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Performance Analysis Of Millimeter-Wave Pathloss Propagation Models For 5G Network In An Indoor Environment

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Abstract : *This paper implores analytical approach to evaluate the levels of propagation losses encountered by the millimeter wave signals in an indoor environment. Free space model, Alpha-Beta-Gamma (ABG) Path loss model, Close-In (CI) model, Stanford University Interim (SUI) Model and Ericsson Model were incorporated for the analysis.Various millimeter wave propagation frequencies operating at 28GHz, 38GHz, 60GHz, 73GHz were deployed in the study with distances ranging from 1m to 5m to determine the varying signal pathloss. Different physical propagation mediums such as the vacuum/Air, Concrete, Wood, Glass, Ceiling Board, Metal and Brick walls were investigated to ascertain the varying penetration losses.The results obtained showed that ABG propagation model stands as the most suitable for indoor application, having the lowest penetration loss followed by the CI model. The Ericsson model was characterized as the model with the highest penetration loss.*

Keywords*-mmWave, Pathloss, Penetration Loss, Propagation Model, Radio Transmission, 5G.*

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I. Introduction

Wireless communication technology has evidently played weighty roles in day-to-day life and has become an integral part of human daily activities and transactions. Its significance has brought about the continual and increase in the demand of high data rate services integrated with enhanced potentials. In recent times, the volume of mobile data traffic was observed to have increased at a rapid pace and based on research studies, there is prediction that this exponential growth will continue in the near future owing to the high demand. The recently deployed Fourth Generation (4G) technology even though has reduced latency and increased data rate could not meet the present needs [1]. More and more devices are being interconnected for data transmission purposes, hence, reduced latency with faster data rates are required in this regard. To address this demand, the evolution of the Fifth Generation (5G) technology has the potentials to bridge the limiting performance of 4G technology using millimeter wave (mmWave) frequencies to offer unprecedented high spectrum performance.

Millimeter wave communication is one of the most promising technologies in fifth generation (5G) mobile networks due to its access to a large amount of available spectrum resources. The 5G is targeted to achieve a high speed of 10Gbps, low power, low latency of less than 1ms, enhanced connectivity, massive Internet of Things (IoT), tactical internet and robotics [2]. This 5G network is believed to establish a reliable communication between machines (M2M), vehicle-to-vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications, ultra-broadband applications. All which will require extremely low network latency and on-call demand for large bursts of data over minuscule time epochs [2]. Despite the theoretical potential of 5G earlier mentioned, the technology is faced with some key technical challenges using mmWave in mobile networks. Some of the challenges include severe pathloss, high penetration loss and narrow beamwidth. Others are atmospheric gases attenuation (water vapour absorption, oxygen absorption), precipitation attenuation (rain, fog),scattering effects (reflections, refraction),multipath,diffraction,blockage (foliage, buildings, towers) both in indoor and outdoor scenarios [3].

Evaluation of Signal strength losses at different points between the transmitter and the receiver remain an important factor to consider during the deployment of 5G network. The difference in signal strength between the transmitter and the receiver is referred to as path loss. This paper investigates the penetration losses encountered on different physical properties in an indoor geolocation using the following mmWave frequencies; 28GHz, 38GHz, 60GHz and 73GHz. Analytical approach incorporating different existing models namely; Free Space model, Close-in model, Alpha-Beta-Gamma (ABG) model, Stamford University Interim model and Ericsson model were introduced to establish the most suitable model for indoor application.

Radio Path Loss Propagation Models

Several radio propagation models are deployed for analysis of signal performance in 5G communication network for indoor application. Some of them include Free space model, Alpha-Beta-Gamma (ABG) Path loss model, Close-In (CI) model, Stanford University Interim (SUI) Model and Ericsson Model.

(a) Free space model

Free space is an ideal path loss model for our analysis because it is dependent on only frequency and distance.A path loss in Free Space L defines how much strength of signal is lost during propagation from transmitter to receiver. Free Space Model is diverse on frequency and distance.It is calculated by using equation (1) [4].

$$L = 32.45 + 20\log(d) + 20\log(f) \qquad (1)$$

Where d is the propagation distance (m), f is the frequency(GHz)

(b) Alpha-Beta-Gamma (ABG) Path Loss Model

The ABG is suitable for 5G communication where a high precision model has to be set up without a complete set of measurement being available for all frequencies and geographical locations. The ABG is specifically used for indoor propagation because it is observed to predicts losses at certain frequencies less than the free space model.The equation for the ABG model is given by [5]:

$$PL^{ABG}(f,d)[dB] = 10\alpha\log\left(\frac{d}{1\,m}\right) + \beta + 10\gamma\log\left(\frac{f}{1\,GHz}\right) \qquad (2)$$

Where

$PL^{ABG}(f,d)$ denotes the mean path loss in dB over frequency and distance

α and γ are coefficients showing the dependence of path loss on distance and frequency

β is the optimized offset of the path loss in dB

f is the carrier frequency in GHz

d is the 3D T-R separation distance in meters

(c) Close-In (CI) Path Loss Model

CI is observed to exhibit very stable behavior over frequencies in the GHz range. It is easily implemented in 5G by replacing a floating non-physically based constant that represents free space path loss in the first meter of propagation.The equation for the CI model is given in equation (3) as [5]:

$$PL^{CI}(f,d)[dB] = FSPL(f,1m)[dB] + 10n\,log\left(\frac{d}{1m}\right) \qquad (3)$$

Where

$$FSPL(f,1m)[dB] = 20\log\left(\frac{4\pi f}{c}\right) \qquad (4)$$

$PL^{CI}(f,d)$ is the mean path loss in dB over frequency and distance

n represents the path loss exponent (PLE)

$FSPL(f,1m)$ denotes the free space path loss in dB at a T-R separation distance of 1 m at the carrier frequency, (f),c is the speed of light. By substitution, Equation (3) transforms to (5):

$$PL^{CI}(f,d)[dB] = 32.44 + 20\log(f) + 10n\,log(d) \qquad (5)$$

(d) Stanford University Interim (SUI) Model

Stanford model is an extension to Hata model with additional correction parameters to cover frequencies above 1.9 GHz [4]. Therefore, this model has been proposed in the literature as a solution for the planning of WiMAX/LTE network on a 3.5 GHz band [6][7]. It can be used to cover 5G frequency range.

$$L_p\text{(dB)} = A + 10 \times \gamma \times \log\left(\frac{d}{d_0}\right) + X_f + X_h + S \qquad (6)$$

Where $\gamma = a - b \times h_b + \left({c}/{h_b}\right)$, A = 20 * $\log_{10}\frac{4\pi d_0}{\lambda}$, λ is the wavelength

$$X_f = 6.0 \times \log\frac{f}{2000} \qquad (7)$$

$$X_h = -10.8 \times \log\frac{h_r}{2000} \qquad (8)$$

(e) Ericsson Model

This model is an extension of Hata Okumura model to be used for higher frequencies (i.e. higher than 3GHz). Sometimes, it is called 9999 model [6].

L_p(dB) = $a_0 + a_1 \log(d) + a_2 \log h_b + a_3 \log h_b \times \log(d) - 3.2 \times (\log(11.75 \times h_m))^2$ + g(f) (9)

Where g(f) = $44.49 \times \log(f) - 4.78 \times (\log(f))^2$ (10)

And $a_0 = 43, a_1 = 68, a_2 = 12, a_3 = 0.1$ *all for suburban areas*

Where d= 1m - 5m, $h_b = 15m$ and $h_m = 3m$

Penetration Loss

According to [8], The attenuation for different materials is calculated from the real values of permittivity and conductivity of the materials. Table 1, illustrates different loss values for different materials.

Table 1:Penetration Loss Values [8]

Material	Real Part of Relative Permittivity		Conductivity	
	a	**b**	**c**	**d**
Vacuum(Air)	1	0	0	0
Concrete	5.31	0	0.0326	0.8095
Wood	1.99	0	0.0047	1.0718
Glass	6.27	0	0.0043	1.1925
Ceiling Board	1.50	0	0.0005	1.1634
Metal	1	0	10^7	0
Brick	3.75	0	0.038	0

II. Methodology

This section introduces analytical expressions for different Propagation models aimed at evaluating the variances in pathloss for indoor applications. Distance of 1 to 5 meters was chosen for frequencies (f) =28GHz, 38GHz, 60GHz and 73GHz. Table 2-6 present the computed pathloss for Free Space Model, Close-In Model, ABG Model, Stanford University Interim Model and Ericsson Model using equations 1-9 respectively

Table 2: Free Space Model

f/d	28GHz	38GHz	60GHz	73GHz
1m	61.39dB	64.05dB	68.01dB	69.72dB
2m	67.41dB	70.07dB	74.03dB	75.74dB
3m	70.94dB	73.59dB	77.56dB	79.26dB
4m	73.43dB	76.09dB	80.05dB	81.76dB
5m	75.37dB	78.03dB	81.99dB	83.70dB

Table 3: Close-In Model

f/d	28GHz	38GHz	60GHz	73GHz
1m	61.38dB	64.04dB	68.00dB	69.71dB
2m	68.91dB	71.56dB	75.53dB	77.23dB
3m	73.31dB	75.96dB	79.93dB	81.63dB
4m	76.43dB	79.09dB	83.05dB	84.76dB
5m	78.68dB	81.51dB	85.48dB	87.18dB

Table 4: ABG Model

f/d	28GHz	38GHz	60GHz	73GHz
1m	58.75	65.65	75.96	80.39
2m	61.31	68.21	78.52	82.95
3m	62.81	69.70	80.02	84.45
4m	63.87	70.77	81.08	85.51
5m	64.69	71.59	81.91	86.33

Table 5: Stanford University Interim Model

f/d	28GHz	38GHz	60GHz	73GHz
1m	98.756dB	102.172dB	107.363dB	109.594dB
2m	119.966dB	123.242dB	128.432dB	130.664dB
3m	132.153dB	135.512dB	140.759dB	142.991dB
4m	140.896dB	144.262dB	149.503dB	151.734dB
5m	147.686dB	151.102dB	156.293dB	158.524dB

Table 6: Ericsson Model

f/d	28GHz	38GHz	60GHz	73GHz
1m	152.776dB	152.95dB	152.90dB	152.77dB
2m	173.280dB	173.45dB	173.41dB	173.28dB
3m	185.272dB	185.44dB	185.40dB	185.27dB
4m	193.872dB	193.95dB	193.91dB	193.78dB
5m	200.388dB	200.55dB	200.51dB	200.38dB

III. Results And Discussion

In an indoor environment, characterized of different physical materials where millimeter wave signals are expected to propagate through, there is this certainty that the signals could encounter different levels of penetration loss due to the physical properties. The variance in the physical properties affects the signal performances differently which is also dependent on the frequency of operation. Table 7 showed different computed penetration losses in relation to the physical materials and frequency of operation.

Table 7: The penetration loss with reference to the operating frequencies and physical materials

Materials	28GHz	38GHz	60GHz	73GHz
Vacuum/Air	0	0	0	0
Concrete	344.00 dB/m	440.65 dB/m	637.82dB/m	747.48 dB/m
Wood	193.87dB/m	268.95 dB/m	438.8 dB/m	541.74 dB/m
Glass	149.36 dB/m	214.97 dB/m	370.71 dB/m	469.2 dB/m
Ceiling Board	32.23 dB/m	45.97 dB/m	78.21 dB/m	98.40 dB/m
Metal	16.36e9 dB/m	16.36e9 dB/m	16.36e9 dB/m	16.36e9 dB/m
Brick	32.11dB/m	32.11dB/m	32.11 dB/m	32.11 dB/m

Table 8: Mean Free Space Model Path Loss + Penetration loss

	28GHz	38GHz	60GHz	73GHz
Vacuum/Air	69.71 dB	72.37dB	76.33dB	78.03dB
Concrete	413.71dB	513.02dB	714.15dB	825.51dB
Wood	263.58dB	341.316dB	515.13dB	619.77dB
Glass	219.07dB	287.34dB	447.04dB	547.23dB
Ceiling Board	101.94dB	118.34dB	154.54dB	176.43dB
Metal	16.36e9 dB	16.36e9 dB	16.36e9 dB	16.36e9 dB
Brick	101.82dB	104.48dB	108.44dB	110.14dB

Table 9: Mean SUI Path loss + Penetration loss

	28GHz	38GHz	60GHz	73GHz
Vacuum/Air	127.89dB	131.26dB	136.47dB	138.70dB
Concrete	471.89dBB	571.91dB	774.29dB	868.18dB
Wood	321.76dB	400.21dB	575.27dB	680.44dB
Glass	277.25dB	346.23dB	507.18dB	607.9dB
Ceiling Board	160.12dB	177.23dB	214.68dB	237.1dB
Metal	16.36e9 dB	16.36e9 dB	16.36e9 dB	16.36e9 dB
Brick	160dB	163.37dB	168.58dB	170.81dB

Table 10: Mean Ericsson Path loss + Penetration loss

	28GHz	38GHz	60GHz	73GHz
Vacuum/Air	181.01dB	181.27dB	181.23dB	181.10dB
Concrete	525.1dB	621.92dB	819.05dB	928.58dB
Wood	374.97dB	450.22dB	620.03dB	722.84dB
Glass	330.46dB	396.24dB	551.94dB	650.3dB
Ceiling Board	213.33dB	227.24dB	259.44dB	279.5dB
Metal	16.36e9 dB	16.36e9 dB	16.36e9 dB	16.36e9 dB
Brick	213.21dB	213.38dB	213.34dB	213.21dB

Table 11: Mean CI Path loss + Penetration loss

	28GHz	38GHz	60GHz	73GHz
Vacuum/Air	71.74dB	74.43dB	78.4dB	80.1dB
Concrete	415.74dB	515.08dB	716.22dB	827.58dB
Wood	265.61dB	343.38dB	517.2dB	621.84dB
Glass	221.1dB	289.4dB	449.11dB	549.3dB
Ceiling Board	103.97dB	120.4dB	156.61dB	178.5dB
Metal	16.36e9 dB	16.36e9 dB	16.36e9 dB	16.36e9 dB
Brick	103.85dB	106.54dB	110.51dB	112.21dB

Table 12: Mean ABG Path loss + Penetration loss

	28GHz	38GHz	60GHz	73GHz
Vacuum/Air	62.29dB	69.18dB	79.5dB	83.93dB
Concrete	406.29dB	509.83dB	717.32dB	831.41dB
Wood	256.16dB	338.13dB	518.3dB	625.67dB
Glass	211.65dB	284.15dB	450.21dB	553.13dB
Ceiling Board	94.52dB	115.15dB	157.71dB	182.33dB
Metal	16.36e9 dB	16.36e9 dB	16.36e9 dB	16.36e9 dB
Brick	94.4dB	101.29dB	111.61dB	116.04dB

Tables 8-11 represent the average propagation loss (dB) for indoor environment, obtained as the Mean path loss plus the penetration loss for the designated mmWave frequencies. It is important to note that high penetration loss significantly degrades the data rate, spectral efficiency and energy efficiency. The tables illustrate the various levels of reflectivity with the mmWave when interacting with different materials. It is observed that metals have the highest propagation loss followed by the concrete and the glass materials. Similarly, the vacuum/air, brick walls and metal attenuation values are somewhat independent of the different frequencies used due to the slight variations observed with respect to the frequencies. The brick walls exhibit the most suitable with the lowest propagation loss followed by the ceiling board which is a relatively good material because of its low penetration loss even though its values slightly change with frequency. Metals exhibit total internal reflection when waves strike on it, that is why the attenuation values is very. They are best employed as waveguides.

Propagation analysis remains significant to identify the preferred propagation models for indoor application. From the computed values as presented in Tables 8-11, apart from the free space model which theoretically is assumed not being influenced by any external element, it is observed that the ABG propagation model stands as the most suitable with the lowest penetration loss followed by the CI model for indoor applications. Figures 1-5 demonstrate the mean propagation losses for the different materials deployed. Furthermore, for mmWave frequency of 28GHz and 38GHz, ABG model gives the lowest values of propagation losses even better than the free space model while Ericsson model gives the highest values of losses. For the 60GHz and 73GHz, the free space path loss model gives the lowest values of propagation losses and the Ericsson model gives the highest values of propagation losses. Based on the obtained results, it can be deduced that the ABG Model is best suited for propagation in the 28GHz and 38GHz frequency band while the Ericsson model is not recommended for use in indoor application. It is important alsoto state that the study did not incorporate for other losses such as foliage and atmospheric losses which are considered negligible in indoor propagation.

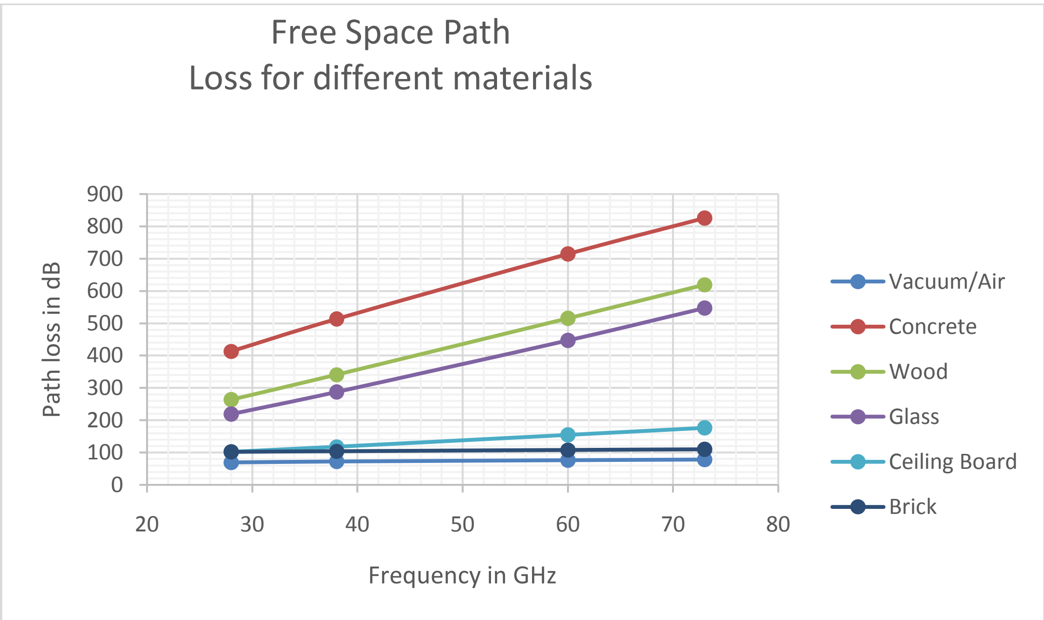

Fig 1: Plot of Pathloss(dB) at 28GHz, 38GHz, 60GHz, 73GHz for FS

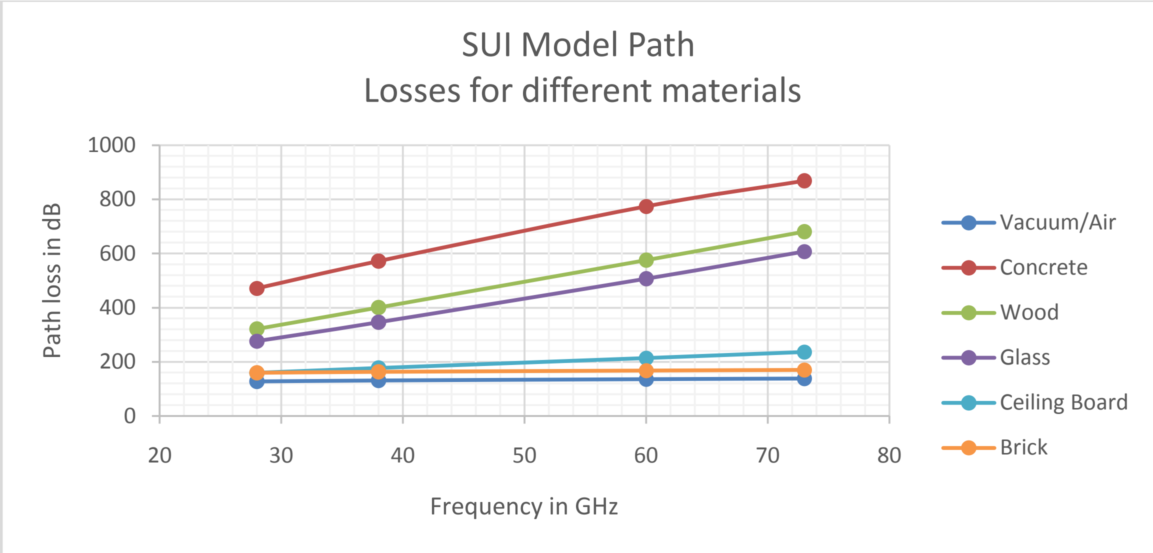

Fig 2: Plot of Pathloss(dB) at 28GHz, 38GHz, 60GHz, 73GHz for SUI

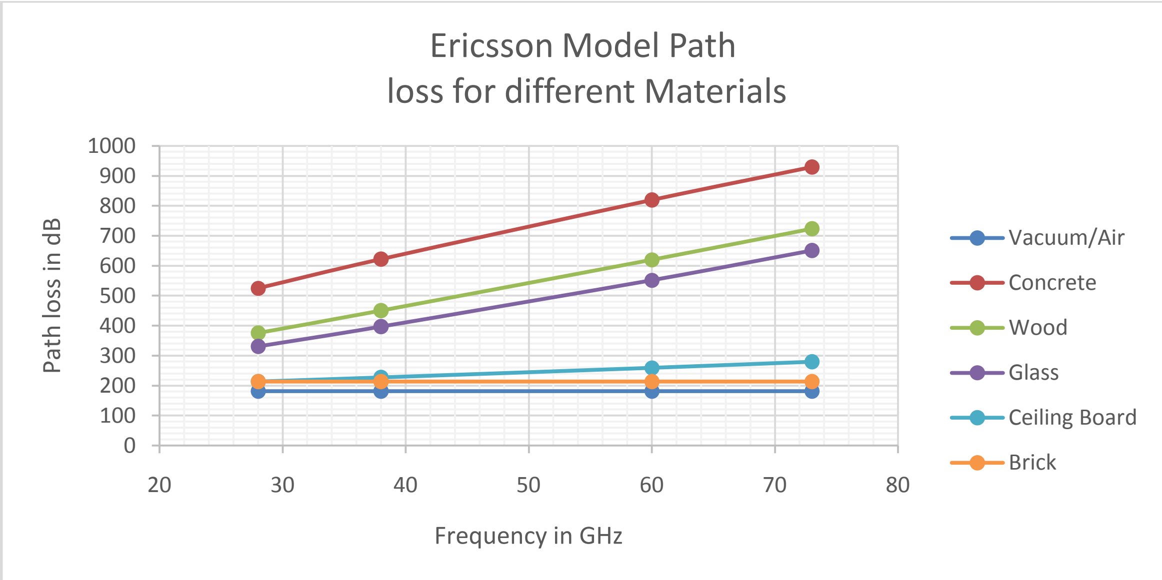

Fig 3: Plot of Pathloss(dB) at 28GHz, 38GHz, 60GHz, 73GHz for Ericsson

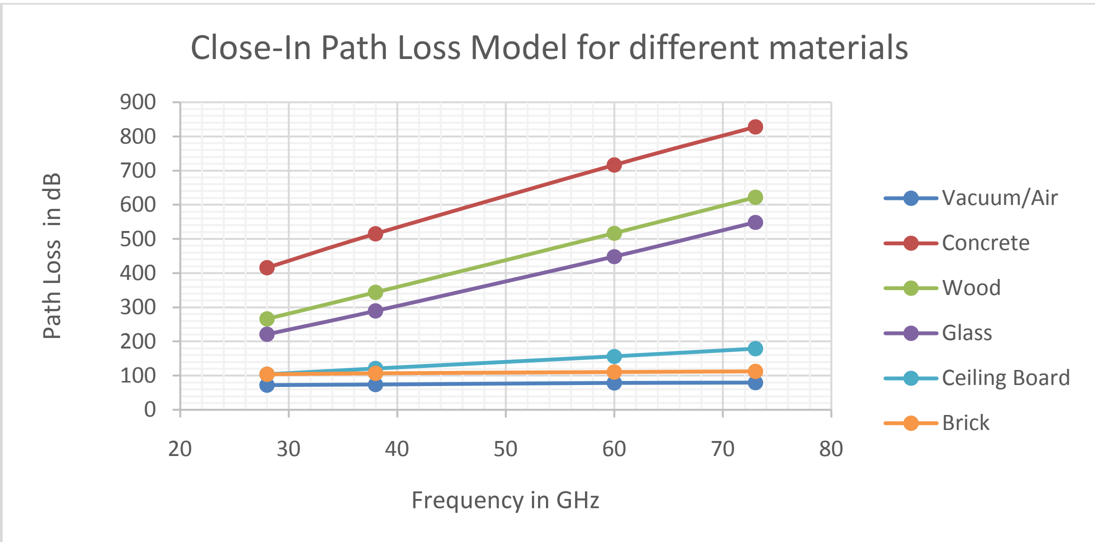

Fig 4: Plot of Pathloss(dB) at 28GHz, 38GHz, 60GHz, 73GHz for CI

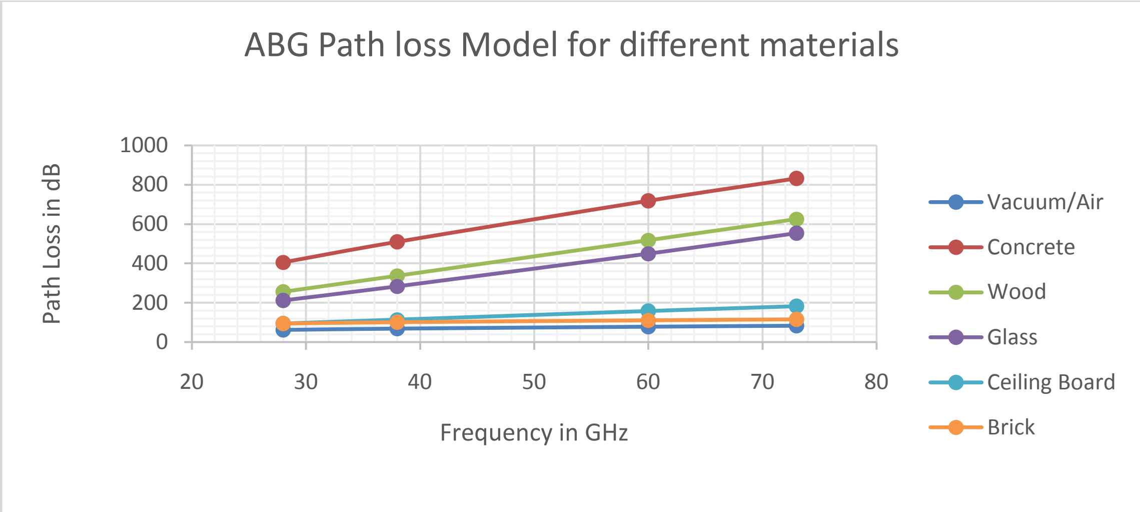

Fig 5: Plot of Pathloss(dB) at 28GHz, 38GHz, 60GHz, 73GHz for ABG

IV. Conclusion

Analytical approach was incorporated in the study to obtain the various levels of propagation losses encountered by the millimeter wave signals in an indoor environment. The study considered the following propagation models viz Free space model, Alpha-Beta-Gamma (ABG) Path loss model, Close-In (CI) model, Stanford University Interim (SUI) Model and Ericsson Model. Millimeter wave propagation frequencies operating at 28GHz, 38GHz, 60GHz, 73GHz were deployed in the study with distances ranging from 1m to 5m. This was significant to determine the varying signal pathloss. Various levels of reflectivity with mmWave signals for different materials were represented with metals exhibiting the highest propagation loss followed by the concrete and glass materials. The brick walls with the lowest propagation loss is considered most appropriate for mmWave signals followed by the ceiling board. ABG model was evaluated as the model with the lowest propagation loss at 28GHz and 38GHz. And also, as the best and suitable model for mmWave signals than all other studied models while Ericsson model which gave the highest values of propagation loss is considered as not suitable model for the mmWave deployment for indoor deployment. It becomes important to introduce correction factors to improve the limiting performance of the existing models that exhibited poor performance in indoor application owing to the rising need to implement mmWave frequencies for future applications

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