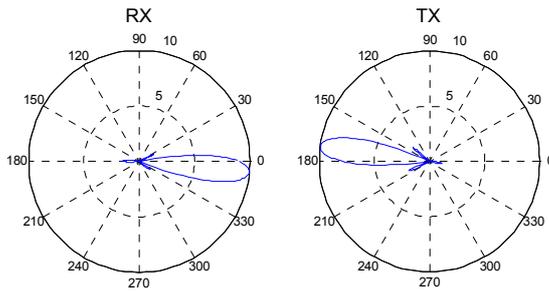


Fig. 7. TX and RX beam forming response in LOS configuration calculated from the 18x54 matrix (dB scale with 5 dB grid).

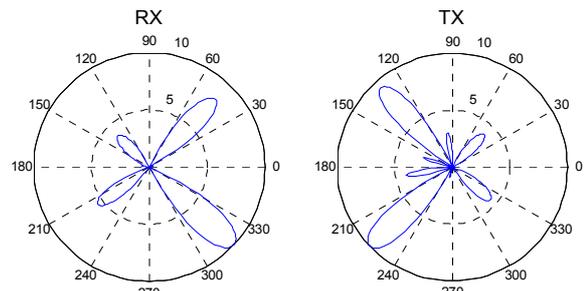


Fig. 8. TX and RX beam forming response in LOS configuration with obstruction calculated from the 18x54 matrix. (dB scale with 5 dB grid).

The preliminary directional analysis was performed simply by forming a beam to different directions by phasing the signals of different elements according to the respective DOA or DOD. Amplitude weighing was uniform. In Fig. 7 we can see the TX and RX beam forming response of the 18x54 channel matrix in the LOS case (antenna array configuration shown Fig. 3b and antenna positions in Fig. 5). It is calculated using beam forming independently at each end of the radio channel.

The standard deviation of the errors in the beam pointing, calculated from 10 successive measurements, is less than 0.3° in RX and TX. The side lobes depend on the array geometry.

In Fig. 8, we can see the TX and RX beam forming response of 18x54 channel matrix in obstructed LOS case with a square absorber (50 cm x 50 cm) placed 1.05 m away from the Rx, in the direction of the TX, see Fig. 5. Antenna arrays configuration is shown in Fig. 3b. As for the LOS case, the back and side lobes are due to the geometry of the antenna arrays. From Fig. 8 we can clearly see that there is no direct signal from TX to RX. The main lobes pointing downward are due to the reflection on the reflector while the main lobes pointing upwards are due to the reflections on the cupboard which is in the room.

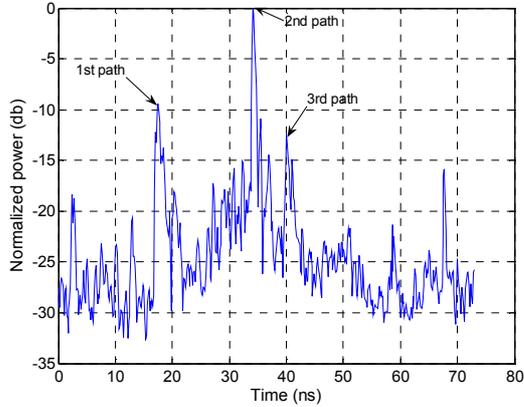


Fig. 9. Power delay profile from a NLOS measurement (position 9 in Fig. 5). Averaged over 625 channels.

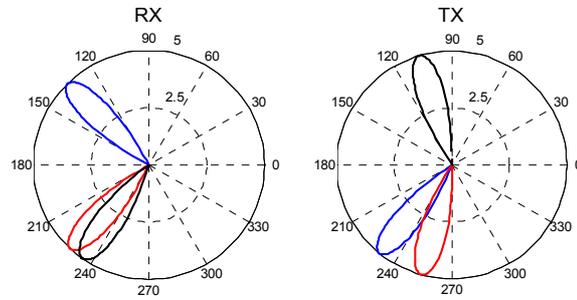


Fig.10. Tx and Rx beam forming responses in a NLOS configuration (position 9 in Fig. 5) for 3 different paths. Calculated from the 25x25 matrix. Independent dB scale for each path.

From the PDP plotted from the NLOS measurement (Fig. 9), we investigate 3 paths. We can see (see Fig.5) that the first path (17.4 ns) contains a reflection from the edge of the door frame. It is plotted in blue in Fig. 10. The second path (34.1 ns) contains at least 2 reflections (plotted in red in Fig. 10). The third path (40 ns) contains at least 3 reflections (plotted in black in Fig. 10).

V. CONCLUSIONS

This paper presents a mm-wave ultra-wideband MIMO measurement system based on the combination of two sub-systems: an ultra wide band (UWB) sounder developed in the Electronic Measurement Research Lab of Ilmenau University of Technology and a mm-wave MIMO system consisting in frequency converters and virtual antenna arrays developed in SMARAD/Radio Laboratory of Helsinki University of Technology. The nominal frequency band of the system is 59.5 GHz - 66.5 GHz and the respective delay resolution 43 mm. The antenna arrays used are squares with 25 elements at both ends or a circle with 18 elements at the TX and a cylinder with 3 circles of 18 elements at the RX (54 elements). To show the wide possibilities this system offers, LOS and NLOS measurements are reported, from which DOAs and DODs are estimated. It is seen that also NLOS measurements are possible at this frequency range.

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