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Millimeter Wave for Industrial Wireless Networks

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Abstract: ***Communication at millimeter wave (mmWave) frequencies is defining a new era of wireless communication. The mmWave band offers higher bandwidth communication channels versus those presently used in commercial wireless systems. The applications of mmWave are immense: wireless local and personal area networks in the unlicensed band, 5G cellular systems, not to mention vehicular area networks, ad hoc networks, and wearable. Signal processing is critical for enabling the next generation of mmWave communication. Due to the use of large antenna arrays at the transmitter and receiver, combined with radio frequency and mixed signal power constraints, new multiple-input multiple-output communication signal processing techniques are needed. Because of the wide bandwidths, low complexity transceiver algorithms become important. There are opportunities to exploit techniques like compressed sensing for channel estimation and beam forming. This article provides an overview of signal processing challenges in mmWave wireless systems, mmWave 5G technologies, requirements, antenna and propagation challenges and some common applications of mmWaves.***

Keywords: Millimeter Wave (mmWave), 5G Technology

1. Introduction

One of the most important features for 5G technology is mm-waves which came as solution for the problem of the available frequency spectrum in the exciting technologies plus the huge bandwidth that can offer to the users. The main objectives of this paper is to study how mm waves can be a better choice for the next generation network. Other objective is to use the NYU simulator to explore the effect of environmental variations related to Tripoli city for different frequency bands. It is expected that the 5G (Fifth Generation) system will address the communication needs for humans and devices far beyond 2020 and enable the all-communicating world. Different from earlier generation changes, 5G will not only considerably improve the telecommunication services currently offered to the end users, but it will enable the support of evolved services tailored for other industries and humankind as such, for instance vehicular safety and transport system efficiency, industrial control, e-health applications. Also 5G came to provide all the need for mobile broadband networks to support ever-growing consumer data rate demands and the need to tackle the exponential increase in the predicted traffic volumes [2].

Millimeter waves spectrum is the band of spectrum between 30 GHz and 300 GHz. Wedged between microwave and infrared waves, this spectrum can be used for high-speed wireless communication. mmWave and 5G are used almost synonymously, but there are key differences between the two. The mm Wave technology is just one part of what future 5G networks will use. The term mmWave refers to a specific part of the radio frequency spectrum between 24GHz and 1000GHZ, which have a very short wavelength. Wireless data traffic has been increasing at a rate of over 50% per year per subscriber, and this trend is expected to accelerate over the next decade with the continual use of video and the rise of the Internet-of-Things [1][2]. To address this demand, the wireless industry is moving to its fifth generation (5G) of cellular technology that will use millimeter wave (mmWave) frequencies to offer unprecedented spectrum and multi-Gigabit-per-second (Gbps) data rates to a mobile device [3]. 5G mmWave wireless channel bandwidths will be more than ten times greater than today's 4G Long-Term Evolution (LTE) 20 MHz cellular channels. Since the wavelengths shrink by an order of magnitude at mmWave when compared to today's 4G microwave frequencies, diffraction and material penetration will incur greater attenuation, thus elevating the importance of line- of-sight (LOS) propagation, reflection, and scattering. Accurate propagation models are vital for the design of new mmWave signaling protocols. Over the past few years, measurements and models for a vast array of scenarios have been presented by many companies and research groups [3][4][5].

The USA and China are leading for first place 5G technology. The 5G standard promises to embody a mobile-connectivity revolution, providing enhanced broadband connectivity and speed for a wide swath of customers. But in reality, many experts believe that 5G and Wife will continue along their current, differentiated paths for the foreseeable future. According to experts on the biological effects of electromagnetic radiation, radio waves become safer at higher frequencies, not more dangerous.

The Most Important Components that 5G Offers

Phantom cell. Network densification using small cells with low power nodes is considered a promising solution to overcome mobile traffic explosion, especially in hot spot areas. The major benefits of the Phantom cell architecture includes enhanced capacity by small cells, easy deployment of higher frequency bands and small cell deployment without impact on mobility management.

*Massive Multi Input Multi Output (MIMO).*MIMO deployment uses multiple antennas that are located at the source (transmitter) and the destination (receiver). Those antennas are linked in order to minimize error and increase efficiency of a network. This method's ability to multiply the capacity of the antenna links has made it an essential element of wireless standards. Massive MIMO takes MIMO technology and scales it up to hundreds or even thousands of antennas and terminals.

Flexible duplex. A frequency separated network deployment, where different frequency bands are individually assigned to different cell layers, may use different duplex schemes such as FDD and TDD for lower and higher frequency bands. Therefore, it is desirable to support the Phantom cell solution irrespective of whichever duplex scheme is used in either the lower or higher frequency bands [1].

Millimeter-Waves. It is being related to the use of mm-waves by allocating more bandwidth to deliver faster, higher- quality video, and multimedia content and services.

2. Millimeter Wave Cellular Background

Millimeter wave communication is an advanced PHY layer technology, which has recently come to the forefront of research interest and may be able to rise to the challenge of providing high-rate mobile broadband services, in addition to offering opportunities for reducing over-the-air latency for NR.

MmWave makes use of the radio frequency spectrum roughly between 30 and 300 GHz, even though the research challenges extend also to lower frequencies which are considered for 3GPP NR. Systems that can operate in these bands are attractive because of the large quantities of available spectrum at these higher frequency ranges and the spatial degrees of freedom afforded by very high-dimensional antenna arrays, which are possible thanks to the smaller size of antenna elements at higher frequencies. Most current commercial wireless systems operate below 6 GHz, where lower frequencies allow for long-range propagation and low penetration loss, which makes them well-suited for radio communications. As a result, the sub-6 GHz spectrum has become heavily congested and individual bands are generally not available in contiguous chunks wider than 200 MHz However, large swaths of spectrum are available at the higher mmWave frequencies, which offer the possibility of very wide bandwidths, in some cases even larger than 1 GHz.

Although the mmWave bands are already used by a variety of commercial applications, such as satellite and point-to-point backhaul communications, until recently they were considered impractical for mobile access networks due to the poor isotropic propagation and the vulnerability to shadowing at these higher frequencies. However, it has now been shown that the limitations of the mmWave channel can be overcome with the help of high-gain, directional antennas so that this vast region of spectrum can now be exploited to provide an order of magnitude or more increase in throughput for mobile devices [3] [32].
Directional smart antennas are the major technology enabler that will make it possible for mmWave devices to overcome the poor propagation effects and unlock this high-frequency spectrum. The theoretical free space path loss is proportional to the square of the frequency, resulting in the magnitude of received power for a mmWave signal being over 30 dB (1000x) less than conventional cellular systems at equivalent distances between transmitter and receiver [33]. Multi-element antenna arrays and MIMO beam- forming techniques offer a means of compensating for this high attenuation. With millimeter waves, the antenna size and spacing shrinks to be on the order of millimeters, making it possible to pack hundreds of elements onto a small cell base station and dozens onto a handheld device. Smaller antenna size also allows for multiple arrays to be integrated onto mobile devices to provide diversity and maintain connective even if the signal from one array is blocked [3].

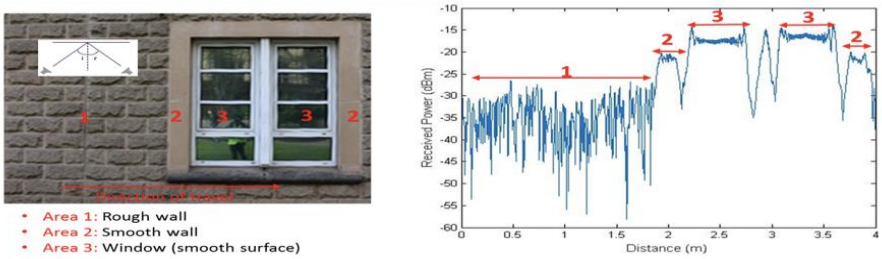
3. Millimeter-Waves 5G Technology

The vision for 5G is expansive, but one aspect of it is fiber-like connections providing multi- gigabit per second data rates to mobile devices. This connectivity will make many applications and services like 3D tele presence and virtual reality available, but these ultra-high-capacity applications will require mastery of millimeter wave spectrum in the frequency bands above 24 GHz for mobile applications. Currently the available frequency below 4GHz are being totally used by cellular communications systems, and by the very nature, these frequencies could only offer a maximum bandwidth of 4 GHz, even if they were all clear for use which is obviously not possible. By having a 5G millimeter-wave interface, much wider bandwidths are possible, and there are several candidate millimeter bands that are being considered for allocation to this type of service.

3.1. 5G Antenna and Propagation Challenges

The entire radio spectrum up to 5.8 GHz that has been used for global wireless communications throughout the past 100 years easily fits within the bandwidth of the single 60 GHz unlicensed band, yet there is so much more spectrum still available above 60 GHz [7][8]. most spectrum above 30 GHz is used for military applications or deep-space astronomy reception, but the recent FCC Spectrum Frontiers ruling has assigned many bands for mobile and backhaul communications. The various resonances of oxygen and other gasses in air, however, cause certain bands to suffer from signal absorption in the atmosphere. Rain or snow attenuation may be overcome with additional antenna gain or transmit power. Also, the size and orientation of rain drops and clouds may determine the particular amount of attenuation on air-to-ground links such that satellites could undergo more localized and perhaps less rain attenuation than terrestrial links at mmWave frequencies.

The larger antenna gains at higher frequencies require adaptive beam steering for general use at both the BS and UE, compared to legacy mobile antennas with lower gain [8]. Beam steerable antenna technologies estimate directions of arrival and adaptively switch beam patterns to mitigate interference and to capture the signal of interest. Adaptive arrays are essential for mmWave communications to compensate the path loss caused by blockage from dynamic obstacles [9][8][10][11][12]. MmWave will need to exploit and rapidly adapt to the spatial dynamics of the wireless channel since greater gain antennas will be used to overcome path loss.



Results of diffuse scattering measurements at 60 GHz, where smooth surfaces (e.g., windows) offer high correlation over distance, but signals from rough surfaces seem less correlated over distance

3.2. 5G Mobile Transport Capacity Requirements

In order to determine the transport requirements across the network, we start from the capacity requirements of typical macro sites, and later combine this information with the network topology to get the transport requirements of the mmWave links in different segments of the network (tail links, aggregation links). Moreover the evolution of mmWave technologies and the availability of new spectrum will allow supporting front-haul applications, with capacities ranging from 10 Gbps to 100 Gbps.

Site Type	Mobile spectrum and type	Cell type	Backhaul Capacity
Dense Urban	• LTE up to 50 MHz • 5G 200 MHz 16L MIMO ~4GHz • 5G ≥ 400 MHz 16L MIMO ~30GHz	Macro-cell: ~4GHz *and* ~30GHz Small-cell: ~4GHz *or* ~30GHz	>10 Gbps
Urban	• LTE up to 50 MHz • 5G 100 MHz 8L MIMO ~4GHz • 5G 200 MHz 8L MIMO ~30GHz	Macro-cell: ~4GHz Small-cell: ~4GHz *or* ~30GHz	<10 Gbps
Sub Urban	• LTE up to 50 MHz • 5G 100 MHz 8L MIMO ~4GHz	Macro-cell	<4 Gbps
Rural	• LTE up to 50 MHz • 5G 50 MHz 4L MIMO ~2GHz • 5G 20 MHz 4L MIMO ~700MHz	Macro-cell	<2 Gbps

Types of mobile site

3.2.1. 5G Networking Requirements

One of the most important requirements for the next generation network is to generate new revenues and reduce TCO. The means to reach that goal there are:

1) Enabling and deploying new types of services (mMTC, uRLLC) in addition to traditional voice and eMBB, on one common transmission network
2) Enabling to deploy and manage those services (and new ones not yet foreseen) in a time that is orders of magnitude quicker than today
3) Automating as many processes as possible (configuration, troubleshooting, multi-layer optimization, resilience)

The aspects of mmWave technology impacted by the above requirements can be summarized as follows:

1) Ultra-low and deterministic transmission latency (a few tens of µs) and jitter. This mainly impacts the design of the data interfaces, the packet processing engines and the radio modem and air interface design
2) Ultra-high precision network-wide, packet-based time and phase synchronization
3) Support for SDN and advanced packet networking (L2/L3, L3 VPN, segment routing etc.)
4) Support for multiple 10G interfaces and nodal capabilities due to increasing network density. All of the networking requirements are addressed in mmWave, leveraging what is developed for every other network segment.

5G Requirements and Targets

4. Application of Millimeter Waves

1) 5G and small cell concept

5G is one of the most discussed technologies in recent times. Due to its requirement to support higher data rate, 5G will be using millimeter waves (between 24GHz and 86 GHz range). Tech companies are testing and investing in WLAN infrastructure with the support of millimeter waves. Small cell concept could choose millimeter waves for its future implementation.

Millimeter waves can replace traditional fiber optic transmission lines connecting mobile base stations.

2) HD video applications

Millimeter waves can be used to transmit ultra high definition (UHD) video to HDTV wirelessly. Tiny transmission modules can be integrated to devices for HD transmission from digital set top boxes, HD game stations and other high definition video sources.

3) IEEE 802.11ad WiGig technology

Wireless Gigabit Alliance – WiGig is a technology designed to support future audio and visual media devices and wireless display interfaces at gigabit rate. High performance transmission of data between devices and computers can be achieved using WiGig transmission protocol.

4) Satellite Communication

Millimeter waves are perfect candidates for satellite communication. At higher altitudes of orbits, it operates perfectly with massive data rate and low latency.

5) Automotive Applications

Autonomous driving is a hot topic in technology world. It requires detection of passengers and other obstruction in real time and low latency. Accurate detection is important and necessary decision has to be made in millisecond time frame. Millimeter waves are best option for detection radar for automobiles.

6) Body Scanners

Millimeter wave human body scanners are getting popular nowadays. It has the ability to scan with high precision and cause less harm to human body. Technology giants like Rohde&Schwarz has recently introduced millimeter wave human body scanner for airport security. It uses transmit power of mmWave and operates at frequency range between 70 GHz to 80 GHz.

7) Radar applications

High frequency radar technology has been developing and emerging for multiple applications. It uses one the property of millimeter waves called beamwidth. Miniature sized radar on single chip has been developed using sophisticated semiconductor technology. It can be used for motion sensors, automatic doors, collision avoidance systems, intrusion alarm devices and speed detection of vehicles etc.

8) Virtual Reality headsets

Virtual reality applications are the future of multimedia world. Millimeter waves perfectly fit for virtual reality devices. It can support high bandwidth which is necessary for high definition video and audio transmission. VR devices allow high speed tethering from computers, other multimedia devices and offers excellent user experience.

9) Medical applications – mmWave therapy

Researchers found that millimeter wave technology can be used in medical applications like treating acute pain. Millimeter wave therapy uses frequency ranges between 40 GHz and 70 GHz to experiment several medical conditions.

5. Conclusions

There are many open research problems relating to channel modeling, preceding, receiver design, channel estimation, and broadband channels, not to mention system design challenges that arise when mmWave is used in personal area networks, local area networks, cellular networks, vehicular networks, or wearable networks. There is a bright future ahead in signal processing for mmWave wireless systems. mmWave wireless communications will revolutionize the mobile industry also – ushering in a new frontier with unthinkable advances. However, there is a little knowledge about cellular mm-wave propagation in densely populated indoor and outdoor environments. Obtaining this information is vital for the design and operation of future fifth generation cellular networks that use the mm-wave spectrum.

The 5G standard promises to embody a mobile-connectivity revolution, providing enhanced broadband connectivity and speed for a wide swath of customers According to experts on the biological effects of electromagnetic radiation, radio waves become safer at higher frequencies, not more dangerous. The vision for 5G is expansive, but one aspect of it is fiber-like connections providing multi- gigabit per second data rates to mobile devices. On the next generation wireless systems, namely 5G, has experienced explosive growth in recent years. The massive multiple-input multiple-output technique and the use of high GHz frequency bands are two promising trends for adoption. Millimeter-wave (mmWave) bands such as 28 GHz, 38 GHz, 64 GHz, and 71 GHz, which were previously considered not suitable for commercial cellular networks, will play an important role in 5G. Currently, most 5G research deals with the algorithms and implementations of modulation and coding schemes, new spatial signal processing technologies, new spectrum opportunities, channel modeling, 5G proof of concept systems, and other system-level enabling technologies. Some of efficiently future works may allow highly valuable for the development of 5G cellular communications at mm-wave bands in the coming decade.

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