Effect of Radiation Patterns on WLAN Delay Spreads for 60 GHz Living Room Environments

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Abstract— **The Parameters, those can affect an indoor Wireless Local Area Network (WLAN) at 60 GHz, are multi-path reflections, polarization-effects, shadowing, interior of the room, main beam lobe, and side lobe level (SLL) of radiation patterns. RMS Delay Spread (RDS) of a channel can be reduced if SLL of antenna radiation pattern can be minimized. RDS is a measure of channel delay and fading characteristics. Minimum RDS can reduce channel deep-fade and multipath effects. This paper investigates the effect of different level of SLL on RDS characteristics considering two different living room environments. One of the approaches is IEEE 802.11ad living room channel model, and the other is Full-3D ray tracing simulation model of a residential apartment. The investigations show that reduced SLL of radiation pattern can effectively reduce the RDS.**

Index Terms— antenna radiation patterns, channel models, multipath channels, millimeter wave propagation, line of sight propagation.

I. INTRODUCTION

Due to an increasingly higher rate of demand for high-speed wireless networks, the utilization of millimeter-wave frequency bands has been receiving more attention. Specially, 57–64 GHz frequency regions have been used for short-distance and indoor communications. 60 GHz wireless system is one promising candidate for short range communication systems [1], [2]. In a wireless communication system with multipath fading channels, arrival of different versions of transmitted signal at the receiver spreads in time. This phenomenon is called delay spread. Propagation at 60 GHz is quasi-optical in nature and most of the transmitted power is propagated between the transmitter and the receiver through LOS, 1st order and 2nd order reflections [3], [4].

Statistical channel model should be used to describe the properties of a channel when detailed knowledge of propagation channel is not available [3]. Some of the Parameters of statistical channel model are Power Delay Profile (PDP), RMS Delay Spread (RDS), and Rician-K factor. RDS is highly dependent on beamwidth [5], [6] and SLL of the antenna radiation pattern. Channel delay at 60 GHz also depends on multipath reflections [7], [8]. Reduced RDS is the indication of a faster communication channel. Deep fade of frequency selective fading channel as well as Inter Symbol Interference (ISI) can be minimized if delay spread is minimized. Some of the factors those affect the RDS of an indoor propagation channel are shown in Fig. 1.

Clustering approach is followed for channel modeling at 60 GHz. A cluster can be defined as a group of multi-path [9] or LOS components having similar delays and directions of departure/arrival. Angular characteristics of clusters are closely related to the geometry of the room and environment that makes it infeasible to model the delay and angular domains independently [9]. In a 60 GHz indoor channel environment it is insufficient to consider only walls, glass wind, floor and Tables. Finer structures such as ceiling lamps, chairs and bookshelves are also needed to be considered [9]. Diffraction at 60 GHz is an insignificant propagation due to sharp shadow zones [9], [10]. 3rd order reflections, diffused reflections, and diffraction can be neglected in case of a 60 GHz outdoor radio propagation channel [11].

Accurate modeling of intra-cluster distributions is very important for the performance evaluation of 60 GHz WLAN channels since the characteristic of beamformed-channel directly depends on the intra-cluster Parameters [8]. Intra-cluster ray identification in angular domain requires very high angular resolution that can be achieved by using highly directional beamforming antennas with very high gain. In case if the LOS path is absent the signal can be steered towards the best reflected path (or cluster). It is possible to reduce the channel delays by using highly directional antennas with minimum side lobe level (SLL). Highly directional antennas with narrower beamwidth (20° ~ 30°) at both Tx/Rx sites are suggested for 60 GHz WLAN systems to compensate the high propagation loss in this band [10].

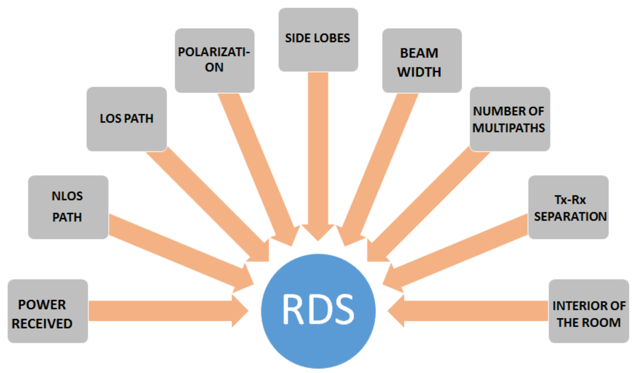

Fig. 1. Some of the factors those affect the RMS Delay Spread (RDS) of an indoor wireless propagation channel.

Three different types of antenna models, which can be applied to the generated space-time channel realizations, are proposed in the channel model described in [12]. The antenna types are isotropic antenna, basic steerable directional antenna and phased array antennas. Antenna with constant side lobe levels [13], [14] is reported in [12] for the channel modeling. Average side lobe level (AvSLL) was calculated through averaging the side lobe power over the angle out of the main lobe [14]. The considered AvSLL for the IEEE 802.11ad indoor channel model was -11.54 dB [12]. It is possible to reduce this value of AvSLL further through an appropriate choice of array antenna system. It is mentioned in the previous paragraph that reduced SLL minimizes channel RDS. Radiation from antenna system should have negligible SLL and narrower main beam for a robust, power efficient, and faster wireless communication system. SLL and main beam of radiation pattern are functions of excitation coefficients of antenna elements. Width of the main lobe and SLL can be optimized by choosing appropriate excitation coefficients of antenna elements [15]. Non-uniform excitation coefficients of antenna elements can produce lower SLL. Dolph-Chebyshev power distribution [16], and Gaussian power distribution [17], [18] are two popular non-uniform power distribution systems of array antenna. Though Dolph-Chebyshev array has some limitations which will be discussed in subsequent sections.

This paper describes the effect of SLL on RDS in different indoor scenarios such as LOS/NLOS paths, Tx-Rx distances, and different half-power beam width (HPBW). The paper is organized in the following way. Section II describes IEEE 802.11ad channel model. Section III describes the effect of SLL on RDS for an IEEE 802.11ad living room model. Section III also describes that lower AvSLL can reduce the RDS. Section IV describes the effectiveness of reduced SLL for a living room propagation model at 60 GHz by using Wireless Insite Full-3D simulation software. Section V compares and discusses the results of section III and IV. Finally, section VI concludes the paper.

II. IEEE 802.11ad WLAN Channel Model

The IEEE 802.11ad standard describes the channel models for Wireless Local Area Networks (WLANs) which is based on the results of experimental and statistical data at 60 GHz [12]. The model generates a channel realization considering space, time, amplitude, phase, and polarization characteristics of all rays [12]. Spatial characteristics of the rays consider both azimuth and elevation angles for both Tx-Rx sides. The model evaluated three basic propagation model scenarios: conference room, cubicle and living room. Detailed of the modelling techniques can be found in [12]. The following sub-section describes the IEEE 802.11ad channel model for a living room scenario.

A. Channel Model in Living Room Environment

The IEEE 802.11ad living room model considers the floor plan [19] scenario according to [20]. Fig. 2 shows the simplified model of the living room used in realizing the channel model [12], [20]. Following are some dimensions and furniture of the living room [19]:

i. Dimensions of the home living room: 7 m x 7 m x 3 m (L x W x H),
ii. A Table in the room,
iii. Two sofas,
iv. An armchair placed around the Table, and
v. One outer wall has two windows and a cabinet is placed between them.

All furniture dimensions are chosen according to [19]. In the simulation scenario the communication can be established between a set top box (STB) transmitting uncompressed video, and a TV receiving the transmitted video. The TV is placed in the middle of one of the walls. The position of the STB in the horizontal plane can be different. A '6m x 7m' rectangular sector of possible STB positions in the horizontal plane is also introduced in the model. The size of the sector is chosen considering all the sitting places around the Table [12]. The average distance between the STB and the TV is approximately 4m~6m for the simulation considered in this paper.

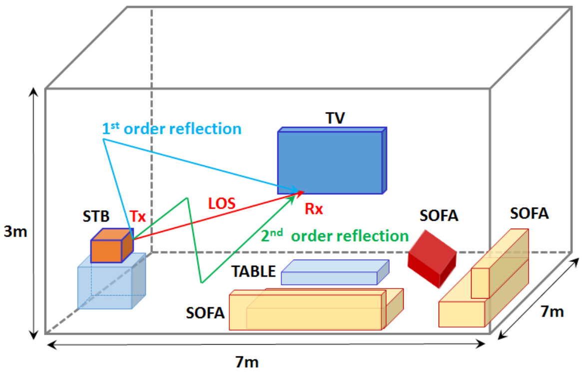

Fig. 2. 3D simplified model of the living room for IEEE 802.11ad channel model [adopted from ref. 12].

B. Intra-Cluster Parameters in Living Room Environment

IEEE 802.11ad channel model [10], [12] generates impulse response of the channel that supports both with/without polarization characteristics. The model also considers beamforming performance. The impulse response of the model with polarization characteristics can be expressed as [10], [12]:

$$h(t,\varphi_{tx},\theta_{tx},\varphi_{rx},\theta_{rx})= \sum_i \mathbf{H}^{(i)} C^{(i)}\left(t-T^{(i)},\varphi_{tx}-\Phi_{tx}^{(i)},\theta_{tx}-\Theta_{tx}^{(i)},\varphi_{rx}-\Phi_{rx}^{(i)},\theta_{rx}-\Theta_{rx}^{(i)}\right) \quad (1)$$

where,

h : channel impulse response.

t, φ_{tx}, θ_{tx}, φ_{rx}, θ_{rx} : time, azimuth and elevation angles respectively at the transmitter and receiver.

$\mathbf{H}^{(i)}$: 2x2 cluster polarization matrices [Gain of the channel impulse response is merged in to $\mathbf{H}^{(i)}$]. Detailed discussions on $\mathbf{H}^{(i)}$ is outside of the scope of the paper.

$C^{(i)}$: channel impulse response for i^{th} cluster which can be expressed as [10], [12]:

$$C^{(i)}(t,\varphi_{tx},\theta_{tx},\varphi_{rx},\theta_{rx})= \sum_k \alpha^{(i,k)}\delta(t-\tau^{(i,k)})\delta(\varphi_{tx}-\varphi_{tx}^{(i,k)})\delta(\theta_{tx}-\theta_{tx}^{(i,k)})\delta(\varphi_{rx}-\varphi_{rx}^{(i,k)})\delta(\theta_{rx}-\theta_{rx}^{(i,k)}) \quad (2)$$

$\delta(\,)$: Dirac delta function.

$T^{(i)}$, $\Phi_{tx}^{(i)}$, $\Theta_{tx}^{(i)}$, $\Phi_{rx}^{(i)}$, $\Theta_{rx}^{(i)}$: time-angular coordinates of i^{th} cluster.

$\alpha^{(i,k)}$:amplitude of the k^{th} ray of i^{th} cluster.
$\tau^{(i,k)}$, $\varphi_{tx}^{(i,k)}$, $\theta_{tx}^{(i,k)}$, $\varphi_{rx}^{(i,k)}$, $\theta_{rx}^{(i,k)}$: relative time-angular coordinates of the k^{th} ray of i^{th} cluster.

Fig. 3 shows the time-domain characteristic of the cluster [12]. The cluster consists of a central ray $\alpha^{(i,0)}$ with fixed amplitude and pre-cursor $\alpha^{(i,-N_f)} \dots \alpha^{(i,-1)}$ and post-cursor rays $\alpha^{(i,1)} \dots \alpha^{(i,N_b)}$. Table I summarizes the Parameters for the living room model [12]. The same Parameters were used in this paper for the investigation of SLL effect on RDS. Similar characteristic of cluster for a conference room channel model is described in [10].

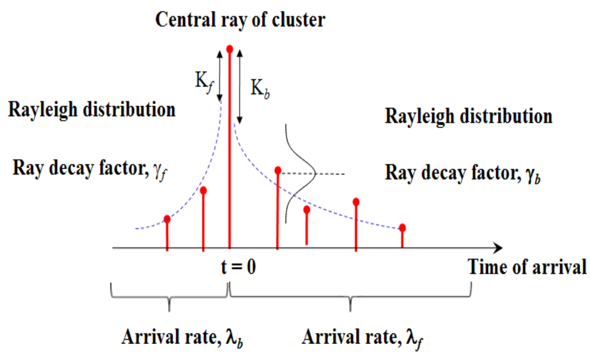

Fig. 3. Time domain characteristic of the cluster.

TABLE I INTRA CLUSTER TIME DOMAIN PARAMETERS FOR THE LIVING ROOM CHANNEL MODEL [12]

Parameter	Notation	Value
K-factor for pre-cursor rays	K_f	11.5 dB
Power decay time for pre-cursor rays	γ_f	1.25 ns
Arrival rate of pre-cursor rays	λ_f	0.28 ns^{-1}
Amplitude distribution of pre-cursor rays		Rayleigh
Number of pre-cursor rays	N_f	6
K-factor for post-cursor rays	K_b	10.9 dB
Power decay time for post-cursor rays	γ_b	8.7 ns
Arrival rate of post-cursor rays	λ_b	1.0 ns^{-1}
Amplitude distribution of post-cursor rays		Rayleigh
Number of post-cursor rays	N_b	8

III. EFFECT OF SLL ON RDS FOR IEEE 802.11ad LIVING ROOM CHANNEL MODEL

It was mentioned in section I that reduced RDS, which is highly dependent on beamwidth and SLL of antenna radiation pattern, is the indication of a faster communication channel. The effect of beam width on RDS can be found in some literatures [8], [10]. But the effect of AvSLL on RDS is hardly found in the literatures. In this section the effect of AvSLL on RDS is investigated for the described living room channel model. Probability of arrival (used in the simulations) of different type of ray at the receiver is shown in Table II. The same probability was used for different AvSLL within the range of -51.54 dB ~ -11.54 dB. Though the probability is variable in real scenario and in most cases these probabilities may decrease with the decrement of AvSLL. The reason of considering the AvSLL within the range of -51.54 dB ~ -11.54 dB is discussed briefly hereafter.

A novel and technically better method of array-elements' excitation by using novel concept of Fractional-Powered Binomial coefficients is proposed by the first author in [21]-[22]. The new method is named as Fractional Powered Binomial Array (FPBA) [21]-[22]. FPBA shows better performance than Binomial or Dolph-Chebyshev array from the perspective of beamwidth-SLL trade off [21]-[22]. Fig. 4 shows the radiation pattern of 25-element FPBA along with that of 20 dB Dolph-Chebyshev array. Fig. 4 also shows the main lobes and AvSLL for the respective array distributions. Element spacing was chosen as 0.6λ for both the distributions. Fig. 4 shows that AvSLL of FPBA is 20 dB lower than that of 20 dB Dolph-Chebyshev array. Estimation process of AvSLL is described in [14]. Detailed discussions of FPBA is outside the scope of this paper.

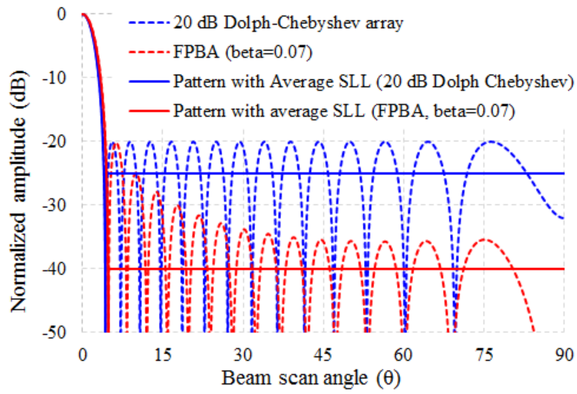

Fig. 4. Radiation patterns of 20 dB Dolph-Chebyshev array and FPBA (β=0.07) showing Average SLL (AvSLL) of radiation patterns for the respective array distributions.

Fig. 5 shows RDS vs. AvSLL graphs for different LOS/NLOS scenario, HPBW, and Tx-Rx separation. Fig. 5 shows that RDS decreases with the decrease in AvSLL. Variation of RDS due to variation of HPBW is less. In some cases reduced-HPBW should reduce the RDS, though there might be exception. Since change of SLL and HPBW also influences some other factors such as multipath effects, polarization effects, and ray paths. Polarization mismatches reduce the received power and increases the RDS. Left Hand Circular Polarization (LHCP) was used for Tx/Rx antennas of all the scenarios of Fig. 5. In the simulation it was found that LHCP-LHCP combination generates the lowest RDS.

TABLE II PROBABILITY OF ARRIVAL OF DIFFERENT TYPE OF RAY FOR THE LIVING ROOM SIMULATION MODEL

Type of Ray	Probability of Arrival at the Receiver
1st order reflections from ceiling	0.3
1st order reflections from floor	0.3
1st order reflections from walls	0.5
2nd order reflections from two walls	0.2
2nd order reflections from ceiling and floor	0.2
2nd order reflections from wall-ceiling and ceiling-wall	0.2
2nd order reflections from wall-floor and floor-wall	0.2

Results of Fig. 5 show that the decrease in RDS is about 4.5 pico-second per dB decrement of AvSLL. Therefore even a one dB change in SLL influences the channel characteristics.

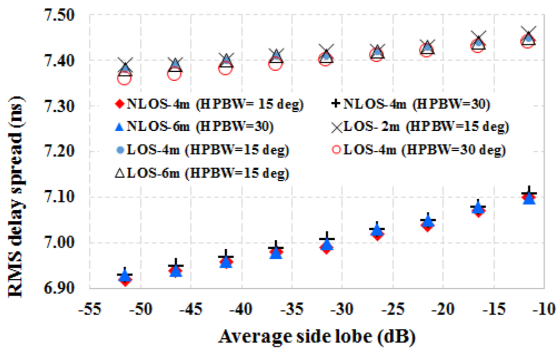

Fig. 5. RMS Delay Spread (RDS) for different values of average side lobe level (AvSLL) and for the NLOS/LOS scenarios.

Fig. 5 shows that the values of RDS are higher in LOS scenarios than those of NLOS scenarios. Average RDS for NLOS scenarios was about 7 ns and that for LOS scenarios was about 7.4 ns. Main reason of this higher RDS is the dissimilar Tx/Rx antenna heights in LOS cases. In LOS scenario Tx-antenna height was 1.5 meter and Rx-antenna height was 1.0 meter. In NLOS scenario Tx/Rx antenna height was 1.0 meter. It is noteworthy to mention here that the values of RDS in LOS and NLOS scenarios are not precisely comparable, mainly due to difference in multipath effects and overall received power. Variation of RDS, shown in Fig. 5, due to variation of Tx-Rx separation is also insignificant in the considered living room. These results agree well with the results of [8].

IV. Full-3D Simulation Model For a Residential Environment Using Wireless Insite

Ray tracing propagation model in a residential indoor apartment (shown in Fig. 6) was also investigated by using Wireless InSite software that supports Full-3D simulations.

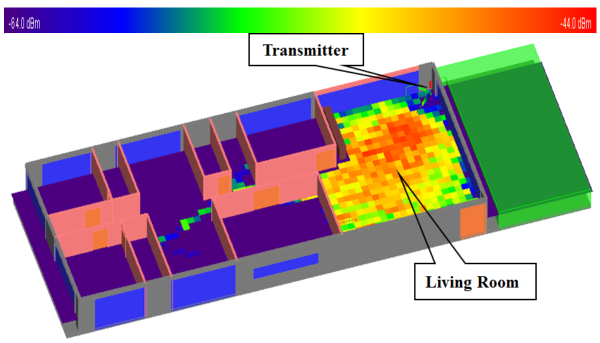

Fig.6. Indoor residential environment with one transmitting antenna array (8 nos. of circular patch elements) and 32×13 receivers-grid. The figure also shows the received power on an XY receivers-grid of the indoor residential apartment.

In this case, size of the apartment was 33m ×13m ×3m (L x W x H) and size of the living room was 10m ×13m ×3m (L x W x H). Full-3D simulation model of Wireless Insite has some attractive features. The software considers all antenna types, all antenna heights, all environments, building of any shapes, frequency upto 100 GHz, geometric ray of diffraction (GFD), ray tracing method, reflection, transmission, and diffraction of electric fields. Total number of receivers for the whole apartment was (32×13). In this paper only the propagation model of living room is discussed. Total number of receivers in the living room was (9×13). At the transmitting side 8-element circular patch array with LHCP was considered. Other antenna Parameters used in the simulations are shown in Table III. In this section two different amplitude-distributions of transmitting antenna elements were considered. One type of distribution is the mentioned FPBA and the other type is Uniform Array (UA). Each receiving antenna was a single element isotropic antenna. Isotropic receiver was considered only for the investigation purpose of total received power from all directions. Table IV summarizes different statistical Parameters of RDS found in the living room simulations. Average RDS for UA was 10.40 ns and that for FPBA was 9.87 ns. Standard deviation of RDS for UA was 9.15 ns and that for FPBA was 8.51 ns. Parameters of Table IV show that FPBA is better than UA from the perspective of RDS. SLL of 8-element FPBA was much lower than that of UA (not shown in the paper). Performance of FPBA over Dolph-Chebyshev array has been discussed in section III. Fig. 7 shows the excess delay of a receiver location in the living room. Tx-Rx distance was 15 m in this case. Fig. 7 shows that the excess delay follows the exponential decay curve. Arrival times of some clusters (LOS-NLOS) are also shown in the figure. In the figure the LOS ray is considered as Cluster-1.

Table III Different Parameters of Tx/Rx antennas used in the indoor living room channel model for Full-3D simulations of Wireless Insite.

Parameters of antenna systems	
Parameters of transmitting antenna array	
Types of amplitude distribution	FPBA
Number of elements	8
Dielectric constant	3.9
Radius of circular patch	0.0025 m
Height	0.001 m
Inter-element spacing	0.0035 m
Polarization	LHCP
Input power	20 dBm
Tx antenna height	1.5 m
HPBW	14.5 degree
Maximum SLL	-54 dB (normalized)
Parameters of receiving antenna	
Rx antenna height	1 m
Rx antenna type	Single element (isotropic)
Total number of receivers	9 ×13

Table IV Summary of RMS delay spreads within the living room for the new FPBA and UA.

Delay Spread	UA (nS)	FPBA (nS)
Maximum RDS	44.70	41.73
Average RDS	10.40	9.87
Standard Deviation of RDS	9.15	8.51

V. Comparison of RDS of Section III and Section IV

In section III RDS Parameters were calculated considering different average SLL. On the other hand in section IV realistic side lobe levels (SLL) of radiation patterns were considered. Properties of building materials (conductivities, permittivities and thicknesses of brick, concrete, glass, wood etc.) were also considered in section IV. Average RDS found in section III was about 7 ns~ 7.4 ns. On the other hand in section IV, the lowest average RDS was 9.87 ns. The difference in RDS of the two sections was mainly due to the difference in room dimensions and multipath environments. In section IV, beam forming was considered only at the transmitter side. In case of simulations described in section IV, RDS can be reduced further through beam forming at the receiver sites. It was reported in [3] that the measured RDS at 60 GHz indoor rooms falls within the range of 10.89 ns ~ 41.01 ns. RDS values at 60 GHz within the range of 15 ns~45 ns for small rooms and within the range of 30 ns ~70 ns for large indoor environment was reported in [11]. About 6 ns RDS was found in a residential environment [8]. It was also reported in [8] that the value of RDS can be reduced to 1 ns by using high gain antennas. RDS values found in sections III and IV agree well with the results found in [3], [8], and [11]. Results of section III and IV also confirm that lower SLL can minimize RDS.

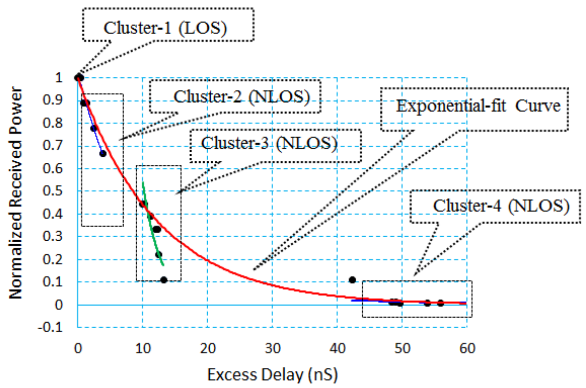

Fig. 7. Power Delay Profile (PDP) of a receiver in the living room of Fig.10. Tx-Rx distance was 15 meter for this scenario.

VI. CONCLUSIONS

This paper presents the delay characteristics of a 60 GHz wireless indoor channel model. Lower RMS Delay Spread (RDS) of a multipath channel increases the bit rate and decreases the bit error rate (BER). RDS depends on many factors, one of them is the side lobe level (SLL) of radiation pattern. It was found that RDS of a multipath channel can be reduced if SLL or average SLL (AvSLL) of antenna radiation pattern can be reduced. The effects of reduced SLL on RDS were investigated through the simulations of IEEE 802.11ad channel model and the Wireless Insite Full-3D ray tracing simulation software. Simulation results discussed in this paper confirmed that lower level of AvSLL can reduce the RDS of a 60 GHz wireless indoor fading channel.

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