International Journal of Scientific Research and Engineering Development— Volume 5 Issue 3, May-June 2022

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Omnidirectional Antenna Characteristics of IEEE 82.11ad WIGig Dock

Adewale Abe[1], Oladunni Juliet Femi-Jemilohun[2] , Emmanuel Taiwo Fasina[3], Bankole Adebanji[4] and Benson Ojedayo[5]

1,2,3,4,5Department of Electrical and Electronic Engineering, Ekiti State University, Ado-Ekiti, Nigeria
[2]oladunni.femi-jemilohun@eksu.edu.ng

Abstract

Wireless communications systems still have problems of dropped connections, reduction of throughput owing to susceptibility of 60 GHz radio signals to obstacles. To addressthese challenges inherent in mmWave communications., we carry outinvestigation and evaluation of the quality of performance of the 802.11ad device standards as related to the omnidirectional pattern of the WiGig antenna, its directivity and connectivity. The results propose the azimuth angles at which the IEEE 802.11ad (the WiGig Dock) can be positioned for various applications for optimal transmitted and received signals achievement. This will reduce latency as well as enhance faster communication since the transmitted signals is at the peak. Also, the manufacturers of the 802.11ad communication devices can employ the results of this work to see how on-chip antenna can be improved upon for increasedQos.

Keyword: WiGig Antenna, Directivity, Omnidirectional, millimete wave, Quality of Service, Dipole Array, Radiation Patterns

1. INTRODUCTION

An omnidirectional antenna refers to a wireless transmitting or receiving antenna that radiates or intercepts radio frequency (RF), electromagnetic fields equally or nearly in all horizontal directions. High gain omnidirectional antenna radiates less energy at higher and lower elevation angles and more in the horizontal directions. This is possible through the use of collinear dipole arrays. Radiation pattern of omnidirectional antenna are produced by the simple practical antennas of monopole and dipole antennas made up of one or two straight rod conductors on common axis. There is increased free space loss at 60 GHz compared to 2.4 GHz or 5 GHz since free space loss increase much higher with frequency. When it comes to blocking effects, omnidirectional antennas are better off in indoor environment because they can still collect contributions of reflected power in the event of line of sight obstruction [1]. Antenna gain (G) refers to the products of antenna efficiency (e) and antenna directivity (D) given as:

$$G = eD \tag{1}$$

A. AntennaDirectivityPattern

Antenna gain increases as the direction of propagation becomes narrowed and gets more and more focused. The gain of an antenna is the ratio of transmitted power in a specific direction to a target reference point and it is expressed in *dB; dBi* or *dBd*. This is a measure of how effectively the antenna transmit the energy towards targeted direction. Figure 1 shows the spherical coordinates that are popular for antennas since the interest is aiming on the antenna response in a particular direction. We are interested in three coordinates which are, *R; θ;* and *φ*.

- *R* is the magnitude of the distance between the origin and the targeted point *P*
- *θ* is the polar angle between z-axis and the vector from the origin to the target point *P* (ranges from 0 to 180 degrees)
- *φ* is the azimuth angle between the x-axis and the projection of the point onto the x-y plane (ranges from 0 to 360 degrees)

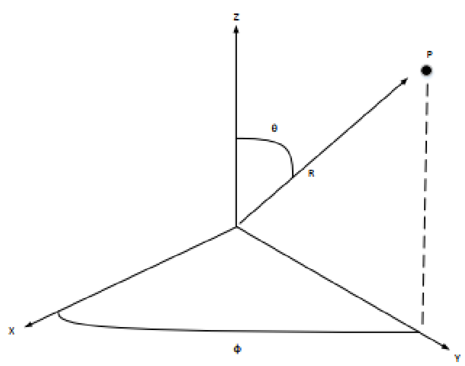

Fig 1: Spherical coordinates

Directivity $D(\theta;\varphi)$ is expressed as given below,

$$D_{(\theta,\emptyset)} = 4\pi\left(\cup\frac{(\theta,\emptyset)}{P_t}\right) \quad (2)$$

where θ and $\emptyset$represents standard spherical coordinates angles, $U(\theta;\ \emptyset)$ is the power density per solid angle-that is, radiation intensity and *Pt* is total radiated power. Radiation intensity $U(\theta;\ \emptyset)$ and total radiated power *Pt* satisfy equation (3),

$$P_t = \int_0^{2\pi}\int_0^{\pi}\cup(\theta,\emptyset)Sin(\theta)d\theta d\emptyset \quad (3)$$

Pt which is the power per solid angle $U(\theta;\ \emptyset)$ which was integrated over a spherical surface. Quantity $Pt/4\pi$ depicts average power for a unit solid angle since there exist 4π steradians on sphere surface.

Thus, the maximum or highest directive gain value from all possible solid angles is the Directivity *D* as defined by [2][3][4] is expressed in equation (4),

$$D = max\left(\frac{\cup}{P_t/_{4\pi}}\right) = \frac{\cup(\theta,\emptyset)max}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}\cup(\theta,\emptyset)Sin(\theta)d\theta d\emptyset} \quad (4)$$

where *Umax*is the amount of energy transmitted in the direction of highest or strongest power, *Pt* is the total energy transmitted in all directions. Equation (4)shows the relationship between the gain, antenna efficiency and directivity. The gain is directly proportional to the product of antenna efficiency and antenna directivity. Mostly, antenna gain is expressed in logarithmic unit as shown below in equation (5),

$$dBi = 10\log(G) \quad (5)$$

An important relationship that exists between omnidirectional radiation pattern directivity as a function of the pattern half power beam width (HPBW) in degrees as reported by [2][5] is expressed thus in equation (6)

$$D_0 = \left[\frac{101}{HPBW(degrees - 0.0027[HPBW(degrees)]^2}\right] \quad (6)$$

According to [5], the most widely used beamwidth is HPBW, and is defined by IEEE as "In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam". It is the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum value-that is, the angular separation in which the magnitude of the radiation pattern decrease by 50 percent or -3 *dB* from the peak of the main beam. Beamwidth is taken to be angle between the two points where the power falls to half its maximum level.It specifies the angular width within which the antenna is sensitive the most. The main beam is focused at 90 degrees and this is the region in the direction where radiation is at its peak, ideally, this region is within 3 *dB* of the main beam peak [5].

2. RELATED WORK

Omnidirectional antenna essentially has non-directional pattern in a given plane and a directional pattern in orthogonal plane [6]. The free space loss at 60 GHz over same distance is at least 28 dB worse than loss at 2.4 GHz and 21.6 dB at 5 GHz. When it comes to blocking effects, omnidirecional antennas are better off in indoor environment because they can still collect contributions of reflected power in the event of line of sight obstruction [1].

Diffraction of waves caused antenna to move up and down and thus results in unstable performance in wireless communication because of signal or data loss.The use of ubiquitous and unlicensed frequency present at 60 GHz band allows for very fast communication, although suffers from high propagation loss than at the 2.4 GHz and 5 GHz bands. The wireless Gigabit alliance (WiGig) resolve this by employing adaptive beamforming technique which allows a robust and scalable multi-gigabit communications at distances greater than 10 meters as specified by IEEE 802.11ad standard. Beamforming employs directional antennas to reduce interference and focus the signal between two communicating devices into a more concentrated beam which permits higher and faster data transmission more than the 10m [7].

Beamforming can be used to improve link performance in wireless communications. Beamforming is a signal processing technique used to control the directionality of the transmission and reception of radio signals through phased array. A phased array of antennas are employed so that the relative phases of signals feeding the antennas are adjusted in a way that the effective radiation pattern of the array is reinforced to experienced constructive interference while others experience destructive interference [8]. The correct combination of beams or streams gives rise to antenna gain or performance gain and the best throughput.

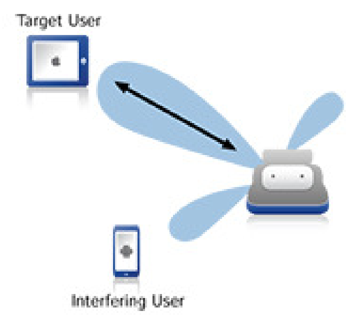

Fig 2: Smart Antenna System-Beamforming

A smart antenna system, as shown in Figure 2 above, consists of an array of antennas that together direct different transmission/reception beams toward each user in the system. This method of transmission and reception is called beamforming and is made possible through smart (advanced) signal processing at the baseband. Provided the noise is uncorrelated and in the absence of directional interferences, the signal-to-noise ratio of a beamformer with L antennas receiving a signal power P is given as:

$$1 / \sigma_n^2 (P.L) \qquad (7)$$

where Noise variance or Noise power is σ_n^2

IEEE 802.11 is a set of physical layer standards for implementing wireless local area network (WLAN) computer communication in the 2.4, 3.6, 5 and 60GHz frequency bands [9]. The Wireless Gigabit Alliance (WiGig), which recently merged with the Wi-Fi Alliance made modifications to both the 802.11 Physical Layers

(PHY) and the 802.11 Medium Access Control Layer (MAC) to enable operation in the 60GHz band via an efficient beam forming technology. In particular, the study [10] propose a solution to the problem of designing a physical layer (channel coding, modulation, diversity) that operate at bandwidth efficiencies that are twice to four times as high as those of today's systems using multiple transmit antennas. The studies in [11,12,13] did not consider the unique features and antenna characteristics synonymous with mmWave networks. The work [14] carried out mmWave channel propagation in outdoor environment while authors in [15] provided the adverse effect of blockages on signal propagation in this band. The evolution of IEEE 802.11ad devices operating on 60 GHz will exploit much wider RF channels having 500 MHz bandwidth or more, and the potential of this devices using several dozens of antennas owing to its smaller wavelength will increase, because of channel leveraged it can offer for both SM and BF purposes [16, 17, 18, 19] on the coverage and spectral efficiency of the system. The directional nature of mmWave propagation is inherent and coupled with its small wavelength, electronically steerable antenna arrays is achievable as patterns of metal on circuit board [20], [21], [22]. By controlling the phase of the signal transmitted by each antenna element, the antenna array steers its beam towards any direction electronically and to achieve a high gain at this direction, while offering a very low gain in all other directions. For maximum beam reception of the transmitter and the receiver, the studies in [23], [24], [25] enumerate the procedure for beam training, and beam training algorithms to reduce the required beam training time. This work is unique because it will investigate and evaluate the quality of performance of the 802.11ad device standards as related to the omnidirectional pattern of the WiGig antenna, its directivity, connectivity, the degree of interference level and signal loss due to obstructions and humans movement. The results will propose the azimuth angles at which the IEEE 802.11ad (the WiGig Dock) can be positioned for various applications for the transmitted and received signals to be optimal.

A. Wigig Docking Stations

According to [26], the Dell wireless WiGig 802.11ad Wireless Dock enable consumers to connect to dual displays, Ethernet LAN, audio, and full USB connectivity over a wireless WiGig 802.11ad link. Greater performance, very low latency, and high bandwidth docking experience with the Dell Latitude 6430u for fast, flexible connectivity between devices and peripherals in the office, conference room or classroom is as a result of combination of DisplayLink's DL-3900 docking chip with tri-band wireless technology from Wilocity and Qualcomm Atheros. The Dell D5000 Wireless Docking Station provides high definition multimedia interface (HDMI) and DisplayPort connectivity for dual monitors via DisplayLink's DL-3900, corporate LAN connectivity, audio and USB ports for peripheral expansion. The tri band WiGigWiFi connectivity is jointly provided by Wilocity and Qualcomm Atheros. The IEEE 802.11ad specification adds a "fast session transfer" feature, which enables wireless devices to seamlessly transit between the 60 GHz frequency band and the legacy 2.4 GHz and 5 GHz bands. The ability to move between the bands ensures that computing devices are always "best connected," enabling them to operate with optimal performance and range criteria [27].

Through the vast improvements in spectral reuse at 60 GHz and an efficient beam forming technology, IEEE 802.11ad enables great improvements in capacity. The dock is based on multi-gigabit tri-band 802.11ad wireless standard known as WiGig and is enabled by the first 60-GHz multi-gigabit tri-band Wilocity chipsets and can provide speeds up to 4.6 gigabits per second. Many users in a dense deployment can all maintain top-speed performance, without interfering with each other or having to share bandwidth as with the legacy frequency. In this work, two Dell wireless WiGig 802.11ad Wireless Docks were used. The WiGig specification has since been contributed to the new 802.11ad amendment, as it is built on existing 802.11b/a/g/n and the 802.11ac standards. Its interoperability affords user's in dense deployment to maintain top-speed performance and range criteria in the absence of

co-channel interference [28], [29]. It is essential to investigate and evaluate the capabilities of the first and newest 802.11ad devices, for example device-to-device (D2D) and/or device-to infrastructure (D2I) functionalities.
Hence this work aims to investigate and evaluate the quality of performance of the 802.11ad device standards.as related to the omnidirectional pattern of the WiGig antenna, its directivity, connectivity, the degree of interference level and signal loss due to obstructions and humans movement.

3. EXPERIMENTAL SET UP

Two WiGig 802.11ad Wireless Docks equipped with Vilocity chipsets, two Dell Latitudes 6430u were used in conducting the experiments in floor two of Network building, University of Essex, UK. The configuration is such that the Wigig dock (802.11ad) served as the A.P and placed permanently on a table which is 1m high and the compatible laptop Dell Latitudes 6430u was placed 2m away from it. Communications between the two devices were initiated via nttcp software. The laptop was moved round the fixed A.P in a clockwise direction. The angle of rotation varies from 0^0 to 360^0 with incremental increase of 10^0. The laptop is Intel i5 CPU operating at 1.90 GHz and A.P is 802.11ad standards operating at 60.48 and 62.64 GHz. For optimum performance and maximum throughputs, the A.Ps maintained clear LOS with latitude 6430u for full signal strength and minimum latency. Whenever the link is broken during transmission, realignmentoccurs automatically. Evaluation of the omnidirectional pattern of the antenna in the 802.11ad device is necessary to determine its directivity. This is to ascertain the device suitability for D2D or D2I applications. The experimental set-up is shown in figure 3. The latitude (PC) was positioned at 0.5m, 1.0m, 1.5m, and 2m away from and turned round fixed docking station 802.11ad A.P in clockwise direction as indicated by the curved arrow. We maintained angular variation of $10^0$from 0^0up to 360^0. Conversely, the dock is equally turned round the fixed latitude. The link speeds were recorded for each turning.

The product specifications of the WiGig docking station use in this research [26] is shown in table 1

TABLE 1: WIGIG D5000 DOCK SPECIFICATIONS

Standard	WiGig1.1 , IEEE 802.11ad
Video Ports	DisplayPort_1, HDMI 1.3_1
Power Supply	19.5V/3.3A (65W)
High Video Resolution	1920_1200@60Hz , 1920_1080p@60Hz ;1600_1200@60Hz

4. RESULTS AND DISCUSSIONS

The polar plot of the throughputs and the link speed measured at 0.5m, 1.0m, 1.5m, and 2m distance is shown in figure 4a, 4b, 4c, and 4d respectively. The 60 GHz wireless connection between the devices was maintained when the PC was turned around the dock in clockwise direction and vice versa Nevertheless, the maximum link speed ≤ 3.850 Gbps was achieved. Moreover, the characteristics of the omnidirectional antennas in the communicating devices caused the maximum wired 1GbE data rate to be less than 980 Mb/s with some fluctuations. The variation in throughput might be due to the capability of the chip dell used in the dock falling back to 2.4 GHz or 5 GHz transmission standards because 60 GHz transmission are short range and prone to obstacles such as walls and human body. The antenna pattern is omnidirectional since the link speed is maintained irrespective of the turnings. This means that it has wholly non-directional pattern in a specified or given plane (azimuth) and in the orthogonal plane (upward), it has directional pattern. Experiments have shown that wireless dock can only maintain connection with only one compatible PC equipped with bespoke chip-set. The advantage of the limited range is the reduction of the possibility of co-channel interference and increases the likelihood of aggressive frequency re-use density.

Both the antenna in the dock and the latitude are omnidirectional since wireless link between the devices is maintained during the period of turning the latitude round the dock up to 360 degrees and vice versa. The dock can be seen to exhibit close to 90-degree azimuth directivity (suitable for a fixed-link setting, e.g. for D2I applications), whereas the laptop can be seen to have a near-omnidirectional 330-degree directivity, making it suitable as a mobile device either for D2D or D2I connectivity. Wireless communications systems still have problems of dropped connections, reduction of throughput owing to susceptibility of 60 GHz radios to obstacles.

5. CONCLUSION

This work proposes the azimuth angles at which the IEEE 802.11ad (the Wigig Dock) can be positioned for various applications. The one requiring higher bandwidth such as uncompressed video streaming (live streaming) and large file transfer can be positioned at a particular azimuth angle where the transmitted and received signals is at the highest. On the other hand, those applications with lesser data rate can be located where the signal reception is lower. This will reduce latency associated with lower bandwidth as well as enhance faster communication since the transmitted signals is at the peak. Also, the manufacturers of the 802.11ad communication devices can employ the results of this work to see how on-chip antenna can be improved upon for optimal Qos.

References

[1] P. Smulders, Exploiting the 60 ghz band for local wireless multimedia access: prospects and future directions," *Communications Magazine, IEEE*, vol. 40, no. 1, pp. 140-147, 2002.

[2] I. T. A. Propagat, Approximate relationship between directivity and beamwidth for broadside collinear arrays," *IEEE Transactions on Antennas and Propagation*, vol. 26, no. 2, 1978.

[3] R. Elliott, Beamwidth and directivity of large scanning arrays," *Microwave Journal*, vol. 7, pp. 74-82, 1964.

[4] C.-T. Tai and C. S. Pereira, \An approximate formula for calculating the directivity of an antenna," *IEEE Transactions on Antennas and Propagation*, vol. 24, p. 235, 1976.

[5] C. A. Balanis, *Antenna theory: analysis and design.* John Wiley & Sons, 3rd ed., 2012.

[6] WiGig, \Wigig and the future of seamless connectivity," 2013.

[7] Y. Tsang, A. Poon, and S. Addepalli, "Coding the beams: Improving beamforming training in mmwave communication system," in *Proc. Of IEEE Global Telecommunications Conference* (Houston, USA), Dec. 5-9, 2011, pp. 1–6.

[8] J. Qiao, X. Shen, J. W. Mark, Y. He, "MAC-Layer Concurrent Beamforming Protocol for Indoor Millimeter-Wave Networks," *IEEE Transactionson Vehicular Technology*, vol. 64, no. 1, pp. 327–338, Jan. 2015.

[9] S. Karl, \Wi-fi alliance and wireless gigabit alliance finalize unification," (Press release) Retrieved November, 2013.

[10]V. Tarokh, N. Seshadri, and A. R. Calderbank, "Space-time codes for high data ratewireless communication: Performance criterion and code construction," *Information Theory,IEEE Transactions on,* vol. 44, pp. 744-765, 1998.

[11] D. Torrieri and M. C. Valenti, "The outage probability of a finite ad hoc network in Nakagami fading," IEEE Trans.Commun., vol. 60, pp. 3509–3518, Nov. 2012.

[12] M. C. Valenti, D. Torrieri, and S. Talarico, "Adjacent-channel interference in frequency-hopping ad hoc networks," in Proc.IEEE Int. Conf. on Commun. (ICC), pp. 5583–5588, June 2013.

[13] T. Rappapport, R. W. Heath Jr., R. Daniels, and J. N. Murdock, Millimeter Wave Wireless Communications. PearsonEducation, Inc., 2014.

[14] T. Rappaport et al, "Broadband millimeter-wave propagation measurements and models using adaptive-beam antennas foroutdoor urban cellular communications," IEEE Trans. Antennas Propag., vol. 61, pp. 1850–1859, April 2013.

[15] T. Bai, R. Vaze, and R. W. Heath Jr., "Analysis of blockage effects on urban cellular networks," IEEE Trans. WirelessCommun., vol. 13, pp. 5070–5083, Sept. 2014.

[16] T. S. Rappaport *et al*., *Millimeter Wave Wireless Communications*,2015, Pearson/Prentice Hall.

[17] F. Gutierrez, S. Agarwal, K. Parrish, and T. S. Rappaport, "On-chip integrated antenna structures in CMOS for 60 GHz WPAN systems," *IEEE J. Selected Areas in Communications*, vol. 27, no. 8, pp. 1367–1378, Oct. 2009.

[18] W. Hong *et al*., "Design and Analysis of a Low-Profile 28 GHz Beam Steering Antenna Solution for Future 5G Cellular Applications," *Proc. 2014 IEEE MTT-S Int'l.Microwave Symp.*, June 2014, pp. 1–4.

[19] M. K. Samimi and T. S. Rappaport, "Ultra-Wideband Statistical Channel Model for Non Line of Sight Millimeter-Wave Urban Channels," *Proc. IEEE GLOBECOM*, Dec. 2014.

[25] J. Qiao, X. Shen, J. W. Mark, Y. He, "MAC-Layer Concurrent Beamforming Protocol for Indoor Millimeter-Wave Networks," *IEEE Transactions on Vehicular Technology*, vol. 64, no. 1, pp. 327–338, Jan. 2015.

[26] W. Dock, Dell wireless dock d5000." online, 02 2013

[27] S. Karl, Wi-fi Alliance and wireless gigabit alliance finalize unification,"
(Press release) Retrieved November, 2013.

[28] Femi-Jemilohun O.J.& Walker S.D (2013). Optimization of Beamforming Technology for Cognitive Spatial Access in Millimetre Wave, in Proceedings of Second International Conference on Telecommunication and Remote Sensing 119-122,

[20] D. Liu and R. Sirdeshmukh, "A patch array antenna for 60 GHz package applications," in *Proc. IEEE AP-S Symp.*, Jul. 2008, pp. 1–4.

[21] S. Alalusi and R. Brodersen, "A 60 GHz phased array in CMOS," in *Proc. IEEE CICC*, Sep. 2006, pp. 393–396.

[22] T. S. Rappaport, J. N. Murdock, and F. Gutierrez, "State of the Art in 60-GHz Integrated Circuits and Systems for Wireless Communications," *Proc. IEEE*, vol. 99, no.8, Aug. 2011, pp. 1390–1436.

[23] J. Wang, Z. Lan, C. Pyo, T. Baykas, C. Sum, M. Rahman, J. Gao, R. Funada, F. Kojima, H. Harada, and S. Kato, "Beam codebook based beamforming protocol for multi-Gbps millimeter-wave WPAN systems,"*IEEE J. Selected Areas in Communications*, vol. 27, no. 8, pp. 1390–1399, Oct. 2009.

[24] Y. Tsang, A. Poon, and S. Addepalli, "Coding the beams: Improving
Telecommunications Conference (Houston, USA), Dec. 5-9, 2011, pp. 1–6.

[29] W. Alliance, WigigR and the future of seamless connectivity," 2013beamforming training in mmwave communication system," in *Proc. Of IEEE Global*

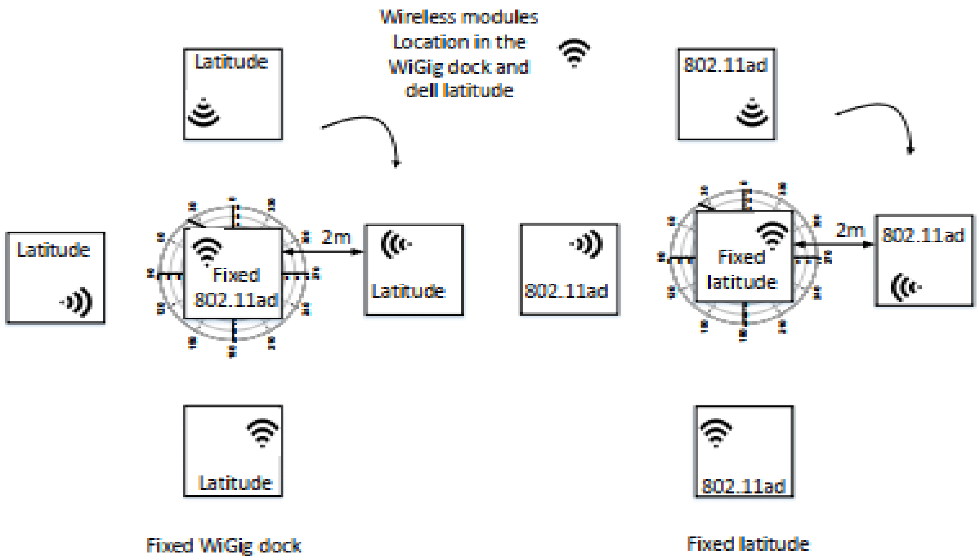

Fig 3: Experimental Set up

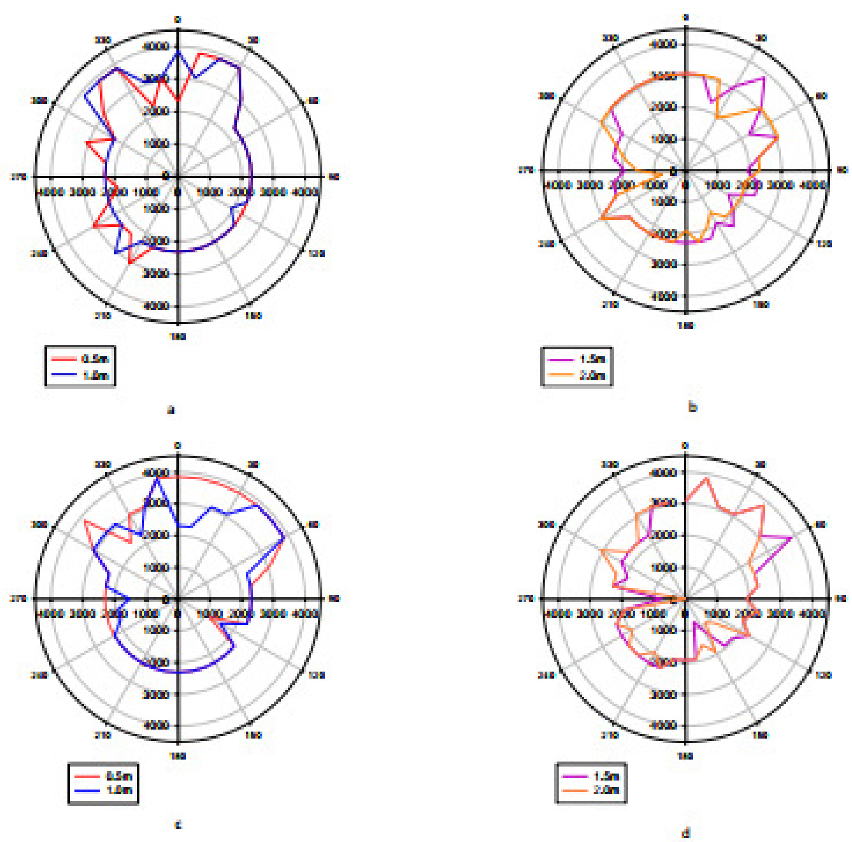

Fig 4: link speed polar plot against distance

