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Human body blockage effect on wireless network performance for outdoor coverage

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ABSTRACT

The rapid development in the field of communications and growing numbers of the population every year stimulate telecommunications companies to develop communications systems to accommodate all users. In this paper, we will study the blockage effect of the student body on the propagation of the signals in the external wireless network. We took various numbers of the student density on the campus to know the extent it affects especially in crowded environments. The student body structure and buildings are designed in the college according to the real dimensions by Wireless InSite software. We compared scenarios for the different numbers of student density, we noticed that whenever an increase in the student density in the college will lead to increased path loss and delay spread time. In addition, note there is a gradual decrease in the received power (RP) if there is no student density highest RP is -28.2 dBm, when there are 300 students highest RP is -34.7 dBm, and when there are 600 students highest RP is -36.5 dBm. The reasons are that signals path spread inside the college will be passing through several collisions whether student body blockage or buildings that are built from different materials.

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1. INTRODUCTION

With the increasing number of smartphone users and the development of various mobile applications in recent years, requirements for wireless data transfer rates in increasing daily [1]. These requirements cannot be met which will need a wide range of frequencies in different fields. There is a technology that is used in the fifth generation (5G) that will solve these requirements and works to reduce the momentum of the users and give each person a private channel that prevents interference between users which is called millimeter waves (mmWave) that sends radio signals to a higher frequency range running from 30-300 GHz [2], [3]. The mmWaves attracted researchers to pay attention to designing wireless networks at very high speeds to meet great advances in various advanced communication fields [4]. This will unlock greater capacity in terms of bandwidth and this will alleviate concerns about wireless traffic congestion in the target environments scene. Therefore, satellites, radar, and most military systems use this range of the spectrum, but it is less occupied than the current spectrum [5]. All these capabilities cannot travel signals properly in space but suffer from the effects of the impending arrival of the signals to the receivers and the most important of these effects are refractions, reflections, and increase noise in environments and others [6]. There is another type of effect, which is the blockage of the human body, which is considered one of the main effects that prevent signals from reaching the receiving points, especially in crowded environments and with people who wear different clothes, and this can show some effects when the position and direction of the receiving devices are different and this will lead to successive losses and different in terms of values [7]. With all this, population density is one of the most important effects that affected the flow of signals transmitted from transmitter devices to receiving point devices unexpectedly, whether in external or internal environments [8].

In this paper, we will study the effect of student blockage in a real scenario to know the effect of this blockage on network performance in the external coverage. We took different numbers of student density within the college to find out their effect on the main parameters of measuring the efficiency of wireless coverage performance and these parameters are received power (RP), path loss (PL), and delay spread time (DST). In this work, the focus was placed on the building of the Electrical Engineering Technical College, Middle Technical University to complete the work. In addition, a focus was placed on the Wireless InSite (WIST) software in order to design the campus environment for the college, as well as design student bodies through this program. Where this program is considered one of the best programs in the design of indoor, outdoor, and mixed environments, this program tracks the signals transmitted from transmitters to receiving devices and the extent of the impact of these signals when they pass through several obstacles and barriers.

The rest of the sections for this paper were organized and arranged as: In section 2, the relevant works were presented and compared with the works and ideas presented in this paper. In section 3, the proposed wireless channel is presented and discussed in this paper as well as the most important parameters to measure the performance of this channel. While in section 4, the simulation environment of the college was designed as well as the design of student bodies. In addition, all the results presented in this paper were discussed and analyzed in section 5. Finally, in section 6, the detailed conclusions of all the ideas presented and proposed in this work are presented with the proposal of ideas and work to be presented in the near future.

2. RELATED WORKS

In this section, we will present recent works related to our work and the works presented by researchers in the previous literature. In addition, we will suggest some solutions that distinguished our work from the work suggested by researchers in previous works. At the end of this section, we will present the main objectives as a comparison between our proposed work in this paper and the works suggested by the authors in the previous recent literature.

Abouelseoud and Charlton [9] have researched productive capacity in the population density (ρ) by using 60 GHz in outdoor wireless networks. The researchers noted that whenever higher the population density will be network performance gradually decrease, therefrom the RP will decrease gradually and the losses of the paths will increase. Zhao *et al.* [10] and Zhadobov *et al.* [11] presented a real measurement of high-rise and low-rise urban networks in external wireless networks, where researchers focused in this work on the frequency of 28 GHz, which is one of the frequencies used in mmWaves. After simulation and showing the results, the researchers noticed that these waves are affected more in indoor environments than outdoor environments when there is a dense population density in the target environment.

Moltchanov *et al.* [12] studied the human skin permittivity models by using mmWave from the 10-60 GHz range. The researchers noted that the mmWaves lead to a solution for various crowded environments that are based on human body blockages. Moreover, Gapeyenko *et al.* [13] studied the effect of human body blockage in the 5G networks on the base stations by using the mmWaves band for outdoor environments. The calculation was based on PL to know the performance of the network when there is a human density in the region. The results clarified that the human body led to impending the direction of the paths and increased the noise in the environment.

In this research, the blockage of student density on the campus of the Electrical Engineering Technical College, Middle Technical University in Baghdad was studied, taking different models of student density to find out the extent of its impact on the behavior of network performance and on the propagation of signals in the regions of the line-of-sight (LoS) and regions other than the non-line-of-sight (NLoS). The student skeleton and buildings of the college were designed according to real dimensions using WIST software. This program is considered one of the best programs to simulate the spread of signals, whether in indoor, outdoor, or mixed environments. We compared the scenarios for different student densities in order to measure the most important parameters by which to know the performance of the wireless network which included PL, DST, RP, and received signal strength (RSS) from transmitters to receivers.

3. WIRELESS CHANNEL PARAMETERS CHARACTERISTICS

The characteristics of signals for various wireless communications, whether internal, external, or mixed, change drastically when they are transmitted from transmitting antennas to receiving antennas. Where these characteristics depend largely on the distance between the antennas of the transmitters to the antennas of the receivers, this distance between the two devices is called the wireless channel model. In general, the power profile of the received signals can be obtained by integrating the power profiles of the transmitted signals as shown in (1) [14].

$$y(f) = H(f) * x(f) + n(f) \tag{1}$$

where $H(f)$ is the field of the channel response, $n(f)$ is noise, and y, H, x, and n are all the functions of the signals during frequency (f).

There are five main parameters to measure the performance of any wireless channel: PL, RP, DPT, shadowing, and multipath between antennas [14]. All these parameters have a special method for determining the causes that encounter the signal path from the sender to the receiver. In addition, it will determine the overall network performance depending on the location of the transmitting stations.

3.1. Path loss

It is to reduce the power density of electromagnetic waves when propagated in free space. It is one of the main important elements in the link analysis of various wireless communication systems. There are many effects that affect the loss of the path when it spreads in free space, the most important of which are the reflections, refractions, diffractions, absorption, and others that the path traveling from the transmitting antennas passes to the receiving antennas [15]–[17]. In general, it can be calculated based on (2).

$$PL(d) = \left(\overline{PL}(d_0) + 10\alpha \log\left(\frac{d}{d_0}\right)\right) \tag{2}$$

where $\overline{PL}(d_0)$ is the average PL over a distance d_0, d_0 is the reference distance in the free space, α is one of the PL exponents and d is the distance between each transmitting antenna and the receiving point antenna measured in meters.

3.2. Received power

In general, it is affected by several effects that lead to an unexpected decrease in this ability. Where these effects negatively affect the performance of the wireless network, the most important of which are the reflections, absorptions, and collisions during the barriers that disperse the receiving power force and other influences [18], [19]. It can be calculated based on (3).

$$P_R(dBm) = \left(10 \log\left(\frac{P_T \lambda^2 \beta}{16\pi^2 d^2}\right) + 30(dB) - L_s(dB)\right) \tag{3}$$

where P_T is the average power time, λ is the carrier frequency wavelength, L_s is the additional loss faced by the wireless communication network system, and β is the frequency spectrum interference for transmitted waves.

3.3. Delay spread time (σ_τ)

In the field of wireless communication systems, it is one of the most important measures to know the performance of the delayed arrival of paths to the receiving points. This can be explained in other words, it is the difference between the arrival time of the first path to the arrival time of the last path [2], [18], [19]. It can be calculated based on (4).

$$\sigma_\tau = \sqrt{\frac{\sum_{i=1}^{N_P} (t_i - \bar{t})^2 P_i}{P_R}} \tag{4}$$

where P_i is the average time to power in watts, N_p is the total paths, t_i is the arrival time for each path i^{th}, and $\bar{t}$ is the mean arrival time. For this, it is possible to determine the time of arrival of any path in the wireless communication network systems in the internal or external environments through (5) [2], [19].

$$t_i = \left(\frac{L_i}{c}\right) \tag{5}$$

where L_i is the total geometric path length and c is the light speed in free space.

In addition, the mean arrival time of any path transmitted from transmitters to receiving point devices can be determined by (6) [2], [19].

$$\bar{t} = \frac{\sum_{i=1}^{Np} P_i t_i}{P_R} \quad (6)$$

While the average power time in watts for each i^{th} path is calculated by (7).

$$P_i = \frac{\lambda^2 \beta}{8\pi\eta_0} |E_{\theta,i} g_\theta(\theta_i, \emptyset_i) + E_{\emptyset,i} g_\emptyset(\theta_i, \emptyset_i)|^2 \quad (7)$$

where η_0 is the free space impedance at 377 Ω, $E_{\emptyset,i}$ and $E_{\theta,i}$ are theta and phi that electric field components of each i^{th} path at the receiving point, θ_i and $\emptyset_i$ are to give the direction of arrival and $g_\theta(\theta_i, \emptyset_i)$ is the direction of arrival. Moreover, the direction of arrival for any path propagated in the environment of the simulated scene is determined according to (8) [20].

$$g_\theta(\theta, \emptyset) = \sqrt{|G_\theta(\theta, \emptyset)|} e^{j\varphi_\theta} \quad (8)$$

where G_θ is the theta gain component of the receiving antennas and φ_θ is the relative phase of θ for electric fields in the far region.

3.4. Scattering or shadowing

If there are any barriers such as trees, buildings, human beings, and other barriers along the path of the signal, then part or all of the signal transmitted through absorption, refraction, reflection, and dispersion will be lost. These effects are called scattering or shadowing as shown in Figure 1 [21], with the rest of the effects such as reflections and diffractions. Therefore, the set of PLs with respect to shadowing can be calculated based on (9).

$$PL(d)dB = \overline{PL}(d_0) + 10\alpha \log\left(\frac{d}{d_0}\right) + \chi \quad (9)$$

where χ is a random variable (Gaussian) distributed in a random form measured in dB with the standard deviation (σ). χ is representing the effect resultant from shadowing.

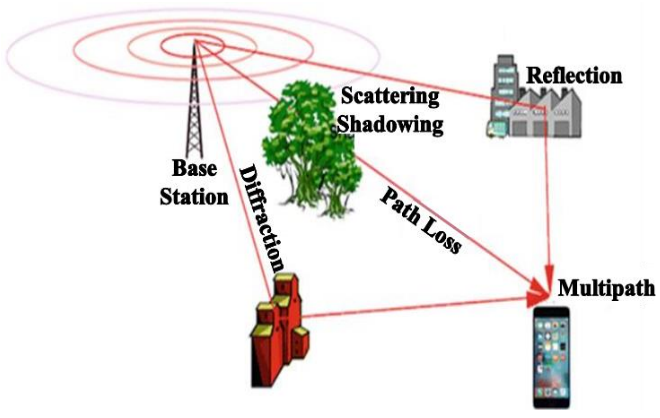

Figure 1. The path of the signal is transmitted from the base station (BS) device to the receiving device when it passes through the shadowing or scattering barrier

3.5. Multipath

The path of wireless communication when collides with any barrier or obstacle, object, or human body. So, these obstacles or barriers or objects reflect signals for this many of these reflections are called multipath as shown in Figure 2. For this, the path of the reflected signal will carry a phase and a capacity different from the signal path directed straight to the receiving point devices without passing through any obstacles [22].

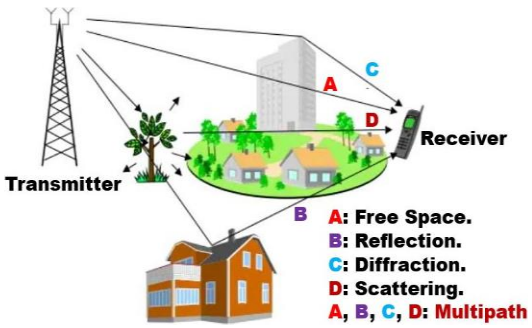

Figure 2. The path propagation of signals (multipath) transmits from the transmitting antennas to the receiving antennas in an external environment

4. SIMULATION ENVIRONMENT

4.1. Scene model

In this paper, we focus on building a simulation scene similar to a rectangle (Electrical Engineering Technical College, Middle Technical University in Baghdad) as shown in Figure 3. It distributes 2-3 floors of buildings on two sides of a square or rectangle. The height of buildings ranges has been 3, 7, and 12 m.

We install the transmitter at the start of the college entrance and deployed 73 receiver points as shown in Figure 4. The body model of a student was designed using the WIST software and as shown in Figures 5(a) to (c), where the model of this body consists of two parts, the first part is the head and the second part is the body, which consists of 6 sides in the form of equal cubes. Therefore, the height of the head, as well as the radius, are 0.2 and 0.15 m, respectively, while the radius of the body is 0.25 m. Three heights have been chosen for the student body: 1.3, 1.6, and 1.8 m, which are widespread on the campus in different ways.

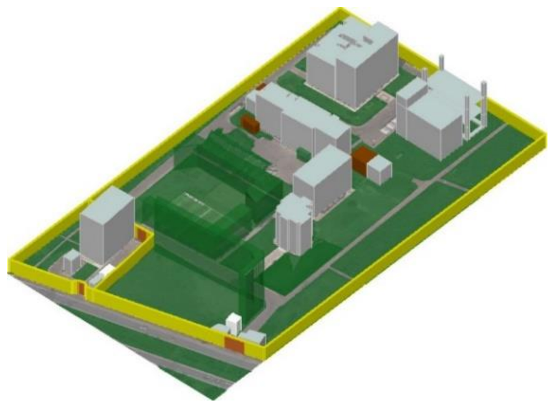

Figure 3. The scene environment of the college was designed using WIST software

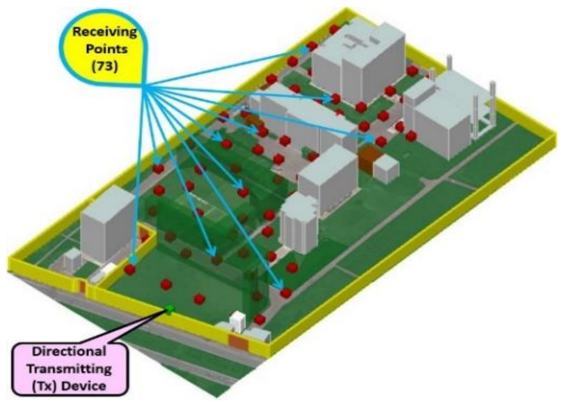

Figure 4. The transmitter and receiver points devices are deployed in the college

In this work, the focus was placed on three types of clothing that the student will wear on campus: cotton clothing, yellow leather clothing, and red leather clothing. The goal of relying on these types of clothing fabric because each type depends on the electromagnetic parameters that differ from one type to another. In addition, we will focus in our study on the change of the type of fabric to know the extent of its impact on the signals scattered in the college environment.

Therefore, the student wearing the cotton clothing is shown in Figure 5(a), yellow skin as shown in Figure 5(b), and red skin as shown in Figure 5(c) respectively. The students are deployed in all areas of the college randomly so that the total area of the college is 144×283 m^2, and the area in which students are deployed is 193×330 m^2. The various student densities on the campus are deployed when they are 0/m^2, the number is 0 students in the college scene as shown in Figure 6(a) when it is 0.007/m^2, the number is 300 students in the college scene as shown in Figure 6(b) when it is 0.014/m^2, the number is 600 students in the college scene as shown in Figure 6(c).

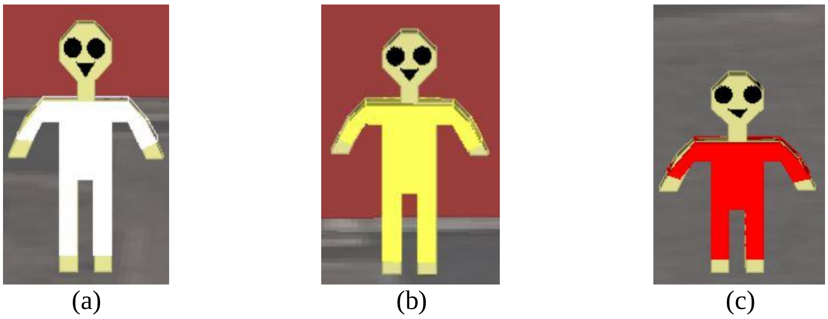

Figure 5. The student model was designed using WIST software (a) the student at a height of 1.8 m, (b) the student at a height of 1.6 m, and (c) the student at a height of 1.3 m

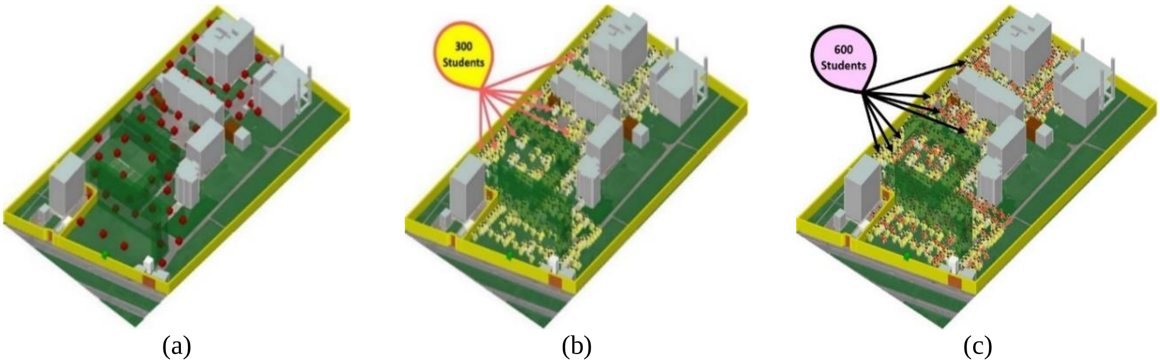

Figure 6. The student density deployed in the college in different numbers: (a) no students in the college, (b) 300 students in college, and (c) 600 students in college

4.2. Properties of Tx and Rx devices

There is one Tx in the simulation scene located at the beginning of the college entrance and it was high at 3 m. This location was chosen for the Tx device based on research published in international journals that built an algorithm to determine the optimal location of the Tx. While the number of Rx points spread in the college is 73 received points, where these points were randomly distributed among students as shown in Figures 4 and 6(a). The properties of transmitting antennas and receiving point antennas are listed in Table 1.

Table 1. Properties of the antennas for Tx and Rx devices

Properties	Tx Device	Rx Device
Waveform	Sinusoid	Sinusoid
Type of antenna	Directional	Omni-Directional
Polarization	Vertical	Horizontal
VSWR	1	1
Transmit power (dBm)	30	--
Temperatures	293	293
Receiver threshold (dBm)	-140	-140
Antenna broadcast beam width	120°	360°
Antenna gain (dBi)	19	2

4.3. Other parameters setting

The materials used in the construction of college buildings and the thickness of the materials are listed in Table 2. The construction was based on the real dimensions of the college in terms of the thickness of the walls as well as the designs of the buildings. In addition, each material used in the construction of this has the characteristics of the electro-electromagnetic parameters of conductivity (σ) and permittivity (ε), which were previously explained in [23], [24]. The values of these parameters change with the change of frequency in the simulation environment, as well as change from one material to another [25]. Therefore, the values of conductivity and permittivity parameters of the materials used in the construction of college buildings at the frequency of 5 GHz as well as at the bandwidth of 20 MHz are listed in Table 2.

Table 2. Materials property parameters for 5 GHz

Types of materials	Thickness (m)	σ	ε
Concrete	0.30	0.483	5.310
Brick	0.28	0.038	3.750
Metal	0.0625	$1\times e^{8}$	1
Wood	0.045	0.167	1.990
Dense Foliage	0.00035	0	1
Skin	0.005	3.06	10.7
Cotton	0.006	0.038	1.7
Red leather	0.014	0.14	2.15
Yellow leather	0.002	0.09	2.3

5. RESULTS ANALYSIS AND DISCUSSION

The beam emission from the Tx device to all the antennas of the receiving points is shown in Figures 7 to 9. We notice that the beam passes through many barriers, whether it is blockage of the student body or buildings built of different materials, some of which work on the reflection of the beam and others work on scattering the power of the beam. In addition, it is clear that the increase in student density leads to an unexpected obstruction in the direction of the signal within the university campus as shown in Figure 8 and Figure 9. Moreover, we show that the increase in the student's density in the college works to dissipate the strength of the signal transmitted to the receiving points because the student's body is made of several materials, whether clothes or parts of the student body, all of these materials are based on absorbing the transmitted power, and the absorption strength changes depending on the materials used in the design.

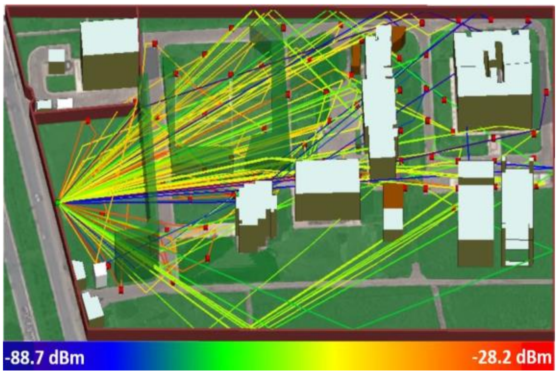

Figure 7. Paths propagation without students

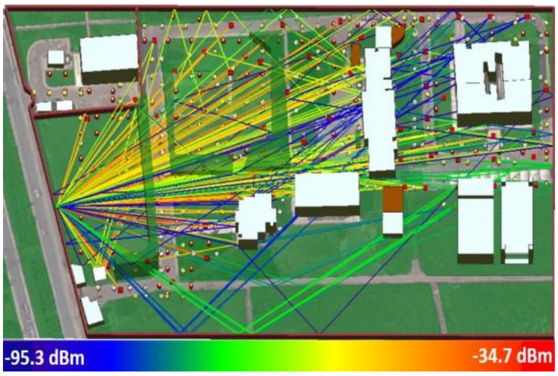

Figure 8. Paths propagation at 300 students

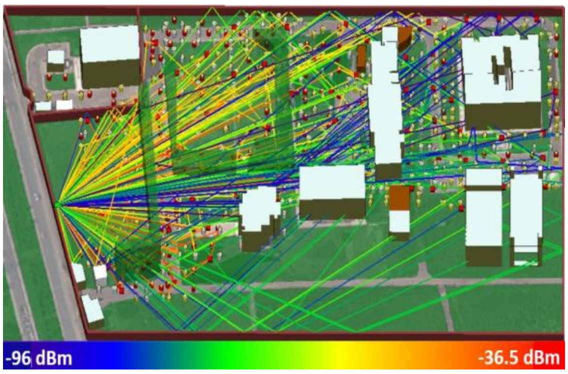

Figure 9. Paths propagation at 600 students

Moreover, each path transmitted from Tx to Rx devices has a color that represents the signal strength for each received point. The red color represents the strongest signal that reaches the receiving points. The yellow color is a medium signal, the green color is weak, while the blue color is weaker than the green and some do not reach the receiving points. Each color has a value of an RP as mentioned in Figures 7 to 9.

Figure 10 shows the number of receiving points versus the DST for no student density, the presence of 300 students, and the presence of 600 students. In general, we have noticed that there is a positive relationship between the increase in the density of students and the delay in the spread of time, where the greater density of students within the college will lead to an increase in the DST because the signal path when it hits the body of a particular student, so it will be delayed in reaching the receiving point in time for this will increase the DST when the student density increases in college.

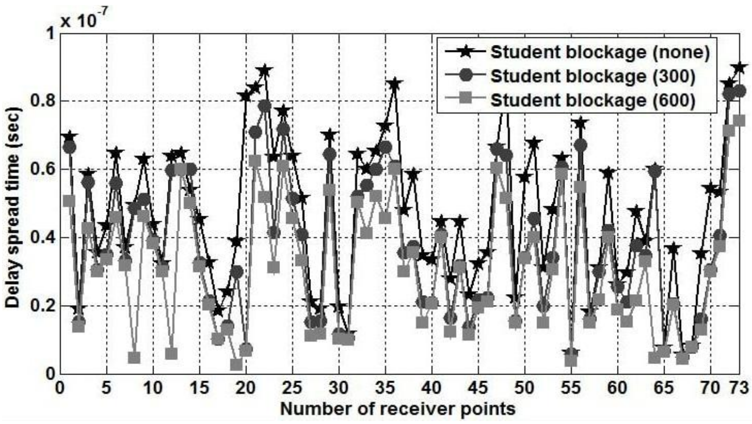

Figure 10. The receiving points versus DST

Figure 11 shows the number of receiving points versus the PL in decibels for no student density, presence of 300 students, and presence of 600 students. In general, we noticed that there is a positive relationship between the increase in student density and the loss of the path, as the greater the student density inside the college will lead to a gradual increase in the loss of the path, because the signal path is affected by many influences, including obstacles, barriers, student's bodies, the thickness of the walls and the surrounding environmental conditions. All of these influences work on the increase reflections, refractions, and absorptions within the environment of the college, and will lead to an unexpected increase in the losses of the paths, especially in the NLoS regions.

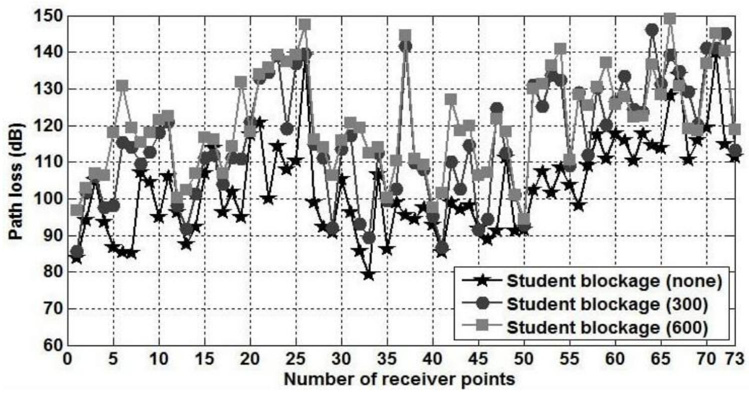

Figure 11. The receiving points versus path loss

On the other hand, Figure 12 shows the number of receiving points versus the RP in dBm for no student density, the presence of 300 students, and the presence of 600 students. We noticed that there is an inverse relationship between the increase in the density of students and the receiving power, as the greater the density of students inside the college will lead to a gradual decrease in the RP because some obstacles and barriers and most of the student's bodies work to disperse and absorb the transmitting power. Therefore, when the path collides with a student, the signal path will it is in the same direction, but the signal strength will be scattered and absorbed, while the scattering and absorption strength depends on the type of material used because each material has its own effect.

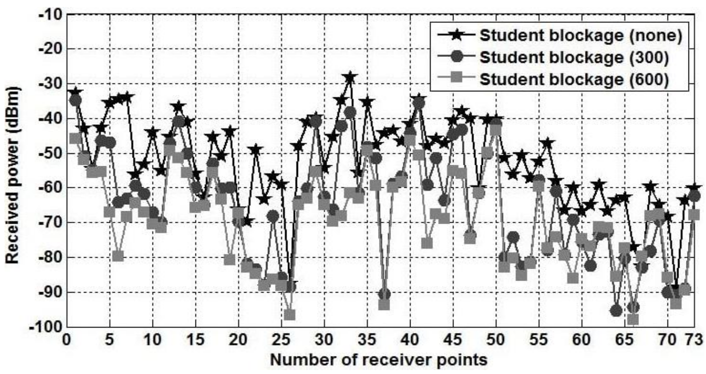

Figure 12. The number of receiving points versus received power

Finally, we note that whenever there are large numbers of student body blockages in the region the network performance will gradually decrease. The reasons are that the student's body and the clothes which wear by students worked to block signals. Also, it worked on the dispersion of the strength of the signals unexpectedly.

6. CONCLUSION

The effect of student self-obstruction on the signals as well as the signal blockage in a dense environment was simulated. It has been demonstrated that dense concentrations of student barriers can have significant effects on wireless communications. One of the most important works that have been studied is that in regions, where there is no, existing student blocking, the signals do not suffer from severe obstructions and where the arrival of signals to the receivers at high speeds and much better than the crowded student density within the college, while areas crowded with student's density will obscure signals and some of them not reach the receiver best correctly and this will lead to interferences among other signals. We also conclude that whenever increased the student density in the college will increase the PL and DST and decrease RP, because the student body and clothes which wear by the student worked to block signals and also worked on the dispersion of the strength of the signals unexpectedly. In future work, we will build an algorithm that works to adapt the optimal of the transmitter in the college in order to obtain optimal coverage of the real measurements.

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REFERENCES

[1] R. Chen, W.-X. Long, G. Mao, and C. Li, "Development trends of mobile communication systems for railways," *IEEE Communications Surveys and Tutorials*, vol. 20, no. 4, pp. 3131–3141, 2018, doi: 10.1109/COMST.2018.2859347.

[2] K. S. Muttair, A. Z. G. Zahid, O. A. S. Al-Ani, A. M. Q. AL-Asadi, and M. F. Mosleh, "Implementation mixed wireless network with lower number of Wi-Fi routers for optimal coverage," *International Journal of Online and Biomedical Engineering (iJOE)*, vol. 17, no. 13, pp. 59–80, Dec. 2021, doi: 10.3991/ijoe.v17i13.24149.

[3] M. Elkashlan, T. Q. Duong, and H.-H. Chen, "Millimeter-wave communications for 5G: fundamentals: Part I [Guest Editorial]," *IEEE Communications Magazine*, vol. 52, no. 9, pp. 52–54, Sep. 2014, doi: 10.1109/MCOM.2014.6894452.

[4] Z. Pi and F. Khan, "An introduction to millimeter-wave mobile broadband systems," *IEEE Communications Magazine*, vol. 49, no. 6, pp. 101–107, Jun. 2011, doi: 10.1109/MCOM.2011.5783993.

[5] C. Dehos, J. L. González, A. De Domenico, D. Kténas, and L. Dussopt, "Millimeter-wave access and backhauling: the solution to the exponential data traffic increase in 5G mobile communications systems?," *IEEE Communications Magazine*, vol. 52, no. 9, pp. 88–95, Sep. 2014, doi: 10.1109/MCOM.2014.6894457.

[6] S. Singh, F. Ziliotto, U. Madhow, E. Belding, and M. Rodwell, "Blockage and directivity in 60 GHz wireless personal area networks: from cross-layer model to multihop MAC design," *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 8, pp. 1400–1413, Oct. 2009, doi: 10.1109/JSAC.2009.091010.

[7] N. Chahat, M. Zhadobov, R. Augustine, and R. Sauleau, "Human skin permittivity models for millimetre-wave range," *Electronics Letters*, vol. 47, no. 7, 2011, doi: 10.1049/el.2011.0349.

[8] S. I. Alekseev and M. C. Ziskin, "Human skin permittivity determined by millimeter wave reflection measurements," *Bioelectromagnetics*, vol. 28, no. 5, pp. 331–339, Jul. 2007, doi: 10.1002/bem.20308.

[9] M. Abouelseoud and G. Charlton, "The effect of human blockage on the performance of millimeter-wave access link for outdoor coverage," in *2013 IEEE 77th Vehicular Technology Conference (VTC Spring)*, Jun. 2013, pp. 1–5, doi:

10.1109/VTCSpring.2013.6692780.
[10] H. Zhao, Q. Wang, and K. Shi, "Analysis on human blockage path loss and shadow fading in millimeter-wave band," *International Journal of Antennas and Propagation*, pp. 1–6, 2017, doi: 10.1155/2017/7540202.
[11] M. Zhadobov, N. Chahat, R. Sauleau, C. Le Quement, and Y. Le Drean, "Millimeter-wave interactions with the human body: state of knowledge and recent advances," *International Journal of Microwave and Wireless Technologies*, vol. 3, no. 2, pp. 237–247, Apr. 2011, doi: 10.1017/S1759078711000122.
[12] D. Moltchanov, A. Ometov, P. Kustarev, O. Evsutin, J. Hosek, and Y. Koucheryavy, "Analytical TCP model for millimeter-wave 5G NR systems in dynamic human body blockage environment," *Sensors*, vol. 20, no. 14, Jul. 2020, doi: 10.3390/s20143880.
[13] M. Gapeyenko, I. Bor-Yaliniz, S. Andreev, H. Yanikomeroglu, and Y. Koucheryavy, "Effects of blockage in deploying mmwave drone base stations for 5G networks and beyond," in *2018 IEEE International Conference on Communications Workshops (ICC Workshops)*, May 2018, pp. 1–6, doi: 10.1109/ICCW.2018.8403671.
[14] R. Jain, "Channel models: A tutorial," *WiMAX forum AATG*. Washington Univ. St. Louis, Dept. CSE, pp. 1–6, 2007.
[15] K. S. Muttair, O. A. Shareef, and M. F. Mosleh, "Outdoor to indoor wireless propagation simulation model for 5G band frequencies," *IOP Conference Series: Materials Science and Engineering*, vol. 745, no. 1, Feb. 2020, doi: 10.1088/1757-899X/745/1/012034.
[16] A. M. Al-Samman, T. A. Rahman, M. H. Azmi, N. R. Zulkefly, and A. M. S. Mataria, "Path loss model for outdoor environment at 17 GHz mm-wave band," in *2016 IEEE 12th International Colloquium on Signal Processing and Its Applications (CSPA)*, Mar. 2016, pp. 179–182, doi: 10.1109/CSPA.2016.7515827.
[17] M.-D. Kim, J. Liang, Y. K. Yoon, and J. H. Kim, "28 GHz path loss measurements in urban environments using wideband channel sounder," in *2015 IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting*, Jul. 2015, pp. 1798–1799, doi: 10.1109/APS.2015.7305288.
[18] K. S. Muttair, O. A. Sh. Al-Ani, and M. F. Mosleh, "Outdoor millimeter-wave propagation simulation model for 5G band frequencies," in *2019 2nd International Conference on Electrical, Communication, Computer, Power and Control Engineering (ICECCPCE)*, Feb. 2019, pp. 40–45, doi: 10.1109/ICECCPCE46549.2019.203745.
[19] Z. Afroze, D. W. Matolak, and H. Dye, "Indoor and outdoor 90 GHz LOS-to-NLOS channel transition characteristics," in *2022 IEEE Wireless Communications and Networking Conference (WCNC)*, Apr. 2022, pp. 938–943, doi: 10.1109/WCNC51071.2022.9771920.
[20] G. Verma, F. T. Dagefu, B. M. Sadler, and J. Twigg, "Direction of arrival estimation with the received signal strength gradient," *IEEE Transactions on Vehicular Technology*, vol. 67, no. 11, pp. 10856–10870, Nov. 2018, doi: 10.1109/TVT.2018.2869817.
[21] Z. Hongmei, Y. Hailong, and G. Shuting, "Research on path loss and shadow fading of ultra wideband simulation channel," *International Journal of Distributed Sensor Networks*, vol. 12, no. 12, Dec. 2016, doi: 10.1177/1550147716679847.
[22] H. Farahneh, A. Khalifeh, and X. Fernando, "An outdoor multi path channel model for vehicular visible light communication systems," in *2016 Photonics North (PN)*, May 2016, doi: 10.1109/PN.2016.7537911.
[23] K. S. Muttair, O. A. S. Al-Ani, and M. F. Mosleh, "Performance comparison of multi-band frequencies for outdoor communication," in *Communications in Computer and Information Science*, Springer International Publishing, 2020, pp. 476–487.
[24] L. Hao *et al.*, "Measurement-based double-directional polarimetric characterization of outdoor massive MIMO propagation channels at 3.5GHz," in *2020 IEEE 21st International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, May 2020, pp. 1–5, doi: 10.1109/SPAWC48557.2020.9154274.
[25] K. S. Muttair, A. Z. G. Zahid, O. A. Al-Ani, A. M. Q. AL-Asadi, and M. F. Mosleh, "A new design of mm-Wave MIMO antenna with high isolation for 5G applications," *International Journal of Microwave and Optical Technology*, vol. 16, no. 4, pp. 370–379, 2021, doi: ijmot.com/VOL-16-NO-4.aspx.

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