An Overview on Millimeter Wave Technology for Future Wireless Communications

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Abstract: Almost all mobile communication systems today use spectrum in the range of 300 MHz-3 GHz. Due to the increasing popularity of smart phones and other mobile data devices such as netbooks and ebook readers, mobile data traffic is experiencing unprecedented growth. In order to meet this exponential growth, improvements in air interface capacity and allocation of new spectrum are of chief important. As the mobile data demand grows, the sub-3 GHz spectrum is becoming increasingly crowded. On the other hand, a vast amount of spectrum in the 3-300 GHz range remains underutilized. The 3-30 GHz spectrum is generally referred to as the Super High Frequency (SHF) band, while 30–300 GHz is referred to as the Extremely High Frequency (EHF) or millimeter-wave band. Since radio waves in the SHF and EHF bands share similar propagation characteristics, we refer to 3-300 GHz spectrum collectively as millimeter-wave bands with wavelengths ranging from 1 to 100 mm. The availability of the 60 GHz band as unlicensed spectrum has inspires interest in gigabit-per-second. In this paper, we justify why the wireless community starts looking at the 3-300 GHz spectrum for mobile broadband applications. The applications of mmWave are immense: wireless local and personal area networks in the unlicensed band, 5G cellular systems, vehicular area networks, ad hoc networks, and wearables.

Keywords: Massive MIMO, Mm wave, 5G.

I. Introduction

The development of wireless communication in the 60 GHz unlicensed band was the topic of tremendous amounts of research. Much more efforts have been involved in developing more power efficient 60 GHz RFICs. In this article, we explore the 3-300 GHz spectrum and describe a millimeter-wave mobile broadband (MMB) system that utilizes this vast spectrum for mobile communication. MmWave makes use of spectrum from 30 GHz to 300 GHz whereas most consumer wireless systems operate at carrier frequencies below 6 GHz [1] [2]. The main benefit of going to MmWave carrier frequencies is the larger spectral channels, high throughput in small geographical areas, gigabit-per-second data rates, high bandwidth and much more. MmWave communication could also provide important benefits in other application scenarios like wearable networks, vehicular communications, or autonomous robots. Thus MmWave is receiving tremendous interest by academia, industry, and government for 5G cellular systems. The potential for MmWave is immense. This article is organized by introducing millimeter wave band in chapter1, Challenges for using MmWave for communications in chapter 2, Need of improvement in architecture of cellular communication for using MmWave in chapter 3, applications of MmWave communications in chapter 4 and concluding with areas of more research enhancement need to use MmWave. Clearly the future is bright for new applications of Mm Wave.

II. Why Milimeter Wave?

Today's 4G, wireless digital networks made it possible for smartphones and tablets to deliver voice and data communications with bandwidths measuring many millions of bits per second. Specific data speeds vary by carrier. The next generation 5G wireless will have to deliver a huge data rate to handle surging mobile network traffic. According to Cisco Systems' most recent Visual Networking Index (VNI), Global mobile data traffic grew 74 percent in 2015. More than half a billion (563 million) mobile devices and connections were added in 2015.

In 2015, on an average, a smart device generated 14 times more traffic than a non-smart device. Mobile video traffic accounted for 55 percent of total mobile data traffic in 2015. Globally, 97 million wearable devices (a sub-segment of the machine-to-machine [M2M] category) in 2015 generated 15 petabytes of monthly traffic [3].

Mobile data traffic will reach the following milestones within the next 5 years:

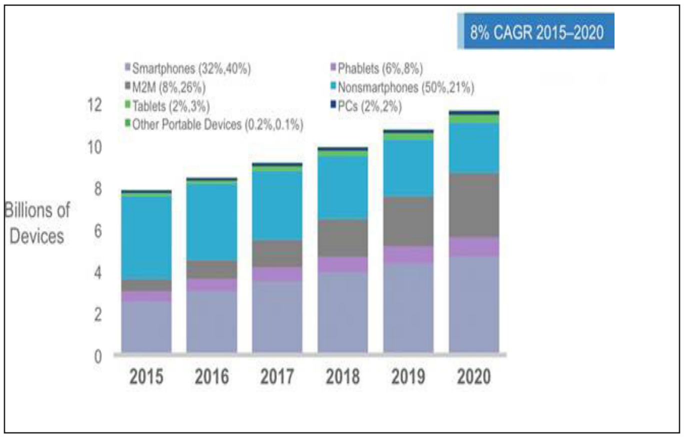
- Monthly global mobile data traffic will be 30.6 exabytes by 2020.

- The number of mobile-connected devices per capita will reach 1.5 by 2020.
- The average global mobile connection speed will surpass 3 Mbps by 2017.
- The total number of smartphones (including phablets) will be nearly 50 percent of global devices and connections by 2020. Global mobile data traffic will increase nearly eightfold between 2015 and 2020.

Overall mobile data traffic is expected to grow to 30.6 exabytes per month by 2020, an eightfold increase over 2015.

Source: Cisco VNI Mobile, 2016

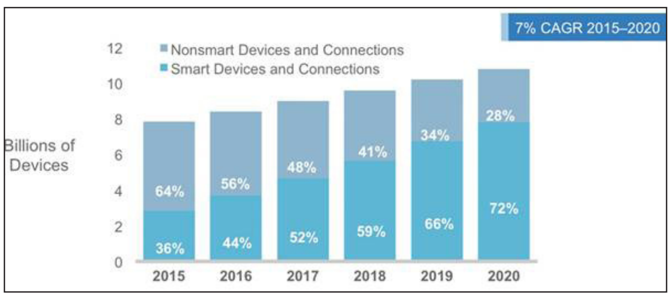
Fig. 1: Global Mobile Data Traffic Forecast by Region



(Figures in parentheses refer to 2015, 2020 device share.)

(Source: Cisco VNI Mobile, 2016)

Fig. 2: Global Mobile Devices and Connections Growth



Percentages refer to device and connections share.

Source: Cisco VNI Mobile, 2016

Fig. 3: Global Growth of Smart Mobile Devices and Connections

One of the most promising potential 5G technologies under consideration is the use of high-frequency signals in the millimeter-wave frequency band that could allocate more bandwidth to deliver faster, higher-quality video and multimedia content. Millimeter wave (mmWave) cellular systems, operating in the 10-300 GHz band, appear to be a promising candidate for next-generation cellular systems by which multiple gigabit-per-second data rates can be supported. Engineers at Samsung estimate that government regulators could free as much as 100 GHz of millimeter-wave spectrum for mobile communications about 200 times what mobile networks use today. Samsung's engineers say their technology can overcome these challenges by using an array of multiple antennas to concentrate radio energy in a narrow, directional beam, thereby increasing gain without upping transmission power. Such beam-forming arrays, long used for radar and space communications, are now being used in more diverse ways [5].

Recent studies suggest that mm-wave frequencies could be used to enlarge currently saturated 700 MHz to 2.6 GHz radio spectrum bands for wireless communications. The combination of cost-effective CMOS technology that can now operate well into the mm-wave frequency bands, and high-gain, steerable antennas at the mobile and base station, strengthens the viability of mm-wave wireless communications. Further, mm-wave carrier frequencies allow for larger bandwidth allocations, which translate directly to higher data transfer rates. Mm-wave spectrum would allow service providers to significantly expand the channel bandwidths far beyond the present 20 MHz channels used by 4G customers. By increasing the RF channel bandwidth for mobile radio channels, the data capacity is greatly increased. Mm-wave frequencies, due to the much smaller wavelength, may exploit polarization and new spatial processing techniques, such as massive MIMO and adaptive beamforming.

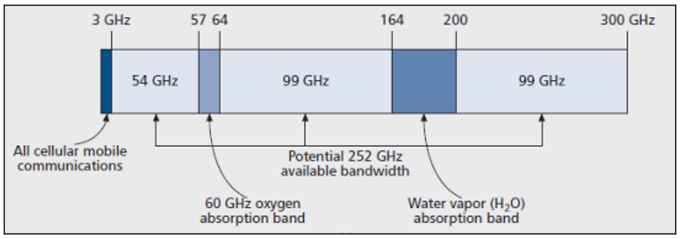


Fig. 4: Millmeter Wave Spectrum

A. Unleashing the 3-300 GHz Spectrum

Almost all commercial radio communications including AM/FM radio, high-definition TV, cellular, satellite communication, GPS, and Wi-Fi have been contained in a narrow band of the RF spectrum in 300 MHz-3 GHz. This band is generally referred to as the *sweet spot* due to its favorable propagation characteristics for commercial wireless applications. The portion of the RF spectrum above 3 GHz, however, has been largely unexploited for commercial wireless applications. Unlicensed use of Ultra-wideband (UWB) in the range of 3.1-10.6 GHz frequencies has been proposed to enable high data rate connectivity in personal area networks. The use of the 57-64 GHz oxygen absorption band It is also being promoted to provide multigigabit data rates for short-range connectivity and wireless local area networks. Additionally, Local Multipoint Distribution Service (LMDS) operating on frequencies from 28 to 30 GHz was conceived as a broadband, fixed wireless, point-to-multipoint technology for utilization in the last mile. Within the 3-300 GHz spectrum, up to 252 GHz can potentially be suitable for mobile broadband as depicted in Fig. 4. Millimeter waves are absorbed by oxygen and water vapor in the atmosphere. The frequencies in the 57-64 GHz oxygen absorption band can experience attenuation of about 15 dB/km as the oxygen molecule (O2) absorbs electromagnetic energy at around 60 GHz. The absorption rate by water vapor (H2O) depends on the amount of water vapor and can be up to tens of dBs in the range of 164-200 GHz. We exclude these bands for mobile broadband applications as the transmission range in these bands will be limited. With a reasonable assumption that 40 percent of the remaining spectrum can be made available over time, millimeter-wave mobile broadband (MMB) opens the door for a possible 100 GHz new spectrum for mobile communication more than 200 times the spectrum currently allocated for this purpose below 3 GHz.

III. Challenges for Using Mmwave for Communications

A. Atmospheric and Rain Absorption

Within the unlicensed 60 GHz band, the absorption due to rain and air particularly the 15 dB/km oxygen absorption are more perceptible. But these absorptions are insignificant for the urban cellular deployments, where base station spacing's might be on the order of 200 m. But actually, these type of absorptions are useful as it will efficiently increase the segregation of each cell by further attenuating the background interference from more distant base stations.

So from the above explanation, it can be informed that the propagation losses for millimeter wave frequencies are resolvable, but only by steering the beam energy with the help of large antenna arrays and then collect it coherently. Fig. 5 and Fig. 6 show the rain attenuation and atmospheric absorption characteristics of mm-wave propagation. It can be seen that for cell sizes on the order of 200 m, atmospheric absorption does not create significant additional path loss for mm-waves, particularly at 28 GHz and 38 GHz. Only 7 dB/km of attenuation is expected due to heavy rainfall rates of 1 inch/hr for cellular propagation at 28 GHz, which translates to only 1.4 dB of attenuation over 200 m distance. Work by many researchers has confirmed that for small distances (less than 1 km), rain attenuation will present a minimal effect on the propagation of mm-waves at 28 GHz to 38 GHz for small cells [4].

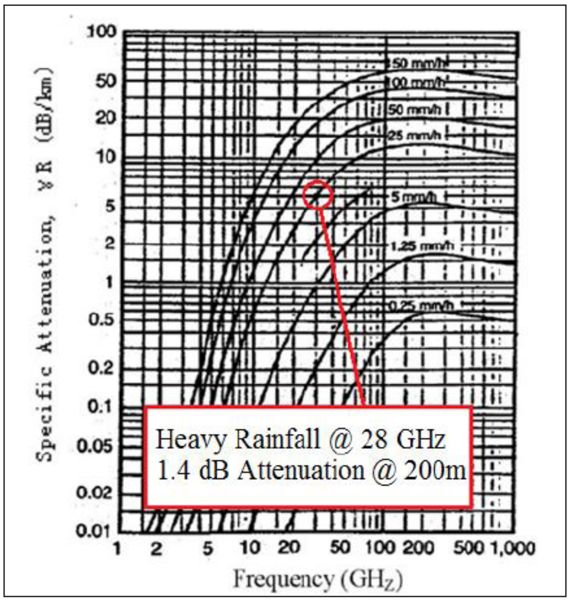


Fig. 5: Rain Attenuation in db/km Across Frequency at Various Rainfall Rates

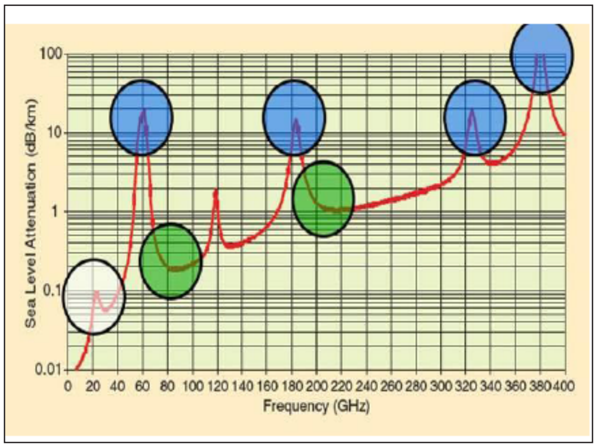


Fig. 6: Atmospheric Absorbtion Across Mm-Wave in db/km

B. Path Loss

The free space path loss is dependent on the carrier frequency, as the size of the antennas is kept constant which is measured by the wavelength $\lambda = c/f$, where f is the carrier frequency. As the carrier frequency increases, the size of the antennas reduces and their effective aperture increases with the factor of $\lambda^2/4\pi$, while the free space path loss between a transmitter and a receiver antenna grows with f^2. So, if carrier frequency *f is chosen* from 3 to 30 GHz, it will correspondingly add 20 dB of power loss irrespective of the transmitter-receiver distance. But for increased frequency, if the antenna aperture at one end of the link is kept constant, then the free-space path loss remains unchanged. Additionally, if both the transmitter and receiver antenna apertures are kept constant, then the free space path loss decreases with f^2.

C. Blocking

Microwave signals are less prone to blockages but it deteriorates due to diffraction. But, mm wave signals suffer less diffraction than the microwave signals and exhibit specular propagation, which makes them much more vulnerable to blockages. Recent studies reveals that, with the increase in the transmitter and receiver distance the path loss increases to 20 dB/decade under Line of sight propagation, but descents to 40 dB/decade plus an added blocking loss of 15-40 dB for non-line of sight.

D. Penetration and Other Losses

For 3-300 GHz frequencies, atmosphere gaseous losses and precipitation attenuation are typically less than a few dB per kilometer, excluding the oxygen and water absorption bands. The loss due to reflection and diffraction depends greatly on the material and the surface. Although reflection and diffraction reduce the range of millimeter - wave, it also facilitates non-line-of-sight (NLOS) communication. While signals at lower frequencies can penetrate more easily through buildings, millimeter wave signals do not penetrate most solid materials very well. The indoor coverage in this case can be provided by other means such as indoor millimeter-wave femtocell or Wi-Fi solutions. It should be noted that next-generation Wi-Fi technology using 60 GHz millimeter waves is already being developed in IEEE 802.11ad.

IV. Architerture of Cellular Communication for Using Mmwaves

A. 5G Cellular Network Architecture

To meet the demands of the user for 5G system, a drastic change in the strategy of designing the 5G wireless cellular architecture is required. This idea will be supported with the help of massive MIMO technology which uses multiple antennas at the transmitter and receiver. They offer many benefits in practicle wireless communications including increase in capacity and spectral effiency, reduction of fading, improvement resistance to interference.

Since present MIMO systems are using either two or four antennas, but the idea of massive MIMO systems has the idea of utilizing the advantages of large array antenna elements in terms of huge capacity gains.

To build or construct a large massive MIMO network, firstly the outside base stations will be fitted with large antenna arrays and among them some are dispersed around the hexagonal cell and linked to the base station through optical fiber cables, aided with massive MIMO technologies. The mobile users present outside are usually fitted with a certain number of antenna units but with cooperation a large virtual antenna array can be constructed, which together with antenna arrays of base station form virtual massive MIMO links. With a rapid increase in the number of connected devices, some challenges appear which will be responded by increasing capacity and by improving energy efficiency, cost and spectrum utilization as well as providing better scalability for handling the increasing number of the connected devices.

B. Massive MIMO

The Massive MIMO system uses arrays of antenna containing few hundred antennas which are at the same time in one time, frequency slot serving many tens of user terminals. The main objective of Massive MIMO technology is to extract all the benefits of MIMO but on a larger scale. Massive MIMO depends on spatial multiplexing, which further depends on the base station to have channel state information, both on the uplink as well as on the downlink. In case of downlink, it is not easy, but in case of uplink, it is easy, as the terminals send pilots. On the basis of pilots, the channel response of each terminal is estimated. In conventional MIMO systems, the base station sends the pilot waveforms to the terminals and based on these, the terminal estimate the channel, quantize it and feedback them to the base station. This process is not viable for massive MIMO systems, especially in high mobility conditions because of two reasons. Firstly the downlink pilots from the base station must be orthogonal among the antennas, due to which the requirement of time, frequency slots for the downlink pilots increases with the increase in the number. of antennas. So Massive MIMO systems would now require a large number of similar slots as compared to the conventional MIMO system [6]. Secondly, as the number of base station antennas increases the number of the channel estimates also increases for each terminal which in turn needed hundred times more uplink slots to feedback the channel responses to the base station. A general solution to this problem is to work in Time Division Duplexing (TDD) mode and depend on the reciprocity amid the uplink and downlink channels.

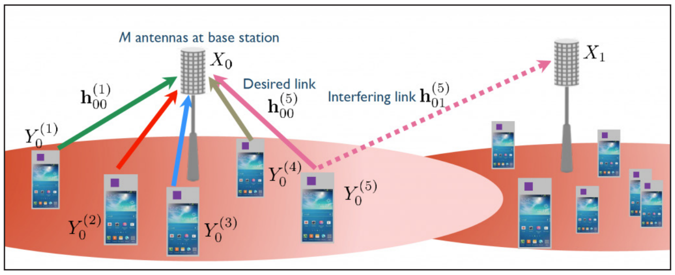


Fig. 7. Analytical Model for Massive MIMO Networks in Sub-6 GHz and mmWave

The carrier frequencies for massive MIMO systems, however, are not clear yet; as the propagation channels and hardware constraints will be much different from sub-6 GHz and millimeter wave (mmWave) band.

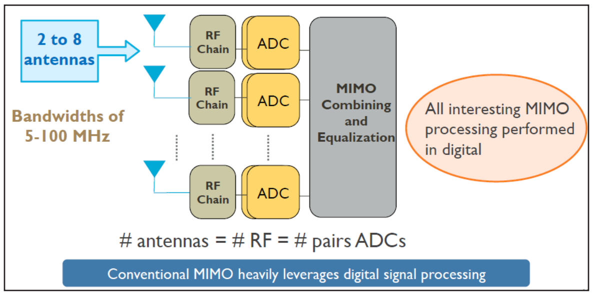


Fig. 8: MIMO Receiver at < 6 Ghz Frequencies

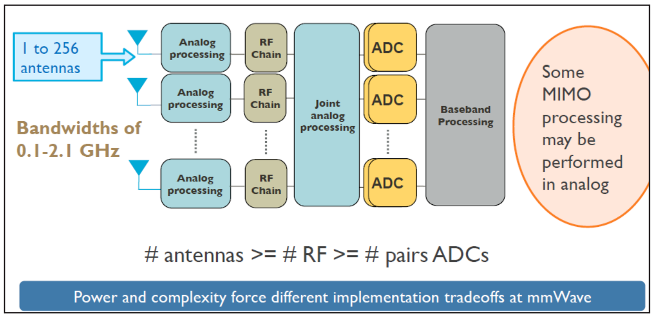
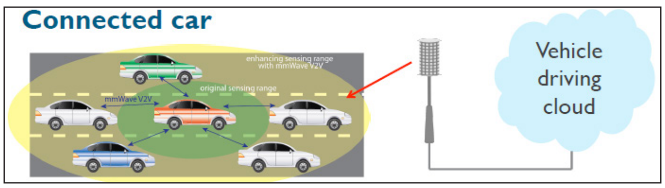


Fig. 9: MIMO Receiver at mmWave Frequencies

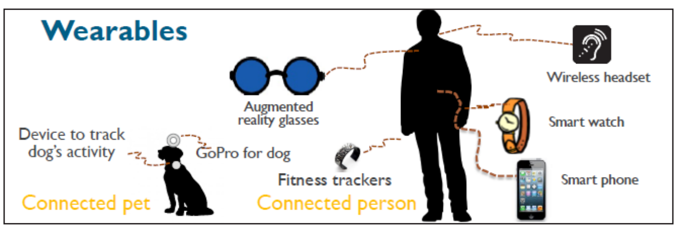
V. Applications of MIMO Communication Using MM Wave in Future Wireless Communications

Single user, multiple user, multi-cell, relay.

Interference and mobility become more of a challenge.



- Attractive for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I).
- Enhanced local sensing capability in connected cars.
- Share high rate sensor data: radar, LIDAR, video, IR video, other sensors.



- Data fusion from other cars can enlarge the sensing range.
- Enables the transition from driver assisted to autonomous vehicles.
- Multiple communicating devices in and around the body.
- 5 or more devices per person based on market trends trend.
- MmWave solves two critical problems.
- Provides high data rates for high-end devices.
- Provides reasonable isolation for low-end devices.

VI. Conclusion

In this paper, a detailed survey has been done on the performance requirements of future generation 5G wireless cellular communication systems which will mainly use millimeter waves. The need of using mmwaves and the challenges behind using mm waves in 5G wireless cellular communications is explained. The A 5G wireless network architecture has been explained in this paper with massive MIMO Applications of MIMO communication using MM wave in future wireless communications Technology such as single user, multiple user, vehical-to-vehical (V2V) and vehical-to-infrastructure (V2I), enchanced local sensing capability in connected cars etc have been explained. This paper may be giving a good platform to motivate the researchers which promises many research opportunities for mmwaves such as multiuser hybrid precoding, broadband channel models, beam training, models for RF impairment, synchronization etc.

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