3

Mm-waves Promises and Challenges in Future Wireless Communication: 5G

Maryam Rahimi[1], Hitesh Singh[2] and Ramjee Prasad[1]

[1]Center for TeleInfrastruktur (CTIF), Aalborg University, Denmark
[2]HMR Institute of Technology and Management, Delhi, India

3.1 Introduction to Millimeter-waves

Frequency bands ranging from 300 MHz to 3 GHz are used for radio communication devices, such as TV, satellites, Global Positioning System (GPS), and Bluetooth. To solve the issue of the band getting crowded, researchers have proposed millimetre-waves for next-generation wireless systems. These waves include a large amount of unused spectrum from 30 GHz to 100 GHz and thus satisfy high-quality and high-speed broadband networks required by users and companies. Moreover, mm-waves provide high transmission rate, wide spread spectrum, and immunity to interference because of their large bandwidth. However, the use of mm-waves for wireless communications presents several advantages and challenges. This chapter starts with a brief introduction regarding mm-waves and discusses methods for channel propagation and characterization. The advantages of mm-waves in terms of their bandwidth and capacity are also discussed. The chapter ends with presentation of the application of mm-waves.

Millimeter-waves (mm-waves) assigned to the electromagnetic spectrum correspond to radio band frequencies ranging from 30 GHz to 300 GHz, with wavelengths of 10 mm to 1 mm. These waves are longer than infrared waves or X-rays but shorter than radio waves or microwaves. The high frequency of mm-waves and their propagation characteristics motivate researchers to apply mm-waves for various applications, including transmission of large amounts of data, cellular communication, radar, and so on. An overview on different frequency bands based on united state frequency allocations is shown in Figure 3.1.

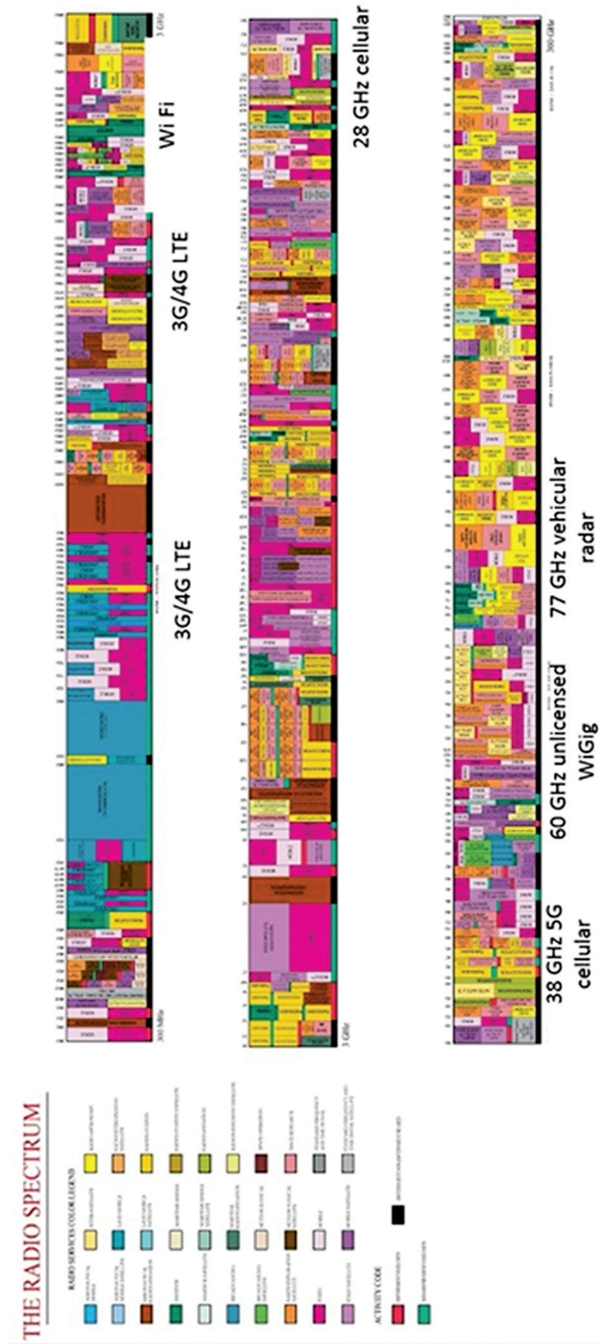

Figure 3.1 United State frequency allocations and mm-waves spectrum.

With its huge amount of available bandwidth, mm-waves are used to transmit large amount of data. Another important advantage of mm-wave propagation is called "beamwidth." This parameter is a measure of the process through which transmitted beam spreads out as it gets farther from its point of origin. Radars take advantage of this specific property of mm-waves. The use of millimeter-length microwaves can help engineers to overcome one of the most important challenges in antenna design. For a given antenna size, beamwidth can be decreased by increasing the frequency and thus, the antenna could also be made smaller.

There are certain advantages in using mm-waves; some of them are listed as below:

- Numerous spectra are available because of less operations occurring at mm-waves.
- Frequency reuse could be done in shorter distance because mm-waves exhibit high attenuation in free space.
- Large antenna arrays for adaptive beamforming can be used for mm-waves.
- Small wavelengths allow reduction in component size, achieve narrow beamwidths, have high resolution, and so on.
- Wide bandwidths, which are around main carrier frequencies (35, 94, 140, and 220 GHz), could provide a high information rate capability; wide-band spread spectrum capability, high immunity to jamming and interference, and so on.
- Extreme high frequencies allow multiple short-distance usages at the same frequency without interfering with one another.

Besides, there are several challenges and open issues about mm-waves, which should be addressed in future studies. For example mm-waves suffer from limited communication range because of atmospheric attenuation (10–20 km), reduced range capability in adverse weather, poor foliage penetration, particularly in dense green foliage, smaller antennas, which collect less energy in a receiving side, thereby reducing the sensitivity and so on. Signals with shorter-wavelength suffer from absorption by fog, dust, and smoke. For example at 60 GHz (5 mm wavelength) oxygen molecules will interact with electromagnetic radiation and absorb the energy. This reaction indicates that 60 GHz is not a suitable frequency for use in long-range radar or communications, because the oxygen absorbs the electromagnetic radiation and signal. Moreover, given that the 60 GHz signal does not travel far before it loses all its energy, this frequency comes in handy for securing short-range communications, such as local wireless area networks used for portable computers, where hackers should not tap into the data stream.

3.2 Channel Propagation of Millimeter-waves

The channel models at mm-wave are different from other frequency bands because the propagation environment has a different effect on smaller wavelength signals. For example, diffraction tends to be lower due to the reduced Fresnel zone. Scattering is higher due to the increased effective roughness of materials, and penetration losses can be much larger. Mm-wave channel models use common properties as low frequency systems (multi-path delay spread, angle spread, and Doppler shift), with different parameters though (few and clustered paths for example leading to more sparsity in the channel). In addition, several new features are introduced to account for high sensitivity to blockages (buildings, human body, or fingers) and strong differences between line-of-sight and non-line-of-sight propagation conditions. Many opportunities use the mathematical properties of sparsity in channel estimation and equalization and recoder/combiner design.

Mm-waves have a special propagation features because of very small wavelength compared to the size of most of the objects and devices in the environment. Understanding these channel characteristics and extracting proper channel model for mm-waves is fundamental to developing wireless network and also signal processing algorithms for mm-wave transmitter and receivers.

In 1998 a measurement on wideband channel at 60 GHz for indoor scenario was carried out to investigate the behaviour of the mm-waves at that certain frequency [1]. The path loss exponent, Ricean K factor and rms delay spread of the mm-waves were extracted from the measurement results. The results show if the transmitter and receiver antenna are aligned and a strong LOS component is present, the K-factor decreases with distance, down to a certain level. Figure 3.2, shows this effect for the measured data presented in [1]. The results also confirm that the rms delay spread (trms) increases with the distance, also to a certain level.

Figure 3.3 demonstrates the changes of the level of the wideband average of the received power with distance at 60 GHz frequency measurement, with omni-directional antenna used. The step was 4 cm. As it is seen, the decay with distance is small. This can be explained with the fact that there are many reflections and that they sum up together [2].

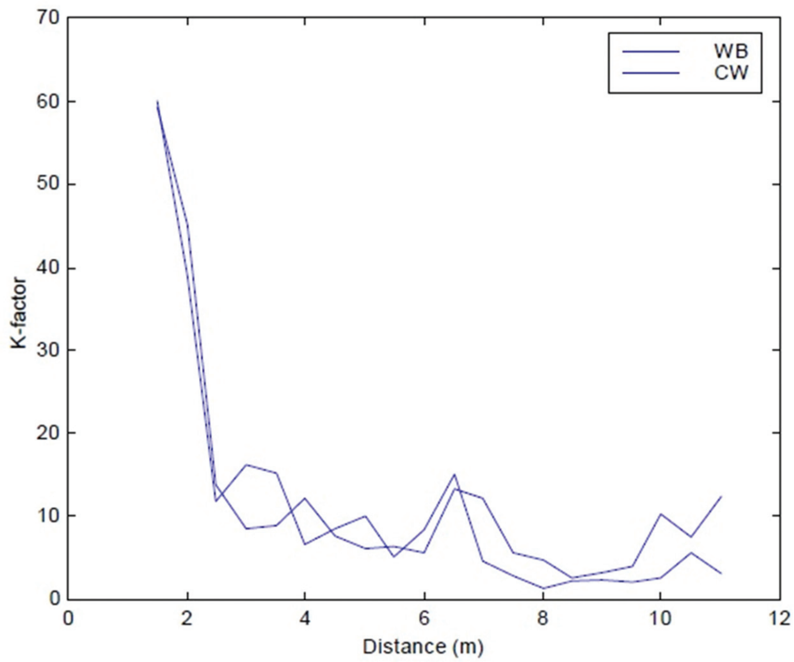

Figure 3.2 The changes of the K-factor in LOS situation in the common room (CW: continuous waves, WB: wide band) [1].

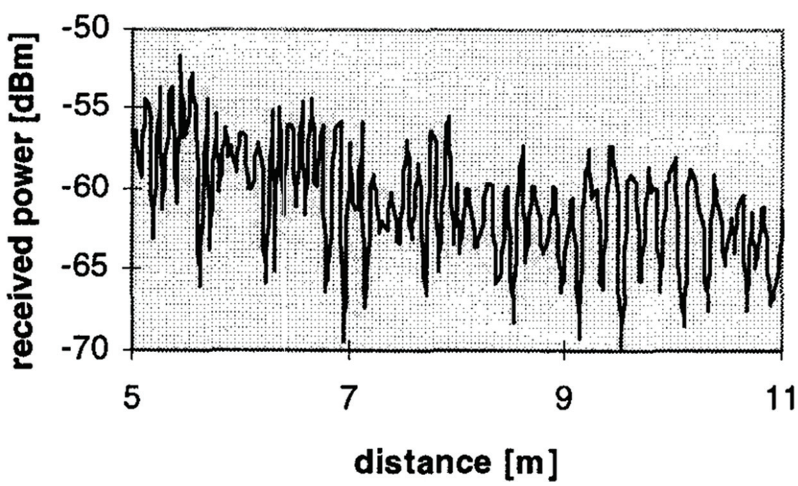

Figure 3.3 Wideband average received power in indoor scenario at 60 GHz [2].

More recent work has focused on path loss models for longer range outdoor links to assess the feasibility of mm-wave pico-cellular networks, including measurements in New York City [3, 4]. An interesting outcome of these studies is that, for distances of up to 200 m from a potential low-power base station or access point (similar to cell radii in current micro- and pico-cellular deployments), the distance-based path loss in mm-wave links is no worse than conventional cellular frequencies after compensating for the additional beamforming gain. These findings suggested the mm-wave bands may be viable for pico-cellular deployments and generated considerable interest in mm-wave cellular systems. At the same time, the results also show that, employing mm-waves frequencies in cellular networks is important for directional transmissions, adaptive beamforming, and other MIMO techniques.

Wideband measurements with 200 MHz of bandwidth discovered that city streets do not cause much multipath, as the rms delay spread was observed to be lower than 20 ns [4]. Measurements and models illustrated that path loss in LOS environments behaves almost the same as free space.

Other outdoor measurements in a city street environment at 55 GHz showed that power decreased much more rapidly with distance through narrower streets compared to a direct path or through wide city streets [5].

Samsung has been active in measuring mm-wave channels for future mobile communications. Initial tests were performed at 28 GHz and 40 GHz to study penetration losses for common obstructions such as wood, water, hands, and leaves [6, 7]. In May of 2013, Samsung Electronics announced the company was able to transmit data up to 1.056 Gbps at 28 GHz over distances up to 2 km by using an adaptive array transceiver with multiple antenna elements [8].

The measurement results are also shown that the range of mm-wave communications is limited because of the rain attenuation and atmospheric and molecular absorption characteristics of mm-wave propagation [9, 10]. Moreover, Oxygen absorption at 60 GHz band has a peak that ranges from 15 to 30 dB/km [11]. The channel characterization in [12] presents that the non-line-of-sight (NLOS) channel suffers from higher attenuation than the line-of-sight (LOS) channel.

Moreover, Electromagnetic waves have weak ability to diffract around obstacles, if the size of the obstacles is significantly larger than the wave-length. With a small wavelength, links in the 60 GHz band are sensitive to blockage by obstacles such as human bodies or furniture. It is shown in the literature; blockage by a human decreases the link budget by 20–30 dB [13].

Collonge et al. [14] carried out propagation measurements in an indoor environment, while human bodies are moving around, and the results show that the channel is blocked for about 1% or 2% of the time for one to five persons. Considering mobility in human bodies plus constant object shows a huge challenge in mm-waves links. Therefore, maintaining a reliable connection for different applications is a big challenge for mm-wave communications.

3.3 Data Rate and Millimeter-waves

The first generation cellular network was introduced and operated in 1978, which was designed for using basic analog systems for voice communications [15]. During the year 1991, 2G was introduced for providing voice and data services with improved spectrum utilization. It was using digital modulation and time division or code division multiple access. During the period of 2001, 3G was introduced with high speed internal access and improved audio and video streaming capabilities. It uses technologies like wideband code division multiple access (W-CDMA) and high speed packet access (HSPA). The 4G of mobile communication was introduced by ITU in 2011 [15]. The technology used in it was the International Mobile Telecommunication – Advanced (IMT-Advanced). Although LTE radio access technology was also used in 4G networks. LTE is an orthogonal frequency division multiplexing (ODFDM) based radio technology which supports up to 20 MHz bandwidth. For enabling high spectrum efficiencies, linked quality improvements and radio pattern adaptation new technology was introduced called Multiple Input Multiple Output (MIMO) [15].

With the tremendous increase of demand for capacity in mobile broadband communications every year, wireless carriers must be prepared for the thousand fold mobile traffic increase in 2020. It forces researchers to find new wireless spectrum which has capabilities to support high data rate demand. The future of mobile communication is 5G technology using mm-waves spectrum [15].

Utilizing mm-waves for 5G wireless technology is a huge step forwards since in the past, mm-wave spectrum was primarily used for satellite communications, long-range point-to-point communications, military applications, and Local Multipoint Distribution Service (LMDS) [16].

The demand for faster and more reliable communication will continue growing at extreme rates, such that annual mobile traffic will exceed 291.8 Exabytes (EB) by 2019 [17]. CISCO has forecasted that mobile data traffic will increase from 2.5 EBs per month in 2014 to 24.3 EBs per month in 2019 [18]. By the year 2020, Nokia and Samsung predict a 10,000x increase in traffic on wireless networks with virtually no latency for content access [8, 19].

The main profit using mm-wave carrier frequencies is the larger spectral channels. For example, at 60 GHz unlicensed mm-wave bands, channels with 2 GHz of bandwidth could be expected. Larger bandwidth channels mean higher data rates, which is the greatest benefit of using mm-waves spectrum in wireless communication.

Besides, massive MIMO is a promising technique for 5G cellular networks. Prior work showed that high throughput can be achieved with a large number of base station antennas through simple signal processing in massive MIMO networks. Massive MIMO promised capability of greatly improving spectral and energy efficiency as well as robustness of the system. In a massive MIMO system, the transmitter and receiver are equipped with a large number of antenna elements (typically tens or even hundreds). Massive MIMO is recommended with mm-waves to overcome challenges of gaining higher data rate. Smaller wavelength captures less energy at antenna due to path loss and so on. Moreover, larger bandwidth means higher noise power and lower Signal to Noise Ratio (SNR). Massive MIMO helps mm-waves to cover those problems and gain higher data rate. Hence, exploiting extra gain from large antenna arrays in the system is promised in massive MIMO.

As a result of the use of large antenna arrays of the transmitter and receiver and combined with radio frequency and mixed signal power constraints, new MIMO communication signal processing techniques are needed. The low complexity transceiver algorithms for wide bandwidths become important. Hence, opportunities abound for exploiting techniques, such as compressed sensing for channel estimation and beamforming.

Precoding and combining is different at mm-wave for three main reasons.

- Parameters have to be configured because of different array. This stage requires different algorithms for finding both analog and digital parameters, and makes the resulting algorithms architecture-dependent.
- The channel is experienced by the receiver through analog precoding and combining. This feature means that the channel and the analog beamforming are intertwined, which makes estimation of the channel directly a challenge.
- More sparsity and structure in the channel result from the use of largely close spaced arrays and large bandwidths. This condition provides structures that could be exploited by signal processing algorithms.

3.4 Application of Millimeter-waves

The applications of mm-waves are enormous in areas such as Wireless Local and Personal Area Networks (WLAN, WPAN) in the unlicensed band, 5G cellular systems, vehicular area and ad hoc networks, as well as wearable devices.

Exploiting frequency bands from 76–81 GHz in different radar ranges for automotive radars has been investigated as one of the major mm-wave applications. WLAN, WPAN, and 5G cellular are being developed with mm-waves. Mm-waves are used in next wireless technology generation to provide high throughput in small cells. There is a huge advantage to utilize mm-waves in MIMO and massive MIMO communication in different applications and scenarios, such as single and multi-user and relay. Vehicle-to-vehicle technology is developing dramatically by using mm-waves, because high data rate for sharing high rate sensors, radar, video, and so on is needed in this technology.

Mm-waves are been used in health science applications for different usages. Wearable devices, such as fitness trackers and smart watches, improve data rate due to usage of mm-waves. The high speed wearable networks provided by mm-waves can connect cell phones, smart watches, augmented reality glasses, and virtual reality headsets [20]. Clearly the future is bright for new applications of mm-waves.

Figure 3.4 shows how the next generation of wireless technology like 5G could evolve human life in terms of healthcare services and devices. Different sensors gather different information from human's body and data loads to the cloud and been monitored by care givers. The solution and help from medical center could be achieved with no delay. Thanks to mm-waves for their wide band to make this dream to the reality.

Mm-waves have plenty of potential applications as well. For example, with the recent interest and research towards communication between cars and data centers also autonomous vehicles, mm-waves may play a role in providing high data rate connections between cars. This feature is natural because mm-waves already form the backbone of automotive radar, which has been widely deployed and developed over the past 10 years [21]. The combination of mm-wave communication and radar is another interesting application [22]. Mm-waves could enable high rate and low latency connections to clouds that allow remote driving of vehicles through new mm-wave vehicle-to-infrastructure applications.

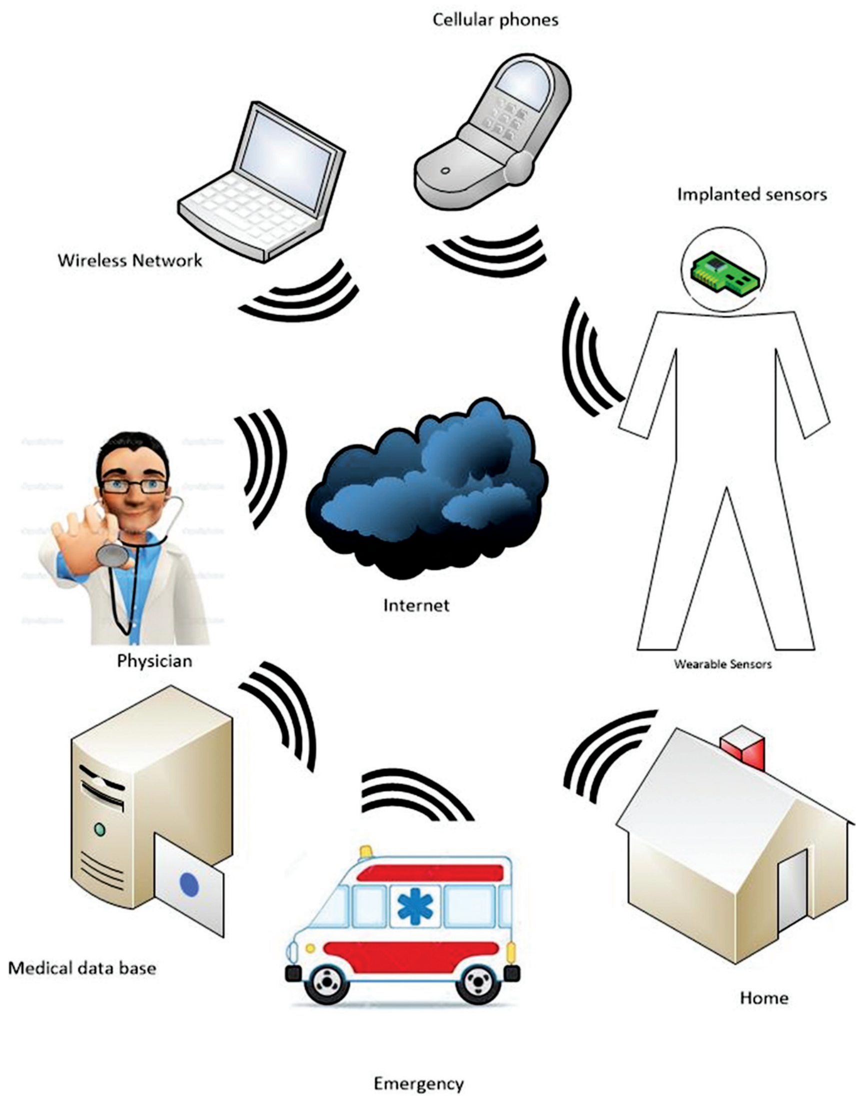

Figure 3.4 Future of medical services using mm-waves in 5G wireless communication systems.

Figure 3.5 shows an overview on how cars are going to communicate to each other and to the base stations in future. It is clear the network infrastructure should be developed for fast and reliable communication, which is needed in the roads. That is one of the 5G promises with help of mm-waves.

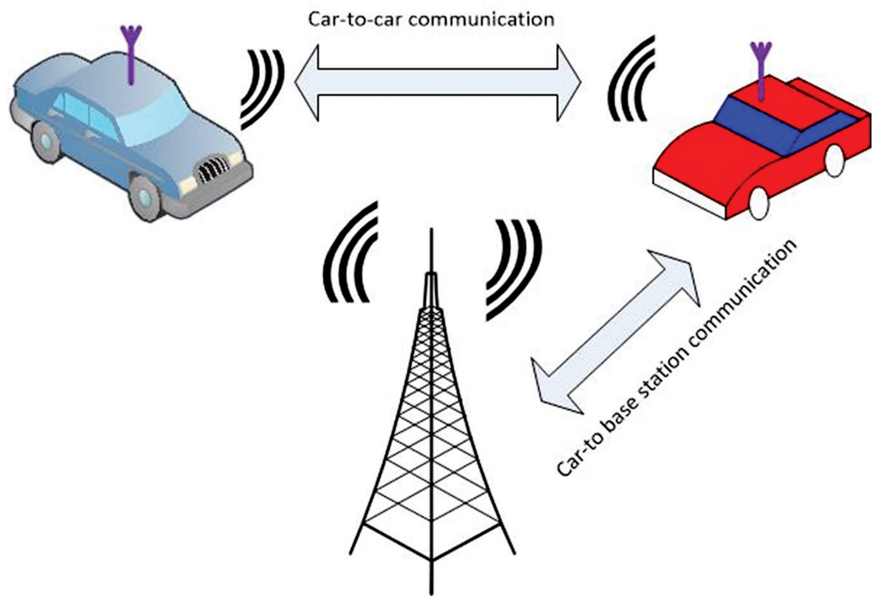

Figure 3.5 Vehicle-to-vehicle communication, and vehicle-to base station communication promised by 5G and mm-waves.

3.5 Conclusions

Mm-waves are as old as wireless technology. The first experiment was conducted by Bose in 1895. Since then, use of mm-waves has been limited for many years. However, the rapid development in wireless communication technology has resulted in giving mm-waves more potential to be part of the future of wireless communication specially 5G technology. The greater capacity besides unique characteristics of mm-waves increases the applications of mm-waves. However, many challenges and open issues should be addressed by researchers concerning the new physical technology, software-defined architecture, measurement of network, and so on to promote the development of mm-waves in wireless communication.

References

[1] J. Purwaha, A. Mank, D. Matic, K. Witrusal, and R. Prasad, "Wide-Band Channel Measurements at 60 GHz in Indoor Environments," in proc. IEEE benelux 6th Symp. Veh. Technol. Commun, Brussels Belgium, vol. Oct. 1998.

[2] D. M. Matic, H. Harada, and R. Prasad, "Indoor and outdoor frequency measurements for Mm-waves in the range of 60 GHz," in 48th IEEE Vehicular Technology Conference, 1998. VTC 98, 1998, vol. 1, pp. 567–571.

[3] Y. Azar, G. N. Wong, K. Wang, R. Mayzus, J. K. Schulz, H. Zhao, F. Gutierrez, D. Hwang, and T. S. Rappaport, "28 GHz propagation measurements for outdoor cellular communications using steerable beam antennas in New York city," in 2013 IEEE International Conference on Communications (ICC), 2013, pp. 5143–5147.

[4] P. F. M. Smulders and L. M. Correia, "Characterisation of propagation in 60 GHz radio channels," Electron. Commun. Eng. J., vol. 9, no. 2, pp. 73–80, Apr. 1997.

[5] H. J. Thomas, R. S. Cole, and G. L. Siqueira, "An experimental study of the propagation of 55 GHz millimeter waves in an urban mobile radio environment," IEEE Trans. Veh. Technol., vol. 43, no. 1, pp. 140–146, Feb. 1994.

[6] S. Rajagopal, S. Abu-Surra, and M. Malmirchegini, "Channel Feasibility for Outdoor Non-Line-of-Sight mm-wave Mobile Communication," in 2012 IEEE Vehicular Technology Conference (VTC Fall), 2012, pp. 1–6.

[7] H. Zhao, R. Mayzus, S. Sun, M. Samimi, J. K. Schulz, Y. Azar, K. Wang, G. N. Wong, F. Gutierrez, and T. S. Rappaport, "28 GHz millimeter-wave cellular communication measurements for reflection and penetration loss in and around buildings in New York city," in 2013 IEEE International Conference on Communications (ICC), 2013, pp. 5163–5167.

[8] T. S. Rappaport, W. Roh, and K. Cheun, "Mobile's millimeter-wave makeover," IEEE Spectr., vol. 51, no. 9, pp. 34–58, Sep. 2014.

[9] Z. Qingling and J. Li, "Rain Attenuation in Millimeter-wave Ranges," in 2006 7th International Symposium on Antennas, Propagation EM Theory, 2006, pp. 1–4.

[10] R. J. Humpleman and P. A. Watson, "Investigation of attenuation by rainfall at 60 GHz," Proc. Inst. Electr. Eng., vol. 125, no. 2, pp. 85–91, Feb. 1978.

[11] R. C. Daniels and R. W. H. Jr, "60 GHz wireless communications: emerging requirements and design recommendations," IEEE Veh. Technol. Mag., vol. 2, no. 3, pp. 41–50, Sep. 2007.

[12] S. Geng, J. Kivinen, X. Zhao, and P. Vainikainen, "Millimeter-wave Propagation Channel Characterization for Short-Range Wireless Communications," IEEE Trans. Veh. Technol., vol. 58, no. 1, pp. 3–13, Jan. 2009.

[13] S. Singh, F. Ziliotto, U. Madhow, E. Belding, and M. Rodwell, "Blockage and directivity in 60 GHz wireless personal area networks: from cross-layer model to multihop MAC design," IEEE J. Sel. Areas Commun., vol. 27, no. 8, pp. 1400–1413, Oct. 2009.

[14] S. Collonge, G. Zaharia, and G. E. Zein, "Influence of the human activity on wide-band characteristics of the 60 GHz indoor radio channel," IEEE Trans. Wirel. Commun., vol. 3, no. 6, pp. 2396–2406, Nov. 2004.

[15] R. Prasad, 5G:2020 and Beyond, vol. 2014. River Publisher.

[16] S. Y. Seidel and H. W. Arnold, "Propagation measurements at 28 GHz to investigate the performance of local multipoint distribution service (LMDS)," in IEEE Global Telecommunications Conference, 1995. GLOBECOM'95, 1995, vol. 1, pp. 754–757.

[17] T. S. Rappaport, "Keynote Speech: Millimeter-wave Wireless Communications – The Renaissance of Computing and Communications," presented at the IEEE International Conference on Communications (ICC), Sydney, Australia, vol. Jun. 2014.

[18] "Cisco visual networking index: Mobile data traffic forecast update, 2013–2018," presented at the CISCO, San Jose, CA, USA, vol. Feb. 2014.

[19] "FutureWorks NSN White Paper: Looking ahead to 5G," presented at the Nokia Solutions and Networks, The Netherlands, vol. Dec. 2013.

[20] Pyattaev, K. Johnsson, S. Andreev, and Y. Koucheryavy, "Communication challenges in high-density deployments of wearable wireless devices," IEEE Wirel. Commun., vol. 22, no. 1, pp. 12–18, Feb. 2015.

[21] H. H. Meinel, "Automotive radar: From its origins to future directions," Microw. J., vol. 2013, no. 9, pp. 24–28.

[22] C. Sturm and W. Wiesbeck, "Waveform Design and Signal Processing Aspects for Fusion of Wireless Communications and Radar Sensing," Proc. IEEE, vol. 99, no. 7, pp. 1236–1259, Jul. 2011.

About the Author

Hitesh Singh is presently working as Assistant Professor in HMR Institute of Technology and Management, Delhi affiliated to Guru Gobind Singh Indraprastha University, Delhi. He has done his Master in computer Science at Indraprastha university, Delhi. Hitesh was involved in several projects and research and he has more than 12 International and National publications. He is currently pursuing his Ph.D. at the Technical University of Sofia, Bulgaria under GISFI program.