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Performance of a 60 GHz Downlink Cellular System with Various Antenna Implementations

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ABSTRACT
The research in 60 GHz band is of a special interest to the upcoming fifth generation (5G) communications. That is due to the large unlicensed bandwidth that may be used for cellular type services. This paper provides a comprehensive Multiple Input Single Output (MISO) downlink system level performance evaluation at 60 GHz carrier frequency. An urban outdoor environment is considered for simulation. Different parameters including path loss, Signal to Interference plus Noise ratio (SINR), throughput, spectral efficiency, and number of antenna elements are evaluated. Furthermore, a comparison between the use of linear and rectangular antenna arrays, cosine and isotropic antenna elements are addressed. From the simulation results, one may conclude that beamforming is essential when operating at such a high frequency. Also, the performance of linear antenna arrays with cosine antenna elements outperforms other implementations.
***Keywords*-**MmWave, 5G, Beamforming, Arrays, SINR

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I. INTRODUCTION

The Millimeter Wave (MmWave) bands have been extensively examined by researchers. The frequency range for this band starts from 30 GHz and goes up to 300 GHz. It is called MmWave because of the small wavelength for these frequencies (λ = 1-10 mm). Experts mainly focus on the suitability of the 28, 38, 60 and 73 GHz bands for future 5G communications. More recently, the 60 GHz band has received much interest from both academia and industry. That is due to the large amount of available unlicensed spectrum [1]. This wide spectrum is translated into achieving multi gigabits of throughput and performance improvement. Furthermore, the evolution of the low cost CMOS and SiGe technologies that can be used to design low power integrated circuits makes this frequency band attractive to system designers with multitude of approaches and options for wireless communications. The 60 GHz band is available worldwide. In the United States, the available spectrum ranges from 57 to 64 GHz. For now, this block of spectrum is the largest ever allocated by the US FCC. In IEEE 802.11ad standard, using roughly 2 GHz of spectrum bandwidth over short range 60 GHz communications can provide up to 7 Gbps of throughput. IEEE 802.11ad working group established a standard which allows session switching between the conventional 4G bands and the unlicensed 60 GHz band [2]. However, the 60 GHz band introduces many technical challenges. It suffers from high oxygen absorption. About 10-15 dB/Km of high attenuation makes this band unfeasible for long range communications. Furthermore, propagation losses are much higher at 60 GHz operating frequency. The traveling signal experiences a loss of almost 20 dB more than at conventional microwave frequencies used for today's wireless communications. However, due to the small wavelength at 60 GHz frequency, this huge loss can be overcome by increasing the gain of the antenna through beamforming. In [3]-[7], extensive measurement campaigns at 28, 38, 60, and 73 GHz bands are performed. Various large scale path loss models are used for channel modeling. For LOS environments, Path Loss Exponent (PLE) ranges from 1.8 to 2.4. On the other hand, PLE ranges from 2.1 to 3.5 for NLOS environments. The effect of using beamforming over omnidirectional antennas is analyzed in [8], [9]. Even though most research of MmWave band outdoor channel focuses on backhaul and point-to-point communications, there is a new trend to investigate micro- and pico-cellular channel characteristics (Base Station (BS) to Mobile Station

(MS)) [10], [11]. Outdoor cellular peer-to-peer communications and into vehicle environments are tested in [3]. Urban Micro (UMi) and Urban Macro (UMa) outdoor environments are considered for performance evaluation in [12]. In [13], outdoor street canyon environment is considered. Results reveals that the LOS path loss exponent is almost equal to the FSPL exponent when the LOS is unhindered.

This paper considers an UMi outdoor environment with 50 m cell radii. The system level performance evaluation is achieved through a development of a standard 3rd Generation Partnership Project (3GPP) system simulator. The simulator is designed to predict various parameters associated with a MmWave communication system. These parameters include path loss, SINR, throughput and spectral efficiency under several antenna elements and arrays implementations.

II. SYSTEM DESCRIPTION

1. Cellular System Topology

An urban outdoor environment is considered for simulation. By adopting Monte Carlo simulation approach, the entire coverage area is divided into small cells. In the center of each site, there is a fixed BS with 3 sectors. Example of that is a 3-tier cell layout with a hexagonal grid of 57 cells (19 sites with tri-sector antennas). Frequency reuse of 1 is applied to the system. In other words, all 57 cells use the same radio frequency channel.

2. System Level Simulator Design

MSs are thrown randomly and uniformly within the coverage area. LOS outdoor environment is considered for this study. It is assumed that all MSs are active at the same time. The carrier frequency is 59.4 GHz and the total occupied bandwidth is 1.8305 GHz. Since all cellular system parameters should remain constant during a simulation run, a snapshot model is assumed. A detailed summary of these parameters used for downlink 60 GHz cellular system simulations is presented in Table I.

The snapshot model is assumed by distributing MSs uniformly and randomly throughout the coverage area. This is followed by calculating the distance d in m from each MS to all BSs. d is then used to get the path loss using the following equations:

$$d(m) = \sqrt{(MS_x - BS_x)^2 + \left(MS_y - BS_y\right)^2} \qquad (1)$$

$$PL(dB) = \alpha + 10\beta \log_{10}(d) + \xi[dB] \qquad (2)$$

Where MSx, MSy give the MS location, BSx, BSy give the BS location, α is the least square fit of intercept, β is the path loss exponent, ξ is the lognormal shadowing with zero mean and a standard deviation of σ. For LOS environment, the theoretical FSPL from Friis equation provides an acceptable fit. Since the maximum cell radius is 50 m, the effects of the oxygen absorption are negligible.

TABLE I. DEFAULT SYSTEM LEVEL PARAMETERS [5], [15], [26]

Parameter	Assumption
BS layout	Hexagonal grid, 19 sites (tri-sector)
MS layout	Randomly dropped
Antenna polarization	Horizontal
Carrier frequency	59.4 GHz
Cell radius	50 m
Frequency reuse	1
Traffic model	Full queue traffic
Log-distance path loss	$68.1 + 20 \log_{10}(d\ [m])$
Log-normal shadowing	0 mean, 5.8dB standard deviation
System bandwidth	1.8305 GHz
EIRP	$82 - 2 \times (51 - G_{BS})$
Noise figure for MS	8 dB
MS antenna gain	0 dBi
BS antenna array	Linear, rectangular
BS antenna elements	Isotropic, cosine
BS height	10 m
White noise power density (KT)	-174 dBm/Hz
Number of MSs per cell	Random

Omnidirectional antenna is not suitable to overcome interference and fading introduced in this band. To compensate for the increase in FSPL, highly directional antennas are used. Linear and rectangular phased antenna arrays with isotropic and cosine antenna elements are tested in the simulation to find which type of these antenna arrays can produce the highest system gain through beamforming. The spacing between antenna elements is $\lambda/2$. As a result, good communication links between the BSs and remote MSs are established. Ultimately, both MISO and directional beamforming help with increasing the capacity and throughput of the wireless communications system. According to FCC regulations, whenever the antenna gain G_{BS} is lower than 51 dBi, Equivalent Isotropic Radiated power (*EIRP*) in total should not exceed 82 dBm minus 2 dB for every dB of antenna gain [15]. This implies that there is a need to increase the number of antenna elements rather than increasing the transmitted power. The following equation illustrates the relation between *EIRP* and G_{BS}.

$$EIRP(dBm) = 82 - 2 \times (51 - G_{BS}) \qquad (3)$$

where the quantities are defined as before.

Therefore, in order to achieve a high *EIRP* at the access point, one has to have a very high gain antenna. This is obtained through the use of a very large number of antenna elements. A benefit of increasing antenna gain is that inter access point interference is reduced. So, there is a definite requirement to understand the performance of the system for various number of antenna elements. The antenna gain computation comes from calculating the azimuth of the MS based on the azimuth of BS and MS location. Fig. 1 illustrates the azimuth of both BS and MS as well as the beamwidth of each sector. This is followed by assigning each MSs to the BS that has the smallest *PL* and the smallest azimuth angle φ. Afterwards, *SINR* is determined by calculating the received signal power *S* using the results from (2) and the antenna pattern, the noise power *N* and the interference using the following equations:

$$S(dBm) = P_{TX} + G(\phi) - PL \quad (4)$$

$$N(dBm) = 10\log_{10}(KTB) + NF \quad (5)$$

$$SINR(dB) = 10\log_{10}\left(\frac{S}{N+I}\right) \quad (6)$$

where P_{TX} is the transmitted power, *K* is Boltzmans constant, *T* is the absolute temperature in Kelvin, *B* is the system bandwidth, *NF* is the noise figure of the RX, *I* is the interference coming from all active BSs except the server BS.

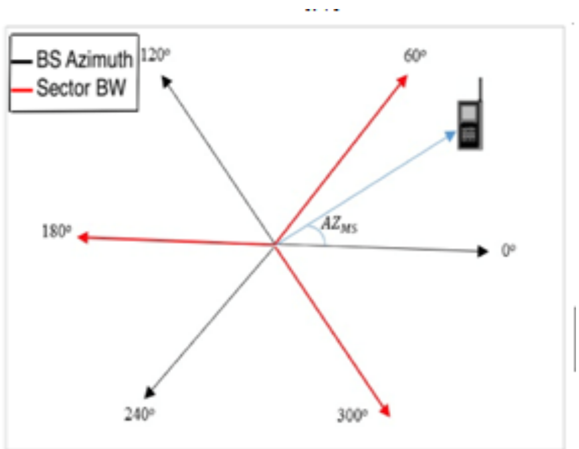

Fig. 1. Geometry for Gain Calculations

The throughput *C* and the spectral efficiency *E* are obtained by adopting Shannons theorem as follows:

$$C(bits/s) = B \times \log_2\left(1 + 10^{0.1(SINR-\gamma)}\right) \quad (7)$$

$$E\left(\frac{bits/s}{Hz}\right) = min\{\log_2\left(1 + 10^{0.1(SINR-\gamma)}\right), \rho_{max}\} (8)$$

where the loss factor γ , and *SINR* are in dB, ρ is the maximum *E*. Paper [16] suggests γ to be equal to 1.6 dB, and ρ is equal to 4.8 bits/s/Hz.

By repeating all of the above steps for n snapshot for different antenna arrays configurations, average data rate C, SINR and E are achieved for the operating system.

III. SIMULATION RESULTS

Fig. 2 - Fig. 4 represent the simulation results for average *SINR*, data rate, and spectral efficiency on the system level respectively. Deploying various types of antenna elements and arrays show that linear array with cosine antenna elements has the best performance relative to all other deployments. That is because the steering is in only one direction, and the interference from other BSs is limited. For the same number of isotropic antenna elements, both linear and rectangular arrays have similar performance.

Since cosine antenna elements have a gain of 6 dBi, an obvious improvement can be seen when implementing those types of elements. Furthermore, linear arrays provide almost 2 times better results for the same number of elements when compared with rectangular arrays that are using cosine antenna elements. For a simulation of 70 MSs, the ideal number of antenna elements on the BS side is proximately equal to 80.

IV. CONCLUSION

In this paper, the effect of using linear and rectangular antenna arrays on the TX side for a downlink cellular system at 60 GHz carrier frequency is evaluated. A 3GPP system simulator is used for analysis of system level performance. Results show a high importance of beamforming technique at 60 GHz band. In addition, the desired average SINR for the operating system is selected based on number of antenna elements on the phased antenna array. This implies that, for example, there is no need to use more than 80 elements to achieve 13 dB of average SINR when implementing phased linear array with cosine elements.

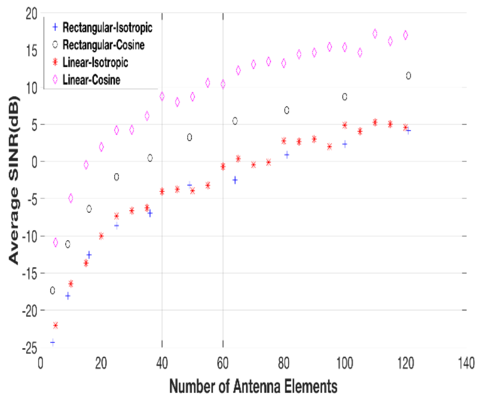

Fig. 2. Average SINR/System

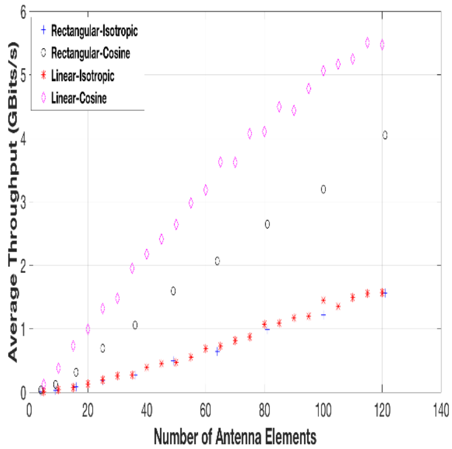

Fig. 3. Average Data Rate/System

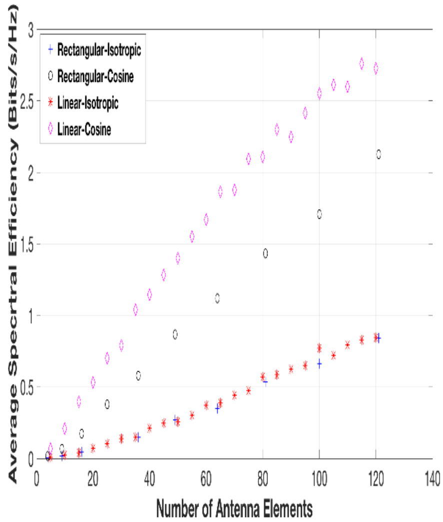

Fig. 4. Average Spectral Efficiency/System

REFERENCES

[1]. J. G. Andrews, S. Buzzi, W. Choi, S. V.Hanly, A. Lozano, A. C. Soong, and J. C. Zhang, "What will 5G be?"IEEE Journal on selected areas in communications, vol. 32, no. 6, pp. 1065–1082, 2014.

[2]. K. Chandra, R. V. Prasad, B. Quang, and I. Niemegeers, "Cogcell: cognitive interplay between 60 ghzpicocells and 2.4/5 ghz hotspotsin the 5g era," IEEE Communications Magazine, vol. 53, no. 7, pp. 118–125, 2015.

[3]. E. Ben-Dor, T. S. Rappaport, Y.Qiao, and S. J. Lauffenburger, "Millimeter-wave 60 ghz outdoor and vehicle AOA propagation measurements using a broadband channel sounder," in Global Telecommunications Conference (GLOBECOM 2011), 2011 IEEE. IEEE, 2011, pp. 1–6.

[4]. M. R. Akdeniz, Y. Liu, M. K. Samimi, S. Sun, S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter wave channel modeling and cellular capacity evaluation," IEEE journal on selected areas in communications, vol. 32, no. 6, pp. 1164–1179, 2014.

[5]. T. S. Rappaport, E. Ben-Dor, J. N. Murdock, and Y. Qiao, "38 ghz and 60 ghz angle-dependent propagation for cellular & peer-to-peer wireless communications," in Communications (ICC), 2012 IEEE International Conference on. IEEE, 2012, pp. 4568–4573.

[6]. T. S. Rappaport, G. R. MacCartney, M. K. Samimi, and S. Sun, "Wideband millimeter-wave propagation measurements and channel models for future wireless communication system design," IEEE Transactions on Communications, vol. 63, no. 9, pp. 3029–3056, 2015.

[7]. A. I. Sulyman, A. Alwarafy, G. R. MacCartney, T. S. Rappaport, and A. Alsanie, "Directional radio propagation path loss models formillimeter-wave wireless networks in the 28-, 60-, and 73-ghz bands,"IEEE Transactions on Wireless Communications, vol. 15, no. 10, pp. 6939–6947, 2016.

[8]. R. Emrick and J. Volakis, "Antenna requirements for short range high speed wireless systems operating at millimeter-wave frequencies," in Microwave Symposium Digest, 2006. IEEE MTT-S International. IEEE, 2006, pp. 974–977.

[9]. T. Manabe, Y. Miura, and T. Ihara, "Effects of antenna directivity and polarization on indoor multipath propagation characteristics at 60 ghz," IEEE Journal on Selected Areas in Communications, vol. 14, no. 3, pp. 441–448, 1996.

[10]. T. S. Rappaport, F. Gutierrez, E. Ben-Dor, J. N. Murdock, Y. Qiao, and J. I. Tamir, "Broadband millimeter-wave propagation measurements and models using adaptive-beam antennas for outdoor urban cellular communications," IEEE transactions on antennas and propagation, vol. 61, no. 4, pp. 1850–1859, 2013.

[11]. D. Jakubisin and C. R. Da Silva, "Feasibility study of outdoor wireless communication in the 60 ghz band," in Military Communications Conference, MILCOM 2013-2013 IEEE. IEEE, 2013, pp. 1244–1249.

[12]. N. Rupasinghe, Y. Kakishima, I.Guvenc, K. Kitao, and T. Imai, "Geometry performance for 5g mmwave cellular networks," in Antennas and Propagation (ISAP), 2016 International Symposium on. IEEE,2016, pp. 874–875.

[13]. W. Keusgen, R. J. Weiler, M. Peter, M. Wisotzki, and B. Goktepe, "Propagation measurements and simulations for millimeter-wave mobileaccess in a busy urban

environment," in Infrared, Millimeter, and Terahertz waves (IRMMW-THz), 2014 39th International Conference on. IEEE, 2014, pp. 1–3.

[14]. M. R. Akdeniz, Y. Liu, M. K. Samimi, S. Sun, S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter wave channel modeling and cellular capacity evaluation," IEEE journal on selected areas in communications, vol. 32, no. 6, pp. 1164–1179, 2014.

[15]. T. S. Rappaport, R. W. Heath Jr, R. C. Daniels, and J. N. Murdock, Millimeter wave wireless communications (Pearson Education, 2014).

[16]. P. Mogensen, W. Na, I. Z. Kovacs, F. Frederiksen, A. Pokhariyal, K. I. Pedersen, T. Kolding, K. Hugl, and M. Kuusela, "Lte capacity compared to the shannon bound," in Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th. IEEE, 2007, pp. 1234–1238.

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