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Applications and Use Cases of Millimeter Wave Communications in 5 G

Shivam Awasthi[1], Vivek Kumar Sharma[2], Jitendra Kumawat[3], Shruti Mathur[4], Satyajeet Sharma[5], Gajanand Sharma[6]

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Abstract - Due to the 5th Generation (5G) mobile communication system's 10 Gbps data throughput and around 1 ms latency, there has been a tremendous rise in data traffic. The actual 3 GHz radio band is become so congested as cellular data demand rises. This prompts the search for newly assigned mobile communication frequency bands that can provide a wide range of spectrum. The use of millimeter wave (mm-wave) can overcome this. In order to support future multi-gigabit-per-second mobility, image, and multimedia applications, mm-wave communications aim to make use of the vast and underutilized bandwidth. Although millimeter wave technology has been around for a while, it has mostly been used in military application**.** The academic community, corporate community, and standards body have significantly boosted mm-Wave technology due to the development of process technologies and low-cost integration solutions. This paper's major goal is to shed somehow mm-Wave can be used for fifth-generation communications and how next-generation customers can greatly profit by making ethical use of the bandwidth present in the mm-Wave spectrum, which ranges from 30GHz to 300GHz. Additionally, we analyze mmWave applications in this study to show how mmWave technology may be used to deliver various services.

Key Words: *Millimeter Wave Communications, Fifth Generation, Millimeter Wave Spectrum, Wireless Communication Community, Bandwidth*

1. Introduction

Mm-wave is a viable technology for coming future in cellular network. There is a certain amount of spectrum that cellular networks can use. Therefore, a variety of methods are employed to boost spectral efficiency. These include interference coordination, multiple-input multiple-output (MIMO), efficient channel coding algorithms, and orthogonal frequency-division multiplexing (OFDM). Along with the usage of heterogeneous infrastructure including macro, Pico, Femtocells, relays, and distributed antennas, network densification has recently been investigated to improve the spectral efficiency of the region. [1]. However, a single increase in spectral efficiency is insufficient to provide high user data rates. Utilizing the mm-wave spectrum is the answer. The 20MHz channels of available bandwidth are used by 4G customers. The mm-wave spectrum may be utilized by service providers to greatly expand channel bandwidth. The data capacity is increased by increasing the RF channel's bandwidth. Additionally, the latency issue for digital traffic may be minimized. This offers improved internet-based access and apps that have low latency requirements. Since mm-wave frequencies have a substantially shorter wavelength, polarization and novel spatial processing methods like massive MIMO and adaptive beamforming may be utilized. The mm-wave spectrum has substantially tighter spectral allocations. This increases the comparability of mm-wave band propagation properties and a single unit. A potentially useful technology relieves the pressure of limited spectrum resources for fifth-generation (5G) mobile broadband, mm-wave communications is particularly promising due to time is out of balance and geographic many ways to use the spectrum as well as the rapidly growing

1Department of Computing Science and Engineering, Galgotias University; shivavasti@gmail.com

2Department of Computing Science and Engineering, Galgotias University; vkshere4every1@gmail.com

3Department of Computer Science and Engineering, JECRC University; drkumawatjitendra@gmail.com

4Department of Computer Science and Engineering, JECRC University; smsavi@gmail.com

5Department of Computer Science and Engineering, JECRC University; sharma.satyajeet24@gmail.com

6Department of Computer Science and Engineering, JECRC University; gajanan.sharma@gmail.com

**Corresponding author: Gajanand Sharma*

number mobile applications with high bandwidth, such as streaming video in high-definition (HDTV) and UHDV. [2].

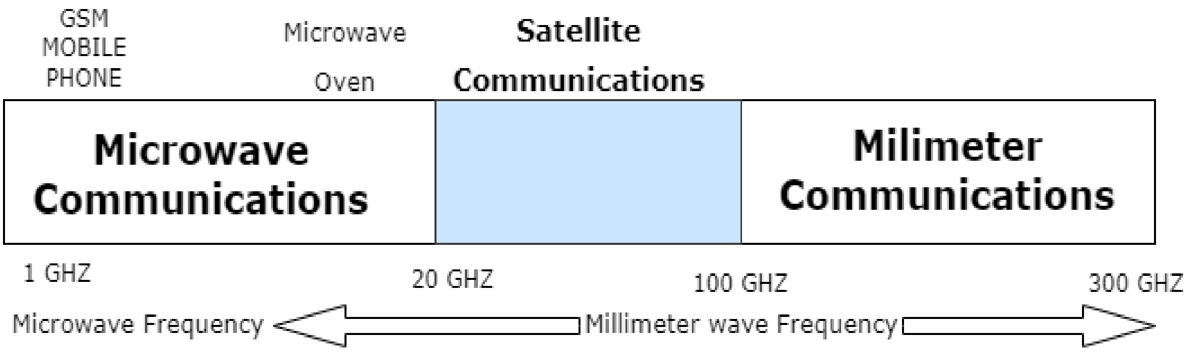

Fig -1: Communication in Millimeter wave frequencies

1. Fifth Generation Wireless Communication

Since fourth-generation (4G) technology requires a lot of spectrums, fifth-generation (5G) technology has advanced and is now widely employed. Unused mm-wave frequency bands, highly directional beamforming antennas at base and mobile stations, longer battery life, fewer outages, and better bit rates across extensive coverage areas are a few of them to decrease in infrastructure costs and an increase in concurrent user capacity across licensed and unlicensed spectrum. One of the main advantages of 5G networks over copper and fiber optic is the deployment of millimeter wave wireless communication, which uses mesh-like networking to help among the base stations. Mobile phone customers may simply access their 5G using any electronic device such as laptop or tablets, to gain readily available broadband internet connectivity in addition to the additional features and competency that this 5G technology offers. The best qualities now supplied and used by 5G technology include bidirectional enormous bandwidth, fast data speeds, high resolution, and excellent Quality of Service (QoS). The key to a 5G mm-wave solution is thought to be the usage of mm-wave Radio Frequency Integrated Circuits (RFICs), which supply a fundamental radio technology [3]. The advantages of RFICs include their tiny size, low power consumption, and inexpensive cost. They also enable highly integrated elucidations.. Future 5G wireless networks will be able to offer mobile users sustained multi-gigabit per second data speeds with little radiation, enabling access to content, apps, and cloud services. The 4G cellular networks that are now being deployed are severely challenged by the present surge of mobile data traffic from portable devices [4]. Future 5G heterogeneous wireless networks must successfully be deployed and operated, and there are significant technological issues that must be resolved, including:

When compared to fixed access, wireless access rates are comparatively lower.

i. Making use of expansive, lightly licensed, or unlicensed frequency zones at mm-wave frequencies to offer flexible spectrum utilization and a peak throughput capacity of 10 Gbps, much exceeding the LTE-Advanced system.

ii. Particularly in the field of mobile radio networks, energy consumption is quickly increasing. To cut down on overall human exposure in the broad 5G frequency spectrum while maintaining user perception of quality.

2. Enabling Technologies

The mm-Wave spectrum in the region of 252 GHz may be easily utilized by the cellular mobile communications system. The major technologies needed for the 5G mobile system to harness the mm-wave spectrum efficiently are listed below –

3.1 Beamforming

Beamforming technology will be used to boost base station antenna gain and focus antenna radiation in the desired direction. Additionally, targeted broadcasts and narrow beams are advantageous for cellular applications because they lessen interference brought on by spatial reuse, which raises the signal to interference ration (SINR). The advantage of millimeter wave radio wavelengths is that a smaller antenna is needed. However, a smaller antenna also has a smaller effective antenna aperture size, which leads to worse antenna gains. A mm-wave signal at 30 GHz, for instance, is expected to have a 20 dB greater path loss than a signal at 3 GHz, according to the free-space equation. The amount of energy captured by a comparable antenna at 30 GHz at mm-W frequencies is therefore 100 times lower than that of a corresponding antenna at 3 GHz. At millimeter waves, multi-antenna array beamforming, also known as smart antenna, can be used to overcome the negligibly small antenna gains and related losses.

Antenna size (/2 dipole or patch) and antenna spacing (d) can both be reduced for beamforming purposes to a very short distance (about /2). Due to the small size and spacing of millimeter-wave antennas, it is possible to install high gain antennas in a comparably small area (for example, tens of antennas per cm area at 80GHz carrier frequency). Two popular types of smart antennas are switched beam systems and adaptive array systems [5]. The switched beam systems provide a variety of beams from which one can choose. The drawback of this approach is that the target user might not be in the center of the primary beam. Obstructers are not located in a radiation null, either. By placing the user of interest in the center of the primary beam while simultaneously cancelling out interference signals, Antenna may direct beam in any desired direction with the aid of adaptive arrays. Another constraint connected to the fact that 5G prioritizes almost-zero latency is that beamforming solutions must rely more on silicon technology and less on software for complicated processing.

3.2 Massive Multi Input Multi Output (MMIMO)

By utilizing several antennas at the transmitter and receiver, the radio technology known as multiple-input multiple-output, or MIMO, enhances the performance of mobile devices. Due to its potential to boost spectral efficiency and network capacity, MIMO systems have drawn more attention. Generally speaking, the more signal routes and antennas a transmitter or receiver has, the more reliable the link will be and the higher the data throughput will be. The modern 4G mobile networks have already included MIMO methods. The next step in MIMO is to keep expanding antenna arrays with orders of magnitude more elements than in currently being produced systems, such as 100 antennas or more; this was referred to as gigantic MIMO. Massive MIMO, also known as full-dimension (FD) MIMO, extremely large MIMO, hyper MIMO, and large-scale antenna systems, will pave the way for 5G cellular networks [6].

3.3 Small Cell Deployment

A strategy to accommodate high traffic demand, particularly in densely populated cities and hotspots like stadiums and retail centers, is network densification. Small cell sites that are located inside the existing macro sites' coverage areas create a network that is described as being multi-layer or multi-tiered. Small cell site deployment shortens the separation between users and base stations, resulting in fewer propagation losses, greater energy efficiency, and faster data speeds. The macro cell provides data and control to the high-speed user equipment as well as those not covered by the small cells. Data from the small cells and control from the microcells are sent to the UEs encased in tiny cells. As a result, it is desirable to use millimeter waves for high data rate communication via tiny cells and microwave (3GHz) radio frequencies to convey specific essential control channel messages [7].

4. Advantages And Limitations Of Mm-Wave

A. Advantaes

1. The mm-wave technology's wider bandwidth can support spread spectrum technology, greater transmission rates, and interference immunity.

2. Several transmitters are frequently set close to one another to accomplish multiple short distances at extremely high frequency ranges while remaining unblocked from one another. Should have a narrower beamwidth. Once the frequency is hyperbolic for an analogous size of the antenna, the beam breadth gets decreased.

3. As a result of the frequency and antenna size being inversely correlated with every modification, the hardware gets smaller.

B. Limitations

1. The cost of production rises when small-scale components have higher accuracy.

2. Very high frequencies, which are seldom ever employed for long-distance applications, have significant attenuation.

3. Less millimeter-wave energy may pass through solid surfaces like concrete walls.

4. More analysis is done to reduce the interference levels since element and rain interferences occur at higher frequencies.

5. Applications Of Mm Wave 5g

In addition to having a greater overall effect than other mobile technologies, 5G has the ability to transform the digital environment in a variety of different societal sectors and businesses. Soon, faster internet phones, automobiles that can interact with other vehicles and a good transit system will all be widely available. Among other new 5G-powered breakthroughs enhance that intelligent industrial infrastructure and the cutting-edge technologies for remote access to education and healthcare. The advantages of 5G are round the globe, with effects and new industry-wide capabilities (such as mining, healthcare, professional services, transportation, and energy production). They combine several use cases (such as industrial automation, next-generation broadband for transportation, remote object manipulation, and high-speed internet for the home and office). However, in order to fully enjoy the advantages of 5G networks, the most recent spectrum must be allocated, especially in high-frequency bands with frequencies more than 24 gigacycles per second, also known as mm-wave [8]. The mm-wave spectrum can allow 5G, which has several advantages for users, businesses and governments all around the world. Due to the creation and preparation of 5G applications, the economic effect of mm-wave 5G may differ and change depending on the goals and problems of each nation. The societal advantages of mm-wave 5G are significant, both from an economic and a social standpoint.

5.1 Smart Logistics hubs and transportation

Transportation hubs on land and ports will be impacted by mm-wave 5G infrastructure. In the framework of smart infrastructure, the application of a number of mm-wave 5G use cases such as fifth-generation broadband for mobility, remote object manipulation, and high-speed internet at the workplace will be taken into consideration. Beyond the obvious advantages for commerce, certain industries might be especially affected by these mm-wave 5G applications. Transport expenses will be decreased in industries like manufacturing, mining, agriculture, and others. Fast cargo loading and unloading into and off of ships, lorries, and rail cars is a key factor in port operation. Coordination of the more sophisticated smart cranes that hoist containers will be possible thanks to remote object manipulation made possible by mm-wave 5G links to a control center. High levels of accuracy are needed for this interaction, along with stringent network requirements for low latency, dependability, and user experience data throughput. These 5G-based mm-wave improvements will boost productivity and lessen risks associated with loading and unloading freight. For multimodal logistics hubs, coordinating the activities of several modes of transport—Road, Rail and Transport—becomes a more difficult task.

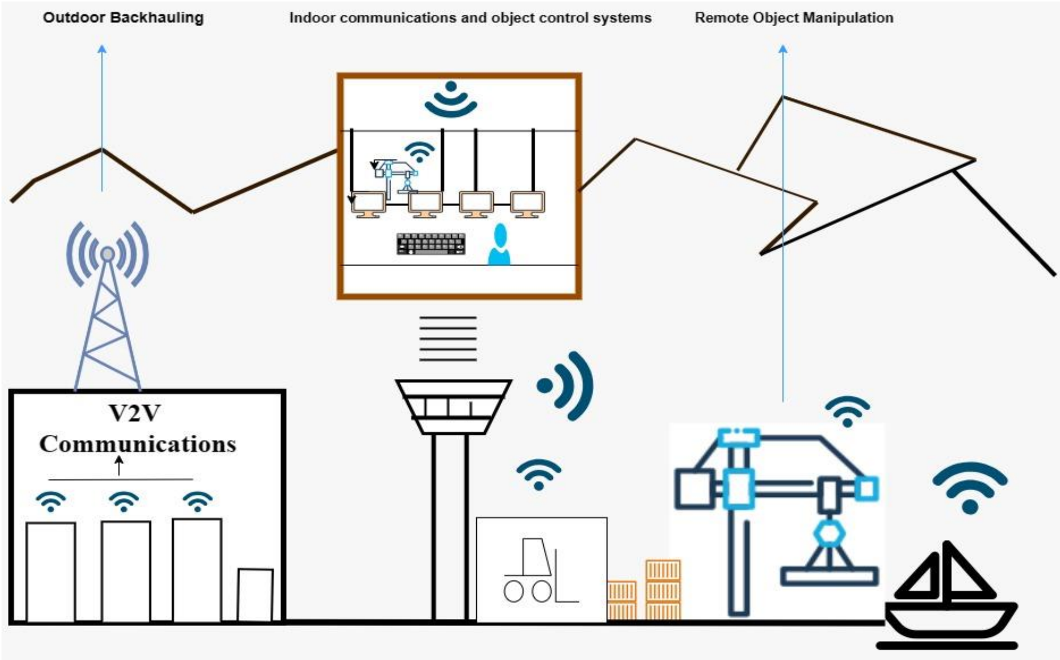

Fig -2: MM Wave 5G communication at Smart Port

The expenses of processing and transferring commodities would be reduced, while port throughput would improve, if these various transport vehicles were connected inside the port's fleets of internal distribution and infrastructure. Transport trucks, roadside units, and logistics managers will be able to share high-definition dynamic map data via vehicle-to-vehicle (V2V) communications systems. To guarantee that containers are delivered to the proper position to load and ship, vehicles will be able to successfully navigate themselves through the complicated and dynamic port environment. Similarly, coordinated warehousing and transport inside the port [9].

5.2 Connectivity

MmWave 5G can boost connection in the area, especially given how quickly it is urbanizing. Urban populations of various backgrounds will be able to connect to data-intensive 5G applications thanks to MmWave the capacity of 5G to give fiber-like speed without the hefty deployment costs of fixed infrastructure. High-speed connections will benefit the neighborhood economy by enabling the full range of mm-Wave 5G use cases across all businesses. A successful urban environment and a vital component of an integrated urban strategy both depend increasingly on high-speed broadband. However, in these metropolitan settings, deploying high-speed internet may be very challenging. In order to lay cable, rights-of-way (ROW) must be acquired, which can be expensive and time-consuming, especially where traffic congestion is already an issue or permission procedures are complicated. Open ducts are rare in these places, and for those that do, obtaining space may need protracted, expensive discussions, bureaucracy, and ongoing fee responsibilities. The implementation of mmWave 5G connection is potential for the area given this confluence of difficulties. When compared to fiber, Mm-Wave 5G can provide high-speed connection in crowded areas at a very low cost since it doesn't need digging up streets or coordinating with multiple levels of government. By broadcasting via antennas on the sides of buildings, roofs and street fixtures (lampposts, traffic lights), mm-wave 5G provides "fiber in the air" connection in metropolitan contexts with multi-gigabit speeds. Small fixed wireless nodes can be mounted on existing buildings to avoid the requirement for extensive civil construction. Until recently, mm-wave 5G technologies were not thought to be a practical choice because of their limited range and vulnerability to obstruction.

However, a number of significant industrial advancements have eliminated many of these barriers. The network may redirect traffic by an indirect route when unplanned, temporary bottlenecks develop (like building construction), in particular by placing several antennas with various line-of-sight transmission channels. In order to guarantee extensive coverage and smooth communication, mmWave will gradually become more integrated with sub-6 GHz bands, encouraging the creation of multimode devices. Users will then connect to both sub-6 GHz bands for extensive coverage and mm-Wave bands for more bandwidth and capacity at the same time. Rapidly expanding metropolitan areas may avoid many of the issues related to deploying fixed broadband networks thanks to mm-wave 5G. By doing this, these communities may adopt more cutting-edge technology and implement innovations made possible by high-speed connection in a variety of contexts, such as in healthcare, education, and transportation, among other areas [10].

5.3 Transportation

In this situation, 5G made possible by mmWave provides a number of solutions to some of the region's present transportation issues. First, the mmWave spectrum's high bandwidth and low latency will support a variety of applications that will enable a connected transport environment. These Applications include "vehicle-to-vehicle (V2V), " "vehicle-to-infrastructure (V2I), " vehicle-to-pedestrian (V2P), and " vehicle-to-network (V2N) ", and ultimately a vehicle-to-ecosystem (V2X) ecosystem communication. The most notable improvement that V2X ecosystems can provide is an increase in safety by platooning of vehicles (V2V), warnings of impending collisions or obstructions (V2V or V2I), alerts for pedestrian crossings (V2P), and improved observance of traffic regulations and adaptive driving under automated or assisted driving situations. Urban public transportation systems, particularly buses, may be among the first to take advantage of future transportation infrastructure, because first 5G installations are anticipated to be restricted to large cities in the area. Governments can utilize mm-wave 5G technologies to create intelligent transportation systems (ITS) that will ease traffic in metropolitan areas.

High-speed and high-capacity internet will also be enabled and supported by mm Wave 5G in automobiles and public transit choices, enabling applications for augmented or virtual reality or high-capacity video entertainment. Applications of mm-Wave 5G in transportation may improve safety for drivers, passengers, and other road users, reduce pollution and improve air quality, and ease urban congestion, improving the wellbeing and health of the community.

Fig -3: MM Wave 5G urban Connectivity

5.4 Education

By enhancing both the availability and both young and adult learners' access to high-quality education, emerging mm-Wave 5G applications can support ongoing government initiatives. By enhancing the potential for distant learning, they can aid in increasing access. Communities may employ a combination of virtual and augmented reality) apps via high-speed broadband to provide rich virtual classrooms, regardless of location, by using mmWave 5G networks. Online learning can help teach manual skills that are now challenging to teach in an online context when tactile Internet apps become accessible. These options might be very helpful for a number of populations, including those younger pupils who might not be able to attend class, Students in secondary, tertiary or vocational training interested in disciplines that may not be taught at locally accessible universities or institutions, as well as adult learners who must schedule their classes around job and family responsibilities. MmWave 5G may potentially be able to raise educational standards, according to recent research. Many tactile and AR/VR Internet apps can raise quality by engaging students more effectively, whether they are in a virtual or actual classroom. In addition to enhancing broadband infrastructure, MmWave 5G will offer the capacity and latency required to handle haptic Internet applications, virtual reality applications, and augmented reality applications. These Applications can greatly expand chances for distance learners to receive high-quality, engaging education and improve the overall quality of learning available to digital and physical learners, regardless of age [11].

Fig -4: MM Wave 5G in Education sector

6. Conclusion

The 5G mobile systems utilized millimeter-wave (mm-wave) communication as a technology. This technology offers multi-Gbps data speeds in the 30GHz to 300GHz frequency range. A focused examination of the millimeter-wave band's difficulties and the key technologies required for the 5G mobile system to effectively utilize this band was established in this article. For developing practical circuits and systems at mm-wave frequencies, high path loss, air attenuation, rain attenuation, and restricted device performance are perhaps the biggest challenges. On the other hand, mm-wave systems are appealing because to their unique properties, which include their enormous potential bandwidth, reduced antenna size, sharper resolution, and capacity to penetrate thin materials. At millimeter-wave frequencies, there is a lot of bandwidth available, which helps with very high data transmission rates. We anticipate that interest in mmWave communications will increase as the 5G era unfolds. We anticipate that our study will provide helpful guidance for anyone who is interested in having a thorough grasp of mmWave technology.

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