Verifying Received Power Predictions of Wireless InSite Software in Indoor Environments at WLAN Frequencies

Huthaifa A. Obeidat [1], Omar A. Obeidat [2], Mahmood F. Mosleh [3], Ali A. Abdullah [4], and Raed A. Abd-Alhameed [4,5]

[1] Faculty of Engineering
Jerash University, Jerash, Jordan
h.obeidat@jpu.edu.jo

[2] College of Engineering
Wayne State University, Detroit, Michigan, MI 48202, USA
omar.obeidat@wayne.edu

[3] College of Electrical and Electronic Engineering Techniques
Middle Technical University, Baghdad, Iraq
drmahmood@mtu.edu.com

[4] School of Electrical Engineering and Computer Science
University of Bradford, Bradford, BD7 1DP, UK
(a.a.abdUllah1, r.a.a.abd)@bradford.ac.uk

[5] Basra University College of Science and Technology
Basra, 61004, Iraq

Abstract **─** This paper introduces a study on verifying received power at WLAN frequencies in indoor environments, Wireless InSite is a popular electromagnetic ray-tracing software which is widely used for predicting channel behaviour in indoor and outdoor environments. The study compares software-generated data with measurements collected through 3rd floor Chesham Building, University of Bradford, at WLAN frequencies, the paper also investigates the effect of changing settings on results accuracy and computational time, and finally, the paper presents a comparison between simulation results with empirical models.

Index Terms **─** FDTD, indoor propagation, ray lanching techniques, ray tracing, received signal strength, WLAN.

I. INTRODUCTION

With the recent revolution in computer and IT technology, possessing a computer with great speed and memory becomes feasible, electromagnetic (EM) modelling software is used extensively nowadays to predict the channel behaviour within indoor and outdoor environments, Wireless InSite (WI) is an example of these software which is a commercial ray-tracing tool that can predict the effects of terrain, buildings and furniture on of EM waves propagation [1]. The software models the physical structure of the environment, executes the EM calculations and then calculates the requested signal propagation outputs. The environment can be constructed using the editing tools embedded within the software or by importing formats like DXF, shapefile, DTED, and USGS [1].

The WI is widely used for simulation the indoor environments [2], [3], [4] outdoor environments [5]. It uses the Shooting and Bouncing Ray (SBR) method [6], where rays are interacting with the environment through reflection, transmission, scattering and diffraction. WI can be used over a wide range of frequencies from 50 MHz to 100 GHz, the software allows the user to select the desired output including the angle of arrival (AOA), the direction of arrival (DOA), delay spread, impulse response, received signal strength (RSS) and propagation paths. At the receiver, rays can be combined with and without phases as will explained in the text [7].

The 3D indoor environment comprises walls and floors, windows and doors, corridors, stairwells and lift-shafts, as well as fixtures and furniture which can be regarded (using radar parlance) as clutter [7].

This highly complex channel structure is captured by ray-tracing software. However, there are practical limits on the accuracy with which the detail of building structures or clutter can be characterised or the extent to

Submitted On: February 4, 2020
Accepted On: June 25, 2020

https://doi.org/10.47037/2020.ACES.J.351003

which the material electrical properties can be accurately described [2]. There are also compromises made in the number of ray paths that can be found by the software within the constraints of a reasonable run-time and memory requirement [1].

The software was validated over the UHF band by authors in [8] and over the VHF band [9] and [10]. The aim of this study is to validate the software over the WLAN frequency range. Section II provides a summary on ray tracing techniques and comparisons with the FDTD method, Section III presents the methodology and experimental and simulation setup, Section IV investigates collected results were comparisons are conducted and observations are recorded. Finally, the conclusion is drawn in Section V.

II. RAY TRACING TECHNIQUES

Deterministic models which utilizes Finite Difference Time Domain method (FDTD) [11] and Ray tracing techniques [12] are widely used. Since the FDTD is a time-domain technique, it is known for its simplicity; however, it is computationally intensive [11]. On the other hand, ray tracing is a frequency-domain technique which requires less computational power. In a comparison between the two approaches, the total number of numerical operations for a 2D FDTD is [13]:

$$F_{FDTD} = \sqrt{\varepsilon_r} \cdot N_{FDTD} \cdot (N_{FDTD} + 2N_{PML})^2, \quad (1)$$

where N_{FDTD} is the number of FDTD grids and N_{PML} is the thickness in grid elements of the absorbing boundary of the perfectly matched layer (PML).

On the other hand, Ray tracing Launching numerical operations is given by [13]:

$$F_{RL} = N_{RL}^2 \cdot i(i+1), \quad (2)$$

where N_{RL} is the number of discretization steps, and i is the number of iterations. As seen, the complexity orders for the 2D FDTD and Ray launching methods are around $\sim N_{FDTD}^3$ and $\sim N_{RL}^2$ respectively. In literature, many hybrid ray-tracing and FDTD techniques are proposed to get the best of the two worlds [14] [15].

In [16], a simulated RSS using Wireless InSite, FDTD, and the event-driven transmission line matrix models were compared to measurements at an indoor room environment, the operating frequency was set to 2.4 GHz. Although the simulation models were accurate, the execution time of the FDTD was 174 times larger than Wireless Insite software.

The ray-tracing tools are considered to be accurate provided that the signal wavelength is smaller than the size of the obstacle within the environment; waves can be considered as rays and hence, ray theory is applicable [17].

There are two general approaches for generating the rays: Ray launching and multiple images [18]. In ray launching, rays are launched through many angles, where those who are above a certain threshold are being considered. Multiple images are performed by considering the only paths between the transmitter and receiver, those paths are established by considering multiple images of the transmitter to the receiver then a line is drawn to connect these images [18]. As it considers multiple reflections, multiple images approach suffers from the exponential increase of the computational time, on the other hand, the ray launching technique is usually preferred as it deals with diffracted and scattered rays along with the reflected rays, however, it has the disadvantage of constant angle increment, which means that some of the surfaces may not be hit [17]. To compensate for that, a reception sphere can be used to capture the rays in the vicinity adequately. While ray launching is preferable for area prediction, multiple image approach is suitable for point to point prediction [17]. Ray-tracing techniques can also be accelerated by using space divisions and simplifications into 2D and 2.5D map techniques [19].

The combination of the uniform theory of diffraction (UTD) and the SBR provides an accurate 3D analysis of indoor propagation [20]. The advantages of fast computation speed of SBR and ray accuracy detection from multiple images method can be combined to produce a hybrid method which enhances signal predictions. The method starts with the SBR to determine the ray paths and multiple images are then applied to adjust the ray trajectory [19].

Removing small fading effect is desired, this issue was the subject of many research papers [21], Wireless InSite provides the ability to remove the effect of small scale fading by considering the power level of all incoming rays, and through considering the effect of phases associated with multipath components, the approaches are termed as Power Sum and Vector Sum respectively. Power Sum (PS) prediction considers only the power level of the multipath rays, where the average value is given by [22]:

$$\langle P_{PS} \rangle = \sum_M P_M, \quad (3)$$

where $\langle P_{PS} \rangle$, M and P_M are the averaged power using the PS method, number of incoming multipath and power of each individual ray respectively. The average value given by the vector sum (VS) prediction approach is given by [22]:

$$\langle P_{VS} \rangle = \left| \sum_M \sqrt{P_M}\, e^{-j\varphi_M} \right|^2, \quad (4)$$

where $\langle P_{VS} \rangle$ is the averaged power using the VS method and φ_M is the M^{th} ray phase in radians. Throughout these simulations, we selected the PS method from WI settings in order to remove the effect of fast fading. The use of empirical models is limited to scenarios where the antenna heights are the same, and over the same range of frequencies, and environments that are similar to those where measurements were conducted [23]. Empirical models also require to perform some measurements in order to generate the empirical parameters [24]. Reflection and diffraction phenomena are not usually considered by empirical models, while they are considered through ray-tracing software; although they will require a fast machine with large memory. On the other hand, ray tracing software accuracy depends on how accurate is the environment modelling [2], and on whether the constitutive parameters (permittivity and conductivity) in the simulation are close to the actual values.

Another indoor propagation modelling approach is the Dominant path model (DPM). DPM is similar to the Motley and Keenan empirical model, however, only dominant rays are considered rather than the direct ray [25]. Dominant paths are assumed to have the main rays which contribute most of the energy, henceforth adopting the DPM will reduce the requirement of having a fine detailed simulated environment; since it considers less number of paths, the computational time is less compared to other approaches [25].

III. METHODOLOGY AND EXPERIMENTAL SETUP

The Wireless InSite software allows the user to model the environment as shown in Fig. 1, it also allows to set the value of many parameters including the type of antenna, transmitted power, operating frequency, signal bandwidth, electrical constitutive parameters, the maximum number of reflections, transmissions and diffractions, propagation model, ray-tracing method, sum complex electric fields and the number of propagation paths …etc. The more considered paths the more accurate the results, however, more processing time is required. We found that having more than 10 paths will not improve the accuracy of the results; therefore, the maximum number of paths was set to 10. Table 1 shows the settings used in our experiment.

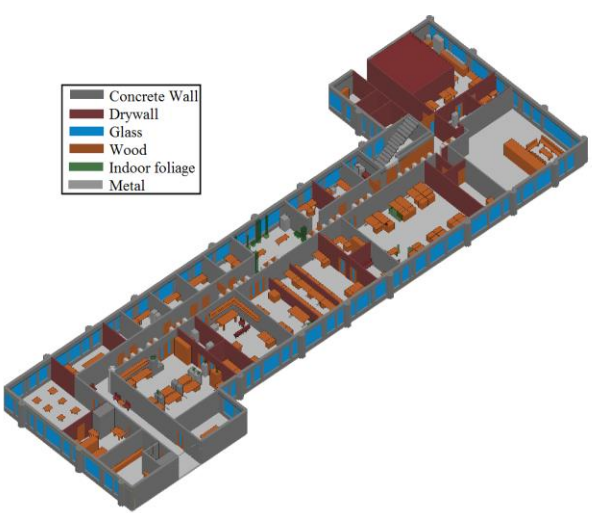

Fig. 1. The simulated environment for the 3rd floor in Chesham building, University of Bradford.

Table 1: Wireless InSite settings

Property	Setting
Transmitter antenna	MIMO omnidirectional
Receiver antenna	Omnidirectional
Transmitted power	23 dBm
Antenna gain	3.5 (2.4 GHz) 4.5 (5 GHz)
Sum complex electric fields	None
Number of reflections	4
Number of transmissions	4
Number of diffractions	0
Number of paths	10
Ray Spacing (^{0})	0.2
Plane-wave ray spacing	0.5 *m*
Propagation model	Full 3D
Ray tracing method	SBR
Ray tracing acceleration	Octree

Table 2 introduces the values used for permittivity ε_r and conductivity σ according to the ITU regulations [26], as shown in the table, ε_r does not change considerably with frequency in opposite to σ.

Table 2: Material properties with frequency

Material		2.4 GHz	5 GHz
Concrete	ε_r	5.31	5.31
	σ	0.0662	0.1258
Glass	ε_r	6.27	6.27
	σ	0.0122	0.0314
Wood	ε_r	1.99	1.99
	σ	0.0120	0.0281
Drywall	ε_r	2.94	2.94
	σ	0.0216	0.0378

The study was conducted over 2.4 GHz and 5 GHz where different routes were examined. For both simulation and measurements, similar antenna types, gain, transmitted power and radiation pattern were used. Also, Access Point (AP) coordinates in the environments for both simulations and measurements were identical. As shown in Fig. 2, for each AP, measurements were collected over two routes, at 1-meter height and 0.5 m spacing between every two concessive measurements. The routes were chosen to be representative of the indoor environment, as it passes through concrete and drywalls. AP1 height is 2.2 m while for AP2 and AP3 heights are 2.75 m. A WLAN scanner software called inSSIDer® was used to collect the measurements using a laptop with a calibrated 802.11a/b/g/ac card adapter, these measurements are averaged to remove the effect of fast fading, PS method requires antenna arrays to detect angle of arrival and record time of arrival of multipath, these are essential to be able to remove the effect of multipath phase, however, it is difficult to meet these conditions with normal handsets, therefore, as seen in literature, measurements are averaged to smoothen the fast fading effect and make the measurements more representative. The RSS reading is updated every one second. In this paper, varying WI settings for indoor environment was investigated to find the settings that have best fit with least elapsed time, these settings include number of reflections, transmission and diffractions, ray-tracing method and propagation model. Also, WI simulations were validated against measurements at WLAN frequencies. Moreover, the ray tracer simulations were compared to two empirical prediction models, and finally, the effect of changing permittivity and conductivity of concrete on WI performance was examined.

IV. RESULTS AND DISCUSSIONS

Since WI allows the user to set many parameters, in our validation process, the first step was to find the best set of parameters that optimise results' accuracy and computational time, the processing machine is a 64-bit operating system Lenovo laptop with a Core i5-5200U 2.2 GHz processor and 12 GB RAM.

Table 3 presents an example of how power predictions change for route 2-2 (47 receiver points, shown in Fig. 2) by changing the WI settings. As seen in the table, the investigated parameters include propagation model, ray-tracing method, and the number of reflections, transmissions and diffraction. The full 3D model is the most powerful propagation model in the software as it allows the user to set many reflections, transmissions and diffractions. It can be used for both indoor and outdoor applications. The X3D is an accelerated version of the full 3D, it considers only reflections and diffractions; therefore, it requires less computational time but at the expense of accuracy as seen in the table. Regarding the X3D, it was noted that adding more reflections or diffractions will not change the RSS.

The full 3D model allows the user to choose among two ray-tracing methods namely, SBR and Eigenray. The SBR is a high-frequency asymptotic approach which is renowned for considering rays scattering from multiple reflections [27], there are three main stages in the procedure of the SBR method: the ray-tracing step, the field tracking step and the physical optics step [27].

The Eigenray is a ray-tracing approach which involves paths between transmitter and receiver that satisfy Fermat's principle with least time without refraction through transmission, this method is suitable for applications require a large number of transmissions [1].

In comparison with SBR, Eigenray is significantly faster, but with less accuracy, therefore, we adopted the SBR method in our analysis.

As seen in Table 3, adding one diffraction will increase the computational time significantly, however, only 0.02 dB enhancement is obtained, therefore, to reduce computational time, diffraction can be neglected. Using 2 reflections, 8 transmissions and 0 diffractions required around 11 minutes, by adding more reflection, the computational time increases significantly with slight enhancement (0.1 dB). While considering more reflections and fewer transmissions, more accurate results are obtained, it was noted that adding more reflection or diffraction will not guarantee better results. This was proven for other routes in the experiment. It is worth remembering that elapsed time depends mainly on the type of machine used, our presented times based on the machine specifications explained earlier.

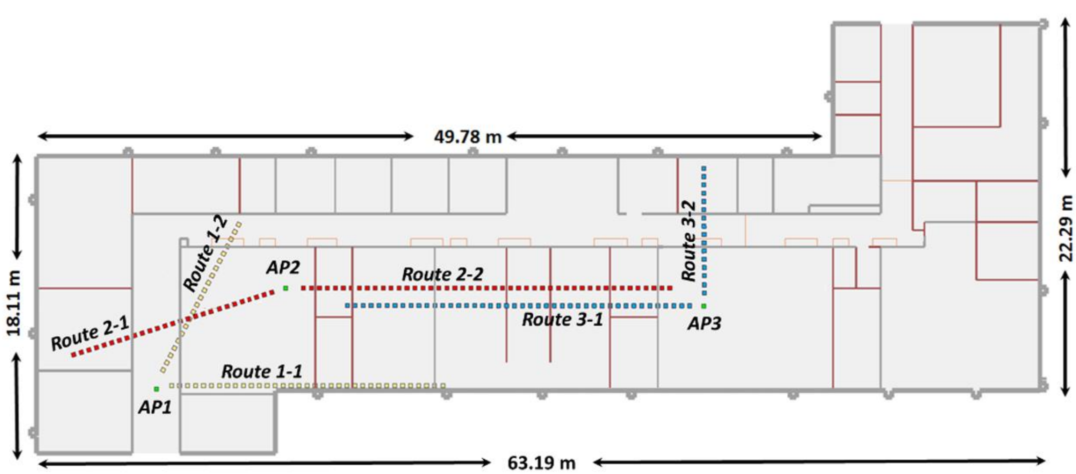

Fig. 2. Experimental routes in 3rd floor, Chesham building at the University of Bradford.

Table 3: Investigated Wireless InSite parameters

No. of Reflections	No. of Transmissions	No. of Diffractions	Propagation Model	Ray Tracing	RMSE (dB)	Elapsed Time hr: min: sec
2	8	0	Full 3D	SBR	5.66	00:10:56
2	8	1	Full 3D	SBR	5.56	01:35:52
3	8	0	Full 3D	SBR	5.15	02:30:43
4	4	0	Full 3D	SBR	4.97	00:27:29
4	4	1	Full 3D	SBR	4.95	02:07:55
5	3	0	Full 3D	SBR	4.95	00:29:46
2	8	0	Full 3D	Eigenray	5.88	00:00:19
2	8	1	Full 3D	Eigenray	5.75	00:50:29
3	8	0	Full 3D	Eigenray	5.71	00:29:28
2	0	0	X3D	-	13.27	00:00:08

In Fig. 3, a comparison is presented between simulation and measurements results for route 1-1 (shown in Fig. 2) at 2.4 GHz. As seen in the figure, a good agreement between simulation and measurements is observed, as the root mean square error (RMSE) is 3.7 dB. For each route, the RMSE is calculated as seen by Equation 5, where L is the number of receiver points in each route:

$$RMSE = \sqrt{\sum_{i=1}^{L} \frac{(Simulated_i - Measured_i)^2}{L}}. \quad (5)$$

Figure 4 presents a comparison between simulation and measurements results for route 3-2 (shown in Fig. 2) at 5.3 GHz. A good agreement between simulation and measurements is observed, as the Standard deviation (STD) is 3.64 dB.

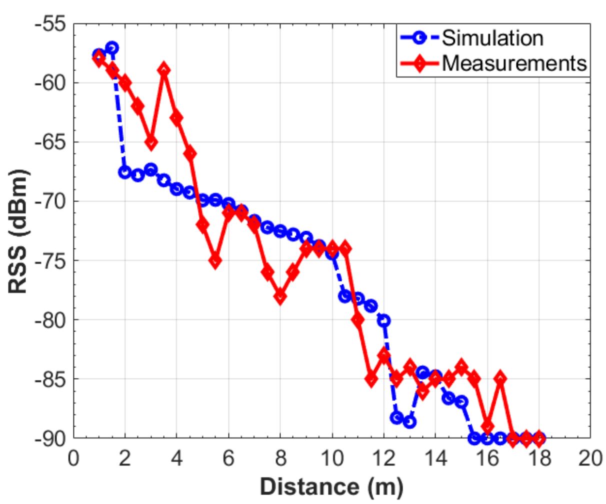

Fig. 3. Wireless InSite validation against measurements at route 1-1 at 2.4 GHz.

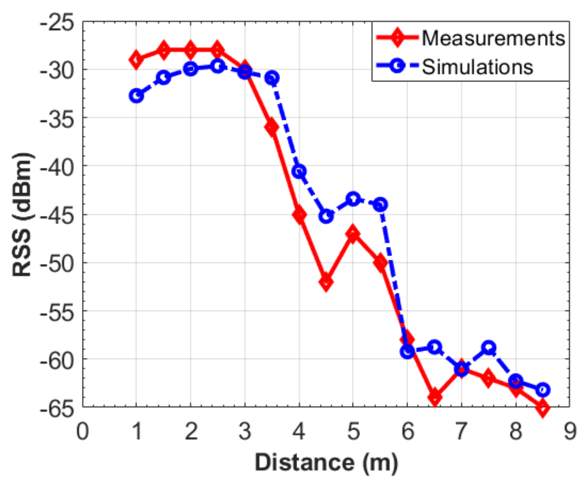

Fig. 4. Wireless InSite validation with measurements at route 3-2 at 5 GHz.

Table 4 shows the RMSE between the WI simulation and measurements, the overall performance is almost the same at both frequencies as its average RMSE at 2.4 GHz and 5 GHz are 4.97 dB and 5.09 dB respectively. The simulation results were also compared to MKM and DPM models, for these models, samples were taken from measurements, then the empirical models are generated, after that, the generated models were compared to the measurements by finding the RMSE. Table 4 shows a performance comparison between the WI simulation, MKM and DPM models. Although MKM and DPM use samples from the measurements; however, WI tend to have the best performance over the examined frequencies as seen in the table, MKM has the second-best performance, however, MKM and DPM performances enhanced with increasing the frequency, this is maybe due to the increased effect of wall penetration losses on the RSS.

Table 4: RSME comparison between empirical models and Simulations at 2.4 and 5 GHz in dB

Route	2.4 GHz		
	WI	MKM	DPM
1-1	3.7	7.69	12.24
1-2	5.66	3.71	4.32
2-1	6.19	11.46	7.48
2-2	3.36	9.76	14.31
3-1	6.85	6.62	6.00
3-2	4.10	4.69	4.88
Average	4.97	7.32	8.21
Route	5 GHz		
	WI	MKM	DPM
1-1	4.5	3.57	5.69
1-2	5.46	5.66	5.54
2-1	6.96	3.08	3.97
2-2	6.06	9.10	9.67
3-1	3.94	5.77	6.29
3-2	3.64	6.00	14.19
Average	5.09	5.53	7.56

Although WI outperforms other empirical models, the averaged RMSE is rather quite large, this can be regarded due to many factors including measurement errors and input settings used for WI. Measurement errors occurred due to people movements, calibration errors and instruments errors, in our experiment we performed averaging over local mean for measurements to reduce the effect of fast fading and the measurements error. Since concrete is the main material used in the building; the effect of changing permittivity and conductivity of concrete was examined to observe WI sensitivity to changing these values. Therefore, we used different values for relative permittivity and conductivity of concrete from literature as shown in Table 5.

Table 5: Constitutive electrical parameters of concrete at 2.4 and 5 GHz

Freq.	ε_r	σ	Reference
2.4 GHz	8	0.01	[28]
	4.94	0.092	[29]
	2.82	0.1307	[30]-a
	7.43	0.1857	[31]-a
	9.34	0.1867	[31]-b
	3	0.0777	[31]-c
	6.75	0.2213	[30]-b
5 GHz	3.34	0.2361	[30]-c
	4.28	0.2000	[30]-d
	7.36	0.7861	[30]-e
	3.87	0.3667	[30]-f
	5.5	0.0501	[32]-a
	4.6	0.0668	[32]-b
	5.1	0.3389	[33]

Figure 5 shows the averaged RSME of WI measurements using different values of conductivity and permittivity of concrete based on values presented in Table 5. As seen in the figure, using the ITU values have the best performance, as it has universal use compared to other values, also, using different values of permittivity and conductivity affects the WI performance which highlights the importance of choosing the correct values of these parameters from literature.

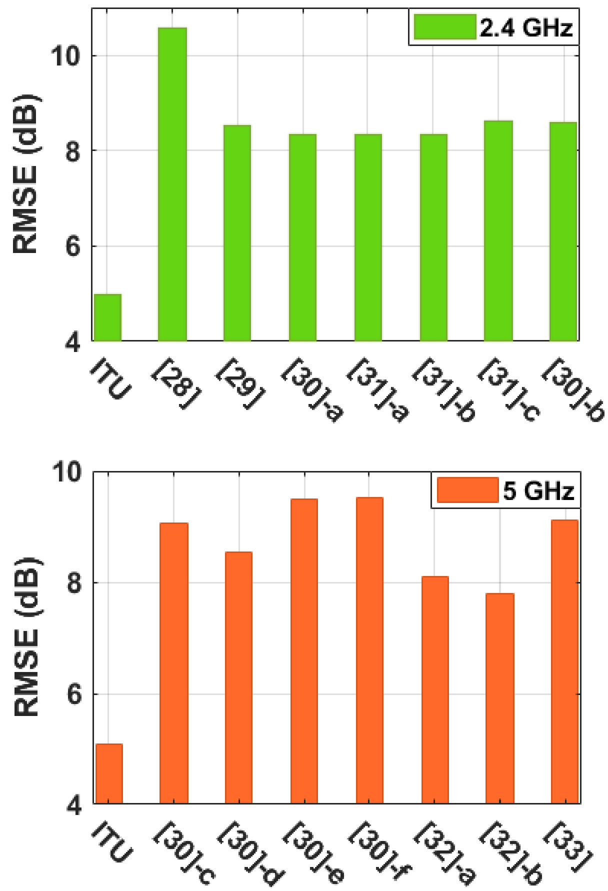

Fig. 5. RSME between measurements and WI using different values of conductivity and permittivity.

V. CONCLUSIONS

A simulated power prediction validation for Wireless InSite software with measurements at WLAN frequencies is presented, the comparison considers the effect of tunning the software parameters on the accuracy of the results. It was found that using SBR with full 3D gives the best performance, also, it was observed that in the indoor environment the diffraction does not contribute significantly compared to reflections and transmissions. Using more reflection guarantee better results.

REFERENCES

[1] Remcom, *Wireless InSite Reference Manual*, 3.1.0. Pennsylvania: Remcom, 2017.

[2] H. A. Obeidat, Y. Dama, R. Abd-Alhameed, Y. F. Hu, R. Qahwaji, J. M Noras, and S. Jones, "A comparison between vector algorithm and CRSS algorithms for indoor localization using received signal strength," *Applied Compu-tational Electromagnetic Society Journal*, vol. 31, no. 8, pp. 868-876, 2016.

[3] H. A. Obeidat, A. Alabdullah, M. F. Mosleh, A. Ullah, O. Obeidat, and R. Abd-Alhameed, "Comparative study on indoor path loss models at 28 GHz, 60 GHz, and 73.5 GHz frequency bands," *Applied Computational Electromag-netics Society Journal*, vol. 35, no. 2, pp. 119-128, 2020.

[4] H.-Y. Chen and S.-H. Wen, "Evaluation of E-field distribution and human exposure for a LTE femtocell in an office," *Applied Computational Electromagnetics Society Journal*, vol. 31, no. 4, 2016.

[5] D. Shi, N. Lv, N. Wang, and Y. Gao, "An improved shooting and bouncing ray method for outdoor wave propagation prediction," *Applied Computational Electromagnetics Society Journal*, vol. 32, no. 7, 2017.

[6] D. Shi, X. Tang, C. Wang, M. Zhao, and Y. Gao, "A GPU implementation of a shooting and bouncing ray tracing method for radio wave propagation," *Applied Computational Electro-magnetics Society Journal*, vol. 32, no. 7, 2017.

[7] Remcom, "Wireless InSite GUI," 2016. [Online]. Available: www.remcom.com/wireless-insite [Accessed: 23-May-2019].

[8] P. Medeđović, M. Veletić, and Ž. Blagojević, "Wireless insite software verification via analysis and comparison of simulation and measurement results," in *2012 Proceedings of the 35th Inter-national Convention MIPRO*, pp. 776-781, 2012.

[9] G. Celik, A. Aitalieva, and H. Celebi, "Comparison of empirical and ray-traced based channel modeling on VHF band," in *2019 27th Signal Processing and Communications Applications Conference (SIU)*, pp. 1-4, 2019.

[10] A. Aitelieva, G. Celik, and H. Celebi, "Ray tracing-based channel modelling for VHF frequency band," in *2015 23nd Signal Processing and Communications Applications Conference (SIU)*, pp. 1385-1388, 2015.

[11] K. A. Remley, H. R. Anderson, and A. Weisshar, "Improving the accuracy of ray-tracing techniques for indoor propagation modeling," *IEEE Trans. Veh. Technol.*, vol. 49, no. 6, pp. 2350-2358, 2000.

[12] Y. Wang, S. Safavi-Naeini, and S. K. Chaudhuri, "A hybrid technique based on combining ray tracing and FDTD methods for site-specific modeling of indoor radio wave propagation," *IEEE Trans. Antennas Propag.*, vol. 48, no. 5, pp. 743-754, 2000.

[13] L. Nagy, "Comparison and application of FDTD and ray optical method for indoor wave propagation modeling," in *Proceedings of the Fourth European Conference on Antennas and Propagation*, pp. 1-3, 2010.

[14] L. Nagy, "FDTD and ray optical methods for indoor wave propagation modeling," *Mikrotalasna Rev.*, 2010.

[15] H. Kim, B. Kim, and Y. Lee, "An accurate indoor propagation analysis for Wi-Fi antenna embedded in a commercial TV set," in *The 8th European Conference on Antennas and Propagation (EuCAP 2014)*, pp. 2111-2114, 2014.

[16] P. T. Kuruganti and J. Nutaro, "'A comparative study of wireless propagation simulation methodologies: Ray tracing, FDTD, and event based TLM," in *Proc. Huntsville Simulation Conference*, 2006.

[17] B. E. Gschwendtner, G. Wölfle, B. Burk, and F. M. Landstorfer, "Ray tracing vs. ray launching in 3-D microcell modelling," 1995.

[18] G. E. Athanasiadou, A. R. Nix, and J. P. McGeehan, "A ray tracing algorithm for micro-cellular and indoor propagation modelling," in *IEE Conference Publication*, pp. 2-231, 1995.

[19] Z. Yun and M. F. Iskander, "Ray tracing for radio propagation modeling: Principles and applica-tions," *IEEE Access*, vol. 3, pp. 1089-1100, 2015.

[20] Y. Dama, R. Abd-Alhameed, F. Salazar-Quinonez, D. Zhou, S. Jones, and S. Gao, "MIMO indoor propagation prediction using 3D shoot-and-bounce ray (SBR) tracing technique for 2.4 GHz and 5 GHz," in *Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP)*, pp. 1655-1658, 2011.

[21] H. Obeidat, A. Alabdullah, N. Ali, R. Asif, O. Obeidat, M. Bin-Melha, W. Shuaieb, R. Abd-Alhameed, and P. Excell, "Local average signal strength estimation for indoor multipath propaga-tion," *IEEE Access*, vol. 7, pp. 75166-75176, 2019.

[22] R. A. Valenzuela, O. Landron, and D. L. Jacobs, "Estimating local mean signal strength of indoor multipath propagation," *IEEE Trans. Veh. Technol.*, vol. 46, no. 1, pp. 203-212, 1997.

[23] R. Eichenlaub, C. Valentine, S. Fast, and S. Albarano, "Fidelity at high speed: Wireless InSite® real time module™," in *MILCOM 2008-2008 IEEE Military Communications Conference*, pp. 1-7, 2008.

[24] K.-W. Cheung, J.-M. Sau, and R. D. Murch, "A new empirical model for indoor propagation prediction," *IEEE Trans. Veh. Technol.*, vol. 47, no. 3, pp. 996-1001, 1998.

[25] G. Wölfle, G. Wol, and F. M. Landstorfer, "Field strength prediction with dominant paths and neural networks for indoor mobile communication," 1997.

[26] P. Series, "Effects of building materials and structures on radiowave propagation above about 100 MHz," *Recomm. ITU-R*, pp. 2040-2041, 2015.

[27] Z. Xie, Z. Liang, H. Yue, and P. Gao, "A shooting and bouncing ray method for dielectric media," in *2017 International Applied Compu-tational Electromagnetics Society Symposium (ACES)*, pp. 1-3, 2017.

[28] M. Raspopoulos, F. A. Chaudhry, and S. Stavrou, "Radio propagation in frequency selective buildings," *Eur. Trans. Telecommun.*, vol. 17, no. 3, pp. 407-413, 2006.

[29] H. Xu, B. Li, S. Xu, and H. Feng, "The measurement of dielectric constant of the concrete using single-frequency CW radar," in *2008 First International Conference on Intelligent Networks and Intelligent Systems*, pp. 588-591, 2008.

[30] A. Regmi, "Reflection measurement of building materials at microwaves," *Diss. Master's thesis*, University of Oulu, 2016.

[31] C. Thajudeen, A. Hoorfar, F. Ahmad, and T. Dogaru, "Measured complex permittivity of walls with different hydration levels and the effect on power estimation of TWRI target returns," *Prog. Electromagn. Res.*, vol. 30, pp. 177-199, 2011.

[32] Y. Pinhasi, A. Yahalom, and S. Petnev, "Propagation of ultra wide-band signals in lossy dispersive media," in *2008 IEEE International Conference on Microwaves, Communications, Antennas and Electronic Systems*, pp. 1-10, 2008.

[33] M. Lott and I. Forkel, "A multi-wall-and-floor model for indoor radio propagation," in *IEEE VTS 53rd Vehicular Technology Conference, Spring 2001. Proceedings (Cat. No. 01CH37202)*, vol. 1, pp. 464-468, 2001.

Huthaifa Obeidat is Assistant Professor at the Communication and Electronics Department at Jerash University in Jordan, he received the Ph.D. in Electrical Engineering from the University of Bradford, UK, in 2018. His research interests include Radio-wave Propagation, millimetre wave propagation, e-health applications, Antenna and Location-Based Services.

Omar Obeidat is currently a Ph.D. candidate at Wayne State University. He received his B.Sc. degree in Electrical Engineering from JUST in 2006, and M.Sc. degree in Wireless Commun-ication from Yarmouk University in 2009. His research interests include Non-destructive evaluation, thermal imaging and indoor and outdoor localization services.

Mahmood Mosleh is a Professor at the Department of Computer Engineering Techniques, College of Electrical and Electronic Eng-ineering Techniques, Baghdad, Iraq. His research interests combination of LMS and RLS Adaptive Equalizer for Selective Fading Channel and in the field of Wireless Sensor Networks, design and implementation.

Ali Alabdullah is currently pursuing the Ph.D. degree in Electrical Engineering with the Faculty of Engineering and Informatics, University of Bradford, Bradford, UK. His research interests include emerging technologies for 5G Wireless Communication System including Adaptive Beamforming Algorithms for wireless networks, Muti-User Massive MIMO.

Raed Abd-Alhameed is Professor of Electromagnetic and Radio-frequency Engineering with the University of Bradford, U.K. He has long years' research experience in the areas of radio frequency, signal processing, propagations, antennas, and electromagnetic computational techniques. His interest in computa-tional methods and optimizations, wireless and mobile communications, sensor design, EMC, beam steering antennas, energy-efficient PAs, and RF predistorter design applications. He is a fellow of the Institution of Engineering and Technology and a fellow of the Higher Education Academy and a Chartered Engineer.