MILLIMETER WAVE COMMUNICATIONS FOR 5G: THEORY AND APPLICATIONS

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Abstract - *The huge increase of the data traffic was exited the borne of 5th Generation (5G) mobile communication system looking at 10 Gbps data rate and around 1ms latency. As the cellular data demand is increasing, the actual 3 GHz spectrum band becoming so crowded. This leads to look for a new allocated mobile communication frequency bands that can offer a broadband amount of spectrum. This can be surmounted by using Millimeter wave (mm-wave).The idea behind mm-wave communications is to take advantage of the huge and unexploited bandwidth to cope with future multi-gigabit- per- second mobile, imaging, and multimedia applications. Despite millimeter wave technology has been known for many decades, the mmWave systems have mainly been deployed for military applications. With the advances of process technologies and low-cost integration solutions, mmWave technology has started to gain a great deal of momentum from academia, industry, and standardization body. The main focus of this paper is to throw some lights on how mm-wave can be used for fifth generation communication and to discuss how the next generation users can be highly benefited by prudently using the bandwidth available in the mm-wave spectrum ranging from 30GHz to 300GHz. In this paper, we also provide a review on the mmWave applications to illustrate how mmWave technology can be employed to satisfy other services.*

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

1. INTRODUCTION

Mm-wave is a promising technology for future cellular systems. The available spectrum for cellular systems is limited. So, various techniques are used to increase the spectral efficiency. These include orthogonal frequency-division multiplexing (OFDM), multiple-input multiple-output (MIMO), efficient channel coding techniques, and interference coordination. Recently network densification has also been studied to optimize the area spectral efficiency, in addition to the use of heterogeneous infrastructure such as macro, Pico, Femtocells, relays, distributed antennas [1]. But increased spectral efficiency alone is not sufficient to guarantee high user data rates. The solution is the usage of the mm-wave spectrum. 4G Customers use the existing bandwidth of 20MHz channels. The service providers can use the mm-wave spectrum to significantly increase the channel bandwidth. Widening the bandwidth of the RF channel increases the data capacity. Also, the latency problem is can be reduced for digital traffic. This provides enhanced internet-based access and applications that require minimal latency. Polarization and new spatial processing techniques such as massive MIMO and adaptive beamforming can be exploited since mm-wave frequencies have a much smaller wavelength. The spectral allocations in the mm-wave spectrum are much closer. This makes the propagation characteristics of mm-wave bands more comparable and homogenous.

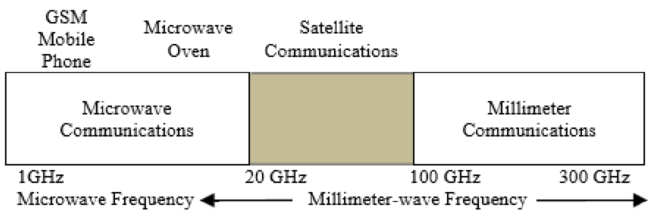

Fig -1: Communication in Millimeter wave frequencies

In particular, the unbalanced temporal and geographical variations of spectrum usage along with the rapid proliferation of bandwidth-hungry mobile applications, such as video streaming with high definition television (HDTV) and ultra-high-definition video (UHDV), have inspired millimeter-wave (mmWave) communications as a promising technology to alleviate the pressure of scarce spectrum resources for fifth-generation (5G) mobile broadband.

2. FIFTH GENERATION WIRELESS COMMUNICATION

Untapped mm-wave frequency bands, highly directional beamforming antennas both at mobile and base stations, extended battery life, lower outage probability, higher bit rates in bigger coverage areas, lower infrastructure costs and higher aggregate capacity for simultaneous users in both licensed and unlicensed spectrum leads to the advancement and implementations of fifth-generation (5G) compared to that of the 4G that uses a greater spectrum allocation [2]. Millimeter wave wireless connection is considered to be one of the major strengths of 5G networks that are transformed from copper and fiber optic which deploys mesh-like connectivity to assist among the base stations. Mobile Phone users can easily access their 5G using any electronic gadgets like Laptops or tablets to obtain accessible broadband internet connectivity in addition to which this 5G technology provides more features and competence. Bidirectional huge bandwidth, high data rates, high resolution, and finest Quality of Service (QoS) are the best features that are offered and implemented by 5G technology as of now. The use of mm-wave Radio Frequency Integrated Circuits (RFICs) that delivers a core radio technology is considered to be the key for 5G mm-wave solution. Highly integrated elucidations are offered by RFICs with benefits of compact size, power consumption, and cost. Millimeter-wave small cell technology can provide sustainable and low radiation multi-gigabit per second data rates to mobile users in future 5G wireless networks, leading to unprecedented access to contents, applications, and cloud services. The current growth of the mobile data traffic of handy devices vividly challenges the 4G cellular networks that are under deployment [3]. There are critical technical problems that need to be addressed for the successful deployment and operation of future 5G heterogeneous wireless networks including:

i. The rates of Wireless access are comparably smaller when compared to that of fixed access.
ii. Taking advantage of wide unlicensed or light licensed frequency bands available at mm - wave frequencies to allow flexible spectrum usage as well as peak capacities above 10 Gbps aggregated throughput, well beyond the LTE-Advanced system.
iii. The consumption of energy levels is raising swiftly, particularly in the part of mobile radio networks.
iv. To reduce the total human exposure without compromising the user's perceived quality in the large panel of envisioned frequency band for 5G.

3. ENABLING TECHNOLOGIES

Within the mm-Wave band, up to 252 GHz spectrum could be easily be exploited by the cellular mobile communications system. The main technologies needed to enable the 5G mobile system to efficiently exploit the mm-wave band is listed below.

3.1 Beamforming

For improving the base station antenna gain and focusing antennas energy in a preferred direction, the beamforming technique will be deployed. Additionally, narrow beams and directional transmissions for a cellular application are useful to reduce interference introduced by spatial reuse which leads to increase the signal to interference ratio (SINR) [4]. An advantage of millimeter wave is the smaller antenna requirement due to shorter radio wavelengths. Nevertheless, a smaller antenna also leads to smaller effective antenna aperture sizes, thus smaller antenna gains. For instance, according to the free-space equation, the mm-Wave signal at 30 GHz will suffer a 20 dB larger path loss compared to a signal at 3 GHz. Therefore, an antenna at mm-W frequencies at 30 GHz captures 100 times less energy compared to a similar antenna at 3 GHz. To overcome the small antenna gains along with other losses at millimeter waves, multiantenna array beamforming can be used which is also known as smart antenna [5]. Along with small antenna size ($\lambda/2$ dipole or patch), antenna separation (d) can be reduced to a very short distance (around $\lambda/2$) for beamforming purposes. The small size and separation of millimeter-wave antennas make it possible for putting plenty of antennas in a small dimension, which gives a high gain antenna implementation in a relatively small area (e.g., tens of antennas per cm area at 80GHz carrier frequency). The well-known two types of smart antennas are the switched beam systems and the adaptive array systems [6]. The switched beam systems provide a predetermined group of beams that can be chosen as appropriate. The defect of this method is that the user of interest may not be in the center of the main beam. Simultaneously, interferers are not situated in a radiation null. Adaptive arrays enable the antenna to steer the beam to any direction of interest, by setting the user of interest in the center of the main beam while at the same time nulling interfering signals. Beamforming techniques is another limiting factor related to the fact that 5G puts a very high priority on almost-zero latency, which implies the need to rely more on silicon technology for complex processing and less on software.

3.2 Massive Multi Input Multi Output (MMIMO)

In radio, multiple-input and multiple-output, or MIMO, is the usage of multiple antennas at both the transmitter and receiver to enhance the mobile system performance. MIMO systems have gained increased attention due to their ability to enhanced spectral efficiency and improve network capacity. Generally, the more antennas the transmitter/receiver comes with, the more signal paths and the better the reliability of the link and the data rate [7].MIMO techniques were previously presented in the current 4G mobile systems. The next thing with MIMO is to maintain increasing antenna arrays with an order of magnitude, more elements than in systems being built presently, for instance, 100 antennas or more; this was popularly known as massive MIMO. Massive MIMO also called large-scale antenna systems, very large MIMO, hyper MIMO, and full-dimension (FD) MIMO and it will be going to lead the way to 5G cellular systems.

3.3 Small Cell Deployment

Network densification is an approach to add more cell sites for supporting thigh traffic demand, especially in densely populated cities and hot spots like stadiums and shopping malls. Small cell sites, inside the coverage area of the already-deployed macro sites, resulting in what is called multi-layer or multi-tier network. Through the deployment of small cell sites, the distance between the users and the base stations is reduced, which leads to lower propagation losses, energy efficiency, and higher data rates. The high-speed user equipment and those not covered by the small cells receive data and control from the macro cell. UEs covered by the small cells receive control from the macrocells and data from the small cells. Consequently, it is useful to transmit particular important control channel signals using the microwave (<3GHz) cellular radio frequencies, whilst employing the millimeter waves for high data rate communication via small-cells [8].

4. ADVANTAGES AND LIMITATIONS OF MM-WAVE

A. Advantages

1. The larger bandwidth of mm-wave is able to provide higher transmission rate, spread spectrum capability and more immune to interference.
2. Multiple short distances are often achieved at very high-frequency ranges (i.e., Multiple transmitters are often placed in proximate location to every other) usages at a similar frequency while not busy one another.
3. Beamwidth should be Narrower. Once the frequency is hyperbolic for an analogous size of the antenna, the beam breadth gets decreased.
4. The size of the hardware is reduced i.e., the frequency and size of the antenna area unit reciprocally proportional to every difference.

B. Limitations

1. Small size elements with bigger exactitude increase the producing prices.
2. Substantial attenuation happens at very high frequencies which will hardly be used for long-distance applications.
3. Millimeter-wave has less penetration power through objects like concrete walls.
4. Interferences with element & rain occur at higher frequencies as a result more analysis goes on to scale back the interference levels.

5. APPLICATIONS OF MM WAVE 5G

5G has the potential to impact societies even a lot of generally than different mobile technologies, driving innovation and reworking the digital landscape across totally different industries and sectors of the society. we are going to shortly see the mass accessibility of phones with quicker broadband, cars that communicate with different vehicles and good transport infrastructure. Augment that intelligent industrial plant, and innovative tools for remote access to education and treatment, among several different new 5G-powered developments. The benefits of 5G is international, with impacts and new capabilities cutting across industries (e.g. energy production, transportation, skilled services, mining, and healthcare). They conjointly mix multiple use cases (e.g. remote object manipulation, high-speed broadband to the house and workplace, industrial automation, next-generation broadband for transport). However, realizing the benefits of 5G networks needs the allocation of the latest spectrum, particularly in high-frequency bands higher than twenty-four gigacycle per second, conjointly called mm-wave.

5G enabled by the mm-wave spectrum can bring comprehensive benefits to people, businesses, and governments around the world. The economic impact of mm-wave 5G can vary between countries and evolve, taking into consideration national priorities and challenges additionally because of the development and preparation of 5G applications. On the far side the on the far side economic impact, the social benefits of mm-wave 5G area unit substantial.

5.1 Smart transportation logistics hubs

Mm-wave 5G will impact transport logistics infrastructures, such as in-land transport hubs and seaports. The application of several mm-wave 5G uses cases will be considered in the context of smart infrastructure, including next-generation broadband for transport, remote object manipulation, and high-speed broadband to the office. Certain industries may be particularly impacted by these mm-wave 5G applications, beyond the direct benefits to trade. For instance, manufacturing, mining, agriculture, and other sectors will see lower transport costs. Rapid loading and offloading cargo to and from ships, trucks, and railway cars is a critical driver of port performance. Remote object manipulation enabled by mm-wave 5G connections to a control center will allow coordination of the increasingly complex smart cranes that lift containers. This interaction requires a high level of precision, involving demanding network requirements in terms of low latency, reliability, and user experience data rate. These mm-wave 5G-based innovations will increase efficiency and lower the hazards related to cargo loading and unloading. Coordinating the activity of multiple types of transport— shipping, road, and rail—is an increasing challenge for multimodal logistical hubs.

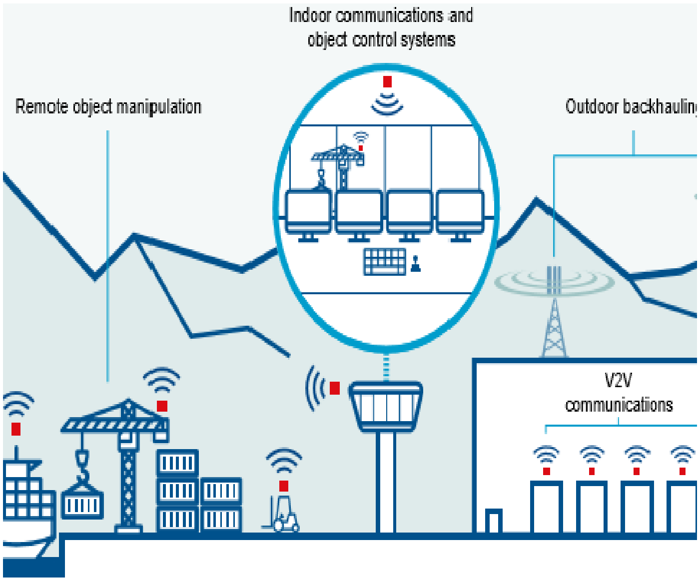

Fig -2: MM Wave 5G communication at Smart Port

Connecting these varied transport vehicles to internal distribution fleets and infrastructure within the port would lower the costs of processing and moving goods and increase port throughput. Vehicle-to-Vehicle (V2V) communications systems will allow connected vehicles to exchange high-definition dynamic map information between transport vehicles, roadside units, and logistics managers. Thus, vehicles will effectively navigate themselves through the complex and changing port environment to ensure containers are brought to the correct location for loading and shipping. Similarly, Vehicle-to-Everything (V2X) communications will improve back-of-port operations by enabling coordinated warehousing and transport within the port facility.

5.2 Connectivity

MmWave 5G can improve the region's connectivity, especially considering its rapid urbanization. MmWave 5G can provide fibre-like speeds without the high deployment costs of fixed infrastructure, enabling urban populations from all backgrounds to connect to data-intensive5G applications. High-speed connectivity will also benefit the regional economy by enabling the full spectrum of mmWave 5G use cases across all industries in the economy. High-speed broadband is becoming a more significant part of a well-functioning urban environment and a key part of an integrated urban policy. Yet, rolling out high-speed broadband can be especially problematic in these urban environments. Laying cable means acquiring rights-of-way (ROW), a costly and time-consuming process, particularly when traffic congestion is already a problem or permit processes are convoluted. Typically, these cities have few available ducts and for those that do, securing space may require extensive and costly negotiations and bureaucracy, as well as recurring fee obligations. This confluence of challenges makes the application of mmWave 5G connectivity promising for the region. MmWave 5G can deliver high-speed connectivity in dense environments at a very low cost when compared to fibre, as it avoids the need to dig up streets and co-ordinate with various levels of government. Mm-wave 5G enables "fiber in the air" connectivity in urban environments achieving multi-gigabit speeds by transmitting via antennae on the sides of buildings, rooftops and street fixtures (lamp posts, traffic lights). Small fixed wirelesses nodes can be attached to existing structures and eliminate the need for significant civil works. Until recently, mm-wave 5G solutions were not considered a realistic option due to their short range and susceptibility to blockage. However, several notable industry innovations remove many of these obstacles. In particular, by deploying numerous antennas with multiple line-of-sight transmission paths, the network can re-route traffic by an indirect route when unforeseen, temporary blockages occur (e.g. passing traffic or building construction). With time, there will be greater integration of mmWave with sub-6 GHz bands to ensure wide-area coverage and seamless connectivity, thus fostering the development of multimode devices. In turn, users will simultaneously connect to both sub-6 GHz bands for wide-area coverage and mmWave bands for additional bandwidth and capacity.

Mm-wave 5G can enable rapidly growing urban communities to avoid many of the problems associated with rolling out fixed broadband networks. In so doing, these communities can embrace more leading-edge technologies and deploy innovations available with high-speed connectivity in various ways, for instance in transportation, healthcare, and education, among others.

5.3 Transportation

In this context, 5G enabled by mmWave offers several applications to address some of the current transport challenges facing governments in the region. First, the capacity and low-latency broadband of mmWave spectrum will allow for many applications to enable a connected transport environment, including V2V, Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), Vehicle-to-Network (V2N) communication, and eventually to a V2X ecosystem. V2X ecosystems can deliver a number of improvements, most notably to increase safety through vehicle platooning (V2V)[9], advance collusion or obstruction alerts (V2V or V2I), alerts of pedestrian crossing (V2P), and better adherence to traffic rules and adaptive driving under cases of automated or assisted driving. As initial deployments of 5G are expected to be limited to major cities in the region, urban public transportation systems, especially buses, have the opportunity to be among the first to benefit from next-generation transport infrastructure. Governments can also take advantage of mm-wave 5G applications enabling V2X ecosystems to implement intelligent transport systems (ITS) to reduce congestion in urban areas.

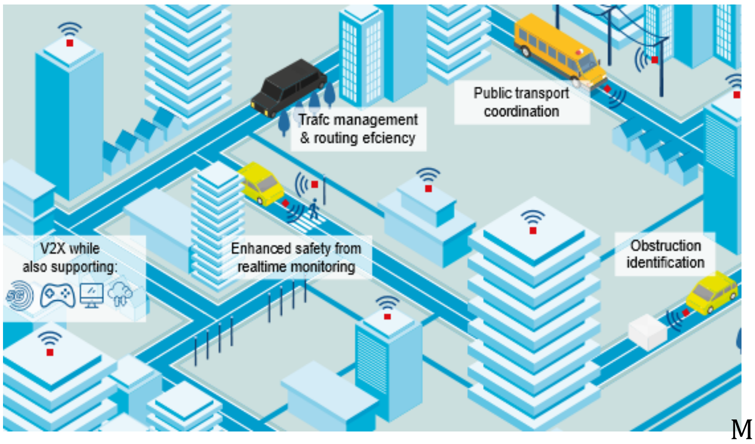

Fig -3: MM Wave 5G urban Connectivity

Mm Wave 5G will also enable and support high-speed and high capacity broadband in vehicles and public transportation options, allowing riders to consume high-capacity video entertainment or augmented or virtual reality applications[10]. Transport can benefit from mmWave 5G applications to improve safety for road users, passengers, and drivers, reduce pollution and improve air quality, and decrease urban congestion, thereby improving the health and well-being of citizens.

5.4 Education

Emerging mmWave 5G applications can further existing governmental efforts by improving access to and quality of education, for both young and adult learners. They can help to expand access by improving distance learning possibilities. By leveraging mmWave 5G networks, communities can use augmented reality (AR) and virtual reality (VR) applications over high-speed broadband to offer rich virtual classrooms, regardless of location. As tactile Internet applications become available, online learning can also teach manual skills that are currently difficult to teach in an online setting. These possibilities could be particularly useful for several groups, including: Young students who may not be able to attend class, Adult learners who must take classes around work and familial obligations and Students in secondary, tertiary, or vocational training interested in subjects that may not be offered at locally accessible universities or schools. Possibilities are also emerging for mmWave 5G to improve the quality of education.

Fig -4: MM Wave 5G in Education sector

Many of the AR/VR and tactile Internet applications can improve quality by better engaging with students overall, whether in a virtual or physical classroom. MmWave 5G will improve broadband infrastructure and provide the necessary capacity and latency requirements needed to support AR/VR and tactile Internet applications which can greatly expand opportunities for access to high-quality and engaging education at distance, as well as improve the overall quality of education for virtual and physical learners, both youth and adult.

6. CONCLUSION

Millimeter-wave (mm-wave) communication was adopted as a technology for the 5G mobile systems. This technology provides multi-Gbps data rates in a frequency range of 30GHz to 300GHz. In this paper a concentrated survey was established on the millimeter-wave band challenges and the main technologies needed to enable the 5G mobile system to exploit efficiently this band. High path loss, atmospheric attenuation, rains attenuation, and limited device performance are probably major obstacles for establishing practical circuits and systems at mm-wave frequencies. On the other hand, huge available bandwidth, smaller antenna size, finer resolution, and penetrating capability through thin materials are unique qualities that make mm-wave systems attractive. There is large bandwidth available at millimeter-wave frequencies which aids very high data transmission rate.

With the advent of the 5G era, we believe that mmWave communications will gain more and more attention. We hope that this work will serve as useful guidelines for interested individuals to have a quick and comprehensive understanding of mmWave technology.

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