INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
(Int Peer Reviewed Journal)
Vol. 05, Issue 10, October 2025, pp : 1067-1077
www.ijprems.com
editor@ijprems.com
e-ISSN : 2583-1062
Impact Factor : 7.001

MILLIMETER WAVE COMMUNICATION: OPPORTUNITIES AND CHALLENGES

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DOI: https://www.doi.org/10.58257/IJPREMS44316

ABSTRACT

Network technologies are changing quickly and the demand of faster and reliable data transfer is increasing. In 5G communication network there is limits for size of the data and transmission speed. Presently, we are moving towards big data and data explosion scenarios to send big data files. We cannot imagine the dream of smart home, smart manufacturing, smart transportation, smart health, and after all smart city without fulfilling the high-speed data transfer. We are still in Gigabyte data transfer rates which will not be enough to sustain in future world of Industrial Internet of Things based on deep learning and artificial intelligence. The Gigabyte per second data transfer rate is not enough to live in smart world of interconnected IoTs. We have to increase it from gigabytes to terabytes, petabytes and Exabyte bytes per second. To fulfill such requirement in future, we will need a new and innovative technology to tackle the problems of big data transmission. The increasing number of users and the high throughput requirements introduced millimeter wave communication (30GHz to 300 GHz spectrum), which is having larger bandwidth with less interference. The millimeter wave communication is having high carrier frequency, with huge bandwidth, narrow beam, high transmission quality and strong detection ability is revolutionizing the present-day transmission networks and by implementation of this technology, we can imagine the future of smart cities. Here on this paper, we will try to understand opportunities and challenges of millimeter wave communication for high-speed data transmission. 6G technologies are set to redefine connectivity by overcoming the limitations of 5G communication networks.

Keywords: Traffic Explosion, Blind Beam Steering (BBS), Device to Device Communication (D2D), Intuitive Remote Access (IRA), Internet Of Things(IoT), Smart Cities.

1. INTRODUCTION

The millimeter wave generally corresponds to the radio spectrum between 30 GHz and 300 GHz, with wavelength between 1 to 10 millimeters. In the contexts of wireless communication, the spectrum 38, 60, 70 and 94 GHz can be allocated for wireless communication in public domain. Millimeter-wave communication achieves multi Gbps data rates via highly directional beamforming to overcome path loss and provide to desired SNR.

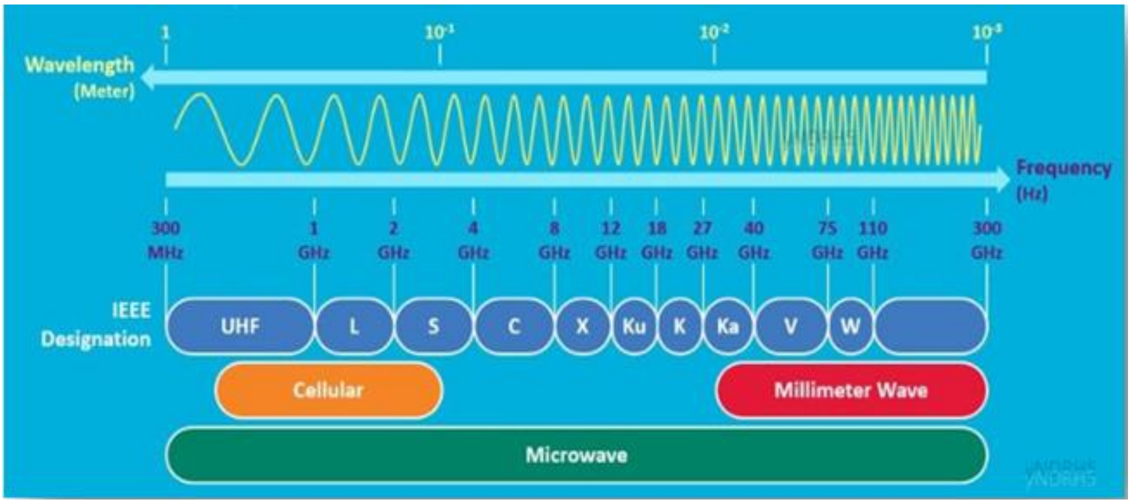

Figure 1: Millimeter Wave Frequency Spectrum (30GHz to 300 GHz)

Reference: What are Millimeter Waves? - everything RF

As we are becoming more edge closer, hyper-connectivity, advanced AI and ubiquitous data transfer, the limitations of existing 5G networks become apparent. We are now looking beyond 5G and 6G and 7G network is now under research, which will revolutionize IoT network further by integrating edge, cloud and quantum computing.

Looking forward towards 6G by 2030s which will require high capacity of data transmission to overcome the requirements of AI native networks, terahertz (THz) communication, quantum security, holographic communication and Brain-Computer interfaces. 1 Terabyte per second data transfer rate will be required to fulfill the requirements.

Millimeter wave communication is also having several disadvantages, e.g., severe signal attenuation, easily blocked by obstacles and small coverage area due to its shorter wavelength.

1.1 GROWTH OF ANDROID MOBILES AND LIVE MEDIA STREAMING:

Every day the use of mobile is increasing, before it was limited to calls, but now it is being used from calling to control the home appliances by using Internet of things technology, from internet browsing to live TV. The capacity requirement and available spectrum shortage is a major issue of present time. The bottleneck of wireless bandwidth becomes a key problem of the fifth generation (5G) wireless networks.

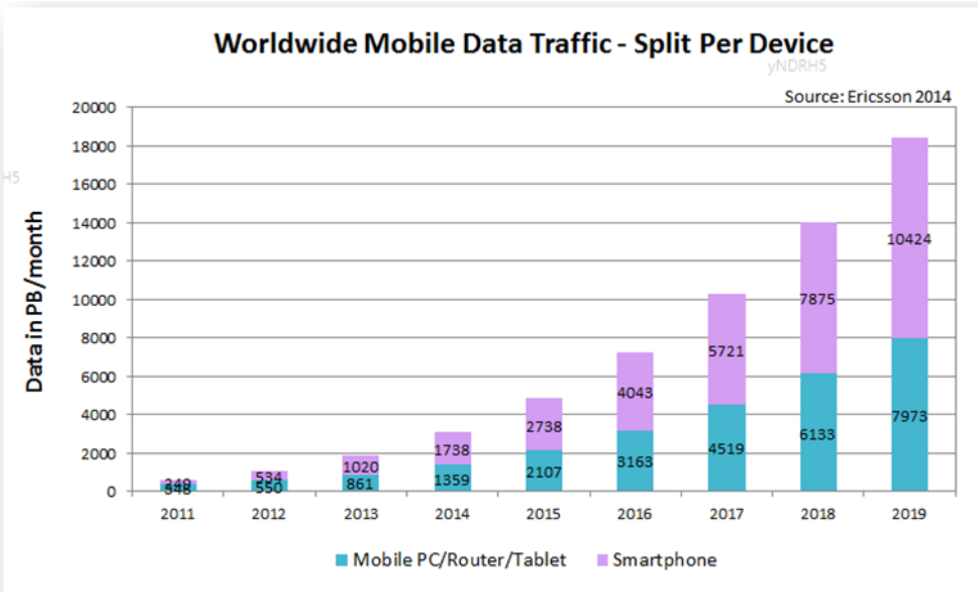

Figure 2: Mobile Internet traffic pushes the limit of mobile broadband networks

Reference: Mobile Data Traffic to Grow by Nearly 6X in 5 Years – Smartphone Subscribers to Double by 2019 – Mobile Web Site Performance Key – May 2014 Bandwidth Report – WebSiteOptimization.com

Table 1: Comprehensive comparison of key breakthroughs and technological advancements across network generations from 1G to 6G

Reference: IEEE Xplore Full-Text PDF:

Parameters	1G	2G	3G	4G	5G	6G
Breakthroughs	Analog Voice calls	Digital Voice, SMS, Encryption	Mobile, Internet, Video Calls	High Speed Broadband, Streaming, VoLTE	IoT, AR/VR, Smart Cities, Ultra-Low Latency	AI-native networks, Quantum security, Holographic communication
Technological Advancements	AMPS, NMT, TACS	GSM, CDMA, Circuit-Switched data	UMTS, WCDMA, Packet Switching HSPA	LTE, OFDM, Massive MIMO, Cloud Services	mm Wave Network, Slicing, Edge Computing Beamforming	Terahertz (THz) spectrum, BCI, Digital Twin
Speed	~ 2.4 kbps	Up to 64 kbps	2 Mbps to 42 Mbps	100 Mbps to 1Gbps	Up to 10Gbps	Up to 1TBps

Abbreviations:

AMPS = Advanced Mobile Phone System, BCI = Brain-Computer Interface, CDMA = Code Division Multiple Access, GSM = Global System for Mobile Communication, LTE- Long Term Evaluation, MIMO = Multiple-Input

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Multiple-Output, NMT= Nordic Mobile Telephony, OFDM= Orthogonal Frequency Division Multiplexing, UMTS= Universal Mobile Telecommunication System, VoLTE= Voice over LTE, WCDMA= Wideband Code Division Multiple Access

1.2 CHARACTERISTICS OF MILLIMETER WAVE COMMUNICATIONS

The characteristics of mm Wave communications should be considered in the design of network architectures and protocols to fully exploit its potential. Below is the summary and characteristics:

1.2.1 Wireless Channel Measurement:

Millimeter wave communications suffer from huge propagation loss. The rain attenuation and atmospheric and molecular absorption characteristics of mm Wave propagation limit the range of mm Wave communications, with smaller cell sizes applied to improve spectral efficiency today, the rain attenuation and atmospheric absorption do not create significant additional path loss for cell sizes in the order of 200 m. Therefore, mm Wave communications are mainly used for indoor environments, and small cell access and backhaul with cell sizes on order of 200 m.

The channel characterization of mm Wave shows that the non-line-of-sight (NLOS) channel suffers from higher attenuation than the line-of-sight (LOS) channel. The large-scale fading F (d) can be modeled as follows.

$$F(d) = PL(d_0) + 10n\log_{10}\frac{d}{d_0} - S_\sigma,$$

where P L(d0) is the path loss at reference distance d0, n is the path loss exponent, and Sσ is the showing loss. σ is the standard deviation of Sσ. To combat severe propagation loss, directional antennas are employed at both transmitter and receiver to achieve a high antenna gain.

1.2.2 Directivity:

MM Wave links are inherently directional. With a small wavelength, electronically steerable antenna arrays can be realized as patterns of metal on circuit board. Then 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. To make the transmitter and receiver direct their beams towards each other, the procedure of beam training is needed, and several beam training algorithms have been proposed to reduce the required beam training time.

1.2.3 Blind Beam Steering System:

The Blind Beam Steering node architecture is based on a multi-band capable device design where mm-Wave and IEEE 802.11ac/n interfaces are combined. We expect IEEE 802.11ac/n devices to comply with this design as the standard foresees a session transfer feature between mm-Wave and legacy bands. For the BBS system design, we assume an mm-Wave interface that comprises an antenna array with predefined highly directional sectors patterns that cover a 360 azimuth. We refer to the mm-Wave system as the Application Band, where the antenna pattern is steered according to BBS information to achieve multi Gbps directional transmissions. We further assume an IEEE 802.11ac/n interface that has a N-antenna omni-directional array usable for inference of bearing to a pairing node.

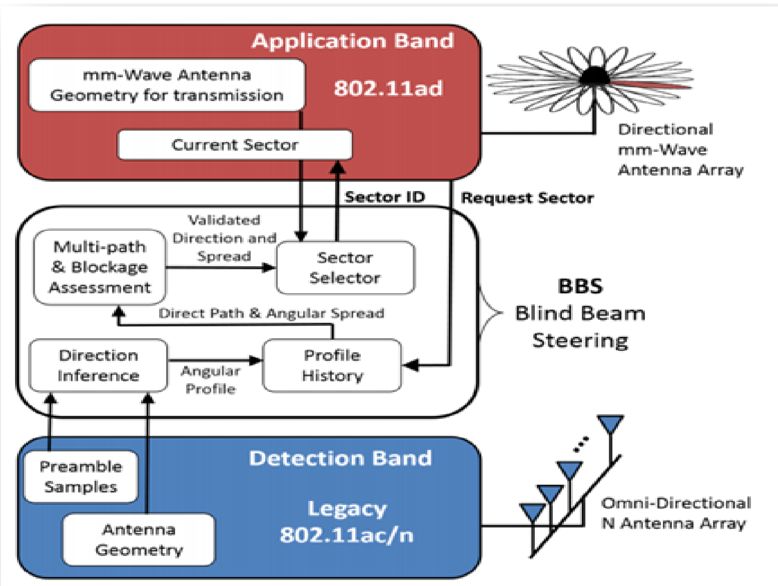

Figure 3: Blind Beam Steering System Architecture

Reference: BBS system architecture. | Download Scientific Diagram

1.2.4 Sensitivity to Blockage:

Electromagnetic waves have weak ability to diffract around obstacles with a size significantly larger than the wavelength. With a small wavelength, links in the 60 GHz band are sensitive to blockage by obstacles. (e.g., humans and furniture). For example, blockage by a human penalizes the link budget by 20-30 dB . Collonge conducted propagation measurements in a realistic indoor environment in the presence of human activity, and the results show that the channel is blocked for about 1% or 2% of the time for one to five persons. Taking human mobility into consideration, mm Wave links are intermittent. Therefore, maintaining a reliable connection for delay-sensitive applications such as HDTV is a big challenge for mm Wave communications.

The extremely shorter wavelengths of mmWave (i.e. 10.7mm at 28GHz, 5mm at 60GHz and 1mm at 300GHz) provides enormous potential for mmWave antenna arrays that are adaptive with high gain, cost effective to fabricate and integrate in mass-produced consumer electronic products. Low cost and high gain can be realized with physically small antennas. From cost perspective, mmWave antenna can be directly integrated with other portions of transceiver and fabricated with either packaging or integrated circuit production technology.

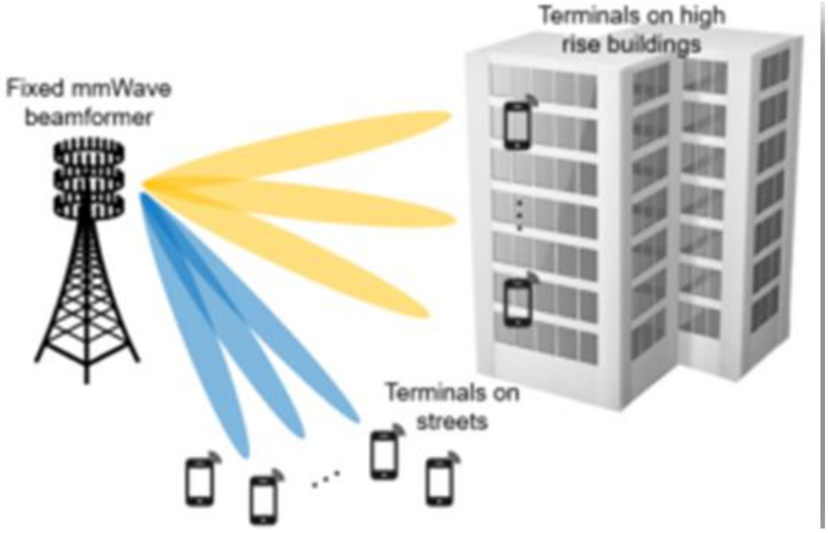

Figure 4: Disruptive Beamforming Trends Improving mmWave 5G

Reference: Disruptive Beamforming Trends Improving mmWave 5G | GSA

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We can classify mmWave antennas into five types: reflector antenna, lens antenna, horn antenna, on-chip integrated antennas and microstrip antenna.

1.2.5 Device to Device Communication

D2D communications are kind of technology that allows terminal to communicate directly with the reuse of cell resources.D2D communications occupy the same carrier frequencies with today's cellular networks to improve resource utilization and network capacity. In mmWave cellular system owing to highly directional links not only to reduce interference with other frequencies.

2. OPPORTUNITIES

2.1 Dream of Smart World in Millimeter Waves ERA

In Millimeter waves, the Dishwashers will fix themselves using information from peers of the same model. The smart refrigerator can recommend a recipe of cuisine to be cooked with ingredients that are already in your refrigerator.

Connected Health and Fitness related wearable devices will record your athletic performance. In large shopping malls, customized alerts for low priced product can be sent to the user's device. The smart office appliances will be connected one another and will share information and nearby computers and input/output devices can recognize a user and change the settings using the user's preferences stored in the IoT cloud. Almost all the office appliances will connect wirelessly, while exchanging massive data through wireless medium without noticeable delay.

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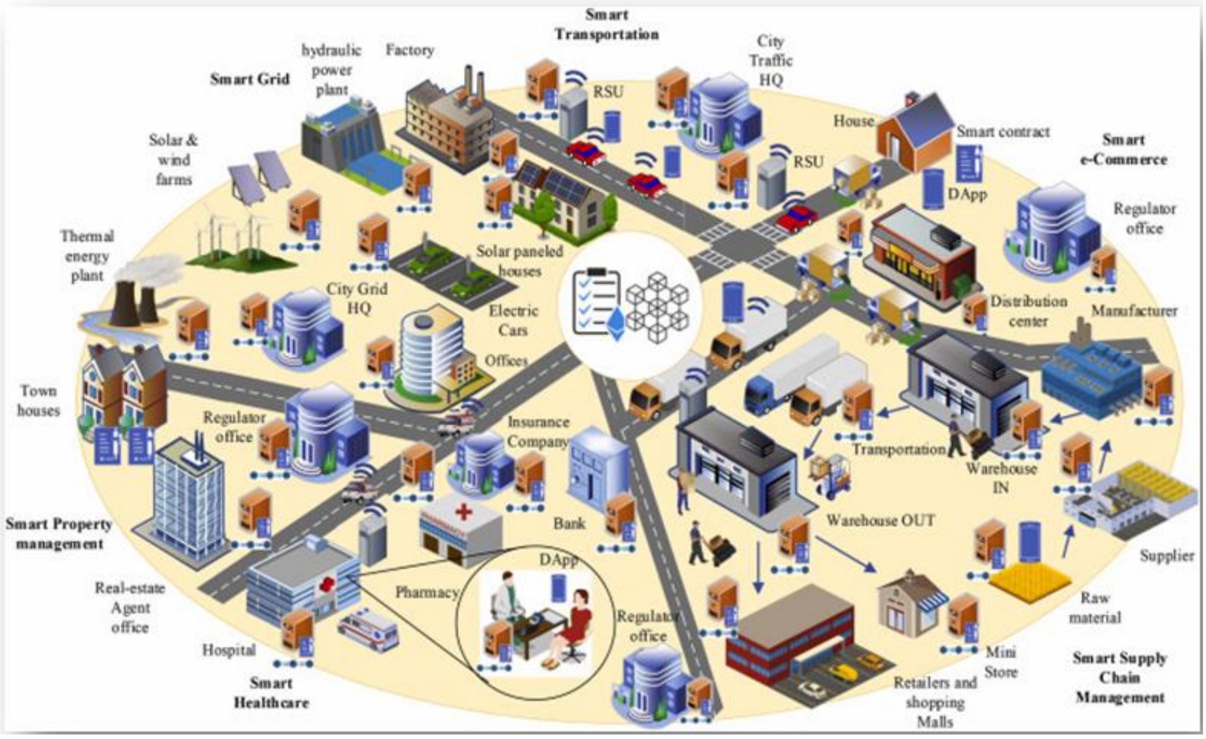


Figure 5: Imagination of smart world

Reference: IoT-based smart cities: Recent advances, requirements, and future challenges - ScienceDirect

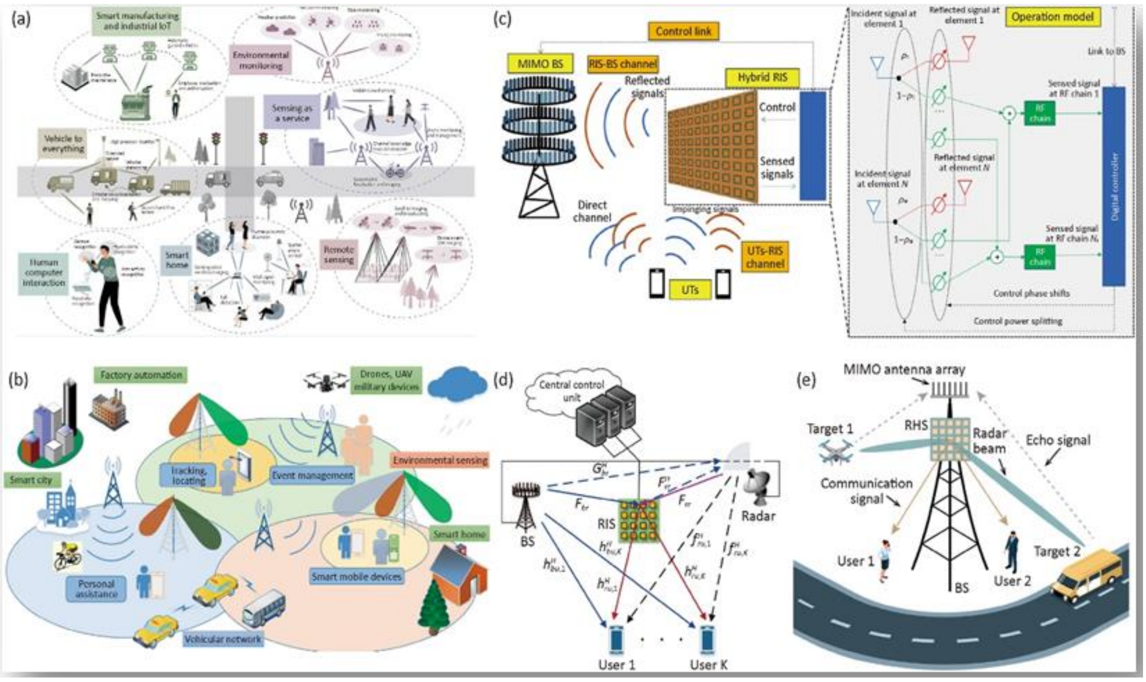


Figure 6: Future of Millimeter Wave Communication System

Reference: Fundamentals and applications of millimeter-wave and terahertz programmable meta-surfaces - ScienceDirect

(a) ISAC technology offers significant potential for the future development of wireless networks.

(b) The integration of sensing and communications capabilities within perceptive mobile network presents a range of potential applications and use cases.

(c) ISAC technology based on RIS. The incident signal at each meta-atom is separated into two components: one portion that is reflected back into the environment after undergoing tunable phase shifting, and the remaining signal that is sensed and processed locally at the meta-surface.

(d) RIS assisted in spectrum sharing between MIMO radar and MU-MISO communication systems.

(e) Schematic of a holographic a beamforming for integrated sensing and communication system

Alerts on the upcoming meetings, materials and documents relevant to that meeting will instantaneously become available to the user's device, while documents and tasks that are modified will be automatically updated. Vehicle diagnostic services are becoming attractive to obtain the information such as battery level, fuel level or engine status on our smartphones. The 'eCall' system can automatically call emergency services in case of an emergency. By 2020 and beyond, more attractive services that wirelessly connect 'cars' around us with 'things will emerge and make people in the vehicles very comfortable.

2.2 The Internet of Things (IoT)

mmWave is offering multi-gigahertz of bandwidth, and giving competition to both cellular and WiFi present networks by over 200 times. 6G communication network in not imaginable without support of mmWave technology. mmWave is an option for addressing the demand of billions of IoT connected devices. mmPlug has been innovated to tackle with high power demand from IoT devices to work on mmWave Communication. mmPlug is compatible with wireless technologies such as (WiFi, Lora etc.) and does not require modifications to the circuit or firmware or communication protocols of the existing IoT devices. The mmWave technology will enable IoT devices to get the advantages such as high data rate, low interference and accurate localization.

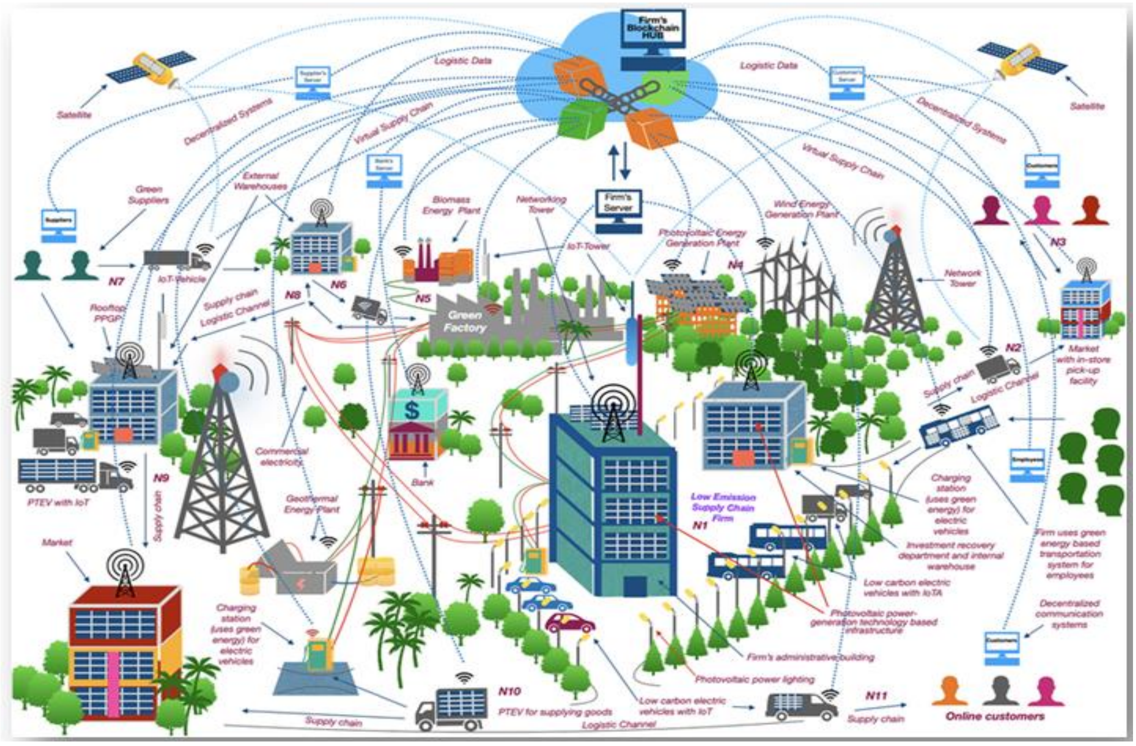


Figure 7: Growing of interconnections of Things with internet and Information Shower

Reference: Unlocking the link between low emission supply chains, blockchain adoption, and financial success: The payoff of socially responsible practices in supply chains - Bhattacharjee - 2024 - Business Strategy & Development - Wiley Online Library

For this, the basic fabric of the 5G system design is expected to provide support for up to a million simultaneous connections per square kilometer, enabling a variety of machine-to-machine services including wireless metering, mobile payments, smart grid and critical infrastructure monitoring, connected home, smart transportation, and telemedicine. Intelligent devices will communicate with each other autonomously in the background and share information freely. IoT services which in turn is expected to change human lives by connecting virtually everything. As shown in Figure 2, the number of connected Internet of Things (IoT) is estimated to reach 50 Billion by 2020, while the mobile data traffic is expected to grow to 24.3 Exabytes per month by 2019. The Showering of information can be mounted on ceilings, walls, doorways, roadside for massive data streaming while walking or driving. The roadside markers can provide safety information, navigation, or even advertisements.

2.4 Extremely wide bandwidth

mm Wave communication employs much higher frequency band between 30- 300 GHz as carrier frequencies. Hence, it has much more abundant spectrum resources of 270 GHz.

2.5 Small element sizes

Due to short wavelength, mm Wave devices enable large antenna arrays to be packed in small physical dimension.

2.6 Narrow Beam

With small antenna size, it is possible to pack more antenna elements at mmWave frequencies than at microwave. Therefore, the formed beam will be narrower, which can help for development of other applications such as detection radar etc.

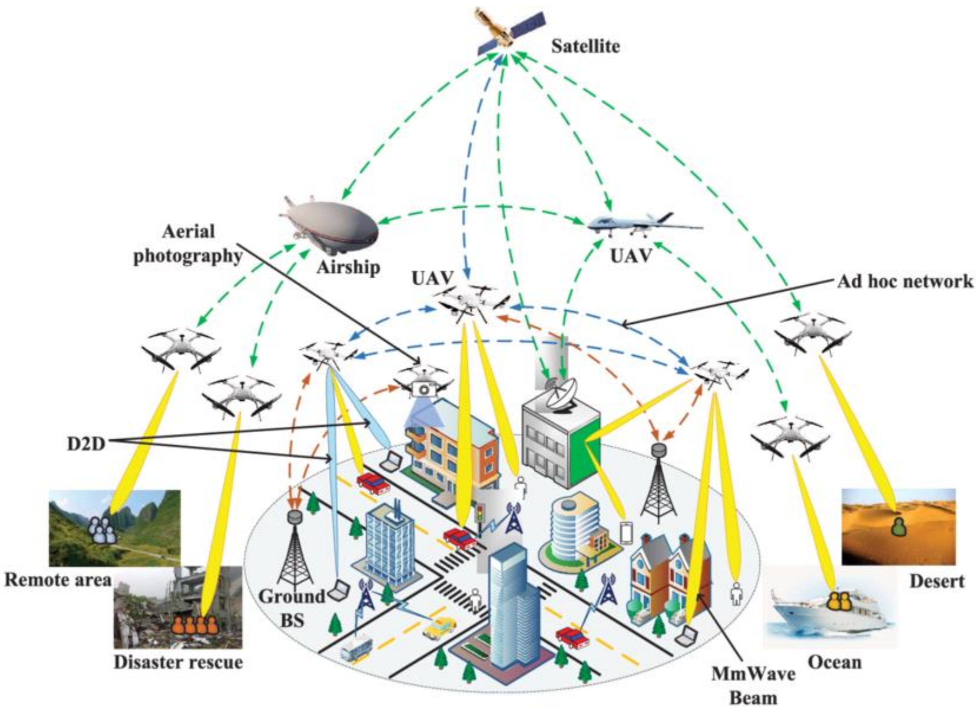


Figure 9: Illustration of the application scenarios for mmWave beamforming enabled UAV communications and networking.

Reference: Illustration of the application scenarios for mmWave beamforming... | Download Scientific Diagram

2.7 Enhanced Speed

mmWave, introduced NR frequency range 2 (24-52 GHz) in the 3GPP specifications, and unleashing 10 Gbps on 5G. Nokia announce in July 2023, that they achieved the sustained downlink speed of over 2Gbps using mmWave spectrum and 5G fixed wireless access (FWA) over a distance of 10.86KM.

2.8 Low Latency

mmWave technology features short wavelength, beamforming and support for real-time applications and achieving ultra-low latency.

2.9 Elevated Capacity

In mmWave, there is availability of large frequency band and short wavelength, it has the capacity to provide up to 1000 MHz bandwidth, which will bring users unprecedented high-speed experience.

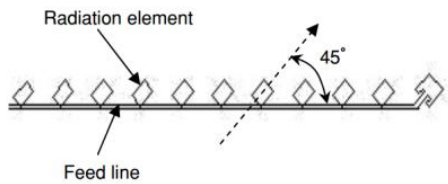
2.10 Smaller Antenna size and lighter equipment

mmWave antennas are smaller in size and equipment are lighter as well, which makes deployment more convenient.

3. CHALLENGES & SOLUTIONS

3.1 Designing of Circuits and System

There are several challenges in the design of Integrated circuit components and antennas for mm Wave communication due to high carrier frequency and wide bandwidth. The huge bandwidth cause severe nonlinear distortion of power amplifiers, phase noise and IQ imbalance are also challenging problems faced by radio frequency (RF) integrated circuits.



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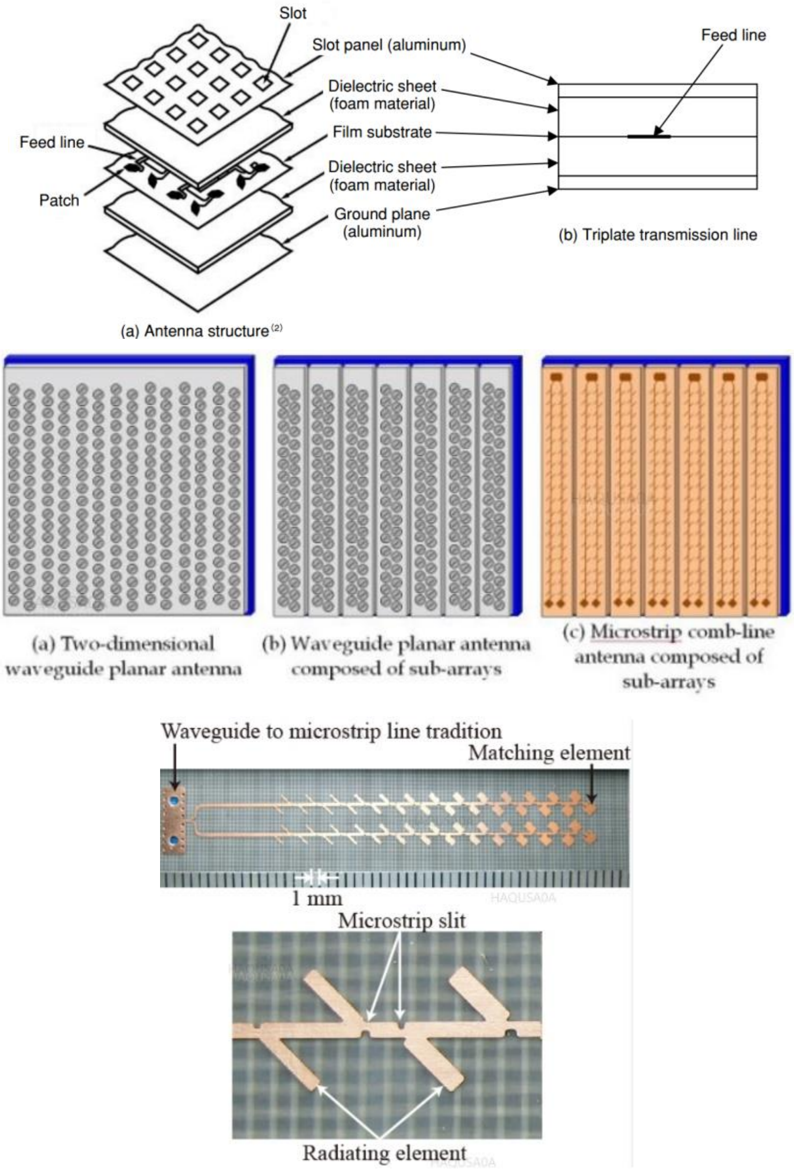

Figure 8: Structure of IC Antenna and feed line and radiation element

Reference: High-Gain Millimeter-Wave Planar Array Antennas with Traveling-Wave Excitation | IntechOpen

Due to this challenge, millimeter-wave Integrated Circuit Antenna and the development of microstrip antenna took place. The materials and structures can be altered to increase the efficiency, temperature characteristic, environment resistance etc. We can go for millimeter-wave microstrip antenna at smaller size to cope up with above mentioned problems.

3.2 Unfavorable mm-wave propagation channel conditions

The mm Wave propagation channel condition such as large pathloss in LoS/NLoS and signal blockage due to atmospheric absorption, and blocking objects attenuation in a cost and energy can affect mm Wave Communication in future. To solve this problem, we can design adaptive beamforming very large antenna arrays. Adaptive beamforming in different propagation conditions, NLoS/LoS in the presence of mobility, flexible support for multiple beams/users, robustness against signal blockage Support for high data rates and low-latencies (services, e.g. X-MBB), high energy and cost efficiency and can use for high frequencies and ultra-wide bands.

3.3 Due to mobility mmWave Communication is Dynamics:

The user of mobile always moves from one place to another, so the mobility poses several challenges in the mmWave communication system. When the users move, the distance between the transmitter (TX) and the receiver (RX) varies, and the channel state also varies accordingly. The channel capacity varies with the distance significantly. Therefore, the selection of modulation and coding schemes (MCS) should be performed according to the channel states to fully exploit the potential of mmWave communications.

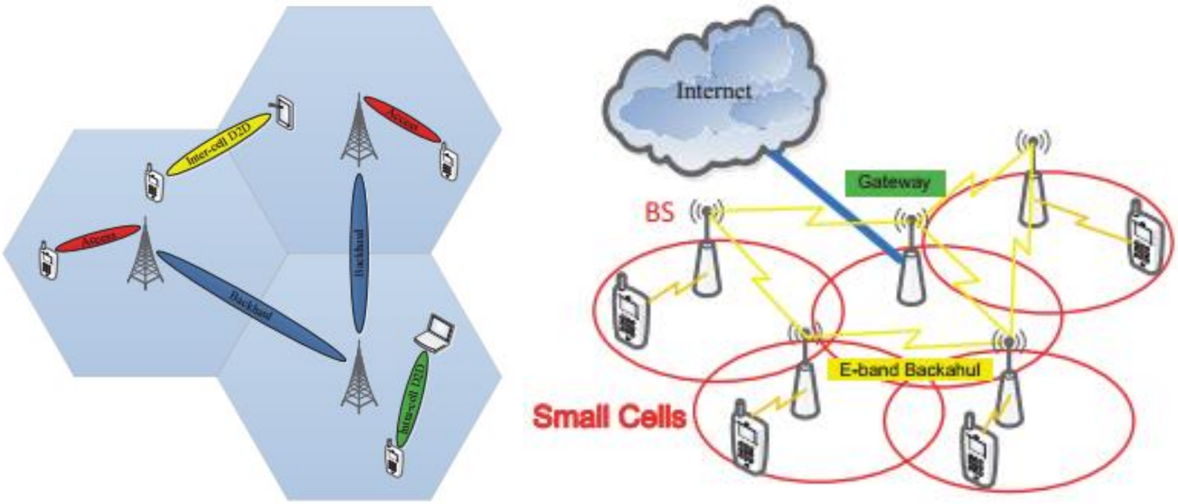

Figure 10: Millimeter Wave 5G cellular network architecture with Device to Device (D2D) Communication with E Band Backhaul for small cells

Reference: MmWave 5G cellular network architecture with D2D communications enabled. | Download Scientific Diagram

With the data traffic explosion and growth of mobile communication, massive densification of small cells has been proposed to achieve the 10 000-fold increase in network capacity by 2030. Small cells deployed underlying the microcells as WLANs or WPANs are a promising solution for the capacity enhancement in the 5G cellular networks. With huge bandwidth, mmWave small cells are able to provide the multi-gigabit rates, and wideband multimedia applications such as high-speed data transfer between devices, such as cameras, pads, and personal computers, real-time streaming of both compressed and uncompressed high-definition television (HDTV), wireless gigabit Ethernet, and wireless gaming can be supported.

4. CONCLUSION

The prospective to offer greater capacity over current communication systems, mmWave communications is promising way to be utilized for the 6G mobile networks. In this paper, we tried to analyze the opportunities challenges and future developments of mm Wave Communication. There is significant room of opportunity to research and can cope up with existing challenges such as propagation loss, anti-blockage, interference management etc. The current solutions for these challenges have been studied by using microstrip antenna, and multi array large scale antenna system.

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