Channel Measurements for Short Range Beam Tracking/Switching Systems

[#] Lawrence Materum [1], Shuzo Kato [1], and Hirokazu Sawada [1]
[1] Research Institute of Electrical Communication, Tohoku University
2-1-1 Katahira, Aoba-ku, Sendai, 980-8577 Japan, Email: lawrence@riec.tohoku.ac.jp

Abstract

In this paper the propagation characteristics of a millimeter wave communication system are measured and analyzed in an indoor environment where a beam-tracking antenna seeks the incoming signal path electronically among signal paths—line-of-sight (LoS) or reflected wave paths—and then switches to the better SNR path so that the communication link could continue. The measurement results show much smaller delay spread with higher gain receiver antenna which then leads to simple and low power portable terminal implementation. Furthermore, depending on the physical positioning of the transmitter and receiver, there is a probability to have two rays received at the same or very close time that results in significant bit-error-rate degradation.

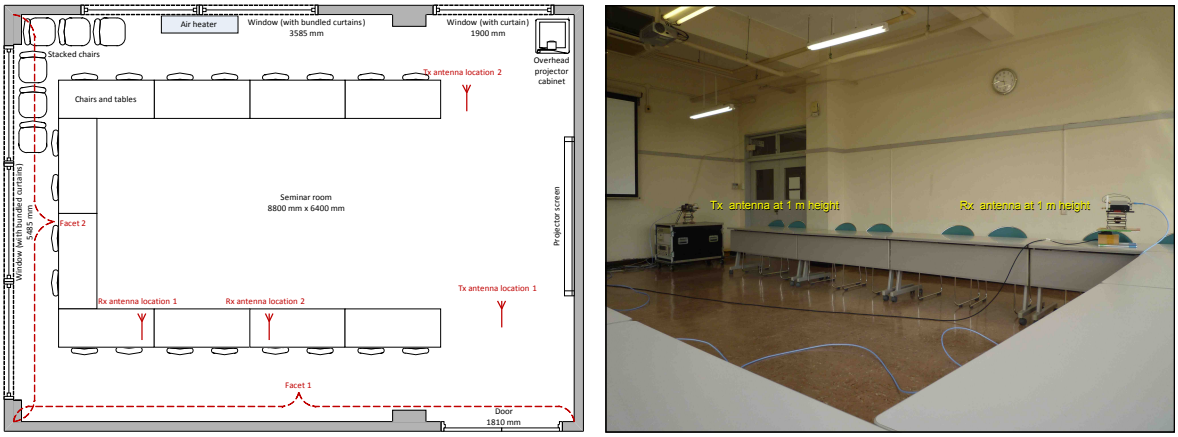
Keywords: Millimeter wave measurements, millimeter wave propagation, indoor environments.

1. Introduction

The IEEE 802.11ad Task Group has been aiming for a throughput of at least 1 Gbps at a range of at least 10 m in non-LoS (NLoS) scenarios [1] as one of the requirements currently being drafted for the standardization of 60 GHz wireless local area networks. Included in the proposal assessment of the group is the physical layer performance, in which the role of the propagation channel is included [1]. One of the shortcomings of their proposed channel evaluations [2] is the lack of channel measurements for interference scenarios. The motivation for this is the application of beam tracking/switching systems to avoid interference scenarios such that the measurement results would be valuable for systems design. In [2], except for most of the multipath intracluster parameters, most of the channel characteristics were taken from the results of ray tracing. Moreover, a 360° azimuth measurement of the channel at one or both terminals were done, which is similar to those performed in IEEE 802.15.3c channel model subgroup [3,4], but such channel characterization could gloss over relevant features of highly directive links in millimeter wave communications. Since one promising application is for beam tracking/switching systems e.g. [5, 6], efficiently pointing to another path would be beneficial when the LoS is unavailable. In this paper, a millimeter wave channel measurement was performed in an indoor environment in which the receiver antenna is steered electronically to a signal path, whether LoS or reflected path, to maintain the communication link. The obtained results indicate relatively low delay spread are achieved with higher gain or equivalently smaller half power beam width (HPBW) receiver antennas. This result lends itself to less complicated and energy-efficient portable terminal applications. Nevertheless, as determined by the physical placement and beam pointing direction of the transmitter and receiver, there are indications of receiving two tightly situated rays that could cause serious performance degradation.

2. Millimeter Wave Radio Channel Measurement

The millimeter wave radio channel of an indoor environment was measured through the use of a vector network analyzer (VNA). The environment is a conference room type composed of concrete walls and ceiling, plain glass windows, vinyl floor tiles, wooden table, metal-framed chairs with cushion, lighting fixtures, and presentation tools. The transmitter (Tx) antenna was assumed to be an access point (AP),



(a) Room layout showing the Tx and Rx antenna locations.

(b) A photo of a Tx-Rx-antenna-location pair.

Figure 1: Indoor channel sounding site: a conference room (kept static during the measurement).

Table 1: Millimeter wave channel measurement system specification.

(a) HP8510C VNA with up/down conversion units.

Frequency	62.5 GHz center; 3 GHz bandwidth
Max. delay	267 ns
Number of points	801
Calibration	Direct port link (no antennas)

(b) Antennas used.

Tx (AP mode)	Conical horn
HPBW [°] (max. gain [dBi])	30 (16); 60 (10)
Rx (STA mode)	Conical horn
HPBW [°] (max. gain [dBi])	15 (22); 30 (16); 60 (10)

whereas the receiver (Rx) antenna as a station (STA). Both the AP and STA used highly directional antennas, which were mounted on a height of 1 m from the floor. In the course of the experiment, the downlink measurement system was in the room while the door and windows were closed. Using the measurement setup, the channel impulse response was obtained by inverse Fourier transform of the measured transfer function. Further details of the environment and antenna locations, and the measurement specifications are shown in Fig. 1 and Table 1, respectively. Given the measurement settings, LoS and NLoS/reflected path scenario measurements were performed. In LoS measurements, the main lobe of the Tx and Rx antennas were pointed directly to each other. In NLoS measurements, the Rx antenna was pointed to facet 1 and facet 2 (Fig. 1(a)), which are referred to as NLoS 1 and NLoS 2 scenarios, respectively. The specific pointing direction of the Rx antenna in NLoS scenarios is steered until the communication link is assured. An average of 16 channel impulse responses composes one received power profile. The motivation for this kind of measurement is for beam tracking/switching systems, where the STA optimally points to a NLoS path that is most likely in the event that the LoS path is blocked or temporarily unavailable (of which afterward the STA could steer to the LoS path). This measurement is somewhat different from typical channel sounding. For example in cellular systems, the mobile antenna is omnidirectional, so the channel all around the mobile is usually measured. In millimeter wave systems, the antennas on the other hand are highly directional. Thus in the measurement, only selective directions that are strongly plausible and have reliable communication links were taken. In a single-input single-output millimeter wave antenna system, aside from the LoS path, the other option for establishing a communication link is through one of the significant reflection paths.

3. Measurement Results and Analysis

3.1 Received Power

Representative relative received power profiles of LoS and NLoS/reflected path scenarios of the measurement are shown in Fig. 2. Indicated in it are certain reflection sources confirmed by putting on/off electromagnetic absorbers in the setups. Considerable bit-error-rate performance degradation could be expected when two significant rays are received and have close arrival time. Examples of these rays are

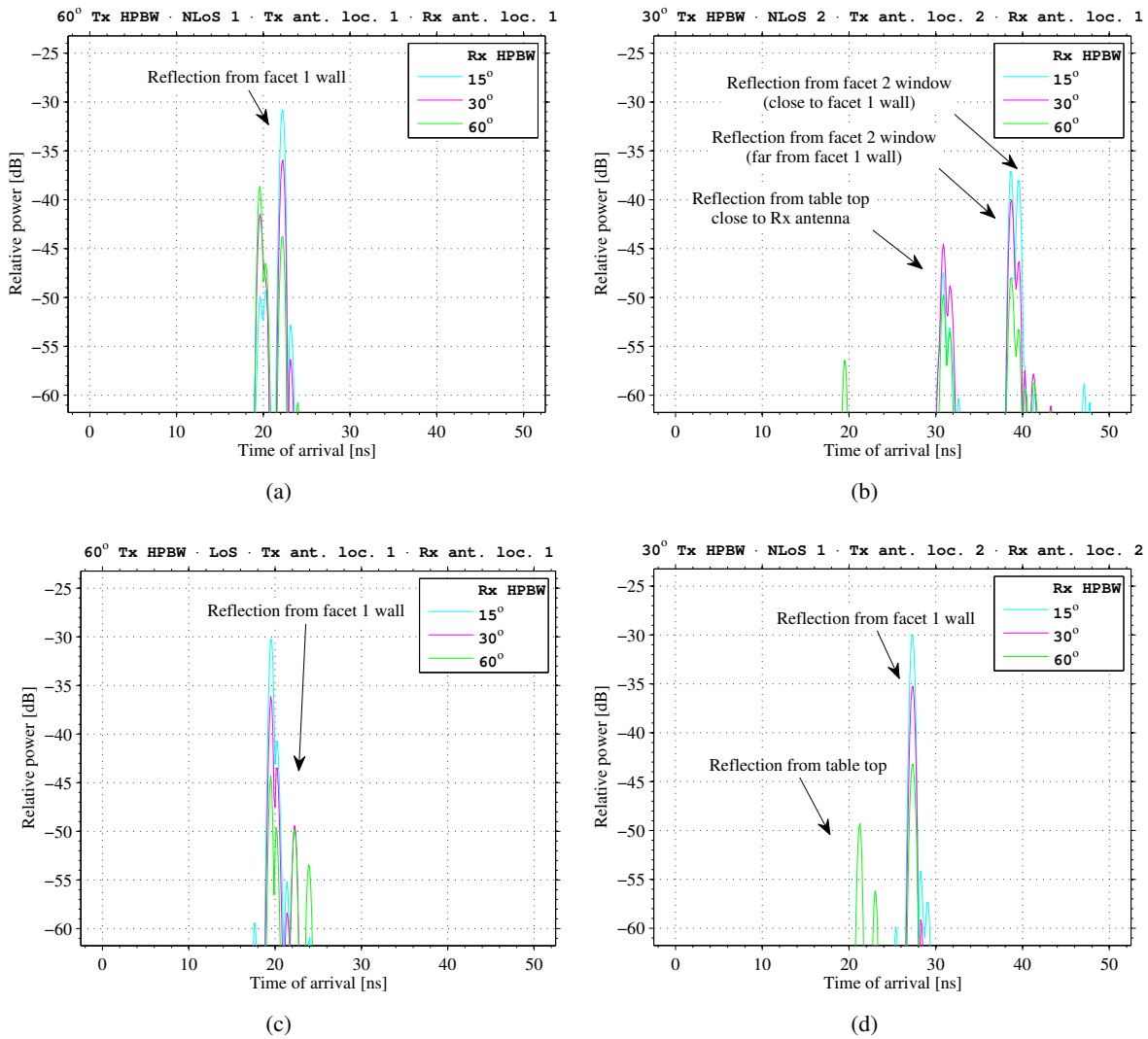


Figure 2: Relative received power profiles.

shown in Figs. 2(a) and 2(b). As was observed, most of the reflections were from lateral objects, like walls (Fig. 2(c)–Fig. 2(d)) and windows (Fig. 2(b)). As seen in Figs. 2(a) and 2(b), the power difference could be observed to be smaller in NLoS scenarios since the primary propagation mechanism of specular paths is through reflection. Furthermore, it was observed from measurements that the received power and time of arrival (ToA) of at least two possible paths are near to each other. Table 2 provides average values of the difference between the first two strong paths. Around 16.3 dB average power difference and 2 ns average ToA difference were observed. These differences are interference-issue scenarios, i.e. one of the received paths becomes a potential interference. The receiver side of the beam switching system must be able to compensate for the performance degradation brought upon by the interference. Simple equalization for these two path received scenarios may not work in single carrier millimeter wave systems. Moreover, considering the whole indoor environment, it is inevitable to receive two rays, which is contingent upon the AP and STA locations and where the main antenna beams are pointing to.

3.2 Delay Spread

Since the symbol period in millimeter wave systems is expected to be narrow, especially for higher modulation schemes, knowing the delay spread would help in compensating for intersymbol interference. The delay spread was computed by obtaining the second moment of the relative received power profile. A plot of a representative delay spread against the Rx HPBW is shown in Fig. 3. As could be observed, the decrease in antenna gain (increasing HPBW) results in increasing the delay spread. The higher delay

Table 2: Difference between the first two strong paths.

(a) Average of the power difference (in dB).

Rx HPBW [°]	30° Tx HPBW			60° Tx HPBW		
	15	30	60	15	30	60
LoS	25.1	23.3	22.1	20.3	19.8	18.3
NLoS	13.6	11.4	8.8	14.0	10.2	8.5

(b) Average of the ToA difference (in ns).

Rx HPBW [°]	30° Tx HPBW			60° Tx HPBW		
	15	30	60	15	30	60
LoS	1.3	1.3	1.6	0.8	0.9	2.5
NLoS	2.3	1.6	3.2	2.4	2.2	3.4

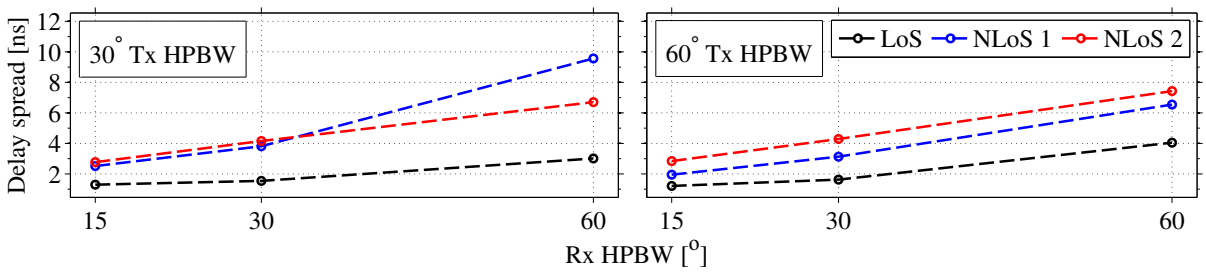


Figure 3: Delay spread of the Tx antenna location 2, Rx antenna location 1 scenario.

spread in NLoS than in LoS scenarios is not surprising. Since more paths would cover longer range in going to the Rx, these paths experience more time dispersion than paths in LoS settings. In comparison with conventional communication systems, the obtained delay spreads are relatively low. The outcomes point to simple and low power portable terminal realization and compels the implementation of beam tracking and switching in IEEE 802.15.3c and possibly for future IEEE 802.11 TGad systems.

4. Conclusion

In this paper, millimeter wave channel measurements in an indoor environment confirm that smaller delay spreads are obtained with higher gain receiver antennas. Conditioned on the location and pointing direction of the transmitter and receiver, there is the possibility of receiving at least two closely located paths that could lead to performance degradation. The results points to simpler portable terminals with beam tracking/switching application.

References

[1] E. Perahia, R. Stacey, D. Engwer, and C. Cordeiro, "TGad functional requirements," *IEEE 802.11-09/0228r4*, Jul. 2009.

[2] A. Maltsev et al., "Channel models for 60 GHz WLAN systems," *IEEE 802.11-09/0334r8*, May 2010.

[3] S. Yong, "TG3c channel modeling sub-committee final report," *IEEE 802.15-07-0584-01-003c*, Mar. 2007.

[4] Y. Shoji, H. Sawada, C.-S. Choi, and H. Ogawa, "A modified SV-model suitable for line-of-sight desktop usage of millimeter-wave WPAN systems," *IEEE Trans. Antennas Propag.*, vol. 57, pp. 2940 –2948, Oct. 2009.

[5] J. Wang et al., "Beam codebook based beamforming protocol for multi-Gbps millimeter-wave WPAN systems," *IEEE J. Sel. Areas Commun.*, vol. 27, pp. 1390 –1399, Oct. 2009.

[6] Y. M. Tsang, S. Lin, and A. S. Poon, "Fast beam training for mmwave communication system: from algorithm to circuits," *Proc. ACM Int. Workshop mmWave Commun.*, pp. 27–32, Sep. 2010.

Acknowledgments

The Ministry of Internal Affairs and Communications of Japan is acknowledged for supporting this research.