# Benefits of 5G Millimeter-wave Communication in IoT applications

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***Abstract*—The fifth generation (5G) of mobile communication systems has brought many enabling technologies with rapid advancements that are expected to generate efficient Internet of Things (IoT) applications within the 5G communication system. Millimeter wave (mm-wave) is introduced as an emerging technology in 5G that enables higher data rate in wireless communication allowing massive data transmission and high-resolution smart devices. In this report, 5G mm-wave technologies are analyzed for use in 5G-IoT based system including mm-wave modulation, error channel coding and multiple input multiple output methods, following with the overviews of current 5G and IoT systems, and the potential as well as the challenges of mm-wave when deploying in these systems.**

***Keywords—5G, Millimetre Wave (mm-wave), Wireless network, Internet of Things (IoT), ITU, MIMO, channel coding.***

## I. Introduction

The Internet of Things (IoT) refers to the connection of billions of physical objects that are integrated with specific software, sensors, and different technologies in other to connect and share the data among other smart devices such as wireless sensors, automotive vehicles, etc. and smart systems all over the world via the Internet. Cisco has provided statistics predicting the number of IoT devices will be over 50 billion by 2020 [1]. Hence, the existing wireless technologies, energy efficiency, network data speed rate, spectrum management, and bandwidth utilization need to evolve extensively to keep up with IoT development [2]. Researchers have carried out many pilots and new technologies to address the issues, including Artificial intelligence, Blockchain, RFID tags, MZM modules, real-time processing, etc. [2-4], and millimeter-wave communication for 5G is one of the promising technologies that can be integrated into IoT.

Compared with current wireless technologies such as 4G or Wi-Fi, mm-wave communication "offers multi-gigahertz of unlicensed bandwidth, which is more than 200 times that allocated to today's Wi-Fi and cellular networks" [5]. 5G mm-wave enables high bandwidth, high transmission speed, and low latency suitable for implementation in massive IoT applications, including smart environment, healthcare, industrial control, transportation, logistics, etc. [6]. However, new challenges such as power consumption and computing power for the 5G mm-wave applications need to be low and affordable for existing IoT users.

In this paper, after the introduction will be the overviews of current 5G and IoT systems in section-II. The 5G mm-wave technologies are analyzed in term of physical layer and mm-wave channel in section-III. In Section-IV, IoT applications within 5G systems using mm-wave are covered. In Section-V, highlights of the existing challenges and promising solutions of mm-wave technology within the 5G-IoT based systems are provided. Finally, Section V summarizes the 5G mm-wave in IoT system and concludes the paper.

## II. Literature Review

### A. 5G Wireless Technology Evolution

The current trends in wireless communication focus on fifth-generation (5G) mobile networks, which are expected to be the core factor that enables multiple disruptive and conventional technologies [7]. 5G indicates the next-generation wireless/cellular communication networks that allow higher data rates in delivering and has more significant data bandwidth than the current Long Term Evolution generation 4G (LTE) [8]. The 5G system is considered an expansion of the 4G environment by adding non-standalone 5G New Radio (NR) capabilities to the existing 4G, which becomes a dual-connectivity network for both 4G LTE and 5G NR [9]. According to the International Mobile Telecommunication 2020 [IMT-2000] has classified 5G mobile network into three prominent use cases: Enhanced Mobile broadband (eMBB), Ultra-reliable Low-latency communication (uRLLC), and massive Machine-type communication (mMTC) [10]. Following the IMT-2020 Standard of the ITU Radiocommunication Sector (ITU-R), requirements are issued for 5G networks including Data Rate, Latency, Density and Energy Efficiency. Table 1 indicates the 5G key performance statistics defined in IMT-2020.

TABLE I. Description of 5G technology
Source adapted from [7, 8, 10]

| Features | Description |
|---|---|
| *Data rate* | Uplink (UL) and Downlink (DL) data rates up to 10 Gb/s and 20 Gb/s<br>"User experience data rate" for UL and DL are 50 Mb/s and 100 Mb/s<br>Achieved spectral efficiency for UL and DL are 15 b/s/Hz and 30 b/s/Hz<br>Area traffic capacity is 10Mb/s/m$^2$ |
| *Latency* | User plane latency for eMBB is 4 ms and for uRLLC is 1 ms<br>Control plane latency is 20 ms (encouraged to reduce it up to 10 ms) |
| *Density* | Minimum requirement for connection density is 1,000,000 devices / km$^2$ |
| *Bandwidths* | Requirement for bandwidth is at least 100 MHz<br>Bandwidths up to 1 GHz are required for higher frequencies (above 6 GHz) |
| *Energy Efficiency* | Energy-efficient data transmission in loaded case<br>Low energy consumption in idle scenarios, characterized by the sleep ration and sleep duration |

To meet mentioned objectives of the 5G system as increasing network capacity or data speed rates, mMIMO, beamforming, the density of small cells in deployment, and mm-wave communication are potential technologies. Moreover, the infrastructure provided by 5G is expected to obtain highly-reliable connectivity with incredibly low latency that can fundamentally transform the current role of telecommunications technology in human society [11]. Figure 1 illustrates the basic concept of 5G network architecture, including the local and central sever operation, which enables the user-end-devices to transfer data quicker and multiple IoT applications.

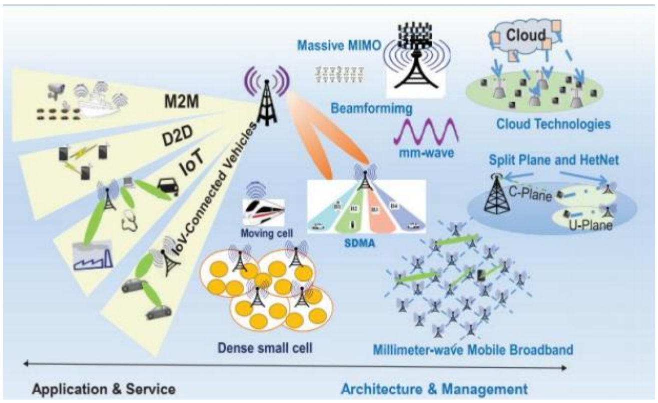


Fig. 1. Schematic diagram of 5G wireless networks

Source Adapted from [11]

Compared to 4G system, the core system of 5G network significantly improves in terms of service-based architectures and network slicing while subsuming critical technologies in 4G system, including secure low latency for data transmission, narrowband IoT (NB-IoT) radios, etc., which brings in great supports for both cloud computing and the Internet of Things (IoT) [12].

## *B. Internet of Things Overview*

The concept of devices connecting with the Internet is not something new. However, the IoT expands and extends the network technology based on available internet technology, allowing computing devices or smart devices to connect and communicate with each other. Although there are many definitions of the IoT with a different perspective, the IoT can be generalized as any objects communicate and exchange data through the Internet to enable orientation tracing, intelligent recognition, tracking, and management by using the information collected by sensors or peripherals, including GPS, thermal sensors, RRFID, etc. [2].

Various IoT architectures were proposed in the last decade, including service-oriented, cloud-computing based, middle-ware-based, and three or five-layer based [13]. Along with that, several infrastructure protocols were introduced, such as Bluetooth low energy (BLE), Routing protocol for Low Power and Lossy Networks (RPL), Z-wave, and 6LowPan [7]. However, even though many prominent applications can be enabled while implementing the IoT, numerous challenges appear, including spectrum, data rate, energy consumption, connection constraints because of the mobility and density of newly added devices in IoT, and so on.

Implementing the 5G network in IoT architectures can address the mentioned challenges. The IoT-based 5G ecosystem enables real-time communication with low latency and improves data exchange speed inside the network. Furthermore, the 5G millimeter-wave (mm-wave) network filters receive sensor data at the edge of the core network to reduce the total load for the whole system, which results in lower energy consumption [14].

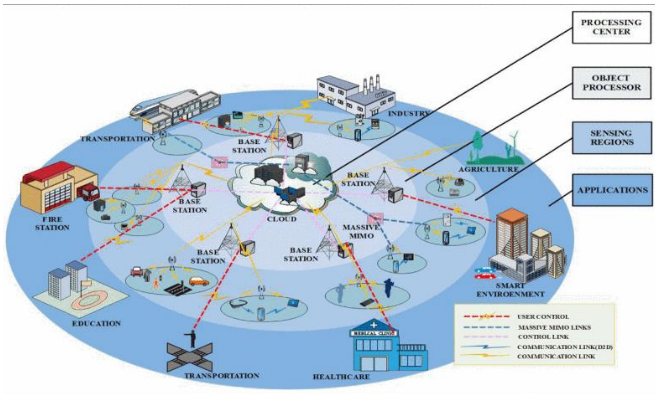


Fig. 2. The architecture of the 5G I-IoT

Source Adapted from [15]

Figure 2 depicts the Intelligent IoT-based 5G paradigm, which includes many crucial technologies such as massive MIMO and small-cell networks. The 5G mm-wave technology will be briefly described with significant characteristics in the next section.

# III. 5G MILLIMETER WAVE TECHNOLOGY

Millimeter-wave (mm-wave) is expected to be one of the most crucial technologies for the next generation of wireless communication [16]. It refers to the radio (electromagnetic) waves that cover the frequency range between 30 - 300GHz and corresponds to wavelength within 1 – 10 nm, which then enables much larger bandwidths that reach the requirements of current IoT systems in terms of high data traffic and stable rates [17].

## *A. Millimeter Wave Channel*

In order to provide such extremely high bandwidth for the IoT system, mm-wave requires a broader spectrum which includes lightly licensed, licensed, and unlicensed portions. Furthermore, using higher frequencies in mm-wave communication also brings more challenges due to the characteristics of the electromagnetic wave and various significantly divergent channel properties [18]. Although these challenges slightly effect when employing the mm-wave communication within 2.4 - 5GHz wireless local area network (WLAN) channels, they are more challenging in the 60GHz industrial, scientific, and medical (ISM) band or even in the 300GHz band of future low terahertz (THz) [18].

For instance, multipath propagation due to environmental obstacles, atmospheric absorptions due to fog, rain, and free space path loss is the main problems restraining the implementation of the 5G mm-wave network. Hence, small cells and short-distance communications need to be focused on to address the aforementioned challenges [8]. Furthermore, the Line-of-sight (LoS) path in antenna transmission of mm-wave also requires more emphasis to ensure consistent connections. Atmospheric attenuation and free-space path loss (FSPL) are two main loss mechanisms of LoS communication path whose values vary diversely depending on the surrounding environment [19]. Therefore, it is important to achieve the requirements of the physical layer techniques to successfully implement the mm-wave communication in IoT-based 5G infrastructures.

### B. Mm-wave technologies at the physical layer

To address the key challenges that prevents the IoT systems to successfully implement the mm-wave communication, some enabling mm-wave technologies were introduced including beam searching, multiple input multiple output (MIMO), channel coding and advanced antenna modulation [12].

#### 1) Millimeter Wave Modulation

Current Long-Term Evolution (LTE), as known as 4G, transmits data from the base station to multiple user devices by using the orthogonal frequency-division multiplexing (OFDM) in LTE downlink. OFDM allows the 4G network to achieve higher data rate than the old 3G network by reducing the multipath effects but still allowing multiple accesses on a single channel [20]. Nevertheless, there are some drawbacks exist in OFDM modulation. For example, in the UTRA LTE uplink, to overcome the inefficient and expensive cost required in PHY layer of OFDM modulation due to the high Peak-to-Average Power Ratio, single carrier frequency division multiple access (SC-FDMA) is suggested as a replaced scheme for the network [21]. Although, OFDM can be used with other technologies existing in 5G such as MIMO to address its shortcomings or increase the data rate, it is not the only candidates that is suitable for 5G systems. Hence, other methods including Orthogonal Time Frequency Space (OTFS), Single Carrier (SC) together with OFDM are examined in this section.

*a) OFDM*

The traditional OFDM has been used long in the 4G system and considered as an attractive method for 5G technology because it allows the fast Fourier transform (FFT) and Inverse FFT (IFFT) to be implemented easily and efficiently in receiver and sender side respectively. It also suffers less from the inter-symbol interference (ISI) or multipath distortion and due to its characteristics, OFDM can be used with the mm-wave MIMO techniques to increase further data rate [22]. However, system using OFDM suffers from the high Peak-to-Average Power Ratio (PAPR) that increases the Bit Error Rate (BER) and reduces the efficiency of the system due to the non-linearity of the amplifiers [23].

*b) OTFS*

Orthogonal Time Frequency Space (OTFS) modulation was firstly introduced in 2017 as a new modulation format that addresses many issues existing in high-frequency dispersive environment including the phase noise and the sensitivity to movement [24]. In order to overcome the challenges, OTFS optimizes the basis waveform to provide a high diversity order that performs better than OFDM in the phase noise and high Doppler spread (the sensitivity to movement) situation which normally occurs in the mm-wave system [25].

*c) SC*

Unlike multicarrier (MC) systems, such as OFDM or OTFS, the single carrier (SC) systems only use a single wideband carrier instead of many subcarriers working as parallel narrowband carriers in MC to transfer the message in the system [18]. Furthermore, the system decision and equalization of MC system operate in frequency domain while in SC system these operations take place in time domain, which increases the complexity of implementation of SC system. However, SC outperforms MC by its low PAPR values that not only reduces the cost for the system but also ensure the efficiency of the transmission power [21].

The comparison of aforementioned mm-wave modulation techniques is given in table 2 based on the assessments of OTFS and OFDM in sub-6 GHz mm-wave channel by Wiffen, the recent advancements of electronics which also brings out the advantages of current SC systems (SC-FDMA) over OFDM by Buzzi and also the characteristic of these methods in the literature [20, 25-28].

#### 2) Millimeter Wave Channel Coding

In order to ensure the security and increase the reliability of the received data, channel coding is used to add extra bits to the data sequence. The receiver (RX) then decodes the encoded sequence to detect any errors and even correct the erroneous bits in the received data if possible. However, to maintain the consistency of the transferred data, this process also consumes power for computation and bandwidth in the network that can also cause serious issue for the system [18].

TABLE II. COMPARISON OF MM-WAVE MODULATION METHODS

SOURCE ADAPTED FROM [20, 25, 27, 28]

| Property | OFDM | OTFS | SC |
|---|---|---|---|
| PAPR | High | High | Low |
| Latency | High | High | Low |
| Ease of implementation | High | High | Low |
| Spectral efficiency | Low | High | High |
| Overhead | High | High | Low |
| Bit error ratio | Good | Good | Depends on SNR |
| Robustness to synchronization errors | Low | Low | Low |
| Compatibility with MIMO | High | High | High |

There are two main policies required after decoding to optimize this process: Forward error correction (FEC) and automatic repeat request (ARQ). FEC is used to detect the errors in the received data and correct it, if possible, whereas ARQ triggers the retransmission from the RXs when discovers errors. Regarding to the high propagation loss of mm-wave communication due to its characteristics, error detection and correction must be effectively arranged to obtain the best possible performances for the system [29]. A comparison of existing channel codes including low-density parity-check (LDPC), non-binary LDPC, and convolutional codes in 3G, 4G and 5G mobile networks was proposed by Costello Jr and Lopez [30, 31]. Simulation conducted in these papers shows that in both line-of-sight and non-line-of-sight cases, LDPC enables better performance in term of spectral efficiency, error correction and lower decoding complexity with low latency for mm-wave band. Considering the coding scheme for mm-wave communication, type II hybrid ARQ (HARQ) is one of the popular schemes that allows the 5G channel code to attain higher capacity and better throughput with different rates [32].

### 3) *Millimeter Wave MIMO*

One of the most promising technologies of 5G is Multiple-input multiple-output (MIMO) antenna system, which enables data transmission for multiple transmit and receive antennas on the same channel. Transmitting data from both direct and indirect transmitter (TX) antennas then can be collected by each receiver (RX) antenna in the other side of the network. Furthermore, with higher frequency available in 5G networks and enabling antenna techniques, such as tapered slot antennas, MIMO system can reduce the antenna interference issue, increase data rate, and optimize energy consumption [33]. When employing in mm-wave communication, MIMO is considered as an attractive method to address the higher path loss issue by reusing the frequency in mm-wave band to enable the densification of the base stations in mm-wave network.

There are mainly two designs for MIMO: Single user (SU) and multi-user (MU) MIMO that are illustrated in figure 3.

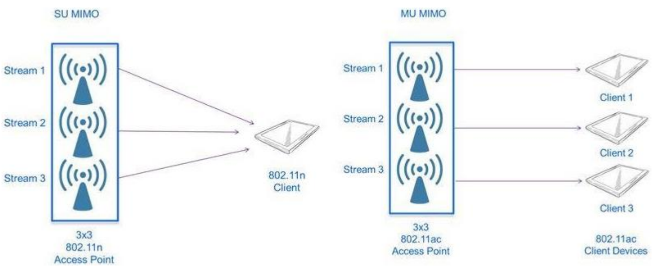


Fig. 3. Differences between SU-MIMO and MU-MIMO
Source Adapted from [34]

The 5G network enables larger bandwidth while increasing the carrier frequency in mm-wave range, which results in shorter wavelength. Hence, these properties allow to reduce the size of current antennas in MIMO while ensuring that they work properly in smaller aperture areas. Therefore, MIMO optimizes the radiation power, increases throughput for 5G systems and provides simultaneous data transmission for multiple devices within the same time-frequency resource using beam forming and spatial multiplexing methods [18].

#### *a) Spatial Multiplexing*

Spatial multiplexing (SM) provides the space division multiplexing on the signal stream, which then will be transmitted simultaneously over multiple independent RF channels using different RX and TX antennas to increase the channel throughput in 5G communication [18]. In an effort to increase the channel capacity, robustness and low latency for 5G network, SM is suitable for addressing the challenges faced in 5G and MIMO system, such as large signal attenuation at high frequency band and high disperse environment. Nevertheless, there are several issues obstruct the efficiency of SM in the massive MIMO systems, such as limitted multiplexing gain due to the spatial correlation, required dense deployment to achieve suitable signal-to-noise ratio values that increases channel capacity and interference in mobile network due to the need of resources needed for SM [35].

#### *b) Beam Forming*

Beam forming (BF) is used in the MIMO systems as an array signal processing technique that adaptively phases the antenna signal to form a desirable direction for the beam pattern [18]. Furthermore, to maximize the signal strength in mm-wave systems, BF helps to reduce the co-channel interference for directional antennas when the system provides the channel properties such as signal propagation and the effect of scattering, fading, etc. (as known as the channel state information) of the communication link between the TX and RX [36].

Hence, in the aim of increasing the capacity and robustness of MIMO systems, spatial multiplexing and beam forming should be applied in MIMO together to attain the requirements of the 5G mm-wave applications. In addition to some advantages including higher robustness, low latency, MIMO can also gain more network capacity, increase radiated energy efficiency and utilize the available low-cost components [18].

## IV. 5G MM-WAVE COMMUNICATION IN IOT APPLICATIONS

The 5G mm-wave communication aims to support several services and applications of the 5G-IoT based systems categorized by the International Telecommunication Union (ITU) [17]. Considering the significant improvements that mm-wave communication can provide in term of high data rate, high bandwidth and low latency, mm-wave technology become an important part that connects the smart devices and edge processing in the IoT systems [14].

Hence, the prominent impact of the 5G mm-wave technology has paved the way to numerous IoT applications such as AR/VR for enhanced real-time experiences, ultra-high-quality video, UHD live streaming for events or smart map, smart city including smart healthcare, smart home and smart factories [6].

Furthermore, many pilots and researches have been conducted over the past decade to establish mm-wave technology in the IoT applications. For examples, Freidl, et al. [37] introduced a new mm-wave RFID system increasing the reading range of RFID in 70 GHz frequency band for the ultra-low power communication in IoT system. A more recent study [19] has proposed the mm-wave networks for IoT-Cloud supported for Autonomous Vehicles by utilizing the multi-gigabit channel capacity and beamforming method together with the cloud computing to support vehicles in sharing an enormous amount of data about the surrounding environment and detect objects in real-time.

## V. 5G MM-WAVE CHALLENGES

Hence, in the aim of increasing the capacity and robustness of MIMO systems, spatial multiplexing and beam forming should be applied in MIMO together to attain the requirements of the 5G mm-wave applications. In addition to some advantages including higher robustness, low latency, MIMO can also gain more network capacity, increase radiated energy efficiency and utilize the available low-cost components [18].

Even though mm-wave technology is expected to enables significant differences to current mobile and wireless network, it also comes with multiple challenges that need to be resolved. Major challenges can be described in table 3.

TABLE III. CHALLENGES AND SOLUTIONS FOR THE 5G MM-WAVE COMMUNICATION TECHNOLOGY

| Challenges | Description | Solution |
|---|---|---|
| *Short range* | Due to mm-wave properties, data signal needed to be in short range communication and no line-of-sight (LOS) obstructions. | New design framework: massive MIMO system, miniaturized antenna arrays, etc. |
| *Access Technology* | 5G-mmwave is composed of both L TE and mm-wave band devices which are different in physical characteristics supporting different access mechanisms. | Ensure the coexistence of multiple standards for existing mobile and wireless network technologies. |
| *Mobility* | Due to its rich scattering environment, high path loss and susceptibility to blockage. | Smart beamforming and beam tracking to minimize interference and increase coverage of mobility of mm-wave. |
| *High power consumption* | Existing mm-wave radios perform complex mechanisms have high power consumption not suitable for low-power IoT sensors. | MIMO system including: Spatial Multiplexing and Beam forming together. |
| *Expensive hardware* | Existing hardware and components are expensive (amplifier, mixer, phase shifter). | MIMO system including: Spatial Multiplexing and Beam forming together. |
| *Beam searching* | Signals decay very quickly with distance and environmental conditions. | Suitable and low-power beam searching techniques. |

## VI. CONCLUSION

This report has examined the potential of the 5G mm-wave communication technology in the 5G-IoT based system, along with its existing challenges. The millimetre-wave network is expected to become a crucial part of the IoT infrastructure that connects edge processing and data from smart devices to enable several IoT applications. In deploying these mm-wave technologies, MIMO signal processing, multi-antenna methods including mm-wave modulation or channel coding should be analysed and discussed further in future research. Therefore, it is important to utilize the mm-wave band in the 5G technology to efficiently deploy numerous promising IoT applications within the 5G networks.

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