Disconnection Probability Improvement by using Artificial Multi Reflectors for Millimeter-wave Indoor Wireless Communications

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Abstract— **In order to solve the problem of multi-Gbps transmission in 60 GHz band – communication interruption by human body crossing, this paper proposes a method to increase reflected waves by installing artificial reflector(s) in two-dimensional arrangement and shows a good improvement of disconnection probability reduction to 1/4 (by one artificial reflector) and to 1/16 (by two reflectors). The interruption by human crossing is modeled and locations of transmitters and receivers are set on any grid of sub-partitioned rooms by grid (room sizes are defined by IEEE 802.11ad) to get statistically meaningful data. The computer simulations have been carried out with various TX and RX antenna HPBWs (Half Power Beam Width), several receiver sensitivities corresponding to 3Gbps to 0.5Gbps transmissions and by assuming a fixed TX antenna direction and a beam-forming receiver antenna that can track the incoming reflected wave(s) in case of LOS (Line of sight) path interruption. The simulation results show that disconnection probability reduction from about 80% to 20-10% by setting an artificial reflector to generate an additional reflected path and a reduction to 5% by setting two artificial reflectors when the TX and RX antennas' HPBWs are 30degree and the receiver sensitivity is -55.0dBm. The improvements by the proposed method are generally applicable to similar indoor communications environments.**

Keywords- Millimeter wave communication, Millimeter wave radio propagation, Ray tracing, Reflection wave.

I. INTRODUCTION

Recently unlicensed 60GHz wireless communications are attracting the attention for multi-gigabit transmission capability. In the IEEE802 standards, IEEE802.15.3c [1] for mmW WPAN was standardized in 2009, and IEEE802.11ad [2] for mmW WLAN is in the process. For the 60GHz indoor wireless communications, a disconnection caused by over 20dB shadowing loss of human body is a critical issue. One solution is a beam-forming technology to receive the reflected waves as another communication path. However, it is depending on room structure and transceiver positions, and there might be no any communication path. In the previous research, we proposed to intentionally place an artificial reflector at optimal positions to improve the disconnection probability, and it gave good improvement [3]. This paper describes the extended work by using multi reflectors and various antenna combinations to obtain a more improvement. The improved probability by this approach is clarified by the developed simulator based on ray-trace method. The simulator can find the optimal reflector size, position and orientation. This paper demonstrated that disconnection probability is more decreased with the additional path by the artificial multi reflectors.

II. SIMULATION OF DISCONNECTION PROBABILITY

An image of millimeter-wave indoor communications system using reflection waves is shown in Fig.1. In this system, it is assumed that RX antenna has beam-forming capability. RX antenna scans in omni-directions to find out possible communication paths above the receiver sensitivity and memorize them before communications start. The receiver sensitivity is set to -55.0 dBm (bit rate: 3Gbps) and -59.7 dBm (bit rate: 1Gbps) by referring the TG3c specification.

A. Propagation Path Simulator Using Ray-Trace Method

To know the optimal reflector position, a propagation path simulator using ray-trace method has been developed. Due to the large path loss in millimeter-wave band, the simulator takes into account only once-reflected waves. Propagation measurements have been also carried out to validate the simulator's performance. Simulator inputs are room size, TX and RX antennas positions, antennas HPBW, wavelength, transmission power, receiver sensitivity, and refractive index of walls and reflectors. The frequency is assumed as 60GHz,

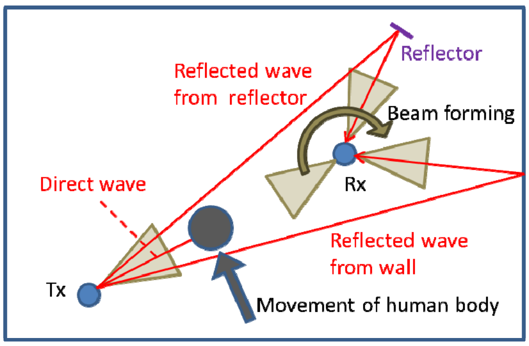

Fig.1 Millimeter-wave indoor communications system using artificial reflector

and the wavelength is 5 mm. Four walls are made of concrete with a permittivity of 6.1 [4], and reflectors are made of metal. The path loss can be calculated by Eq.1 [5].

$$PL[dB] = 20\log_{10}\left(\Gamma\frac{\lambda}{4\pi d}\right) \tag{1}$$

$$\Gamma = \frac{\cos\theta_i - \sqrt{n^2 - \sin^2\theta_i}}{\cos\theta_i + \sqrt{n^2 - \sin^2\theta_i}} \tag{2}$$

where Γ is the reflection coefficient for vertical polarized waves calculated by the Eq.2, and θ_i is an incident angle and n is a refractive index.

B. Interruption Model

A human interruption model as shown in Fig.2 is assumed to evaluate the proposed approach. By the following simulation procedure, the disconnection probability is calculated.

(1) A human body, treated as a cylinder shape absorber with radius of 10cm, is moved at the speed of 1m/s over a path determined by θ and d.

(2) θ (0°<θ<180°, 1.8°step) and d (10cm<d<d-10cm, (d-20cm)/100cm step) are set. The total number of tries is 10000.

(3) Occurrence frequency when human body blocks all paths is counted, and the probability of occurrence is defined as "Disconnection probability".

C. Search Process of the Reflector Positions

The search process of reflector positions is as follows.

(1) Input parameters are TX and RX positions and areas where the reflector can be set. In this paper, the areas from 4 walls to less than 30 cm are assumed as the reflector position.

(2) A reflector is set on a matrix of position (10cm grid) in each area, and the simulator finds the position which has the lowest disconnection probability based on the interruption model.

(3) Reflector position varies within all matrix of position in each area. Then above parameters are found for another new path.

(4) The best position and 2nd best position of reflectors are decided by selecting smaller disconnection probability.

D. Effects of Installed Artificial Reflector

To evaluate the statistical disconnection probability improvement by using the proposed method, disconnection probabilities for various TX and RX positions in the rooms has been studied. The simulation procedure is described as following by using a living room environment (which was defined by TGad).

(1) TX antenna is set on any grid of sub-partitioned rooms by grid as shown in Fig.3

(2) RX antenna is set on any grids near the wall as shown in the same figure.

(3) Reflector is set at the optimal position for each TX and RX position found by the simulator.

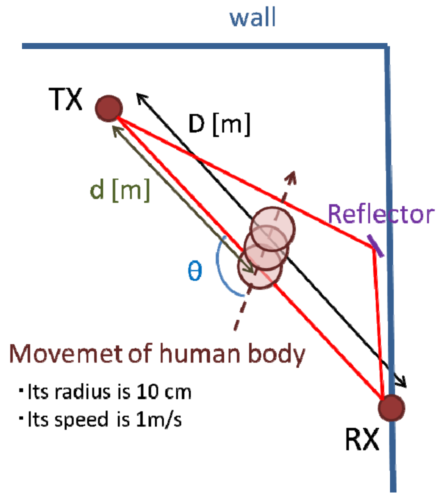

Fig.2 Interruption model

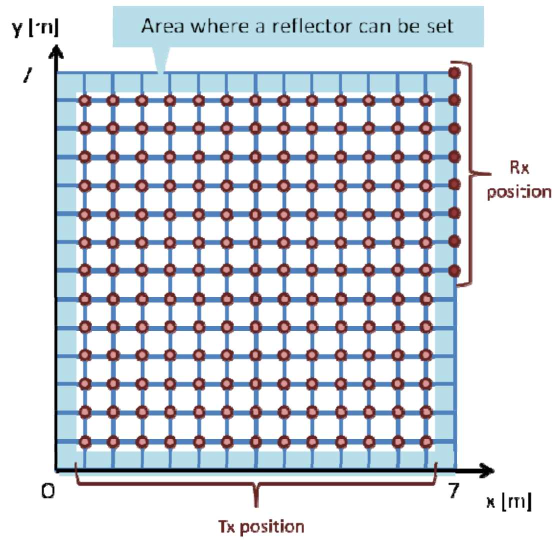

Fig.3 Example of TX and RX positions in the room.
(Room size: 7.0x7.0m, grid size: 50cm)

(4) The average of disconnection probability is calculated when the number of reflectors is 0, 1, and 2.

I. CONSIDERATION OF ANTENNA HPBW AND RECEIVER SENSITIVITY

The effect of installed artificial reflectors is evaluated in several environments, and the simulation has been done by changing the room size, antennas HPBW, and receiver sensitivity. These simulation parameters are as follows.

(a) Room size: 4.5x3.0m (conference room defined by TGad)
6.5x4.5m (middle size)
7.0x7.0m (living room defined by TGad)

(b) TX antenna HPBW: 10-110 degree (10 degree step)

(c) RX antenna HPBW: 15, 30, 45 degree

(d) Room grid size: 50cm

(e) Transmission power: 10dBm

(f) Receiver sensitivity (according to bit rate):

-55.0dBm (3Gbps), -59.7dBm (1Gbps)
(g) The number of reflectors: N =0, 1, 2
(h) The reflector radius: Fresnel radius R [3]

First, simulation results are shown in Fig.4-6 when the receiver sensitivity is -55.0dBm. The disconnection probability has been reduced by increasing the number of reflectors. From these simulation results, it is confirmed that using the wider Tx antenna beam width more than 30 degree as far as received power is more than receiver sensitivity is effective because reflectors can be set on the place distant from the direct path. In Fig.5 and Fig.6, disconnection probability increases when antennas gain is not enough to communicate. It is also confirmed that using the narrower beam width for Rx antenna to obtain the antenna gain is effective. The disconnection probability has been reduced from about 80% to 10-20% by setting an artificial reflector to make an additional path, and it has been reduced to less than 5% by setting two artificial reflectors when the TX and RX antenna beam width are 30 degree. Fig.7 shows the disconnection probability when TX and RX antenna HPBW are 30 degree, and receiver sensitivity is -55.0 dBm.

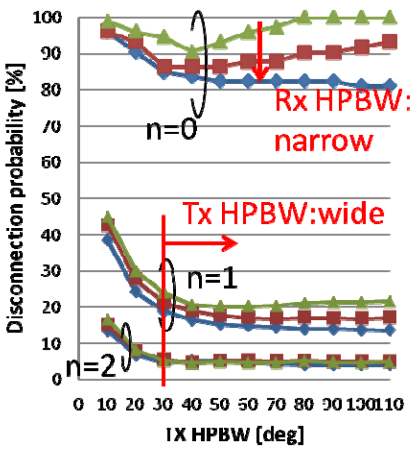

Fig.4 Disconnection probability for each antennas HPBW
(room size: 4.5x3.0m, receiver sensitivity: -55.0dBm)

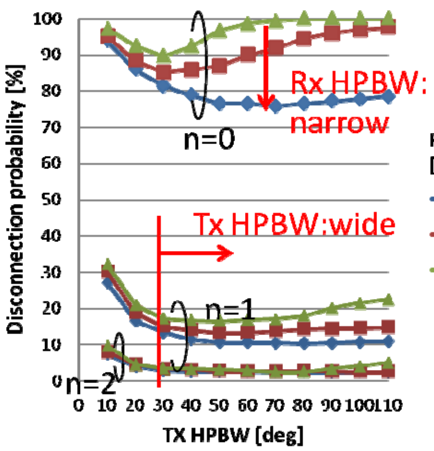

Fig.5 Disconnection probability for each antennas HPBW
(room size: 6.5x4.5m, receiver sensitivity: -55.0dBm)

Secondly, simulation results are shown in Fig.8 when TX and RX antennas HPBW are 30 degree and the receiver sensitivity is -59.7 dBm. Disconnection probability is reduced compared with Fig.7 results. It is because reflector can be set on the place more distant from the direct path.

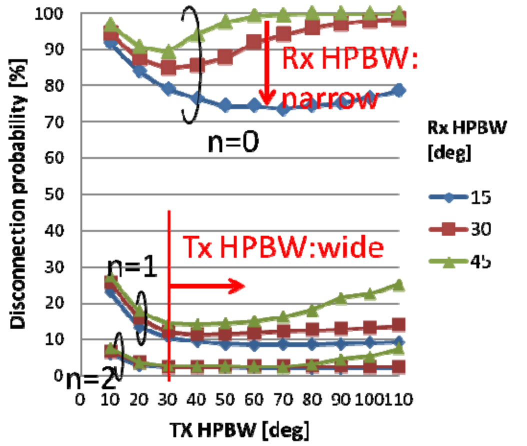

Fig.6 Disconnection probability for each antennas HPBW
(room size: 7.0x7.0m, receiver sensitivity: -55.0dBm)

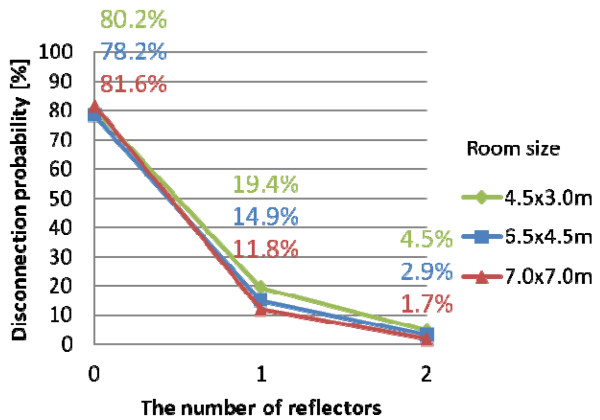

Fig.7 Disconnection probability improvement
(receiver sensitivity: -55.0dBm)

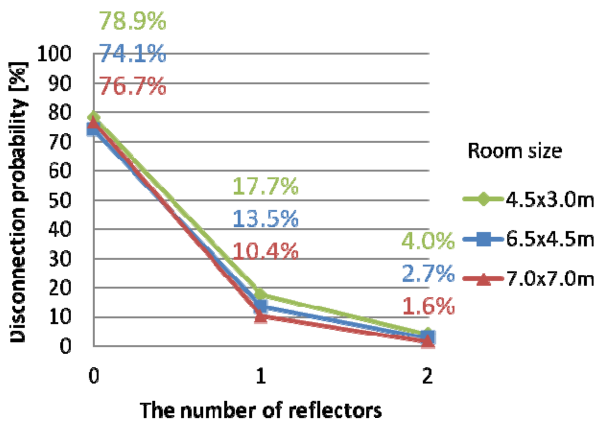

Fig.8 Disconnection probability improvement
(receiver sensitivity: -59.7dBm)

II. Consideration of Reflector Size

Very large reflectors are not suitable in most rooms, and smaller reflectors are desirable as far as reflected wave power is larger than the receiver sensitivity. Simulation has been done by changing the reflector radius, and simulation results are shown in Table.1-3. R is Fresnel radius (no reflection loss). When the reflector radius is R/2 and R/4, the reflection loss is 6dB and 12dB. Disconnection probability increases when the reflector radius is small because of the reflection loss. And blanks of Table.2 and Table.3 are the cases that reflected wave is not able to be used. From these simulation results, there is a limit in making the reflector radius small. Moreover, large reflector is needed when the receiver sensitivity is high or the room is large.

Table.1 Disconnection probability for each reflector radius (room size: 4.5x3.0m, antennas HPBW: 30 degree)

(a) receiver sensitivity: -55.0dBm

Reflector radius r	Disconnection probability[%]		
	n = 0	n = 1	n = 2
R	80.2	19.4	4.5
R/2	80.2	21.7	5.6
R/4	80.2	26.2	9.0

(b) receiver sensitivity: -59.7dBm

Reflector radius r	Disconnection probability[%]		
	n = 0	n = 1	n = 2
R	78.4	17.7	4.1
R/2	78.4	18.9	4.7
R/4	78.4	21.6	6.2

Table.2 Disconnection probability for each reflector radius (room size: 6.5x4.5m, antennas HPBW: 30 degree)

(a) receiver sensitivity: -55.0dBm

Reflector radius r	Disconnection probability[%]		
	n = 0	n = 1	n = 2
R	78.2	14.9	2.9
R/2	78.2	17.3	3.5
R/4	78.2		

(b) receiver sensitivity: -59.7dBm

Reflector radius r	Disconnection probability[%]		
	n = 0	n = 1	n = 2
R	74.1	13.5	2.8
R/2	74.1	14.7	3.2
R/4	74.1	17.2	4.0

Table.3 Disconnection probability for each reflector radius (room size: 7.0x7.0m, antennas HPBW: 30 degree)

(a) receiver sensitivity: -55.0dBm

Reflector radius r	Disconnection probability[%]		
	n = 0	n = 1	n = 2
R	81.6	11.8	1.7
R/2	81.6	14.7	2.2
R/4	81.6		

(b) receiver sensitivity: -59.7dBm

Reflector radius r	Disconnection probability[%]		
	n = 0	n = 1	n = 2
R	76.7	10.4	1.6
R/2	76.7	11.4	1.8
R/4	76.7		

Figs.9-10 shows the disconnection probability versus reflector radius in each room size. The disconnection probability achieves less than 5% by setting the enough reflector radius when two reflectors are installed. From simulation results, the required minimum reflector radius is confirmed. Smaller room size or smaller receiver sensitivity causes the smaller minimum required reflector radius.

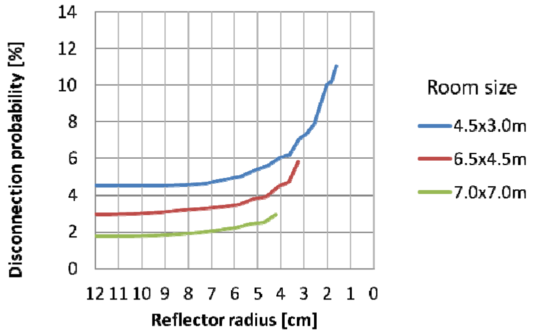

Fig.9 Disconnection probability for each reflector radius
(n=2, antennas HPBW:30degree, receiver sensitivity:-55.0dBm)

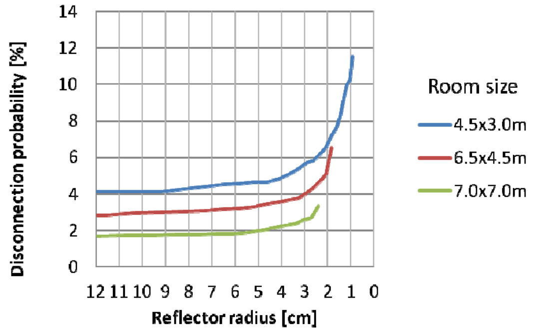

Fig.10 Disconnection probability for each reflector radius
(n=2, antennas HPBW:30degree, receiver sensitivity:-59.7dBm)

The minimum required reflector radius for each room's diagonal length and bit rate has been obtained. Simulation parameters are as follows.

(a) Room size: 3.0x3.0m, 4.5x4.0m, 4.0x4.0m, 6.0x3.0m, 5.0x5.0m, 6.5x4.5m, 6.0x6.0m, 7.0x7.0m
(b) TX antenna HPBW: 30 degree
(c) RX antenna HPBW: 30 degree
(d) Grid size: 50cm
(e) Transmission power: 10dBm
(f) Receiver sensitivity (bit rate): -55.0dBm(3Gbps),-59.7dBm(1Gbps),-62.9dBm(500Mbps)
(g) The number of reflectors: n = 2

Simulation results are shown in Fig.11. Although it depends on room size and sensitivity, it shows that a small reflector of several centimeters radius works effectively.

From simulation results, these curves are fitting with the straight line and the minimum required reflector radius (r_{min}) can be obtained by Eqs.3-5 with the parameter of diagonal length of the room.

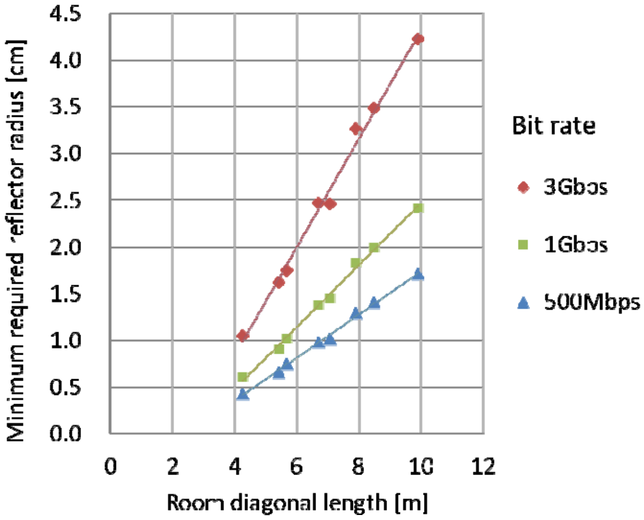

Fig.11 Minimum required reflector radius for each room diagonal length and bit rate

$3Gbps$

$$r\min[m] = \frac{1}{100}(0.6l - 1.6) \tag{3}$$

$1Gbps$

$$r\min[m] = \frac{1}{100}(0.3l - 0.6) \tag{4}$$

$500Mbps$

$$r\min[m] = \frac{1}{100}(0.2l - 0.3) \tag{5}$$

$(4.2m \le l \le 9.9m)$

III. Conclusions

A connectivity enhancement approach using artificial multi reflectors has been proposed. By the interruption model, it has been confirmed that the disconnection probability has been reduced from about 80% to 5% by setting two artificial reflectors to make an additional communication path when the receiver sensitivity is -55.0dBm. Moreover, when the receiver sensitivity is -59.7dBm, it is confirmed that disconnection probability is more reduced because of the margin in received power. Furthermore, relationship between the minimum required reflector radius and the room diagonal length are expressed by the equations. Although it depends on room size and sensitivity, it shows that a small reflector of several centimeters radius works effectively. Thus this method is very useful against shadowing for millimeter-wave indoor communications.

References

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