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Performance analysis of millimeter wave 5G networks for outdoor environment: propagation perspectives

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ABSTRACT

To cope with the massive growth in global mobile data traffic for 2020 and beyond, the Fifth Generation (5G) system is required to be developed as the current 4G system is expected to fall short behind the provision of such growth. 5G systems is anticipated to use millimeter wave (mm-wave) frequency bands (20 to 90) GHz, due to the availability of wide chunk of unexploited bandwidth. This is revolutionary step to use these bands because of their very different propagation conditions, atmospheric absorption and hardware constraints. However, such challenges could be compensated by means of beamforming/beamsteering and larger antenna array. In this paper, a comparative study aided with ray-tracing simulation has been performed to assess the feasibility of mm-wave in 5G system. Propagation characteristics of the 28GHz and 73 GHz bands have been studied and compared in a street canyon outdoor environment to simulate 5G outdoor mobile access. Simulation results were shown along with their comparison for both of the aforementioned frequencies. The results of propagation comparison have been reported in terms of path loss, k-factor, delay spread and received power for both 28 and 73 GHz bands.

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1. INTRODUCTION

Due to the significant development and the huge use of data hungry devices such as smart phones, tablets, laptop.etc, Global Mobile Data Traffic (GMDT) is forecasted to reach 77 exabytes per month by 2022, which is approximately 7 times the figure of 2017 as shown in Figure 1. Mobile data traffic will have an annual growth rate of 46 % from 2017 to 2022 [1]. Due to the spectrum scarcity at the microwave (MW) bands, there is a need to move to the millimeter wave bands (mm-wave) due to the availability of wide lightly used spectrum ranging from 3 to 300 GHz. These bands are located at 28–30 GHz, 38-40 GHz, the license-free band at 57-71 GHz, in addition to a 12.9 GHz located at the E-band in 71–76 GHz, 81–86 GHz, and 92–95 GHz. These bands could become accessible for 5G system as a candidate solution for achieving 1000 folds capacity increase compared to the current Long Term Evolution Advance(LTE-A) networks [2-5]. Many researches have been conducted in order to study the channel characterization in the mm-wave band. In [6], the authors have conducted a simulation analysis for channel measurements at 60GHz using ray tracing tool in busy urban area, their work is focusing on path loss evaluations to assess the mm-wave propagation in mo0bile access system. A study has been conducted by [7] to measure the impact of polarization on the performance of mm-wave link in an indoor small office. Here, the impact of polarization on angle spread and channel rank is investigated. Furthermore, the characteristics of propagations channels are investigated in [8] using ray tracing at 26GHz, 28GHz and 60GHz with omnidirectional antenna. The author investigated indoor-to-indoor and indoor-to-outdoor scenarios, to measure the received power, direction of arrival and delay spread. The effect of frequency allocation on the performance of mm-wave has been studied in [9], where the authors have used fractional frequency reuse technique to improve the network capacity in outdoor environment. A novel framework for indoor environment in mm-wave has been developed in [10], the authors have provided an indoor approach to support extremely high data rates to indoor users using multi-objective optimization and ray tracing tool. Additionally, the impact of the roughness of the building surfaces on the reflection of mm-wave at 60 GHz has been investigated in [11] using ray tracing technique. Minimizing the shadow fading and improving the coverage probability has been considered in [12] using distributed antennas in an outdoor area at 26 GHz. An extensive ray tracing simulation on mm-wave and terahertz band has been conducted in [13] to study the path loss and propagation characteristics using very detailed environment that comprise building, street furniture, and vegetation. The channel measurements show that object in the channel that is negligible in MW channels can indeed influence mm-wave channel characteristics at higher frequency bands [2, 14].

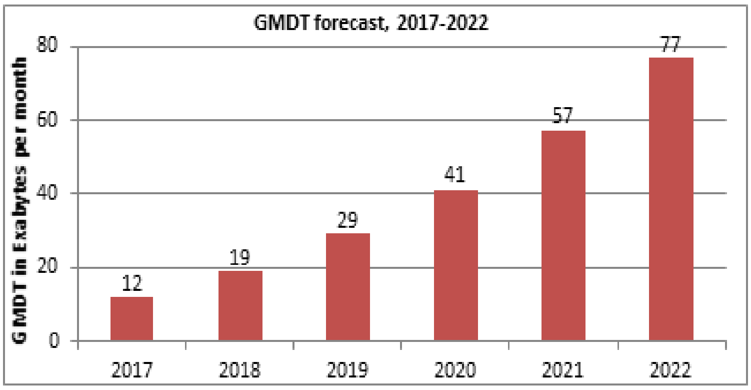


Figure 1. Global mobile data traffic [1]

In this paper, however, an outdoor model has been developed to assess the mm-wave band in outdoor environment. The study has been conducted from propagation perspectives, in order to evaluate the performance of 28 and 73 GHz in terms of received power, path loss, k-factor, and delay spread, by estimating the power delay profile from different receivers. The presented results in this work demonstrate that mobile access at mm-wave are possible and reliable when considering some important factors, such as power, distance, antennas type etc. Two bands from the mm-wave bands were considered; the first band is the 28 GHz, this band has the best performance in term of propagation path loss compared to the higher mm-wave frequencies such as (70, 80) GHz [2], which is the second band considered in this paper. However, the (70, 80) GHz band has a potential wide bandwidth of 10GHz (5GHz at each band) for high speed data compared to the 28 GHz. Therefore; a trade-off should be made when planning 5G network to achieve high spectral efficiency on a hand, and high path gain signal for better propagation characteristics on the other hand [2, 9].This paper is organized as follows. Section 2 presents 5G system motivation and its relative challenges. Section 3 introduces our network model in an outdoor environment and clarifies its geometry. Section 4 explains the simulation results and the system evaluation. Finally, conclusions are drawn in Section 5.

2. 5G SYSTEM MOTIVATION AND CHALLENGES

2.1. Motivations

The current 4G LTE-A already use modern technologies such as orthogonal frequency division multiplexing (OFDM) as well as multiple input multiple output (MIMO) to improve the spectrum efficiency and bring it close to Shannon fundamental limits [15]. This left no room for further improvement in term of the spectral efficiency. Recently, however, the attention of wireless communication has been drawn to the mm-wave bands, to take advantage of the unexploited wide bandwidth. The adoption of mm-wave communications is to harness the 20–90 GHz spectrum in mobile communication [16]. This will enable low cost mm-wave mobile backhauls to replace the current fiber connection, and provide an invaluable multi Gbps mobile system [17]. Furthermore, due to their small wavelength, very large antenna array design will became feasible (with shorter wavelengths, many antennas can be fitted together in the same area) thereby utilizing beamforming gains to cope with signal losses as well as enabling the Massive MIMO [2, 18, 19].

2.2. Challenges

One of the obstacles in mm-wave band 5G system will be the high pathloss compared to traditional cellular bands below 6 GHz. Generally, the path loss is [2, 20, 16]:

$$L_{FS} = 32.4 + 20\log_{10} f + 20\log_{10} R \quad (1)$$

where f: is the carrier frequency in GHz and R: is the distance in meters between transmitter and receiver in meters. Therefore, 22.9 and 30.9 dB of extra path losses are expected when moving the operating frequency from 2 GHz to 28 GHz and 70 GHz, respectively. However, such losses would be compensated by other means such as hybrid beamforming and larger antenna array, commonly known as massive Multiple-Input-Multiple-Output (m-MIMO) [2, 20]. Secondly, the atmospheric attenuation [21] (water vapour and oxygen absorption) in mm-wave is a serious issue as shown in Figure 2, an attenuation of 0.12 (dB/km) at 28GHz bands, 0.6 (dB/km) at 73 GHz and 0.36 (dB/km) at 83 GHz (green encircled). However, mm-wave deployment is suitable with the trend of small-cells densification that assumes smaller distances between transmitters and receivers. Therefore, their relative loss will be further smaller. High attenuation (15dB) at 60GHz (red encircled) could limit signal propagation; however this band can be used for interference limited communications. Therefore many commercial standards have been developed to operate in the free-licensed band at 60GHz, such as IEEE 802.15.3c and IEEE 802.11ad due to the availability of 7 GHz of contiguous bandwidth [20, 22, 23].

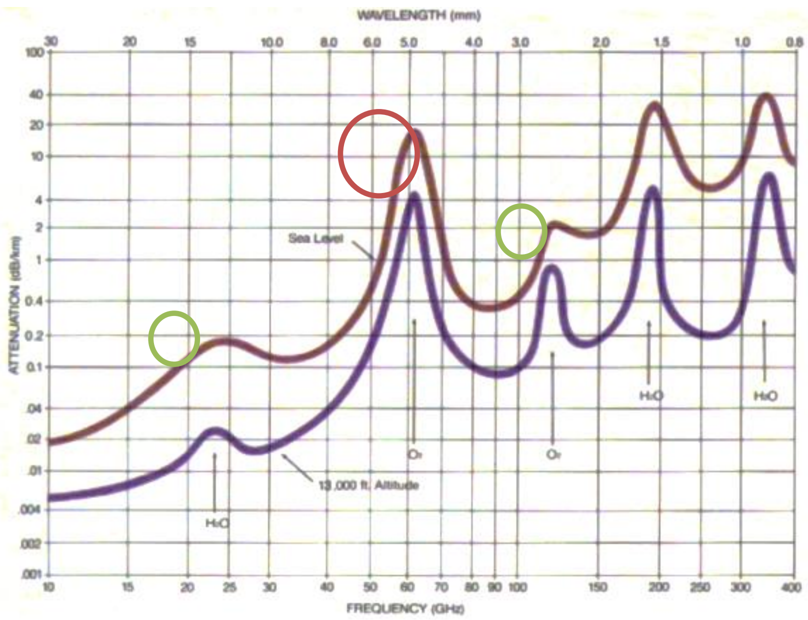


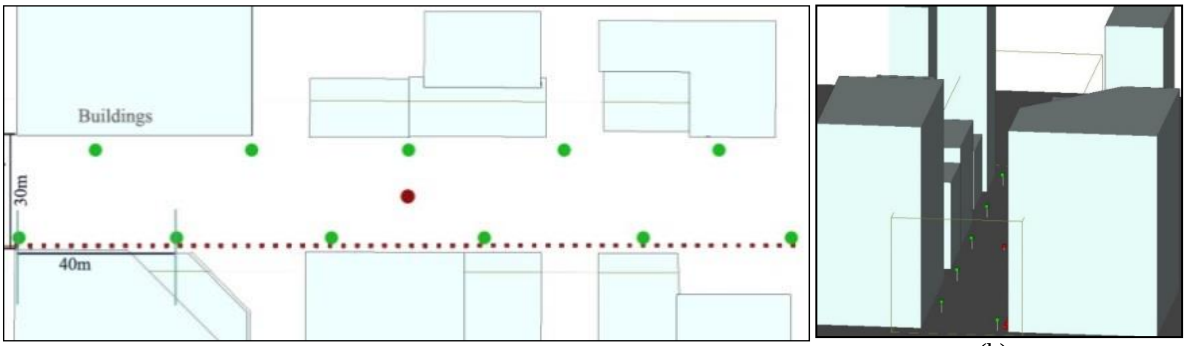
Figure 2. Average atmospheric attenuation on mm-wave band [2]

3. NETWORK MODEL

In this paper, we have used ray tracing tool [24] to simulate mm-wave signal propagation and assess its feasibility as a potential candidate for future 5G mobile system. Ray tracing techniques rely on the principles of physics to deal with wave propagation, ray tracing is an effective simulation tool to predict the signal transmission and reception in a pre-defined environment.

3.1. Outdoor environment geometry

A simulation of an outdoor mm-wave mobile access scenario has been studied through ray tracing tool. A street canyon was modelled with small cells deployment as shown in Figure 3. The street has a width of 30 m, with simulated distance of 200 m. Eleven mm-wave transmitters has been placed 40m apart, with 4 meter height (on street poles for instance) and have been shown as a green circles at both sides of the street, with receiver height of 1.5m. The building walls are made from concrete and the ground is from asphalt. Four reflections have been allowed by the simulation as the signal got highly attenuated after that. Propagation characteristics have been studied for 28 GHz and 73 GHz.



(a) (b)

Figure 3. (a) Simulation of street canyon (top view), (b) 3D view, red dot denotes the transmitter (Tx), whereas green dots denote the receivers (Rx)

3.2. Reception scenario

Two reception scenarios were made. Initially, 58 receivers were made on one side of the street to simulate the pedestrian mobiles (the red dotted line). Here, multipath components have been identified and studied. All antennas are vertically polarized omnidirectional antennas with 3 dBi gain and a 20 dBm transmit power. The second scenario is a single receiver in the center of the simulated area (represented by the red circle) receiving transmission from 11 transmitters.

4. RESULTS AND ANALYSIS

4.1. Average and individual path loss

Channel characteristics evaluations have been made to characterize the average pathloss (PL) as well as the individual path loss for the Line of Sight (LOS) and the strongest non-Line of Sight (NLOS) components. Furthermore, the received signal strength and Complex Impulse Response (CIR) have been shown and presented to examine signal strength and path properties along with its propagation from the transmitter to all receivers. These evaluations were made for both 28GHz and 73 GHz frequency bands. Up to eight transmissions and four reflections have been admitted during the simulation with no scattering is allowed. The scattered path loss in Figure 4 has been shown as an average values for the signal received at 28/73 GHz. It's worth mentioning that the path loss for 28GHz and 73GHz are very close to their corresponding free-space propagation.

To further investigate the reliability of radio channel throughout our pre-specified environment, individual path loss from the five strongest multipath components have been identified and analysed for both of the proposed mm-wave bands. In average, the first strongest NLOS1 is approximately 10dB weaker than the LOS signal measured at 5 m LOS distance. NLOS2 is 7dB weaker than NLOS1 at 10m. However, the difference reduces to few decibels at 100m and beyond as shown in Figure 5. Furthermore, NLOS3 and NLSO4 are present with less strength, while the other multipath components have been excluded from our measurement due to their very weak signal strength. The Direct LOS component is almost always present between transmitter and receiver points, however, if this signal shadowed by any means, the NLOS components could contribute into a good signal to afford a reliable link between transmitters and receivers. According to these figures, the 28GHz LOS and their relative components contribute to a more powerful signal than the 73 GHz signal; this can be mitigated for longer distances where deeper penetration is required. However by considering the very wide bandwidth on the 73 and 83 GHz band of (5+5) GHz compared to a 1.5GHz bandwidth on 27GHz band, a better trade-off could be made by considering signal penetration on a hand and the availability of the wide bandwidth on the other hand. All of these path loss components have been measured with respect to the LOS distance (direct path) and not to the length of path undertaken by the signal to reach the receiver. This has been estimated from the complex channel response, by considering the shortest time of arrivals of the strongest received signals. Then, by direct multiplication of this value by the speed of light, it will lead to the shortest LOS distance.

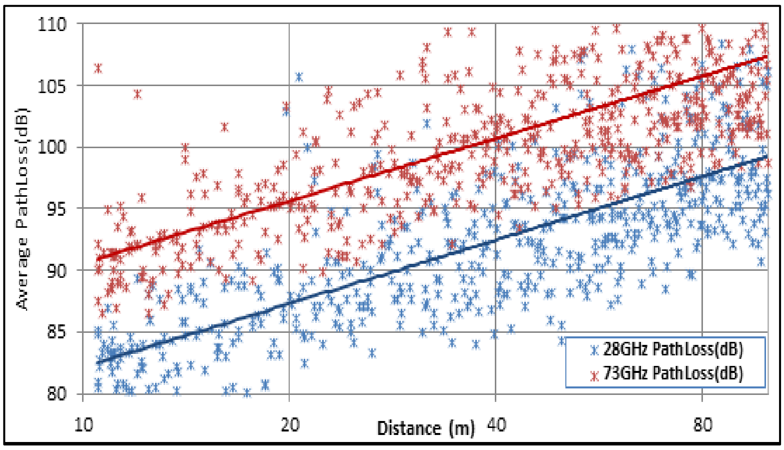


Figure 4. Average path loss for 28GHz and 73 GHz

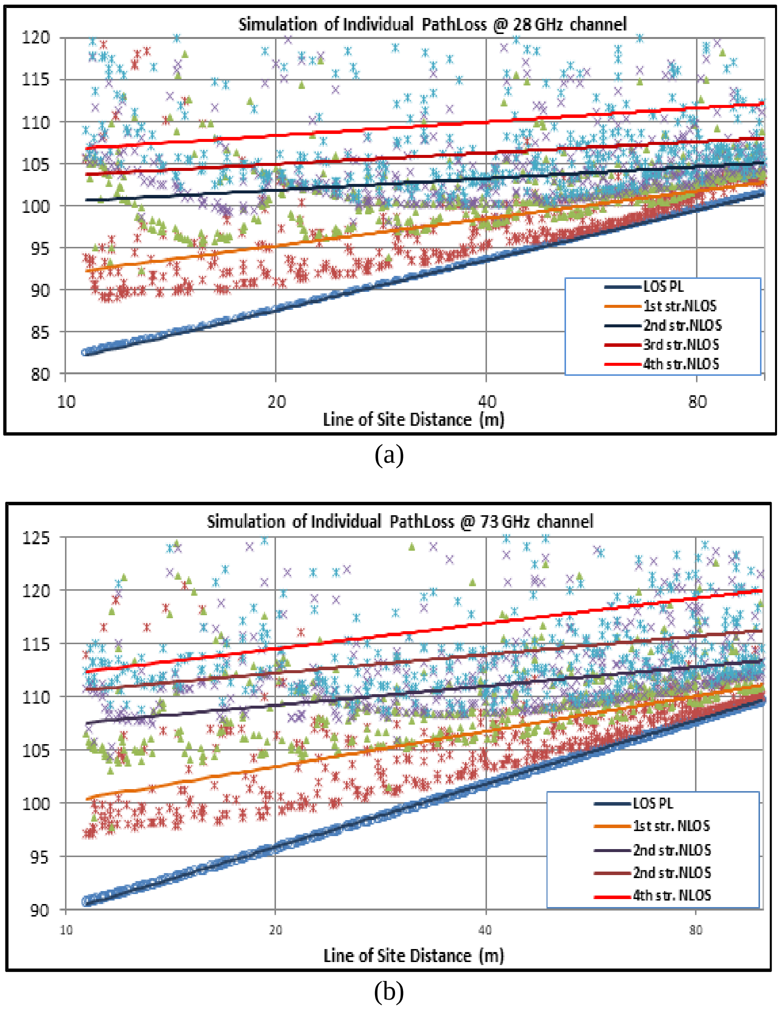


Figure 5. Individual path loss components for (a) 28GHz and (b) 73GHz

4.2. Factor and delay spread

K-factor is the power ratio between the direct path to the scattered paths. The simplest way to estimate the K factor could be by the ratio of the LOS signal power to the sum of the permitted NLOS power. According to the tool we have used, the Complex Impulse Response (CIR) gives all of the signals received at different time of arrival with their relative phase. The signal which has the strongest received level (dBm) as well as the shortest time of arrival (sec) is designated as the (LOS) component, which represents the direct path between the transmitter and receiver points. The sum of the other remaining signals permitted by the analysis (here 4 components in addition to the LOS have been considered) represents the scattered power. K-factor estimation describe accurately how the fading distribution on the link, where lower K-factor indicates deeper fading. Anyhow, both bands have shown almost the same performance in term of fading; however 28GHz has a better performance as depicted in fig.6. Delay Spread is “the difference between the arrival times of the earliest and latest rays”[25]. The delay spread is:

$$\boldsymbol{\tau} = \Delta \boldsymbol{L}/\boldsymbol{c} \qquad (2)$$

where: ΔL is the difference between the lengths of the longest and shortest paths, and c is the speed of light. High delay spread can causes frequency dependent fading and inter-symbol-interference (ISI) [25].

4.3. Average signal measurements

In this scenario, the same environment has been considered here with the same eleven transmitters’ properties, however, only one receiver was set at the mid-point of the simulated area to gather signal information from all the surrounding transmitters and record their attitude for both of the designated frequencies as shown in the Figure 6. Here, only permitted paths from Tx1 to Rx were shown in the figure.

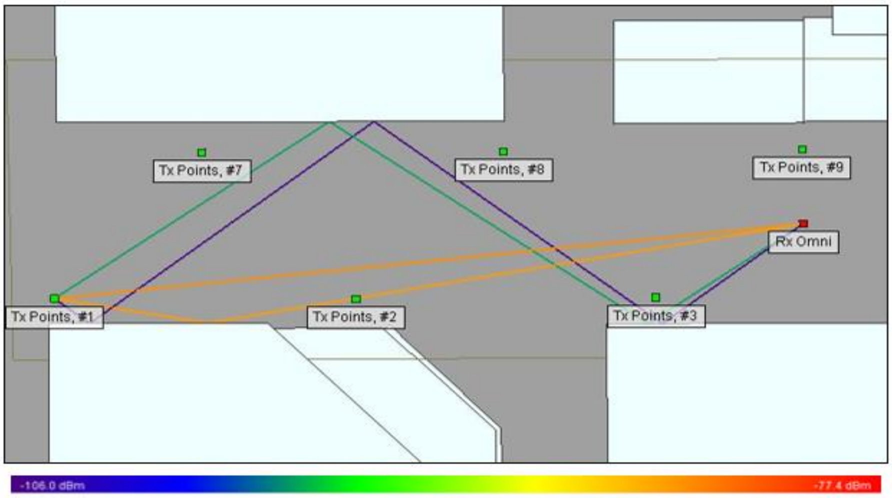


Figure 6. Propagation paths showing Tx1 to Rx Omni multipaths

This scenario has applied for both the proposed frequencies as well, to assess and examine their attitude to the geometry of the environment. K-factor, delay spread and received signal strength has extracted to assess each transmitter link to the receiver according to our street geometry and the number of reflections allowed. As per the results of the simulation, the receiver showed different attitude to the transmitters in these frequencies. Figure 7 shows the average received signal from eleven transmitters with different distances at 28 and 73 GHz. Here, it is noticed that the 28GHz system has a better path gain and receive better (stronger) signal. Almost similar figures were shown with respect to Tx3 and Tx9. However, 28GHz transmission show good signal reception from Tx11, where its signal is not received well at 73GHz. Furthermore, every transmitter has yield LOS signal plus five to eight NLOS signals. These signals were used to calculate their relative K-factor. Again every frequency show different k-factor response that indicates how much that link is faded. Fig.7 demonstrates these figures, the 28GHz shows very high k-factor on the Tx9 link, with a little favourite to Tx2 link, the remaining links suffer a deep fading. However, for the 73GHz, it has shown a moderate values on Tx9 and Tx6 then Tx2. These attitudes could help attaching the receiver to the optimum Tx performance among the surrounding transmitters. In addition to what mentioned, delay spread (the last part of Figure 7) are very different in 28GHz from 73 GHz. At 28GHz, minimum delay spread shown to Tx9 link (which has the shortest Tx-Rx separation among the other transmitters), while it is higher on Tx2. However, this is not the case on 73GHz system; lower delay spread was reported from Tx7 then Tx1 links.

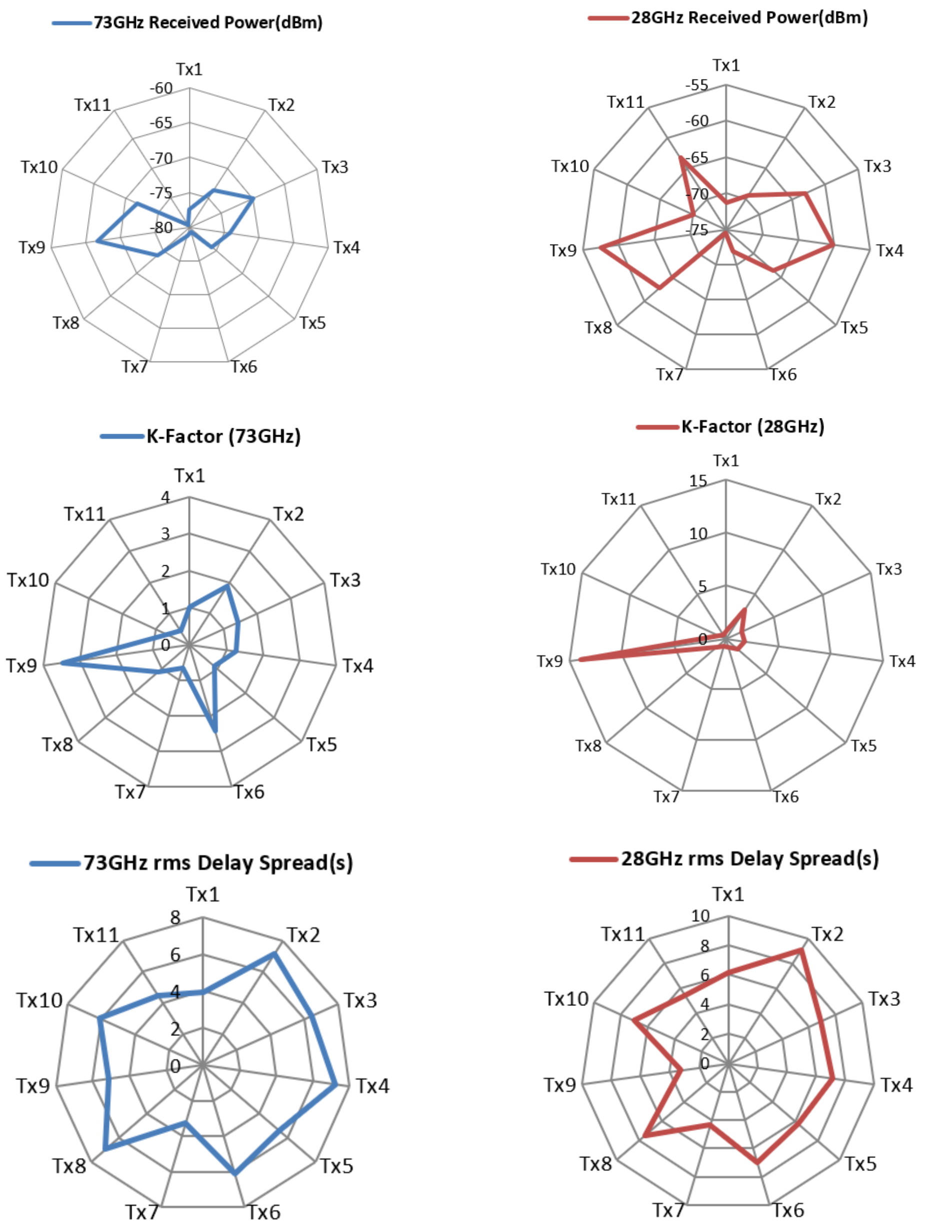


Figure 7. Performance comparison of eleven transmitters surrounding a single receiver showing: average received power, K-factor, and delay spread.

5. CONCLUSION

This paper presents a study of specific bands from the millimeter wave bands, which can potentially provide wide bandwidth required for mobile broadband applications in 5G systems and beyond. In this paper, we have analyzed the suitability of different millimeter wave bands for mobile access, namely; 28 and 73 GHz. We have discussed the propagation characteristics of these two bands, including their individual multipath components and K-factor. As shown in the simulation results, millimeter wave signal can provide reliable link in the LOS path, however, the strongest NLOS paths can contribute to a goods signal level to establish a link when the direct path is faded or shadowed. Furthermore, it is recommended to consider the 28/38GHz band for outer zone mobile access due to their low path loss among other mm-wave bands, and designate the 70/80 GHz band for the inner zone due to the availability of wider bandwidth.

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