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VNA-Based Wideband 60 GHz MIMO Channel Sounder With 3-D Arrays

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Abstract — **This paper presents a wide band 60 GHz MIMO channel measurement system using a VNA and 3-D arrays at both ends. It uses virtual antenna arrays which can be reconfigured easily. The bandwidth of the system is 3.5 GHz, which leads to a time resolution of 0.29 ns. This fine resolution is suitable for characterizing dense multipaths in indoor environments. Line of sight (LOS) and obstructed line of sight (OLOS) measurements were performed with 64-element arrays at both TX and RX. Preliminary results (power delay profiles) are presented.**

Index terms — **Antenna arrays, millimeter wave communication, millimeter wave measurements, MIMO systems, radio propagation, WPAN.**

I. Introduction

The need for short-range very-high data-rate wireless communication channels is increasing all the time and will definitely continue to increase in the future. The new Wireless Personal Area Networks (WPANs) are expecting to allow Gbit/s applications such as wireless high speed internet access, wireless HDTV transmissions, wireless laptop docking stations and wireless USB. To allow such high data rate, a wide bandwidth is needed. A very promising solution is to use the 60 GHz frequency band [1]. First of all, there is at least 5 GHz licence-free bandwidth available worldwide in this band. Moreover, due to the oxygen absorption, it allows frequency re-use in piconets. 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, a PDA (Personal Digital Assistant) or a 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 delay and directional propagation characteristics. For this purpose, wide bandwidth (several GHz) is necessary to resolve the propagation paths occurring in a typical indoor environment. Most of the solutions for characterizing the radio channel in the 60 GHz band with adequate bandwidth are single input single output systems (SISO) based on vector network analyzers (VNA) [2],[3]. A 60 GHz MIMO measurement system with 7 GHz bandwidth has been published in [4] but the delay range of the reported results is only 73 ns which is not enough to fully characterize the channel. Another 60 GHz MIMO channel sounder reported in [5] exhibits large delay range (8.5 μsec) but narrower bandwidth (60 MHz). Both of the previously mentioned measurement systems are based on dedicated channel sounder with fast sampling rate. The 60 GHz MIMO channel measurement system presented in this paper exhibits a bandwidth of 3.5 GHz and a delay range of 143 ns.

II. Measurement Setup

A. RF Part

The measurement system presented in this paper is based on VNA and frequency converters, as shown in Fig. 1. The VNA used in this work is an Agilent E8363A. A detailed description of the frequency converters is given in [6]. The output power of the up converter is 17 dBm, which enables non-line-of-sight (NLOS) measurements. The frequency of the local oscillator is 14 GHz. The phase continuity is a major concern when defining the direction of arrival (DoA) and departure (DoD) [7]. In order to synchronize the transmitter and the receiver and avoid phase drifts, the same 14-GHz synthesizer was used. The phase of the local oscillator was locked to the VNA.

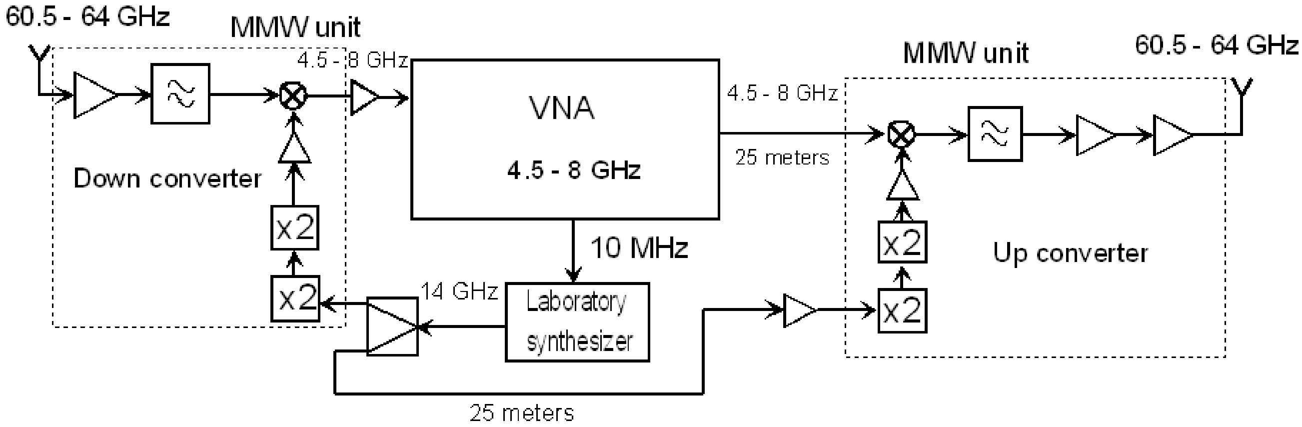

Fig. 1. Measurement setup (RF part).

After warming up, the RMS phase drift of the whole chain was measured to be 0.7 degree over more than 10 hours, which is good enough to calculate later the capacity of the channel [8]. The frequency of the base band signal is 4.5 - 8 GHz which leads to a RF frequency of 60.5 – 64 GHz. The 3.5 GHz bandwidth corresponds to the 5dB bandwidth of the frequency converters which are the main limitations of the setup. The number of frequency points was set to 501.

A first order approximation of the delay resolution *DR* and spatial resolution *SR* are given by

$$DR = \frac{1}{BW}, \quad (1)$$

and

$$SR = \frac{c}{BW}, \quad (2)$$

where *BW* is the bandwidth, and *c* is the celerity of light. Then, the estimated delay resolution is 0.29 ns and the spatial resolution is 8.6 cm. The delay range *t* can be approximated with

$$t = \frac{N-1}{BW}, \quad (3)$$

where *N* is number of frequency points (501). Then the delay range is about 143 ns, which limits the maximum measurement range to approximately 43 meters.

B. Antenna Arrays

The up and down converters are small enough so that they can be moved with linear stages to create virtual (or synthetic) antenna arrays (see Fig. 2). The advantages of virtual arrays for channel measurements as compared to real antenna arrays are:

- Decreased hardware complexity (only one RF chain and one antenna at each end)
- Possibility to have whatever shape of arrays in 3-D (cube, cylinder, sphere, etc…)
- Ease of reconfiguration of the arrays (only software modification)
- Simplified calibration (only one RF chain)
- No mutual coupling

The drawback is that it is relatively slow and, therefore, allows only static measurements (frozen environments).

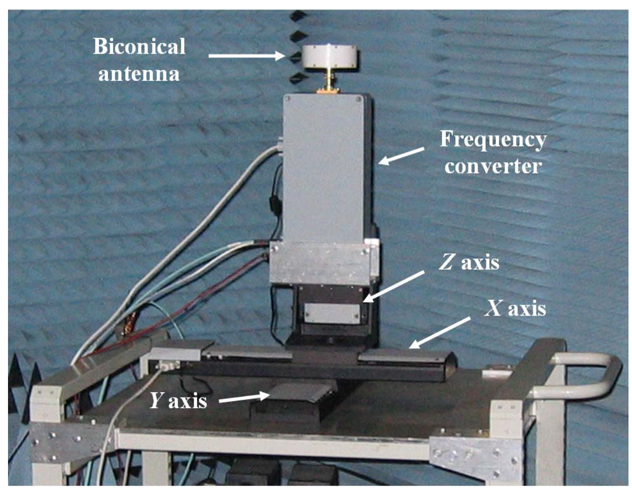

Fig. 2. Picture of the transmitter.

The VNA and the linear stages are controlled by a single computer using *Labview*. The triggering of the VNA is based on the position of the antennas on the linear stages. In order to allow direct capacity estimation from the measurement data, a cube shape has been chosen for the arrays, as shown in Fig. 3. It is made of four elements per side with half the wavelength spacing between elements. The same array configuration was used at TX and RX. Those arrays allow us to perform DoD and DoA estimation in three dimensions at both ends. Then, the total number of measured channels is $(4 \times 4 \times 4)^2 = 4096$. Since the phase drift of the whole chain is very small over several hours, the phase stability is not a limitation when choosing the number of elements per array. To decrease the measurement time, the IF bandwidth of the VNA has been set to 10 KHz. The small increase of noise at the receiver due to the increase of IF bandwidth is not an issue since the dynamic range of the whole RF chain is about 115 dB. The measurement time of one snapshot (4096 channels) is about 21 minutes. Most of the measurement time (about 17 minutes) is used to move the linear stages to form the arrays. Therefore, the use of VNA does not make the measurement significantly longer as compared to measurements performed with dedicated channel sounders. The biconical antennas at TX and RX are omnidirectional with 5 dBi gain in the azimuth plane and a half power beam width of 11° in elevation.

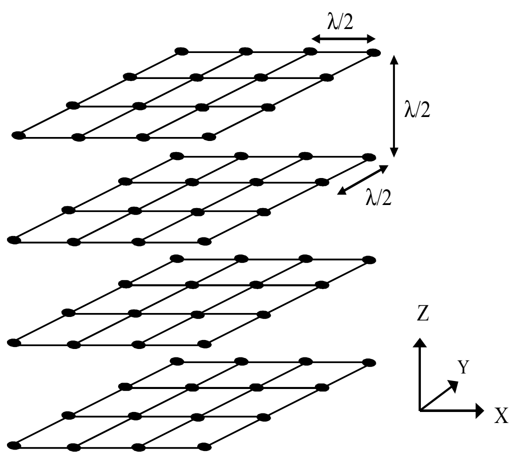

Fig. 3. Shape of the antenna arrays.

III. Measurement scenario

A first set of measurements was performed in two environments to check the performance of the system. In the first environment, a laboratory room of the Department of Radio Science and Engineering of TKK, two scenarios were considered: line of sight (LOS) and obstructed line of sight (OLOS). The room contains metal shelves, computers and laboratory equipment as it can be seen in Fig. 4a. Both TX and RX antennas were placed 1.5 m high above the floor. The distance between the antennas was 4.3 m. For the OLOS measurement a 50 cm x 50 cm mm-wave absorber was placed between the antennas. For an application such as WPAN, the OLOS case is a realistic scenario where the absorbing material represents a person blocking the direct path between two communicative objects. In the second environment, a meeting room at the same Department, the LOS case was considered (see Fig. 4b). For each measurement, nobody was present in the room in order to keep the channel static.

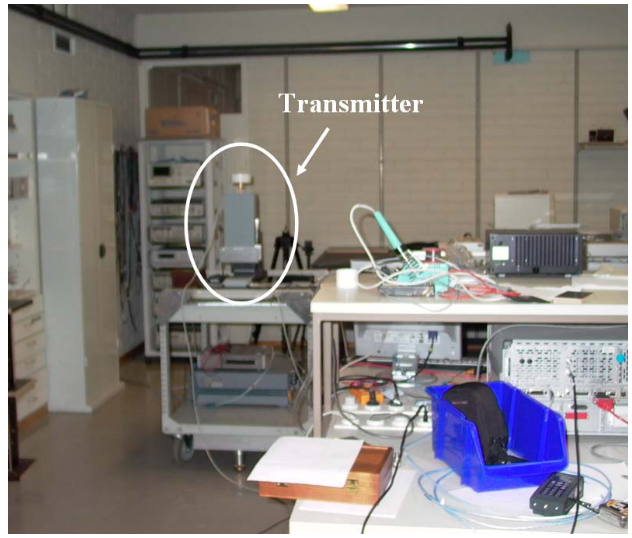

Fig. 4a. Measurement environment. Laboratory room.

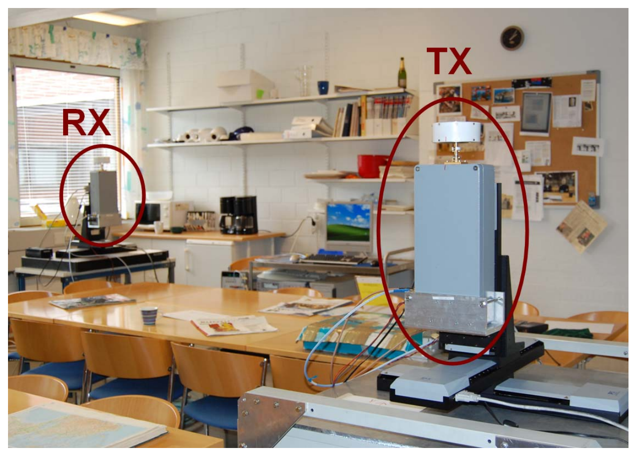

Fig. 4b. Measurement environment. Meeting room.

IV. Measurement Results

Fig. 5 shows the normalized power delay profiles (PDPs) for the LOS and OLOS cases in the laboratory room. The normalized PDP for the LOS case in the meeting room is plotted in Fig. 6. In order to remove the fast fading effects, for each case the PDPs were averaged over the 4096 channels. It can be noticed that there are many multipath components in all cases. It is seen from the OLOS PDP that even without direct path there is still significant quantity of energy arriving at the receiver. In both environments, it can be noticed from the LOS cases that the second path (first multipath) signal is only 10 dB below the direct path signal. In addition, in both LOS cases, it is shown that there are at least three multipath signals which are within 25 dB from the direct path signal.

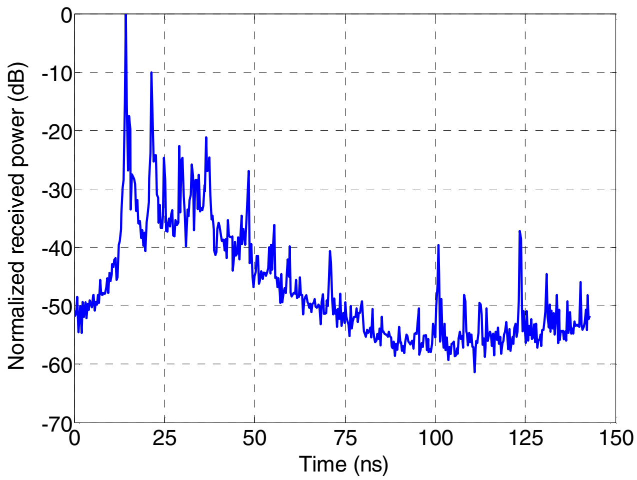

Fig. 5a. Normalized PDP. Laboratory room, LOS case.

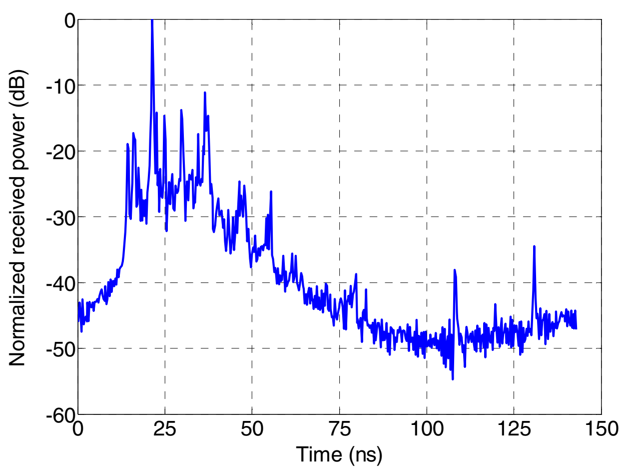

Fig. 5b. Normalized PDP. Laboratory room, OLOS case.

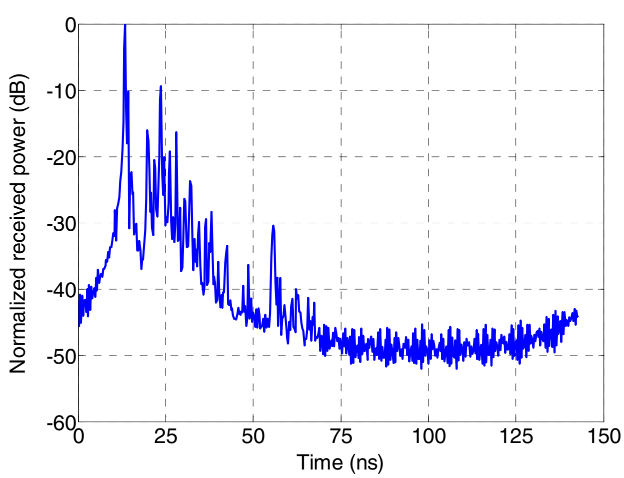

Fig. 6. Normalized PDP. Meeting room, LOS case.

V. CONCLUSIONS

A wide band 60 GHz MIMO channel sounder using VNA and 3-D arrays at both ends is presented. It uses virtual antenna arrays which can be reconfigured easily. The bandwidth of the system is 3.5 GHz, which realizes time resolution as fine as 0.29 ns. The fine resolution is suitable for characterizing dense multipaths in indoor environments. Test measurements were performed in two environments. Preliminary results are shown and it can be seen that even with obstructed line of sight, a significant part of energy is transmitted from TX to RX through several multipaths. Furthermore, in both environments, it is seen that the first multipath signal is only 10 dB below the direct path signal.

REFERENCES

[1] P.F.M. Smulders, “Exploiting the 60 GHz band for local wireless multimedia access: prospect and future directions”, IEEE Communications Magazine, Jan. 2002, pp. 140-147.

[2] Y. Haibing, P.F.M. Smulders, M.H.A.J. Herben, “Indoor channel measurements and analysis in the frequency bands 2 GHz and 60 GHz”, *IEEE* 16^{th} *International Symposium on Personal, Indoor and Mobile Radio Communications*, IEEE Volume 1, September 11-14, 2005, pp. 579-583.

[3] V. Guillet, “Narrowband and wideband characteristics of 60 GHz radio propagation in residential environment”, *IET Electronics Letters*, Volume 37, Issue 1, October 11, 2001, pp.1310-1311.

[4] S. Ranvier, M. Kmec, R. Herrmann, J. Kivinen, J. Koivunen, R. S. Thomä, P. Vainikainen, “Mm-Wave Wideband MIMO Channel Sounding”, *Proc. of XXVIIIth URSI General Assembly*, New Delhi, India, October 23-29, 2005.

[5] S. Ranvier, J. Kivinen, P.Vainikainen, “Mm-wave MIMO Radio Channel Sounder”, *IEEE transactions on Instrumentation and Measurement*, June 2007, Vol. 56. issue 3, pp. 1018-1024.

[6] J. Kivinen, ”60-GHz wideband radio channel sounder”, *IEEE Transactions on Instrumentation and Measurement,* October 2007, Volume 56, No. 5.

[7] J. Laurila, K. Kalliola, M. Toeltsch, K. Hugl, P. Vainikainen, and E. Bonek, “Wideband 3D characterization of mobile radio channels in urban environment,” *IEEE Trans. Antennas Propag.*, vol. 50, no. 2, pp. 233– 243, Feb. 2002.

[8] D. S. Baum and H. Bölcskei, “Impact of phase noise on MIMO channel measurement accuracy,” in *Proc. IEEE VTC4—Fall*, Los Angeles, CA, Sep. 26–29, 2004, pp. 1614– 618.