In this paper, an open-source simulator named NYUSIM is utilized to find the impact of the Human Blockage loss and Outdoor to Indoor (O2I) loss on the best candidate of 5G mmWave (38 GHz) in the NLOS UMi environment which has been proven the authors in their previous study. For accurate channel modeling, the human blockage and O2I losses play a vital role as in real life situations these losses occur. The previous study includes an ideal condition in which these losses were not considered.

NYUSIM uses a four-state Markov process to determine human blockage and two modes for O2I losses which include “High loss mode” for highly lossy materials like concrete walls and infrared reflecting glasses and “Low loss mode” for low loss materials like standard glasses and woods etc. These works are proof to the statement that there is a significant impact of the human and O2I losses on 5G mmWave bands which includes a smaller number of spatial lobes formed, lesser power is received, the path loss is increased, etc. Therefore, these losses must be considered for modeling the next-generation mobile communication system i.e 5G.

Keywords: 5G, mmWaves, Human Blockage Loss, Outdoor to Indoor Loss, NYUSIM, Mobile Communication

I. Introduction

The race among different tycoons in the field of both academia and industry upon the state-of-the-art mobile communication system is on fire because of the ever-
increasing demand for mobile traffic, low latency requirements, and gigantic amount of connecting devices. CISCO predicts the mobile traffic demand of about 930 exabytes in the year 2022 which shows an increment of 113th fold for the year 2012 [XVII]. Similarly, a minimum latency (up to 1ms) is also the need of the day for mission-critical situations like driverless and auto parking technology in today's cars. The number of connecting devices due to IoT and high mobility requirements due to bullet trains, hyperloop trains, and airplane communications are the factors which are tending us to move from traditional LTE-A mobile communications towards the next generation mobile communications known as 5G.

As discussed earlier the research on 5G is on its peak in both the academia and industry, different researchers around the globe are trying to figure out the properties of mmWaves as they haven’t been used for communications before and they are more susceptible to the environment as compared to the traditional communication signals. A similar study has also been carried out by us on the name of “Analysis of Channel Modelling for 5G mmWave Communication” in which we analyzed different mmWave bands (28, 38, 60, and 73 GHz) in the NLOS scenario for the UMi environment using world-renowned open-source simulator named “NYUSIM”. An analysis based on Angle of Arrival, Angle of Departure, Directional Power Delay Profile, Omni-directional Power Delay Profile, Small-scale Power Delay Profile, and path losses in non-line-of-sight (NLOS) scenario for a T-R separation of 150m 38 GHz band is the best suitable candidate carrier frequency for 5G new radio (NR).

In this study, we’ll incorporate 38 GHz band with a new module of human blockage shadowing loss and outdoor-to-indoor (O2I) penetration loss which was not considered for our previous research [XXVIII]. The current microwave communications (below 6 GHz) paid no attention to such losses because blockage from human shadowing has almost negligible impact on the [V] but the mmWave bands are much more sensitive to these losses as they can’t flick through human or even diffract from such blockages because of their short (few mm) wavelengths. For the maximum accuracy in the link budget analysis, the shadowing caused by the vehicles and humans must be considered [V]. According to the studies of [XXVII], [XXIX], and [IX], O2I affects the mmWave bands significantly because of the concrete walls, wood, and infrared reflecting glasses due to which the signal of mmWave bands may attenuate during transmission. For the deployment of 5G outdoor and indoor communication systems, the accurate prediction of O2I penetration loss is of extreme importance [VIII].

The study aims to find out the effect of O2I penetration and human blockage losses on the 38 GHz band of mmWave in the NLOS UMi environment with a TR separation of 150m. The 38 GHz band is selected from the result of the previous result of our study in which it performed very well as compared to 28 GHz, 60 GHz, and 73 GHz bands. We’ll use the NYUSIM simulator as a tool for our analysis which is free to download and is open-source software.

The rest of the paper will follow a sequence in which Section II will give a brief background to our study followed by Section III which introduces the NYUSIM
channel model while results discussion and simulation environment will be discussed in Section IV. Section V concludes the study.

II. Background

The theory for mobile radio reception was proposed in the late 60’s by Clarke [VII], while Smith [XVIII] used the theory of Clarke to make a computer simulator for indoor and outdoor propagation channels. In [IX] an extended version of the Wireless World Initiative for New Radio (WINNER) named QuaDRiGa channel model has been shown for the 3D antenna patterns and propagation with variable user terminal (UT) speeds. The indoor channel model for M2M communication is shown by Yu [X] while a simulator named SIRCIM [XVIII] was based upon the measurements of WiFi’s initial deployment. In [V] the author, utilized the stochastic geometry to give a framework able to calculate the coverage of mmWave downlink while, in [XII] [VI] the authors compared the path loss models of 3rd Generation Partnership Project (3GPP) and the International Telecommunications Union - Radiocommunications (ITU-R) in which both models lack consistency. This might be due to the strange behavior of mmWaves, as very few researchers have experienced them before.

Similarly, lots of simulators specifically for the mmWave bands are there in the market which includes Riverbed Solutions, MathWorks’s MATLAB 5G Toolbox, Network Simulation 3 (NS-3), Vienna-5G-Simulators, Siradel S-5G Channel, PyLayers, Open Air Interface (OAI), Wireless InSite, REMCOM, OMNET++, and NYUSIM. Among these simulators, some are free, some are even open source while for most of the simulators one must purchase a license which is extremely costly in most cases.

For the sake of our research, we chose NYUSIM for our analysis which is not only free to use but also open source for customization. The real-world scenario measurements as well as the accuracy and ease of use also make the NYUSIM dominant over the paid simulators. Researchers around the globe are using NYUSIM for their studies. In [XV] the author introduced the NYUSIM channel model and simulator to the world. In [VII] Uniform Linear Arrays (ULA) with beamforming and spatial multiplexing for 5G mmWave bands are presented, while the author in [XI] the author proofs that the NYUSIM simulator is more accurate especially when the NLOS environment is selected.

III. System Model

In NYUSIM spatial and temporal Channel Impulse Responses (CIRs) are generated from directional and Omni-directional channel models that are heavily based on 1 TB data obtained real-world measurement campaigns [XVIII], [XXII], and [XXII]. Its CIRs are based on 800 MHz wide bandwidth which has a very precise resolution of 2.5 ns, but it also works fine with narrow bands. Here path loss model, power delay profiles, and received power of the NYUSIM model will be discussed.

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Path Loss Model

The close-in free space reference distance (CI) path loss model with a 1 m anchor point, with an extra attenuation term due to various atmospheric attenuation factors [XVIII], is employed in NYUSIM, which is expressed as [XVIII], [XX], [XIII]

\[
PL_{CI}(f_c, d_{3D})[dB] = FSPL(f_c, 1m) + 10n\log_{10}(d_{3D}) + AT + \chi_{a}^{CI}
\]

where \( f \) denotes the carrier frequency in GHz, \( d_{3D} \) is the 3D T-R separation distance, \( n \) represents the path loss exponent (PLE). AT is the attenuation term induced by the atmosphere, \( \chi_{a}^{CI} \) is a zero-mean Gaussian random variable with a standard deviation \( \sigma \) in dB, and FSPL \((f, 1 \text{ m})\) denotes the free space path loss in dB at a T-R separation distance of 1 m at the carrier frequency \( f \): \n
\[
FSPL(f_c, 1m) = 20\log_{10}\left(\frac{4\pi f \times 10^9}{c}\right) = 32.4[dB] + 20\log_{10} f_c
\]

where \( c \) is the speed of light, and \( f \) is in GHz.

The term AT is characterized by:

\[
AT[dB] = \alpha[dB/m] \times d[m]
\]

where \( \alpha \) is the attenuation factor in dB/m for the frequency range of 1 GHz to 100 GHz, which includes the collective attenuation effects of dry air (including oxygen), water vapor, rain, and haze [XVIX] \( d \) is the 3D T-R separation distance.

Received Signal Power

The received signal power \( (P_r[dBm]) \) can be given by:

\[
P_r[dBm] = P_t[dB] + G_t[dB] - PL(d)[dB]
\]

where \( P_t, G_t, G_r \) and \( PL(d)[dB] \) is the transmitted power, transmitter’s gain, receiver’s gain, and average path loss at distance “d” respectively.

Omni-directional Power Delay Profile

The Omni-directional power delay profile is given as [XXIII]:

\[
h_{omni}(t, \Theta, \Phi) = \sum_{n=1}^{N} \sum_{m=1}^{M_n} a_{m,n} e^{j\phi_{m,n}} \times \delta(t - \tau_{m,n}) \times \delta(\Theta - \Theta_{m,n}) \times \delta(\Phi - \Phi_{m,n})
\]

where \( t \) is propagation delay, \( \Theta = (\theta, \phi)_{TX} \) represents a vector of azimuth and elevation angle of departures, \( \Phi = (\theta, \phi)_{RX} \) represents the vector of azimuth and elevation angle of arrivals, \( N \) is the number of TCs, \( M_n \) is the number of sub-paths (SPs), \( a_{m,n} \) is the magnitude of \( m^{th} \) sub-path belonging to \( n^{th} \) time cluster, \( \Theta_{m,n} \) is the azimuth/elevation AODs of each multipath component and \( \Phi_{m,n} \) is the azimuth/elevation AOAs of each multipath component.

Directional Power Delay Profile

Directional power delay profile (DPDP) is given by [XXII]:

\[
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\]
\[ h_{dir}(t, \vec{\Theta}_d, \vec{\Phi}_d) = \sum_{m=1}^{N} \sum_{n=1}^{M_n} a_{m,n} e^{i\varphi_{m,n}} \times \delta(t - \tau_{m,n}) \times G_{TX}(\vec{\Theta}_d - \vec{\Theta}_{m,n}) \times G_{RX}(\vec{\Phi}_d - \vec{\Phi}_{m,n}) \] (6)

Where \((\vec{\Theta}_d, \vec{\Phi}_d)\) are desired pointing angles of transmitter and receiver, \(G_{TX}\) is the azimuth and elevation pattern of the transmitter, and \(G_{RX}\) is the complex amplitude of multi-element antenna arrays of the receiver.

**O2I Penetration Loss**

O2I penetration loss is an option in NYUSIM latest version in which a user can select/deselect it. If a person selects it, then NYUSIM offers two options depending upon the construction of the building [I] [X]. A “high loss” represents loss due to high lossy building material like the concrete walls and infrared reflecting glasses etc and a “low loss” represents the loss due to the low loss building materials like wood and generic glasses etc [IX] [I].

In our case, we use standard glass as our reference to O2I penetration loss. This scenario leads to a parabolic loss model [I] given as:

\[ BPL[dB] = 10 \log_{10}(A + B \cdot f_c^2) + N(0, \sigma_p^2) \] (7)

where \(f_c\) is 38 GHz in our scenario, A and B are constants for low loss medium which corresponds to a value of 5 and 0.03 respectively, and the value of \(\sigma_p\) is 4 for our case while, for the high loss their values become 10, 5, and 6 respectively.

**Human Blockage**

The NYUSIM uses a four-state Markov model for human blockage loss [III]. These four states are named as transition rate from unshadowed state to decay state (default value is 0.20 for HPBW of 10°), the transition rate from decay state to shadowed state (default value is 8.08 for HPBW of 10°), the transition rate from shadowed state to rise state (default value is 7.85 for HPBW of 10°) and the transition rate from rising state to unshadowed state (default value is 6.70 for HPBW of 10°). The figure below shows how unshadowed, decaying, shadowed, and rising states are selected by NYUSIM using the four-state Markov model [XII]:

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This four-state Markov model can be mathematically represented by the matrix given below:

$$A = \begin{bmatrix}
1 - \rho_{\text{decay}} & \rho_{\text{decay}} & 0 & 0 \\
0 & 1 - \rho_{\text{shad}} & \rho_{\text{shad}} & 0 \\
0 & 0 & 1 - \rho_{\text{rise}} & \rho_{\text{rise}} \\
\rho_{\text{unshad}} & 0 & 0 & 1 - \rho_{\text{unshad}}
\end{bmatrix} \quad (8)$$

The transition from one state to another can also be denoted linearly by equations given below:

$$\lambda_{\text{decay}} = 0.2 \quad (9)$$
$$\lambda_{\text{shad}} = 0.065 \times \text{HPBW} (\degree) + 7.425 \quad (10)$$
$$\lambda_{\text{rise}} = 0.05 \times \text{HPBW} (\degree) + 7.35 \quad (11)$$
$$\lambda_{\text{unshad}} = 6.7 \quad (12)$$

IV. Simulation Environment and Result Discussion

Our study mainly focusses on the impact of human shadowing loss and O2I penetration loss on 38 GHz mmWave bands. We considered a 38 GHz carrier frequency in the NLOS UMi environment with an RF bandwidth of 800 MHz. A standard (10-500 m) distance range with the upper bound distance of 150m and a lower bound separation of 150m is selected. The transmitter power is selected is 30 dBm with the transmitter height of 35 meters and the user terminal height of 1.5 meters is selected. The number of receiver location is selected as 1 as we’re using a single receiver. Talking about the environmental condition the barometric pressure of 1013.25 mbar is selected with the humidity of 50% and a temperature of 20 degrees Celsius is selected. Similarly, foliage attenuation of 0.4 TB per meter is selected and O2I penetration loss is selected as yes with the low loss medium. Talking about the antenna properties the

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transmitter and the receiver antenna type are selected is uniform linear array (ULA) type with the number of antenna elements on the transmitter and receiver side it is kept as 4. Both the transmitter and receiver antenna spacing is kept is 0.5 λ while the antenna is azimuth for both the transmitter and receiver is kept is 10 degrees while the elevation is also kept as 10 degrees. Talking about the human block is parameters the attenuation is kept is 14.4 dB while the transition rate from a Shadow to decay is kept is 0.2 per sec, the transition rate from decay to Shadow is kept is 8.08 per second, the 7.85 per second and transition rate from rising to a Shadow is kept as 6.70 per second. These properties are summarized in Table. 1.

Table 1: Characteristic Properties of Channel.

| Environment | Carrier Frequency | Scenario | Humidity |
|-------------|-------------------|----------|----------|
| UMi         | 28, 38, 60 and 73 GHz | NLOS     | 50%      |
| R Location  | TR Azimuth Angle  | BS height| Rain Rate|
| 1           | 10°               | 35m      | 5 mm/hr  |
| R Elements  | TR Elevation Angle| Separation| Polarization|
| 4           | 10°               | 150m     | Co-Pol   |
| T Elements  | TR Array Spacing  | Array Type| Foliage loss|
| 4           | 0.5λ              | ULA      | 0.4dB/m  |
| O2I Loss    | Tx power          | UT height| RF band width|
| Yes         | 30 dBm            | 1.5m     | 800 MHz  |
| Loss type   | Human blockage    | Mean att. | Shadow to decay|
| Low loss    | Yes               | 14.4 dB  | 0.2/sec  |
| Shadow to rise | Rise to shadow | Default | Decay to shadow|
| 7.85/sec    | 6.7/sec           | No       | 8.08/sec |

Angle of Departure

AoD illustrates the position of multipath components (MPCs) at which the power of the signal is communicated from Tx. The NYUSIM utilizes time cluster (TC) and spatial lobe (SL) technique to sample the Omni-directional channel impulse response as well as the corresponding 3D power spectra of AoA and AoD. TC is a group of multipath components (either from the same or different angular directions) traveling in a definite interval of time (propagation time window). SL is the main direction of arrival or departure where energy is received or sent in several hundred nanoseconds. The discussion begins with Fig. 2 which shows the 3D representation of 38GHz frequency in the NLOS UMi environment with human blockage loss and O2I penetration loss.

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The 3D graph of Fig. 2 shows that a single SL is formed with 117 multi-path components (MPCs). In our previous study [XII] where we ignored the loss due to human and O2I penetration, there were 3 spatial lobes formed with 33, 27, and 33 multipath components (MPCs) respectively, each MPC comprises 5 different resolvable multipath components named as path delay (ns), path power (mW), the phase difference (rad), AoD (deg) and the zenith of departure (ZoD) in degrees.

**Angle of Arrival**

The AoA shows the angle of multi-path components at which power arrives at the receiver. Each multipath component in the AoA is composed of 5 resolvable multipath components just like the angle of departure and are named path delay (ns), pathPower (mWatts), pathPhase (rad), AoA (degree), and ZoA (degree). Figure 3 shows AoA of 38 GHz which shows that 4 SL is formed with 40, 23, 31, and 23 MPCs respectively. Comparing it to our previous study [XXVIII] we also obtain 4 SL in the 3D plot of 38 GHz band which comprises 26, 27, 19, and 21 multipath components respectively.
Directional Power Delay Profile

A power delay profile determines the transmission of the received signal at the receiver with fluctuating signal strength as it is transmitted through a multipath channel with larger propagation delays. Figure 4 shows the directional power delay profile. According to the plot the received power is -77.5 dBm, propagation delay is 1.4 ns, the directional path loss is 156.8 dB and the directional path loss exponent is 4.3. The difference from the previous study [XII] is summarized under Table. 2 where the same band has the received power of -47.4 dBm, the propagation delay of 3 ns, the directional path loss is 126.6 dB and the directional path loss exponent is 2.9.

Fig. 3: Angle of Arrival of 38 GHz band.

Fig. 4: Directional PDP.

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Table 2: Directional Power Delay Profile.

| Directional Delay Profile |
|-----------------|-----------------|-----------------|-----------------|
| Frequency        | $P_r$ (dBm)     | $\sigma_r$ (ns) | PL (dB)         |
|-----------------|-----------------|-----------------|-----------------|
| 38 GHz with losses | -77.5           | 1.4             | 156.8           |
| 38 GHz without losses | -47.4           | 3.0             | 126.6           |

Omni-directional Power Delay Profile

The Omni-directional power delay profile is given in Figure 4, according to which the received power is -124.3 dBm, propagation delay is 11.9 ns, Omni-directional path loss is 154.3 dB and the Omni-directional path loss exponent is 4.1. Comparing it to our previous results where the received power is -93.2 dBm, propagation delay is 41.8 ns, Omni-directional path loss is 123.2 dB and the Omni-directional path loss exponent is 2.7. These are summarized in Table 3 in which one can notice a significant difference in the received power, path loss, and path loss exponent.

Fig. 5: Omni-directional PDP.
Table 3: Omni-directional delay profile.

| Frequency             | $P_r$ (dBm) | $\sigma_T$ (ns) | PL (dB) | PLE |
|-----------------------|-------------|-----------------|---------|-----|
| 38 GHz with losses    | -124.3      | 11.9            | 154.3   | 4.1 |
| 38 GHz without losses | -93.2       | 41.8            | 123.2   | 2.7 |

Small-Scale Power Delay Profile

Small scale power delay profile is given in Fig. 5. As we consider a 4×4 system having an inter-antenna element spacing of 0.5$\lambda$, therefore, a small scale power delay profile shows the small-scale properties (i.e. received signal power and propagation delay) of all antenna elements 38 GHz. The maximum propagation delay for the 38 GHz is 2494.8 ns while the maximum power received is -126.76 dBm. Comparing it to our previous analysis for 38 GHz without a lossy medium, the maximum propagation delay was 2061 ns and the maximum power received power for 38 GHz was -96.634 dBm. These differences due to the inclusion of human blockage loss and outdoor to indoor loss can be summarized under the Table. 4 where one can notice that considering the human blockage loss and outdoor to indoor loss can attenuate the received power.

Fig. 6: Small-scale PDP.
Table 4: Summary of the Small-Scale PDP.

| Band                      | Max Propagation Delay | Max Received Power |
|---------------------------|-----------------------|--------------------|
| 38 GHz with losses        | 645 ns                | -102.87 dBm        |
| 38 GHz without losses     | 2061 ns               | -96.634 dBm        |

Pathloss

Pathloss is the measure of power attenuation of signal as it moves from the transmitter to the receiver in the presence of power attenuators like rain, haze, and other things which can cause signal attenuation. Fig. 6 shows the Pathloss of 38 GHz band in the presence of human blockage loss and outdoor to indoor loss. The directional and Omni-directional path loss is shown in the plot generated by NYUSIM for which the transmitter’s half-power beamwidth azimuth and elevation are kept at 10°. Similarly, the receiver’s half-power beamwidth azimuth and elevation are also at 10°, while the antenna gain for both the transmitter and receiver is 24.6 dBi. The plot also shows path loss, path loss exponent and shadow fading standard deviation for directional, Omni-directional, and directional with the strongest power received (denoted by dir-best in the legend of the plot). The difference in the directional and Omni-directional path loss is due to the higher loss in directional antenna as compared to the Omni-directional antenna. The path loss can be summarised in the Table. 5 where one can notice the difference in the received power due to the inclusion of human blockage loss and outdoor to indoor loss.

![Fig. 7: Pathloss.](image)

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Table 5: Summary of the pathloss plots.

| 38 GHz Band | Directional best PL (dB) | Omnidirectional PL (dB) | PLE Directional best | PLE Omnidirectional |
|-------------|--------------------------|-------------------------|----------------------|---------------------|
| With losses | 156.8                    | 154.3                   | 4.3                  | 4.1                 |
| Without losses | 126.6                  | 123.2                   | 2.9                  | 2.7                 |

V. Conclusion

The deep analysis of different mmWave bands (28, 38, 60, and 73 GHz) has already been done in our previous paper which concludes that the received power is maximized for 38 GHz band. Similarly, a minimum path loss and path loss exponent is observed for the same band using both the directional and Omni-directional antennas. Minimum propagation delay is also observed for 38 GHz thus, making the 38 GHz band as the best candidate frequency among 28, 38, and 60 GHz. But in our previous study, we consider an ideal situation where we didn’t consider the realistic situation where losses due to human and vehicular blockage could occur. So, to execute more realistic simulations, we consider the human blockage and outdoor to indoor losses for simulating the best candidate frequency i.e. 38 GHz.

The purpose was to find the impact of these losses on the previous analysis of the 38 GHz band. The impact of the losses was much more significant than our expectations. These losses not only decrease the number of spatial lobes in Angle of Departure from 3 SL to 1 SL. AoA SL number was the same, the only difference was in the number of MPCs formed. The directional path loss and PLE in directional power delay profile are significantly increased and the received power is decreased due to human blockage loss and O2I penetration loss as shown in Table. 2. The Omni-directional power delay profile also indicates that the received power is decreased and path loss and PLE are increased due to the human blockage loss and O2I penetration loss as shown in Table. 3. Table. 4 shows the small-scale PDP where power received is less than the previous study. Table. 5 summarizes the path losses both the directional and Omni-directional as well as the path loss where maximum power received (dir-best) which also shows the path loss is increased.

Hence, we conclude that the Human Blockage Loss and Outdoor to Indoor (O2I) Penetration loss have a great impact on any mmWave bands as these bands are highly susceptible to the external environment. The impact of the Human Blockage Loss and Outdoor to Indoor (O2I) Penetration loss on 38 GHz is significant. Thus, modeling any 5G models needs to incorporate these losses as well as others. This research will help the 5G network modelers to accurately model the next generation of mobile communication networks.

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Conflict of Interest:

There is no conflict of interest regarding this article.

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