Millimeter Wave Communications with OMA and NOMA Schemes for Future Communication Systems

ShaikRajak, Chappalli Nikhil Chakravarthy, Nafisa Nikhath Shaik, Sunil Chinnadurai

Abstract—Millimeter-wave (mmWave) communications had been considered widely in recent past due to its largely available bandwidth. This paper describes a detailed survey of mmWave communications with orthogonal multiple access (OMA), non-orthogonal multiple access (NOMA) schemes, physical design and security for future communication networks. mmWave provides super-speed connectivity, more reliability, and higher data rate and spectral efficiency. However, communications occurring at mmWave frequencies can easily get affected by interference and path loss. Various schemes such as small cells, heterogeneous network and hybrid beamforming are used to overcome interferences and highlight the prominence of mmWave in future communications systems.

Keywords—Millimeter-wave, non-orthogonal multiple access, multiple-input multiple-output, interference, path loss, hybrid beamforming, heterogeneous network.

I. INTRODUCTION

In recent times, people are getting addicted to their screens because of the explosion of the video content, although low internet speeds play a spoilsport. The demand for faster data transmission rate and reliable communication makes researchers and organizations invest time and cost into 5G communication systems. As we all know that the smart phone users are increasing every day around the world, which is also another important reason to look into the future communication systems. More importantly, 5G communications is not a standalone technique, it comprises small cells, massive multiple input multiple output (MIMO), hybrid beamforming, non-orthogonal multiple access (NOMA), smart grid, femto cells, heterogeneous networks, mmWave and so on [1 - 3]. Here in this paper, we have given importance to mmWave and summarized the impact of mmWaves in future communication systems. Data rate and latency will be playing a major role in deciding the future of communication networks. For example, latency can be less than 1 milli second in 5G communications, compared to more than 40 milliseconds in the current generation communication systems [4 - 6]. In addition, spectrum crunch also paves the way for creating new technologies to satisfy a greater number of users with the available bandwidth. MmWaves can able to provide the answer for the above bandwidth crunch problem with its frequency spreading from 30 to 300 GHz and wavelengths (1 to 10mm) [7,8]. MIMO-multiple input multiple output where multiple users share the same network resources simultaneously. MIMO allows messages from different users to travel through the same data pipeline and then be sorted to individual users when the data arrives at their mobile devices [9]. Serving multiple users with the same transmission where each signal travels at a different frequency (frequency known at the receiver end respectively) over such a huge range of bands from 30-300 GHz without overlapping with one another increase capacity and allows for better utilization of resources [10 - 12]. That adds up to the ability to download with a better experience for the user even in a crowded area. So due to the huge range of spectrum of millimeter waves, multiple users can have the benefit of faster transmission at the same time through MIMO [13]. Small cell base stations are now deployed both indoor and outdoor to address the hot spot areas where capacity uplift is needed. Many numbers of small cell base station (SCBS) have to be deployed while using mmWave communications in order to overcome the signal loss due to obstacles and weather conditions. Radio frequency integrated circuit (RFIC),complementary metal-oxide-semiconductor (CMOS) and large-scale antenna system design in recent times have paved the way for mmWaveand sub-mmWavebands [14 - 15]. We have discussed the technologies included with 5G in the subsequent sections to get a better understanding about mmWave powering the future communication system. Section II and Section III describes aboutmmWavewith OMA and NOMA schemes respectively. Section IV illustrates the physical layer security issues in mmWave communication systems. Section V will elucidate the utilization of mmWavein heterogeneous networks. Section VI demonstrates the effect of the Hybrid beamforming scheme in mm Wavesystems. Open research problems and future research directions for mm Wavecommunication systemsareelaboratedinsectionVIIandVIIIrespectively.Finally,thepaperconcludesinsectionIX.

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II. MMWAVE WITH OMA

Orthogonal multiple access (OMA) technique is part of the current 4G communication technology and in particular orthogonal frequency division multiple (OFDM) access have a huge role in delivering the long-term evolution (LTE) systems. MmWave along with OMA have huge number of antennas at the base station. Here in OMA, power cannot be varied for different users with respect to their distance from the base station. Spectral and energy efficient resources are not allocated efficiently in OMA as it is used in NOMA [16, 17]. The data rate provided with OMA can satisfy a smaller number of users than NOMA, but the computational complexity involved in deploying the NOMA makes OMA more preferable in future communication systems. Averagesum-rate capacity and signal to interference noise ratio (SINR) of ultra-dense small cellular systems had increased due to the deployment of mmWave and massive MIMO technology [18, 19]. In mmWave communications, dynamic antenna arrays and zero forcing techniques helps to reduce the interference at the base station for full duplex systems [20].

III. MMWAVE WITH NOMA

Orthogonal multiple access technique cannot vary the power level, where as non-orthogonal multiple access can allocate different power levels to users based on many factors like distance, received signal strength indication, etc. For example, Users in a single cell can be differentiated into cell centric users and cell edge users. Cell centric users are located close to the base station, where as cell edge users are identified at the edge of the cell, which is far away from the base station. In the above case, NOMA allocates more power to cell edge users than the cell centric users, so that both the users can satisfy their needs and get a good data rate at their ends [21, 22]. This variable or dynamic power allocation is one the major highlight in the case of non-orthogonal multiple access systems. Moreover, NOMA along with mmWaves can be vastly helpful in multicellular systems in the future communication networks. The main drawback of NOMA is that the complexity gets added at the receiver end (mobile phones), where successive interference cancellation is used to avoid the unwanted signals [23, 24]. At the transmitter side (Base station), superposition of one signal over the other is done in non-orthogonal multiple access systems. NOMA is also compatible with other standardized techniques used in 5G communication systems. Interferences within the cells, clusters and inference in between the users can be avoided by using massive MIMO combined with mmWave NOMA technique. Mmwave prefers directional antenna radiation over the omnidirectional antenna due to the occurrence of huge free space path loss. MmWave with NOMA (different beamforming schemes were used) also greatly increases the spectral efficiency, energy efficiency and also reduce the interferences [25 - 28]. The comparisonbetweenOMAandNOMAisexemplifiedinFig.1. “MmWaves play a key role in 5G which helps to differentiate the fifth-generation network with other networks by increasing the bandwidth to a huge extent”.

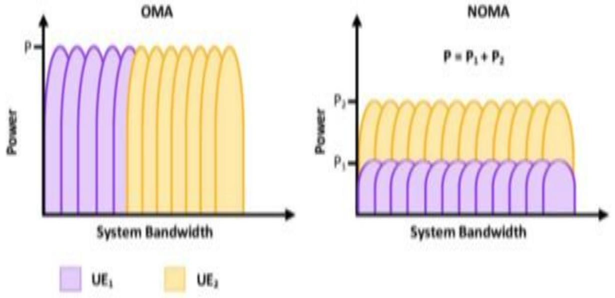

Fig. 1. Comparison of OMA and NOMA

IV. PHYSICAL LAYER SECURITY IN MMWAVE

Millimeter- wave is used in a broad range of products and services like high speed, point-to-point wireless local areas network (WLANs) and broadband access. Millimeter-wave technology opens the door for a high date rate for various mobile and wireless services. A wide range of spectrum availability of mmWavewill change the future wireless networks, HD multimedia, HD gaming, and security services. It transmits personal and confidential information through this wireless network. So, security remains a key concern in the 5G network [29]. Basically, security relies on bit-level cryptographic technique. But cryptography will protect the processed data after the communication phase. So, we need to go for other techniques for securing our information from eavesdropping. Physical layer security is identified as a promising strategy that provides secured wireless transmissions. Unlike the traditional cryptographic approaches, physical layer security (PLS) can effectively degrade the quality of signal received at the eavesdropper, and prevent them from acquiring confidential information from the received signal. Secure and reliable communications can still be achieved in the 5G networks with the help of powerful computational devices [30]. Multiple antenna technology becomes a powerful tool for enhancing physical layer security in random networks. Two artificial-noise-aided multi-antenna transmission strategies based on antenna beamforming [31]. Point-to-point mmWave secure communications were made possible by designing antenna subset modulation and generating randomness, which in turn deceive the eavesdropper [32, 33]. Legitimate receivers and eavesdroppers can obtain their own Channel State Information, but mmWaveBase Stations do not know the instantaneous Channel State Information of eavesdroppers. In the low transmit power regime, the use of low mmWavefrequency achieves better secrecy performance when increasing transmit power, a transition from low mmWavefrequency to high mmWavefrequency is demanded for obtaining more secrecy rate [34 - 36].

V. HETEROGENEOUS NETWORK ARCHITECTURE FOR MMWAVE COMMUNICATION

In the present wireless network, the data usage is very high so, small cell base stations are now deployed both indoor and outdoor to address the hot spot areas where capacity uplift is needed.

Since the one drawback in millimeter-wave is building blockage (even rain can absorb the signal and cause attenuation) therefore 5G networks will have to adopt the small base station method to enhance the heterogeneous network [49]. So, authors in [37] and [38] recently proposed concept of downlink and uplink decoupling (DUDe), where mmWaveBSs can merge with the sub-6-GHz, which will provide long-distance coverage and high data rate mmWavein device-to-device (D2D) communication is contemplated method to reach the requirements of futurenetworks.wheremmWaveandbeamformingwascombinedwithD2Dnetworktosuppresstheinterferenceandbetter spectrum utilization. A heterogeneous antenna array system was also implemented in the above work to transmit the data to longerdistances [39]. Toconnectthe 5G BSs,fiberwillthebestoptionforbackhauldueto lowlatencyandincreasedthroughput [40]. Phased-array-based backhaul implemented in the unlicensed 60 GHz which reduces the installation cost, latency and Full- Duplex (FD) would provide such operation using a single frequency band [41]. Recently, FD is well-investigated for sub-6GHzapplications.Theauthor'sin[42]producedamodeltoexplorethevalidityofFDovermmWave.

VI. HYBRID BEAMFORMING FOR MMWAVE COMMUNICATION

Today's cellular antennas broadcast information in every direction it wants and in particular massive number of antennas are used at the base station deliver the data rate required by the end users with the help of the advanced beamforming techniques as shown in Fig 2. Beamforming is used to narrow down the antenna radiation so that the desired user can get the good signal strength. In case if the antenna gets radiated in different directions, then the received signal strength will be poor and there is a high chance of the beam getting affected due to interferences [43 - 45]. Beamforming, Massive MIMO and mmWaves will play a huge role in providing the fastest data rate and reliable communications in the next generation communication systems. Huge implementation cost and computational complexity for deploying hybrid beamforming in the modern communication systems, however due to its ability to deliver high spectral efficiency makes it desirable for mmWave wireless networks [46 - 48].

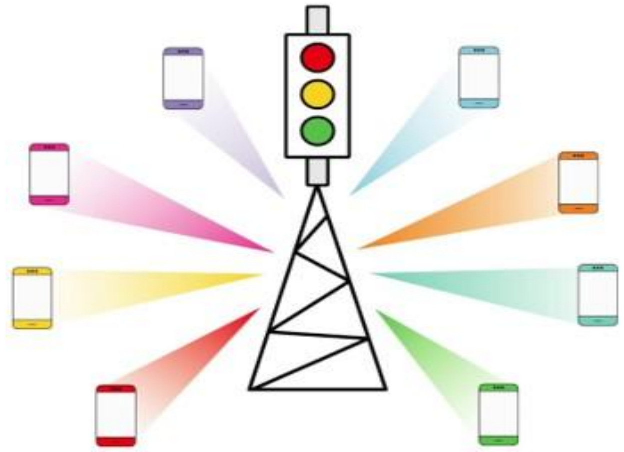

Fig. 2. Beamforming

VII. OPEN RESEARCH PROBLEMS IN MMWAVE

The frequency ranges that lies from 30-300 GHz were a band of radio frequencies in the electromagnetic spectrum are generally called as extremely high frequency. The wavelength of radio waves in this band ranges from ten to one millimeter. The world is facing a huge advancement in terms of emerging technologies like: VR, UHD video, IoT, mobile internet, etc. Hence, there is an urgent need for more bandwidth, High-speed Internet, etc. Hence in order to meet those needs, we need new technology something like millimeter-wave communication technology. It had eventually become a hot topic for many scientistsandresearchersinacademiaandalsofortheIndustrypersonnelinthecommunicationsdomain.

- MmWaves suffers from path and data loss with obstacles for long-range communication. So, we need to arrange small receivers in the path. To protect from other antenna devices, advanced algorithms and detection mechanisms must beimplemented.
- mmWavecould provide a high data rate for the UEs. For transmitting the mmWavewith desired speed, the existing system should be modified, we need to design new transmission characteristics, interference cancellation. Researchers could do moreexperimentalworktoovercomethesechallenges.
- mmWave- NOMA to provide services for ever-extending the number of users. And the challenge in this issue is multi-user interference mitigation inmmWave-NOMA.
- mmWavecommunications for both low altitude and high-altitude UAVs, where fast beam tracking, mobility improvement, andblockageissuesaresomeofthechallengesinthisapplication.
- mmWavecommunications for 5g technology, where the challenges would be security,high expectations of data rate andlong-distance mmWavedata links and multi-accessissues.
- The integrated design of the mmWavecapable devices should require proper modeling. There is a strong implication on-device testing, verification, certification processes. Very high-level integrated components are required as they need to support highfrequencies.
- And we do require innovative solutions for area restrictions, thermal limitations, battery life, acceptable RF exposure.
- Propagation loss or path loss is actually directly proportional to the frequency of the wave. Hence, the mmWave beingthehigh-frequencyspectrumhasahighpathlossandit'sachallengetoreducethepathlossasgoodaspossible.

mmWave, as the name suggests, it has very low wavelength i.e. 10 to 1 mm. And there is a property that small wavelengths are more likely to get blocked by obstacles (like building walls, people, vehicles, etc.). Hence, even this is a challenge to be considered while selecting anetwork.

VIII. FUTURE RESEARCH DIRECTIONS FOR MMWAVE

It has been predicted that world smartphone traffic would be like 50 petabytes in 2021 which is a 12-fold increase when compared to 2016. Many national-level research organizations are working on 5G, and recentlyEUhadstartedresearchbeyond5G using millimeter-wave frequencies. Huawei had permitted the Ka-band which is 26.5-40 GHz band for mobile accesswith20Gbpsrate.

- Largeavailablebandwidthcanleadtoampleamountsofgigabytepersecondperuser.
- Thenarrowbeamwhichishighlyadvantageousforlasertechnologies(especiallyundersea).
- Hightransmissionqualityisrelatedtoabiterrorrate(BER) andalsoQ-factor.

Strongdetectionabilitywhichisacommongoalofanycommunicationnetworkchannel

Ithadbecomeoneofthekeyaspectsof5Gtechnologywhichaimsforahighdatarateandalsotoachieveultrahighdefinition. Millimeter-wave communications play a major role in increasing the transmission capacity for Satellite communications and unmanned aerialnetworks

IX. CONCLUSION

In this paper, we have summarized and appraised mm Wavecommunications with OMA and NOMA schemes. We have discusseditsimplementation,physicaldesign,securityandalsobrieflyanalyzedthedifferentbeamformingschemestomaximize the utilization of millimeter-wave systems. MmWave communications already started gaining more attention due to the instigation of the 5G in the current wireless communication system. Open research problems and future research directions for mmWavewere also explained in detail. This study can also help the individuals in their research towards mmWave and their applications infuturecommunicationsystems.

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