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Investigation of QoS Performance Evaluation over 5G Network for Indoor Environment at Millimeter Wave Bands

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***Abstract*—One of the crucial advancements in next-generation 5G wireless networks is the use of high-frequency signals specifically those are in the millimeter wave (mm-wave) bands. Using mm-wave frequency will allow more bandwidth resulting higher user data rates in comparison to the currently available network. However, several challenges are emerging (such as fading, scattering, propagation loss etc.), whenever we utilize mm-wave frequency wave bands for signal propagation. Optimizing propagation parameters of the mm-wave channels system are much essential for implementing in the real-world scenario. To keep this in mind, this paper presents the potential abilities of high frequencies signals by characterizing the indoor small cell propagation channel for 28, 38, 60 and 73 GHz frequency band, which is considered as the ultimate frequency choice for many of the researchers. The most potential Close-In (CI) propagation model for mm-wave frequencies is used as a Large-scale path loss model. Results and outcomes directly affecting the user experience based on fairness index, average cell throughput, spectral efficiency, cell-edge user's throughput and average user throughput. The statistical results proved that these mm-wave spectrum gives a sufficiently greater overall performance and are available for use in the next generation 5G mobile communication network.**

***Keywords*—5G; millimeter wave; CI-path loss; propagation channel; channel characterization; small cell**

I. Introduction

TREMENDOUS innovations have been observed in recent communication methods due to its ability to easily and effortlessly transfer information over either short or long distances. The current solutions are not able to fulfill the higher user data demands. This leads to increase in demand of service to users with high-quality service, higher data rates for audio/video streaming and lower energy consumption for wireless devices. Studies suggest that this demand will grow exponentially with time as more and more devices are increasing with the requirement of higher data rates [1, 2]. Universal Mobile Telecommunication System (UMTS) [1] projected an increase in overall traffic to at least 800 Mbps/subcarrier by the year 2020. A similar trend is presented by IC insights [2] where the author predicts that the annual subscription of cellular systems worldwide may cross the 8.2 billion mark by 2018. In order to address future demands, the next generation networks need to be innovated and designed to avoid any gap between users demand and available resources. In this regard, 5G potentials cannot be overlooked which plans are able to fulfill the futures network demands. However, 5G is still in research phase but researchers are working unremittingly on the advancements of 5G which can ultimately answer the future demands. Some of the promising features of 5G offers are higher data rates for close proximity users (indoor office users) of up to 1 Gbps while adequate data rates of 100 Mbps for vast open areas, less source-to-user delay times that is less than 1 ms as compared to LTE-Advance, ability to connect and control thousands of wireless sensor network (WSN) devices simultaneously [3, 4]. Moreover, the achieved data rate of 1 Gbps is a minimum settled value but it targeted for up to 20 Gbps data rate [5]. The 5G design will have the capability to seamlessly integrate with other future generation networks including high-frequency mm-wave bands [6], small-cell network [7], Device to Device Communication (D2D) [8, 9], cooperative and Heterogeneous Network (HetNet) [10, 11], Coordinated Multipoint (CoMP) [12], Internet of things (IoT) [13], Carrier Aggregation (CA) [14], Cognitive Radio (CR) [15], Passive Optical Network (PON) [16], Ad-Hoc Network (AD-HOC) [17, 18], Massive Multiple Input Multiple Output (MIMO) [19] and Non-Orthogonal Multiple Access (NOMA) [20] and smart grids [21].

The basic idea for 5G is to use frequency spectrum above 6 GHz which will provide enough bandwidth to every user that higher data rates are possible [22]. 5G technology can employ cm-waves to mm-waves frequencies ranging from 20 GHz to up to 300 GHz. Frequencies above 6 GHz were already in use for defense and military operations but this is the first time, it will be used in any commercial consumer-based network [23]. The research community around the globe are busy exploring the new horizons of spectrum and frequency channels in the range of 25 GHz to 86 GHz for 5G communication [24]. 5G communication standards and specifications are expected to be finalized and delivered by 2020 as per [25]. Before expecting anything from the 5G feature set, there are still many open problems, which need to be addressed, only then any specification-based standard can be set. Apart from adopting different techniques and a mechanism to support higher data rates e.g. Modulation and coding schemes (MCS), frequency

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channels, media access techniques, MIMO proves to be a promising technique in order to maximize the received signal. Massive MIMO technology exploits multipath propagation phenomena of the environment to use to its own advantage such as minimization of propagation losses, improve channel capacity and provide higher data rates. Due to its simplicity in design and features it offers, it is keeping researchers interested in deploying it in various different technologies as MIMO can be used to provide service to a higher amount of mobile devices simultaneously in a single cell at a single frequency [26]. A communication system using massive MIMO technique will require channels to be accurately modeled as the available models are focused on frequency bands less than 6 GHz and are not appropriate due to random nature of the channel of different frequency bands and wireless channel impairments [27]. The quality of a wireless channel largely depends on the channel impairments as it affects the communication devices the most. Wireless channel impairments are mostly caused by the losses during transmission of the data due to various factors including distance, an environment where the link is, weather conditions, various fading, shadowing and other uncontrolled parameters [28]. These effects combined are termed as path loss, which has an involvement to all those factors mentioned. Path loss modeling may differ for different environments, frequency channels, medium access techniques and other factors. Therefore, different path loss models have been proposed to various scenarios so that a particular model is responsible for a particular set of environment variables.

In this paper, we have optimized the most conventional CI propagation model for path loss in indoor small cell environment proposed by [29, 30]. We evaluate the various network performance parameters such as fairness index, average user throughput, spectral efficiency, cell-edge user throughput and average cell throughput for 28, 38, 60 and 73 GHz frequency band in relation to varying capacity of users. The rest of the paper is organized as follows. Section II illustrates some of the latest pertinent work in this field. Section III highlights the CI propagation path loss system model for large scale. The simulation setup and corresponding results will be discussed in section IV and in the end, we will conclude the paper and propose future work in section V.

II. Related Work

The use of mm-wave spectrum provides great opportunity to increase bandwidth and capacity. However, several channel propagation issues are also affecting in high frequencies transmission, which can be mitigated by knowing the channel performance. Several studies have been done in recent time to examine the behavior of path loss and propagation channel response for high-frequency spectrum. Moreover, various probability-based methods have been proposed recently to optimize the channel for wireless communication using path loss models on various frequency bands. These methods are sometimes presented with experiments and trials conducted operating in a limited environment to verify their hypothesis. Most of the work done in the past is based on current generation systems and operate on frequencies less than 6 GHz [31]. While those path loss models provide experimental results, but as we move to higher frequencies in order to peruse our requirement of higher data rates and future-proof next-generation systems, those models are not sufficient to predict the behavior at a frequency greater than 6 GHz. Some work based on high frequencies channel propagation path loss models for 5G communication are presented in this section.

The frequency spectrum of 60 GHz was explored in [32] for the purpose of HD (high definition) streaming of video in a short range indoor environment imitating a surgical room. The author has devised an IEE 208.15.3c based simple ray tracing model and used it to characterize 60 GHz indoor radio channel. The authors concluded that capability of a system to achieve the required key performance indicators (KPI) for video transmission is strongly related to the environment e.g. a room, corridor or surgical room. Apart from a theoretical model, they also carried out several experiments and published their findings at mm-wave in a short-range indoor environment. In [33], experimental tests in an urban environment have been carried out in 38 and 60 GHz frequency ranges. The measurements were carried out at the University of Texas at the Austin campus with the transmitter to receiver separation distance varying from 19 to 129 meters and many configurations of antenna pointing angles. The paper provides evidence of large multipath delay spread in non-line of sight (NLOS) configuration at 38 GHz and hence providing propagation links with many pointing angles. While 60 GHz has less multipath delay spread, more path loss, and lesser pointing angles availability for the antenna. Beam steering and beam combining methods are proposed in [34] by taking advantage of multipath propagation at 73 GHz in a dense urban environment of New York City to support next-generation cellular communication systems. The results are presented for both line of sight (LOS) and NLOS scenarios for more than 30 transmitters to receiver combinations with varying transmitted-to-receiver separation distances for up to 200 meters. In [35], measurements were recorded at 60 GHz for propagation path loss in an underground mining environment. Short range findings at 5 meters were investigated for LOS scenarios and found out to be similar to those found in other indoor environments. Large indoor environments like railway station and airport terminals were the focus of study in [36]. The authors used 28 GHz band and used steerable directional antennas to measure path loss in LOS and NLOS configuration. The results were presented with boresight angle orientation and transmitter to receiver separation distance which proves the same results for free space path loss and directional path loss model. The authors in [37] have proposed a novel but simple large-scale path loss model for 28 and 73 GHz bands. Cross, co-polarization and combined polarization were used to provide multipath time dispersion data. Also, maximum received power can be achieved by reducing the root mean square delay spread by utilizing different configuration of receiver and transmitter antennas pointing angles. The authors in [38] have tested several material penetration testing at the frequency of 73 GHz including glass doors and windows, closet and steel doors on 21 unique locations. The paper presentation attenuation levels for co-polarized and cross-polarized antennas, in which co-polarized exhibits consistent attenuation levels between 0.8 to 9.9 dB/cm for all the materials tested, while there is some variation in attenuation with cross-polarized antennas. Another channel model for 28 and 38 GHz has been analysis in [39], which uses both omni and a directional antenna. This approach not only estimates the path loss exponents but also gives the time delay, angular spread, and clustering parameters. The path loss exponents and shadow fading factors for CI free space model and floating-intercept (FI) model have been measured for typical indoor office environment at for 28 and 38 GHz frequency spectrum [40]. Its experimental results proved that the CI model is more suitable for this environment as compared to FI model for same standard deviation is used for both models.

III. Large Scale Path Loss Model

Due to the random nature of the wireless channel, the signal behavior is varied when it reaches to the receiver end. Rather than calculating the channel behavior which is a hectic task and require a lot of resources and time, if we are able to predict the nature of the channel by estimating the signal through path loss models, we can optimize it to obtain maximum performance. The path loss model is used to calculate the level of signal attenuation when it is propagating over a wireless channel from the base station to users. It can be estimated by using various models such as stochastic, empirical and deterministic models. Moreover, the path loss model which is based on experimental measurement can offer the best-correlated understanding of the propagation channel for the real-time scenario. Thus, in this paper, we have focused on the most formidable candidate path-loss models for the 5G system, which is the CI free space path loss models [41-43]. The analytical models cited can describe the nature of large-scale propagation path loss with their corresponding distance values at any given frequency bands in the mm-wave region for outdoor as well as indoor scenarios. These models often use *d* as distance to represent 3D separation between transmitter and receiver based on actual measurements. The CI free space reference distance model is dependent on the free space constant and function of frequency which is based on a 1 m standard free space reference distance that guarantees accuracy, stability, and usefulness beyond the limited original number of field measurements with the minimum number of parameters.

The CI path loss model provided in (1) also describe path loss exponent (PLE) which includes single model parameter *n*.

$$PL^{CI}(f,d)[dB] = FSPL(f,d_0) + 10n\log_{10}(\frac{d}{d_0}) + \chi_\sigma^{CI} \tag{1}$$

where the free space path loss of the anchor point is given by:

$$FSPL(f,d_0) = 20\log_{10}\left(\frac{4\pi d_0 f}{c}\right) \tag{2}$$

where c is the speed of light in free space in meters per second and f is the carrier frequency. The large-scale signal fluctuations resulting from large obstacles in the surrounding environment are embedded in the model by the shadow factor χ_σ^{CI}, which is a zero mean Gaussian random variable written as:

$$\chi_\sigma^{CI} = PL^{CI}(f,d)[dB] - FSPL(f,d_0) - 10n\log_{10}\left(\frac{d}{d_0}\right) \tag{3}$$

while its standard deviation σ^{CI} in dB is:

$$\sigma^{CI} = \sqrt{\frac{\sum\left(\chi_\sigma^{CI}\right)^2}{N}} \tag{4}$$

Where χ_σ^{CI} is a zero mean gaussian random variable which is denoted by with standard deviation σ in dB and d_0 is a physical reference distance and N denotes the overall number of measured points in the measurement campaign.

Minimum mean square error optimizing method can be used to analyze the CI path loss model by getting the PLE n that is similar to the collected data along with the minimum error using a real-time applicable fixed point that governs the transmitted power in free space from the Tx antenna to the CI reference distance d_0. The minimum standard deviation and PLE are taken by a minimum mean square error technique as shown in (5) and (6), respectively.

$$n = \frac{\sum\left(PL^{CI}(f,d)[dB] - FSPL(f,d_0)\right)\left(10\log_{10}\left(\frac{d}{d_0}\right)\right)}{\left(10\log_{10}\left(\frac{d}{d_0}\right)\right)^2} \tag{5}$$

$$\sigma_{\min}^{CI} = \sqrt{\frac{\sum\left(PL^{CI}(f,d)[dB] - FSPL(f,d_0) - 10\log_{10}\left(\frac{d}{d_0}\right)n\right)^2}{N}} \tag{6}$$

IV. Results And Discussion

In this section, the different network performance parameters have been calculating to validate the potential of various 5G frequency bands such as 28, 38, 60 and 73 GHz. Here, some simulations have been carried out by using CI propagation path loss model as shown in (1) for indoor LOS environment and PLE (*n*) is used 1.6 as suggested in [44, 45]. For the simulation of a small sized indoor environment, Vienna LTE-A system level simulator based on MATLAB is utilized. There are varying number of users from 10 to 50 exist in each cell including both active and inactive users that are positioned randomly in such a manner that there is equal separation exist and they are scattered over the entire region of the cell.. The classification of active users specify that they are users who are connected to eNodeB (eNB) and also exchanging information or data with eNB, while inactive users are those who are also connected to eNB but not participating in any exchange of information or data. The transmission power of 46 dBm is selected with 4x4 MIMO antenna array configuration utilizing the bandwidth of 40 MHz as per described in . [1]. As it is small cell environment so the eNBs are placed at the 100 m of separation. The eNBs is set at 10 m height and UEs are places at 1 m height from the ground. The user's average speed is set to 5kmph in random directions and no users are configured to be static. The algorithm of PFS (Proportional Fair Scheduling) is utilized for the communication between eNBs [46]. The results presented in this paper describes the network performance by providing estimated values for cell-edge user throughput, average user throughput, fairness index, spectral efficiency and average cell throughput for various number of users in each cell. Table I highlights the parameters used in simulation with their equivalent values.

The presented average user throughput is obtained from varying number of users. In order to calculate the average user throughput, ratio of total number of bits transferred by active users with total transmission time is considered and inactive users are ignored as they are not exchanging any data [14].

Table I
Simulation Parameters

Parameters	Values
Frequency Band	28, 38, 60 & 73 GHz
Channel Bandwidth	40 MHz
No. of Cell users	10, 20, 30, 40, 50
No. of Base Stations	21
Network Scenario	Small cell Indoor LOS
Propagation Model	CI path loss model
PLE (n)	1.6
Network Geometry	Regular Hexagonal Grid
Antenna Type	Tri-Sector Tilted
UE's Speed	5 km/h
No. of Tx Antennas	4
No. of Rx Antenna	4
Scheduling	Proportional Fair (PF)
UE Height	1 m
Antenna Height	10 m
Mode of Transmission	Closed Loop Spatial Multiplexing
Separation between BSs	100 m
Channel Model	Rayleigh fading
Iteration	1000

To keep this in mind, Fig. 1 presents the average throughput of the cell at various users' capacity l including active and inactive users. The exponential decrement of the graph for all frequency bands is obvious because when a number of user's increases, more users share the total cell capacity that causes low average cell throughput [47]. Furthermore, when a number of users are at a minimum of 10, it can clearly be observed that the high frequencies are providing greater average user's throughput, as 73 GHz is achieving the highest data of 23.6 Mbps and 28 GHz can produce the lowest throughput of 20 Mbps as compared to others. However, 38 and 60 GHz frequency band can also able to deliver correlated throughput of 20.7 and 21.3 Mbps, respectively, but cannot reaches to the performance which achieved at 73 GHz. This is because of the availability of higher bandwidth at higher frequency signal band. For the maximum user capacity case which is 50 users, no significant difference is evident between the values, as all frequencies band can able to deliver nearly 5 Mbps for this case. This is due to the congestion of users, which cause restriction of limited bandwidth, when more users demand higher RBs in a single cell.

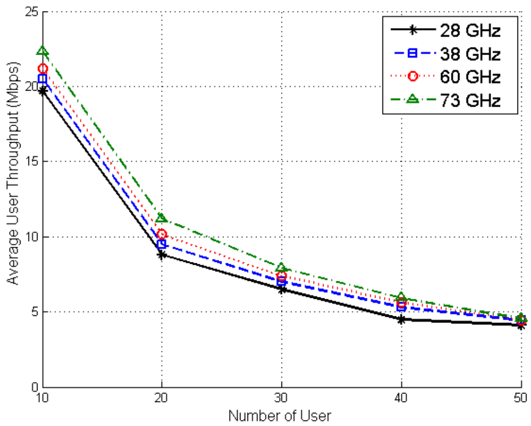

Fig. 1. Number of User vs Average User Throughput

The users that exist on the edge of the cell are clearly, most difficult to serve to. These users cause signal attenuation that reduces received signal strength (RSS) at receivers. This can be caused by penetration losses with distance or interference such as Inter-Cell Interference (ICI) that is the signals from the neighbor segment and Co-Channel Interference (CCI), which is due to the same frequency reuse in the neighbor cells. The outer area of a cell is stated by the help of a threshold value (Ω: outrange users), where the users who have larger distance than Ω is stated as cell-edge users. Figure 2 depicts the throughput performance for the cell-edge users at the different mm-wave frequency band for various user's capacity. The significant decrement in performance of cell-edge users with increasing the user's capacity is not only because of the limitation of RBs but also achieving less RSS value at the cell-edges. Here, it can be seen the 28 GHz frequency range is delivering the upper bound values as compared to all other frequency ranges. It achieved highest cell-edge throughput of 16.2 Mbps at minimum users capacity of 10 users and 3.9 Mbps for the maximum number of 50 users. The 38 and 60 GHz are also giving a acceptable cell-edge throughput of 14.5 and 15.6 Mbps for 10 users and 3.67 and 3.75 Mbps for a higher number of users of 50. On the other hand, the cell-edge performance for the 73 GHz frequency range is the worst as compared to other low-frequency signals. The reason is that high-frequency signals are facing serious penetration and attenuation losses with respect to distance even in the small cell and shadowing and fading losses due to more obstacles present in the indoor environment between the transmitter and receiver.

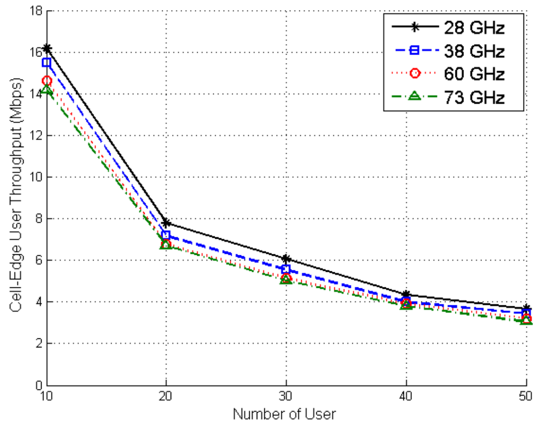

Fig. 2. Number of User vs Cell-Edge User Throughput

The below figure illustrates the affect caused on the average throughput of cell users at higher users' capacity. For minimum number of cell users, the average cell throughput is minimum and it increases slowly when number of users are increased in the cell. This happens because each user is allowed to have large number of resource blocks (RBs) in order to meet its user's requirement. In other words, when number of users increase in a cell, they utilize more resource blocks and therefore, achieve maximum performance in terms of throughput. Figure 3 illustrates the effect of varying number of users with average cell throughput. The lowest throughput is achieved for 10 users while 50 users get causes the cell throughput to increase for all frequency ranges. As discussed in Fig. 1, 73 and 28 GHz frequency band achieving the highest and lowest data rate respectively. The 60 and 38 GHz mm-wave frequency are

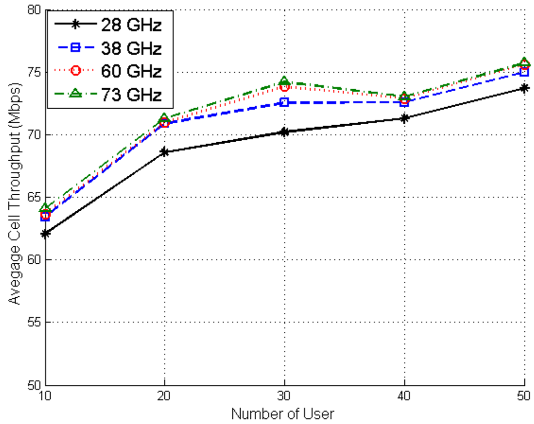

Fig. 3. Number of User vs Average Cell Throughput

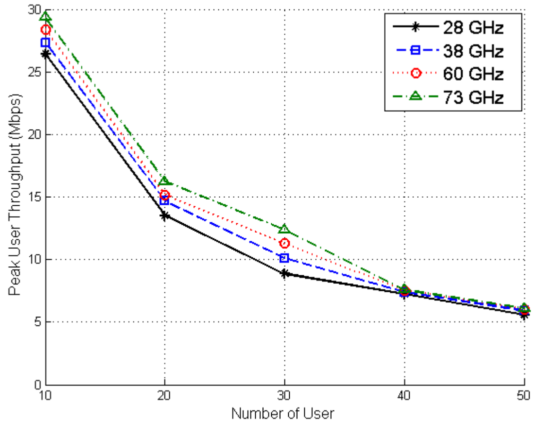

Fig. 4. Number of User vs Peak User Cell Throughput

achieving quite comparable as achieved for 73 GHz. Both achieved approximately 64 Mbps for a minimum of 10 users' case and delivers around 75 Mbps for a maximum of 50 users' capacity. Conversely, the 28 GHz frequency range is getting the lowest overall cell average throughput of 62 to 73 Mbps for highest and lowest users' capacity, respectively. It clearly states that the high-frequency signals deliver better overall performance when working on small indoor network scenario due to the availability of higher bandwidth with less signal attenuation.

The peak user's data rate has defined by the maximum throughput that can be achieved at any point in time by checking the received throughput. It defines the ability of the particular system from highest to average and mean values. Figure 4 explains the relation between the peak user achievable throughputs with respect to various user capacity values. As expected, the peak achieved throughput is maximum for a minimum number of users of 10 and it gradually decreasing with respect to the number of users increases. This is due to the limitation of RBs, when more users are sharing data in a cell, which causes low individual users and overall system throughout and vice versa. As discussed in Fig. 1 and Fig. 3, here also 73 and 28 GHz achieved the maximum and minimum of 30 and 26 Mbps for the minimum case of 10 users, respectively. While 38 and 60 GHz able to deliver a moderate throughput of 27 and 28 Mbps respectively. On the other hand, when the number of users is higher up to 40 users, a number of throughput differences are negligible and all frequency bands are achieving similar throughput of 7 to 5.5 Mbps between 40 to 50 user's value, this is also referred as a breakpoint of the system. This is because the network achieved to its maximum capability to deliver to highest throughput at around 40 users.

The available radio spectrum for the current wireless network is extremely scarce, while the demand for high data services is growing at a rapid pace. Spectral efficiency is therefore of major concern in the design of the future 5G mm-wave network. Spectral efficiency defines the transmission rate for a provided bandwidth in a particular communication network that can be transmitted over a channel. It can also be used to compute the maximum number of users in each cell that the system can support while providing ample amount of bandwidth to each user. Since, for each cell, frequency is very much limited, therefore, only efficient utilization of it will provide minimum bandwidth for smooth performance of the communication system. Results for spectral efficiency in Fig. 5 validates that the spectral efficiency is slighting increasing with respect to the user's capacity higher number of users getting more throughput hence utilizing available spectrum more efficiently. As expected, here also 73 GHz frequency band outperform other frequencies and gives upper bound throughout the user's capacity range. It gives 2.05 b/s/Hz for 10 users and 2.3 b/s/Hz for 50 users. However, 38 and 60 GHz also produce moderate performance and gives correlated results clearly for higher user's capacity in contrast with 73 GHz. Besides that, the 28 GHz frequency is giving the lowest performance of 1.90 and 2.26 b/s/Hz for the minimum and maximum user's capacity, respectively due to inefficient spectrum utilization at lower frequency band.

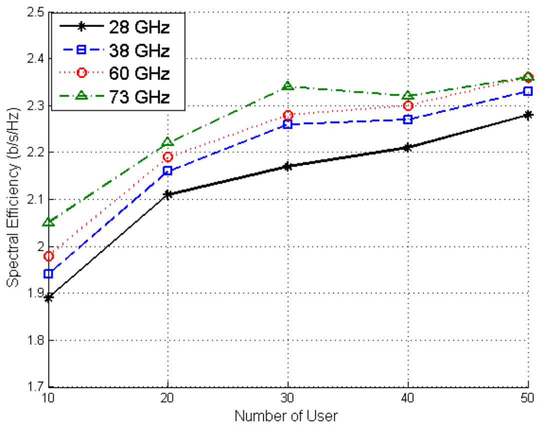

Fig. 5. Number of User vs Spectral Efficiency

The sharing of resources from base station to the users must be fair in any wireless network in order to provide its users equal rights to the bandwidth[48][49][48]. Here, the PF algorithm is used to calculate the fairness among the several users [49, 50]. Figure 9 shows the fairness for different frequency spectrum with respect to various user's capacity. The slight increment in fairness index with increasing the users can understand that fact more users leads to more fair resource distribution causes high fairness index value. It can clearly be observed that the fairness index for 28 GHz is the highest and nearly equal to the 97 %, which defines the better-received signal quality at low frequency with equal RBs distributions among the users. On the other hand, 73 GHz gets the lowest fairness value varying from 93.5 % to 96.4 % for users 10 and users 50, respectively. Moreover, the 60 GHz frequency band also achieving the correlated results as we get in 73 GHz frequency. Though the fairness we get at 38 GHz is 95.5 % for minimum user case of 10, but it reaches to nearly 97 % as achieved for 28 GHz frequency band for a maximum of 50 users. This fairness values simply depends on the resource sharing among different users depending on the variation of the received signal quality, which is, in this case, achieving exceptionally.

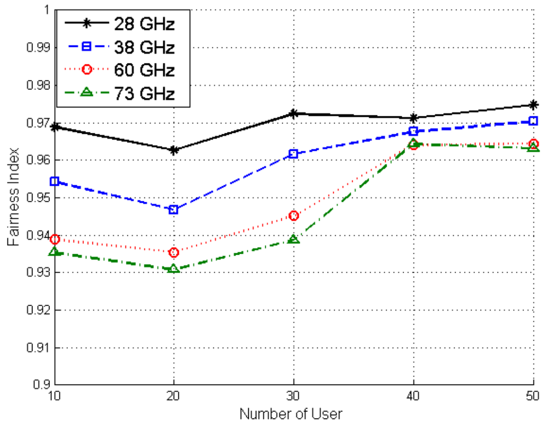

Fig. 6. Number of User vs Fairness Index

V. Conclusion

5G next generation networks cannot be forced to lower frequency bands due to limited bandwidth and operators need to opt for higher frequency bands to meet the requirements for future networks. Higher frequencies provide ample amount of bandwidth but comes with some new challenges that we did not face with lower frequencies. For best level of customer satisfaction and its needs, signal quality from the base-station to the consumer should be increased, so that maximum performance of the network can be achieved. Channel is the only part of the communication system that cannot be controlled but if somehow, we are able to predict the channel behavior and signal propagation characteristics, we can optimize sender and receiver to make out the best of the available channel. To keep this in mind, this article offers a propagation channel findings by characterizing and investigating the ability of 28, 38, 60 and 73 GHz mm-wave frequency for the indoor small cell network. It utilizes the most potential CI model to investigate the channel behavior with various outcomes such as spectral efficiency, average user throughput, fairness index, throughput for cell-edge users and average cell throughput. We analyze that, however, 28 and 38 GHz frequency spectrum has the ability to serve a huge amount of throughput for the future 5G network but by utilizing more high frequencies band such as 60 and 73 GHz, the overall network performance can be much more increased. We are hopeful that findings presented in this paper can be used to test as well as implement 5G in real scenarios for the next-generation mobile network. For future work, various channel characterization like fading and bandwidth at different advance MIMO antenna configuration with more competent propagation model like FI, alpha-beta-gamma (ABG) and frequency-weighted CI (CIF) models will be investigated.

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