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Research Article

Design Tradeoffs in 60 GHz Based Wireless Communication - A Vision of the Future

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Abstract

Wireless communication has witnessed tremendous growth in the recent past due to its advantages such as mobility and ease of use. Wireless devices are used in everyday life for communication, entertainment, remote learning, healthcare, business etc. For most of these applications, radio spectrum below 5GHz is already allocated. Its becoming increasingly challenging to cater to the growing needs of the future networks. Therefore, it is inevitable to explore the millimeter band of the radio spectrum for the future generation wireless systems. This requires us to develop new modulation schemes and circuit design, simulation and implementation techniques for future networks. In this paper, we present various challenges and possible solutions in 60 GHz millimeter wave communication. The future network need not only be fast, but also be green. Scientists and standardization forums all over the world have come up with several techniques to meet these requirements. But, the miniaturization of the device and reduction of interference between adjacent circuit elements still remain a major concern. The only possible solution is for future generation networks to be backward compatible with the existing infrastructure. High data rate, low energy consuming and green systems are the need of future generation networks.

Index Terms**—**Millimeter Wave, Attenuation, Channel Modeling, 5G Communication, MIMO

I. INTRODUCTION

Wireless communication systems offer several advantages over wired communication systems such as mobility and ease of use. Due to this, the number of wireless communication devices has increased tremendously over the past few years. Wireless devices are used in day-to-day life for communication, entertainment, remote learning, healthcare, business etc.This number is only expected to grow at a faster rate in the upcoming years. Apart from the increase in number of users, there is also a growth in number of users requiring high data rate for their applications. There are several wired standards such as Gigabit Ethernet and High Definition Multimedia Interface (HDMI) which can provide data rates as high as 1 giga bit per second (Gbps). But currently there are no wireless communication standards that provide such high data rates. Table 1 shows several frequency bands allocated for different applications. While current wireless standards utilize the licensed and unlicensed spectrum below 5 GHz [1], it becomes imperative for future wireless networks to explore 60 GHz band to meet the growing requirements. At 60 GHz, the amount of bandwidth available is much higher than the available bandwidth below 5

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GHz. Therefore, the future generation wireless networks are expected to use this frequency band heavily to provide service to the customers.

Table 1. Allocation of Frequency Bands for various Applications

Frequency Band	Applications
64-95 GHz	Unallocated
57-64 GHz	Indoor Communication
31.5-57 GHz	Unallocated
27.5-31.5 GHz	LMDS band
6-27.5 GHz	Unallocated
3-6 GHz	Bluetooth, NFC
Less than 3GHz	Cellular Mobile Communication, AM Radio, FM Radio, TV Transmission, Satellite Communication, Military Communication, Bluetooth, Zigbee

Fig. 1 highlights the key use cases of future generation networks. In future generation networks, number of smart and connected devices is going to increase by a huge factor. These networks are no more limited to voice and data communication. Future networks should provide for self-driven vehicles, intelligent devices, smart health care devices, tactile internet, ultra-high definition video streaming and several real time applications. Because of advancements in internet of things (IoT) and artificial intelligence and machine learning, there is going to be huge demand for data processing at user plane and back end. As devices become smarter and connected, requirement for acquiring, storing, processing and communicating data will also grow.Fig. 2 shows a comparison of 4G and future 5G communication systems. In the near future, a thousand times higher data traffic is expected than the current 4G networks as the number of smart and connected appliances is going to increase by a huge factor. To cater to this requirement, the future wireless networks should have 10-20 times the currently available data rate [1]. Wireless communication is not limited to voice communication anymore. Future network should have capability of providing for real time gaming, tactile internet, internet of things etc. While the current 4G networks have the latency of about 15 ms, the future networks should have a latency of less than 1 ms [1]. Furthermore, next generation networks are expected to be 10 times more energy efficient and leave less carbon footprint than the present networks.

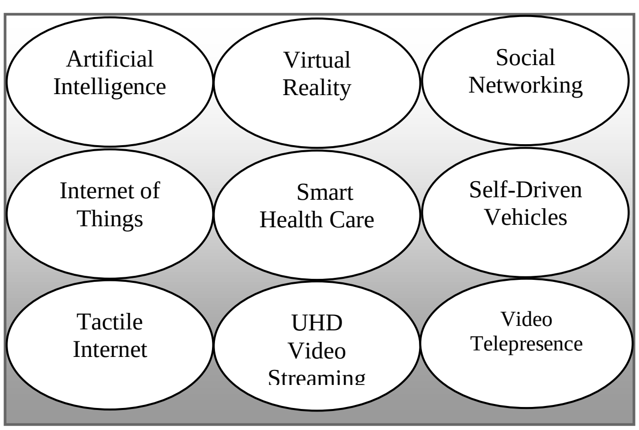

Fig. 1. Key Use Cases for 5G

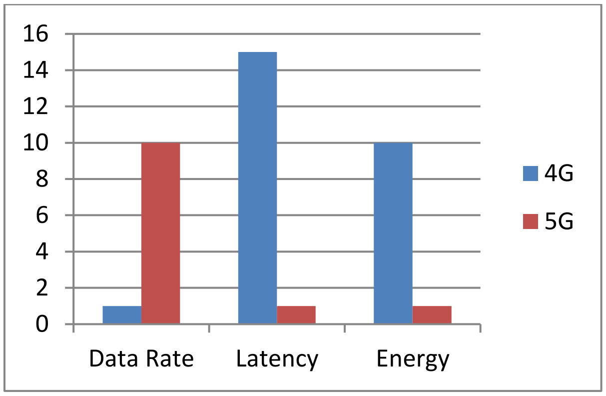

Fig. 2. A Comparison of 4G and 5G Networks

Fig. 3 shows the key enabling technologies for the future networks. Most of the current wireless standards and devices use frequency bands less than 5 GHz. As these frequency bands are not able to cater to the growing needs of future networks, it becomes important to further explore mm wave band. 60 GHz band is one such unutilized band of frequencies. There are several unlicensed frequency bands across the world around 60 GHz [2].

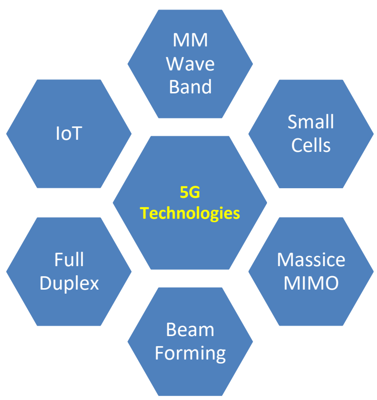

Fig. 3. Key 5G Enabling Technologies

Table 2 shows unlicensed frequency bands around 60 GHz in different countries. There is a growing need to explore 60 GHz band to cater to the needs of future networks.

Table 2. Unlicensed Frequency Bands in Various Countries

Frequency Band	Country
57-64 GHz	North America
59-66 GHz	Europe
59.4-62.9 GHz	Australia
57-64 GHz	Korea
59-66 GHz	Japan

But communication at 60 GHz comes with its own challenges. One of them is the increased material absorption at 60 GHz. Table 3 presents material loss experienced by 2.5 GHz and 60 GHz signals.

Table 3. Comparison of Attenuation at 60 GHz and 2.5 GHz

Material	Loss at 2.5 GHz	Loss at 60 GHz
Drywall	2.1 (dB/cm)	2.4 (dB/cm)
Whiteboard	0.3 (dB/cm)	5.0 (dB/cm)
Mesh Glass	24.1 (dB/cm)	31.9 (dB/cm)

It is evident that at 60 GHz, attenuation experienced by the signal is much higher compared to 2.5 GHz [2]. To overcome this challenge, small cells can be deployed at various indoor and outdoor environments.But this will lead to frequent handoff and call drops. Also, inter cell interference becomes pronounced as the frequency reuse distance will be much lesser. Beamforming techniques will assume greater importance to reduce inter cell interference. Beamforming will direct the radiation towards the required user avoiding interference with the undesirable users. Furthermore, to meet the growing requirement for higher data rate massive MIMO is to be deployed. 60 GHz based communication is going to be a key solution to all future networks.

The organization of the paper is as follows. In section II, we explain the various challengesand possible solutions at 60 GHz. We highlight the design tradeoffs from both algorithm and circuit design and implementation point of view. In section III, we explain the way forward for future generation networks.

II. 60 GHz BASED COMMUNICATION – DESIGN TRADEOFFS

Smulders et al. explain how 60 GHz based wireless communication systems can be designed and developed for wireless local area network (LAN) applications [3]. The authors highlight the channel characteristics at 60 GHz. Orthogonal Frequency Division Multiplexing can still be an attractive choice at 60 GHz which offers several advantages such as mitigation of inter symbol interference (ISI) and high spectral efficiency. The authors opine that 60 GHz systems must be able to operate in tandem with 5 GHz systems so that interoperability can be maintained to use the existing infrastructure and also 5 GHz system can be used as a fallback option in case communication at 60 GHz fails to meet the expected quality of service. In [4], Chen et al. summarize the challenges and possible solutions in future 5G systems. The authors propose the changes to be made in control plane and user plane in future 5G networks. The authors suggest the design of a hybrid network topology to accommodate small cells and device to device communication. The authors conclude that full duplex communication and non-orthogonal modulation techniques may revolutionize future networks. In [5], Rappaport et al present the various measurement data obtained by performing experiments in Austin and New York. The authors use 28 GHz carrier frequency in New York and 38 GHz carrier frequency in Austin. The experimental results show that having cell radius of 200 meters, we can achieve acceptable coverage. The authors highlight the repeated use of repeaters and points of access to overcome path loss and delay spread.

Pi et al. explain beamforming techniques for millimeter wave communication in [6]. Also the authors explain the development of local multipoint distribution service to provide broadband service over mobile user equipment. The authors present experimental data for proving higher attenuation at 60 GHz compared to 3 GHz band. The authors also provide link budget analysis for 60 GHz communication which shows an additional 20 dB margin to compensate for path loss. In [7], Park et al. present various developmental and standardization issues for 60 GHz communication. 60 GHz carriers can be used for future personal area networks with ZigBee as a crucial standard for low power short range networks. The authors highlight that 60 GHz wireless personal are networks are yet to be standardized with details such as channel models, modulation schemes and channel bandwidth. The authors suggest the use of hybrid multiple access techniques for 60 GHz wireless personal area networks. Finally, the authors conclude that a global standardization forum is required for 60 GHz communication. In [8], Boccardi et al. present the research directions for future 5G networks. The authors underline the need for millimeter wave communication for future networks along with smart and connected devices with device centric network architecture. The authors opine that there could be shift from cloud computing to device centric communication to deal with growing need for data processing requirement. This may lead to the usage of local devices with large amount of memory devices. But this will help to reduce the burden on cloud computing devices and hence help to ease data communication through high frequency carriers to some extent. Daniels et al. highlight the challenges in antenna design for 60 GHz communication. The authors suggest the use of rhombic on chip antennas to achieve higher package efficiency. The authors also explore other antenna configurations such as switched beam antennas and phased array antenna along with beam steering to achieve high efficiency. The authors also explain the use of CMOS and SiGe based technology than the more expensive GaAs based technology for circuit implementation at 60 GHz. The authors highlight the fact that the best suited modulation technique at 60 GHz is still an open challenge since phase noise becomes pronounced at 60 GHz. The authors conclude that effective MAC layer protocols are needed to interface networks with directional antennas. Banelli et al. give an overview of contending modulation schemes at 60 GHz. While OFDM is widely used in 4G, it may fail to meet data rate, latency and spectral efficiency requirement in future 5G networks. The alternative candidate for OFDM should consider receiver complexity, delay spread in the channel and Doppler spread. The authors opine that at this point of time, it could be difficult to pick an absolute winner in all aspects.

In [11], Andrews et al. discuss key challenges in future 5G wireless communication systems with an overview of standardization activities. The high bandwidth carriers are going to be crucial in realizing future 5G networks. Along with that advancements in Massive MIMO is going to be a key enabling technology in providing high data rates in future networks. Due to highly dense small cell networks, computational capabilities and memory requirements of user equipment are going to grow by a huge margin. The authors conclude that apart from protocol development and implementation at all layers of communication hierarchy, regulatory policies and viable business solutions are going to be key in realizing the 5G dream. In [12], Ruffini et al. explain the need for network convergence to meet future wireless network requirements. The authors highlight the need for a complete network architecture overhaul for future networks. As the future networks have to provide for a large dimension of services, piecewise approach for the design of network architecture is not an optimal solution, but one should look for a converged view of network architecture. The authors conclude that while allocating resource and developing protocols, an end to end optimization approach must be followed to meet the future requirements. In [13], Rappaport et al. present measurements and channel models for four millimeter bands namely 28 GHz, 38 GHz, 60 GHz and 73 GHz. A new impulse response channel model is developed which is found to agree with millimeter wave measurements carried out. The channel model considers multipath delay spread, Doppler delay spread and path loss at millimeter band. The authors opine that the data presented in [13] can help to develop new channel models for 60 GHz communication. Ding et al. present non-orthogonal multiple access as an enabling technology in future 5G networks. Using non-orthogonal multiple access, several users can access the channel with different power levels resulting in a significant increase in spectral efficiency [14]. The authors explain the connection between non-orthogonal multiple access and cognitive radio in LTE and future 5G networks. However, the advantages of these techniques come with an increased system complexity which is a big challenge. In [15], Maccartneyet al. present a path loss model for millimeter wave propagation along with measurement data. The authors conduct measurement campaigns in New York and Austin and provide data for the development of channel models. For modelling the channel, 3 dimensional ray tracing and network capacity simulators can be used. The data presented in [15] can be used to validate channel models developed for millimeter wave communication.

In [16], MacCartneyet al. present measurement data for indoor propagation environments at 28 GHz and 73 GHz. The measurement campaign was carried out at both line of sight and non-line of sight indoor scenarios with co-polarized and cross polarized antennas. The measurement data and the developed channel models provide a great insight into indoor millimeter wave communication. It is found that NLOS environment results in greater attenuation than LOS environment. These results are of great significance in developing millimeter wave systems that support future internet of things systems. Ali M. Niknejad details silicon based radio frequency circuits and microwave circuits in [17]. The author concludes that even though there are many non-silicon based solutions for circuit design at 60 GHz, they are expensive and not commercially viable. Silicon based CMOS technology will continue as the right choice for 60 GHz based devices. Moving forward, the major challenge will be the reduction in power and size of silicon based circuits to keep up with Moore's law. Gutierrez et al. present several structures for on-chip antennas for millimeter wave applications [18].The authors explain several challenges with the existing CMOS technology at millimeter wave frequency bands. The low efficiency of on chip antennas because of interconnection losses and stray capacitances is a great challenge for chip designers. However, the authors opine that integrating antennas with the processing circuit will greatly advance personal area network device technology by lowering the cost of production. In [19], Zhang et al. present a novel slot antenna design for 60 GHz integrated circuits. The authors mention that the proposed design can reach an efficiency of 94% at 61.5 GHz. Zhang et al discuss various aspects of green technology for future networks [20]. The authors compare energy efficiency and bandwidth efficiency and power efficiency of several contending technologies of future networks such as orthogonal and non-orthogonal modulation schemes. Chih-Lin et al. provide a green and soft perspective to future 5G networks [21]. For a sustainable future technology, green tradeoffs are going to be a crucial parameter.

III. WAY FORWARD

The next generation wireless systems should not only be fast and efficient, but they are also required to leave less carbon footprint. While new algorithms and modulation schemes are to be developed to achieve higher data rates, the challenges in physical realization of these systems will continue to exist. Moore's law may reach its limit and further miniaturization of devices may no longer be possible. At micro scales, inter device interference becomes more pronounced and limit the performance of the device. Furthermore, future generation devices will not be standalone but, backward compatible.

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