A Review of Millimeter Wave Communication for 5G

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***Abstract*— The millimeter wave (mmWave) bands give new facilities with tremendous amount of spectrum to fifth generation (5G) mobile communication network to supply mobile data demand, which is expanding out of control. Essential differences are considered between conventional systems and mmWave communications, regarding directivity, sensitivity to blockage and high propagation loss. mmWave brings various challenges in communication on some issues such as anti-blocking, interference management, spatial reuse, dynamic control and system design for fully utilizing. In this study, we surveyed on solutions and standards for these challenges and we proposed design principles in architecture and protocols for mmWave communications. And previous studies in the literature on whether the millimeter wave band can be tested in small cell access in 5G, cellular access in 5G and wireless backhaul in 5G or not have been investigated. Also, we described prospective using areas of mmWave in 5G.**

Keywords—Millimeter wave communications, 5G communication systems, small cell access, cellular access, wireless backhaul.

I. INTRODUCTION

With rapid rise of mobile traffic demands, the bottleneck between spectrum constraints and capacity requirements is becoming increasingly apparent. The chokepoint of wireless bandwidth becomes a major issue for 5G telecommunication. Conversely, mmWave with great bandwidth from 30 GHz to 300 GHz are being proposed for multi-gigabit communication services which are claimed to be leading applications of 5G like high definition television (HDTV) and ultra-high definition video (UHDV) [1-2]. Actual researches have kept up on 28, 38, 60, 71-76 and 81-86 GHz. Expeditious advances are expected in hardware such as CMOS radio frequency equipments in mmWave frequncies [3-4]. Meanwhile some standards were needed for indoor wireless local area networks (WLAN) or wireless personal area networks (WPAN), such as IEEE 802.11ad, IEEE 802.15.3c and ECMA-387 [5-7], which warns increasing in outdoor mesh networks or cellular systems in mmWave bands [8-10].

Due to structural differences between conventional systems are capable with the microwave band (eg 2.4 GHz and 5 GHz) and mmWave communications, mmWave has many difficulties in routing layers, medium access control (MAC) and the physical (PHY). New insights and thoughts are required in architectures and protocols to handle the challenges, such as sensitivity to blockage, directivity, high propagation loss and Dynamics.

In this study, we realized a survey on mmWave for 5G communications. Firstly, we summarized the characteristics of mmWave communication. MmWave communications suffer from enormous propagation loss owing to high carrier frequency. And beamforming (BF) is adopted as a fundamental technique, which points out that mmWave communications are naturally directional. In addition, mmWave communications are precision to blockage by obstacles such as people and furniture owing to its poor diffraction ability.

The milestones of the contributions of this study are presented as follows in comparison to actual studies in the MmWave field:

- We performed a more detailed an analysis and summary of mmWave communications, its characteristics, comparison with other wireless techniques, and its applications.
- Recently, owing to significant step-up of mmWave technology, plenty of research on mmWave has been served out. Therefore, we considered these research studies in this article to summarize the development trends of mmWave.
- We provided several applications (e.g., small cell access) to show where mmWave communication is used to meet the requirements of 5G services based on their properties.
- In addition we offered available mmWave resources, including experimental platforms, often used mmWave frequencies, mmWave based protocols, regulations and books.

We invesitgated and compared two main wireless communication techniques and mmWave communications. The advantages and disadvantages of sub 6-GHz WiFi technique and sub-6 GHz 4G LTE technique over mmWave communication were discussed in terms of security, data rate and capacity, and the 802.11 protocol was also described. MmWave networks should be collaborated with other networks, such as WiFi and 4G LTE. The key to discovering the potential for heterogeneous networking is the interaction between different types of networks. With the bandwidth provided by mmWave networks, in orders of magnitude data can be transferred with millimeter wave communications. Moreover, the transmission distance of the millimeter wave signals is very short due to near field losses and blockage. Small cell access, cellular access, and wireless backhaul are expected prospective applications of mmWave communications in 5G. Previous studies on the use of the mmWave band in small cell access, cellular access and wireless backhaul were investigated.

In Section II, we summarized the characteristics of mmWave communications. In Section III, millimeter wave communications were compared with conventional systems

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such as WiFi, 4G LTE. And in Section IV, expected applications of millimeter wave in 5G were described.

II. MMWAVE COMMUNICATION FEATURES

The specific properties of the MmWave communication shoud be taken into account while designing network structures and protocols to adapt plenty of wideband. Following subsections summarize and present the characteristics of MmWave communication.

A. Channel Measurements

Propagation loss of mmWave bands are more than conventional systems using lower carrier frequencies. Molecular (such as rain, dust) and atmospheric (such as air density) absorptions prevent the range of mmWave communications as seen on Fig. 1. [11-12]. However, the propagation loss of the cells, in which the distances between receiver and transmitter is less than 200 m., were measured insignificantly. In same situation is valid for path loss and spectral efficiency [13]. So, backhaul, small cell access and indoor applications can be supported by mmWave communications.

Significant studies have been carried out on the mmWave propagation in the 60 GHz [4, 14-18]. The loss of free space propagation is directly proportional to the square of the carrier frequency. The loss of free space propagation (FSP) at the wavelength of 5 mm, which is 60 GHz band, is 28 dB, which is higher than loss of FSP in 2,4 GHz [10]. And, the peak of oxygen absorption in 60 GHz ranges from 15 to 30 dB/km [19]. The line of sight (LOS) channel has a less attenuation than the non-line-of-sight (NLOS) channel, as expressed in channel characterization [20]. 28 GHz, 38 GHz and 73 GHz bands are also used for channel measurement [21]. Urban propagation at 28 GHz was tested in NY. [16] The distance was altered 75 to 125 meters between the transmitter (T_X) and the receiver (R_X). The results were obtained the LOS path loss exponent (PLE) is 2.55. And, the NLOS, the average path loss exponent (PLE) is 5.76. Another observation and measurement was applied in Manhattan as well [22]. The signal was received as decayed 57% within 200 meters due to obstructions. It has been shown that to increase the maximum coverage distance, the antenna gains are increased and the path loss exponent is reduced. When the gain of the antenna is 49 dB, 200 m. is accepted a limit distance in a highly obstructed environment. At 28 GHz, penetration and reflection losses were measured on brick pillars and tinted glass as well. Penetration losses of them were measured as 28.3 dB and 40.1 dB, respectively. The losses are relatively low, 6.8 dB and 3.6 dB as for indoor materials like drywall and clear non-tinted glass, respectively. The reflection coefficients of outdoor materials were measured greater than the indoor materials [23]. And the angles of arrival and departure were measured in urban. It was used highly directional steerable horn antennas and observed multipath with an average of 2.5 signal lobes at any receiving location [24].

Spatial statistics models of channels were developed developed including the channel parameters such as number of spatial clusters, the path loss, outage and angular dispersion at the bands of 28 and 73 GHz in NY [25]. Even in highly NLOS environments, it has been found that strong signals ranging from 100 to 200 m from potential cellular regions can be detected and diversity and spatial multiplexing are supported in many locations where multiple path clusters have been obtained. Another measurement about wideband propagation was observed at 73 GHz by using rotating directional antennas, morever an experimental ray-tracing model was invented to predict propagation characteristics [26]. According to the measurement results, a preliminary 3GPP-style 3D mmWave channel model was improved by using ray tracer to obtain the elevation model parameters [27]. The propagations at 38 GHz was measured in Austin, Texas. With 25 dBi horn antennas, in the case of LOS the path loss exponent was measured as 2.30 and in the case of NLOS, the path loss exponent was measured as 3.86. It has been shown that the root mean squared (RMS) delay is higher and antenna gain is versa. Regarding an outage survey, the lower heights base stations coverage was seen better and the most of outages appeared over than 200 m from the base [28-29]. Regarding the results, AOAs appear mainly R_X azimuth angle is incase between ±20° about the boresight of the T_X azimuth angle [28]. The features of mmWave communications in different bands are seen on Table 1. At 200 m, oxygen absorption and rain attenuation are low at 28 and 38 GHz bands, but they are measured at the bands of 60 GHz and 73 GHz more. Also we can see that there is additional propagation loss when comparing NLOS transmission with LOS transmission in the four bands.

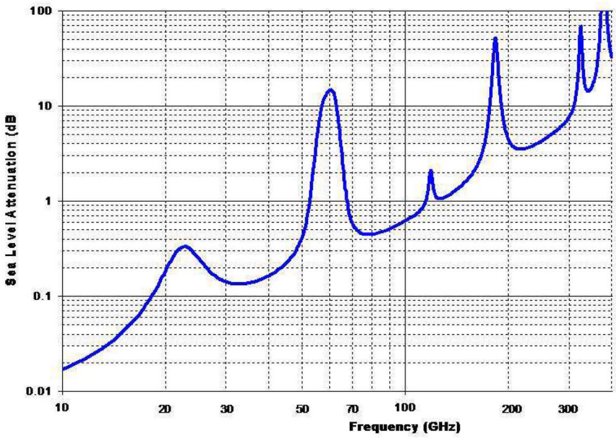

Fig. 1 Molecular absorption at the frequencies of mmWave [18].

B. Directivity

Millimeter wave links propagate intrinsical and directional. So, the antenna arrays, which are directed by electrical signals, can be obtained as patterns of metal on the circuit board [30]. And, the phase of each antenna transmitting signal can be electronically directs the beam in any direction and provides a very low gain for all directions to achieve a high gain in this direction. The beam training procedure is required to allow directing the transmitter and the receiver the beam to each other, also various beam training algorithms are invented to reduce beam training time [31-32].

C. Sensitivity to Blockage

Electromagnetic waves can diffract around obstacles substantially, when the wavelength is larger than it. Around 60 GHz band, small wavelengths are susceptible to be blocked by obstacles (eg, people and furniture). For instance, the loss of human blockage was measured between 20-30 dB [33]. Collonge *et al.* [34] performed propagation measurements in the presence of human activity in a realistic indoor environment. Regarding the measurements, for 1-5 people, the loss is about 1% or 2%. Considering human mobility, the mmWave links are sparse. Therefore, providing a reliable connection to delay the applications.

III. MMWAVE APPLICATIONS IN COMMUNICATION

A. Small Cell Access

It has been proposed to concentrate on small cells to achieve a 10,000-fold increase by 2030 to provide a network capacity to keep up with the huge increase in mobile traffic demand [38]. WLANs or WPANs that are supported by small cells, are accepted promising solutions to supply this demand with 5G. mmWave small cells can support wideband multimedia applications like high-speed data transfer with multi-gigabit rates bandwidth. Also mmWave small cells can provide real-time streaming for HDTV Technologies and gigabit ethernet and wireless game.

To use the mmWave bands for enhanced local area (eLA) access in 5G, in particular to use the bands 28, 38, 71-76 and 81-86 GHz, by Ghosh *et al.* [38] created a case. The eLA system achieves peak data rates exceeding 10 Gbps and edge data rates of more than 100 Mbps with large bandwidth. A mmWave system is proposed to provide HD video up to 3 Gb / s [39] Multimedia QoS characterization was modelled by critical measurements and designed a QoSaware multimedia scheduling scheme to succeed the complexity with optimum performance [40].

B. Cellular Access

Much wider bandwidth of mmWave offers great opportunity to use it for 5G cellular access [6], [13]. The coverage of the cellular networks established on mmWave is measeured higher and capacity potential as long as the infrastructure is intensely deployed in [41]. The feasibility and efficiency of applying mmWave communication in cellular access, based on spacious propagation measurement campaigns at the mmWave frequencies, are shown by the cell size of 200 meters at 28 GHz and 38 GHz. The gains of the capacity of the directional antennas, which are based on the arbitrary pointing angles, were measured and the results determined, that they are 20 times greater than 4G [42]. These capacity gains are promising in the most powerful transmit and receive directions in case directional antennas, especially for power saving and evolving spectral efficiency on Device-to-device (D2D) communications. D2D must be activated in mmWave cellular systems to promote sensetive applications to source that involve detecting and communicating with nearby devices. A D2D 5G cellular network architecture is offered with mmWave on Fig. 2. When the cellular cells are intensively deployed in the system, two D2D modes can be activated. It is including inter-cellular and intra-cellular D2D transmissions as well. Services such as backhaul link, access link, intra-cellular and inter-cell D2D links are enabled. Efficient and flexible radio management schemes, including transmission planning, power control, user association and user access, are required to fully expose the potential.

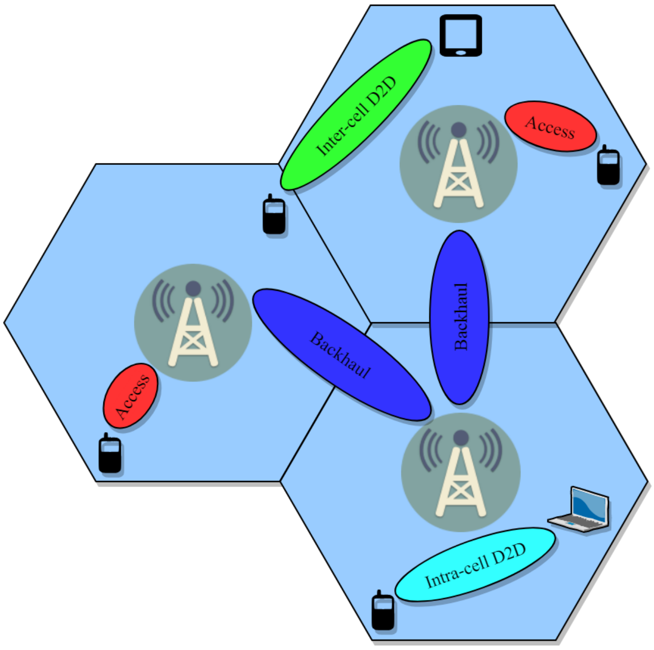

Fig.2 Network architecture of mmWave 5G cellular network while D2D communications are active.

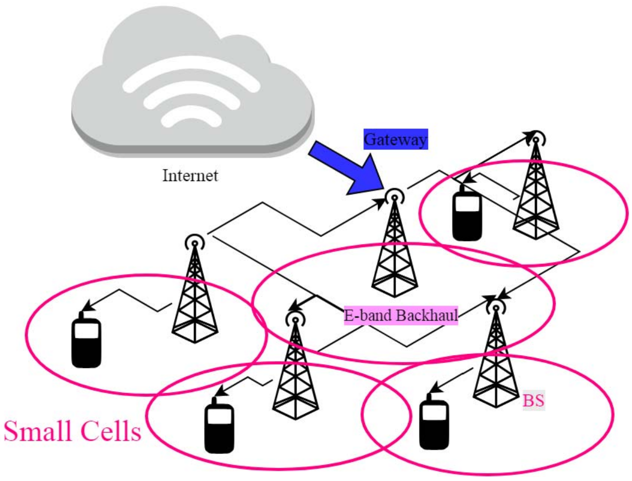

Fig. 3 In small cells E-band backhaul densely used.

C. Wireless Backhaul

Small cells are used extensively in 5G, which is named as next generation. Connecting base stations each others and and to the network is pricey because of using fiber based backhaul in 5G [43]. Additionally connecting via wireless backhaul is more easier, flexible and cost-effective to deploy. Such as the 60, 71–76 and 81–86 GHz, with existing great bandwidth wireless backhaul in mmWave bands, can provide a few Gbps data rates. So, it can be feasable solution for small cells. The E-band backhaul supports the transmission between BSs and the gateway or small cell base stations (BSs) as shown in Fig. 3.

Use of in-band wireless backhaul to achieve a low-cost and scalable wireless backhaul solution by Taori *et al.* proposed [44]. As a solution, multiplexing the backhaul and access was proposed in the same frequency band. In same study, a time division multiplexing (TDM) was offered. It was based on planning scheme that supports, mmWave backhaul, point-to-multipoint, NLOS. The common design of backhaul and access will further optimize resource allocation in the in-band backhaul [45]. Lately, a common transmission planning scheme for radio access and backhaul of small cells in 60 GHz. D2DMAC was proposed as a path selection method, which aims to improve performance and also to enable D2D transmissions [43].

Characteristic works by frequency band, scenario and main application are seen in Table II. Many studies on indoor WLAN / WPAN applications are seen in 60 GHz band.

V. CONCLUSIONS

MmWave communication systems are turning into a promising platform for 5G, with more potential than conventional communication systems to supply larger capacities. In this study, we surveyed on mmWave communications for 5G. To address the challenges and the properties of mmWave communications to support re-design of protocols and architectures; interference management and spatial re-use, dynamics owing to mobility integrated circuits and systems design, anti-blockage. At first conventional solutions were reviewed and compared in terms of efficiency, effectiveness, and complexity. Two main wireless communication techniques and mmWave communications were reviewed and compared. In addition, potential implementations of mmWave communication in 5G were discussed. Previous studies on the use of the mmWave band in small cell access, cellular access and wireless backhaul were investigated.

TABLE I. MMWAVE PROPAGATION CHARACTERISTICS.

Frequency Band		28 GHz	38 GHz	60 GHz	73 GHz
Path loss exponent	**LOS scenario**	1.8~1.9	1.9~2.0	2.23	2
	NLOS scenario	4.5~4.6	2.7~3.8	4.19	2.45~2.69
Rain attenuation at 200 m	**5 mm/h**	0.18 dB	0.26 dB	0.44 dB	0.6 dB
	25 mm/h	0.9 dB	1.4 dB	2 dB	2.4 dB
Oxygen absorption at 200 m		0 .04 dB	0.03 dB	3.2 dB	0.09 dB

TABLE II. IN DIFFERENT BANDS APPLICATIONS OF MMWAVE COMMUNICATIONS.

Frequency Band (GHz)	Application	Scenario	Ref.
28	in-band backhaul	outdoor cellular	[43]
28, 38, 71-76, 81-86	access and backhaul	urban street	[49]
60	HD video	WPAN	[40]
60	access, backhaul and D2D	small cells in heterogeneous networks	[43]
60	transmission between devices	WPAN	[46]
60	flows with QoS requirements	WPAN	[47]
60	internet access	indoor office	[33]
60	uplink channel access	WLAN	[48]
60, 70	multimedia	indoor	[39]
not specified	access, backhaul and D2D	outdoor cellular	[50]

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