WILL MILLIMETRE WAVE WORK FOR 5G? A REVIEW OF MILLIMETER WAVE TECHNOLOGY, ITS CHALLENGES AND POSSIBLE SOLUTIONS

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Abstract
Millimetre-wave (mm-Wave) band offers the potential for high-bandwidth communication channels in cellular networks. It is a promising technology for future 5G cellular networks. This article, explained the need for 5G to re-enforce or

Keywords: millimetre wave, 5G, 4G, Possible, Technology

INTRODUCTION
Future fifth generation (5G) cellular networks are being developed to satisfy dramatically increasing data traffic among mobile devices with the emergence of various high-speed multimedia application (Qiao et al., 2015). Table 1 summarises the evolution of cellular networks from 1G to 4G from the aspect of implemented key technologies and must supported applications. A new generation emerges every decade to significantly improve transmission rate and support more applications. 5G cellular networks are expected to have much higher network capacity and provide multi-gigabits-per-second data rate for each user to support multimedia applications with stringent quality of service (QoS).
replace 4G and the need of millimetre wave to pave the way for 5G. The paper also discussed the potentials of millimetre wave, and some solutions to the challenges involved in exploiting millimetre wave, and requirement. For example, uncompressed video streaming requires a mandatory data rate of 1.8/3.6 Gb/s. These newly emerging bandwidth-intensive applications create unprecedented challenges for wireless service providers to overcome a global bandwidth shortage (Pi et al., 2011).

Millimetre-wave (mm-Wave) communication is a very promising solution for future 5G cellular networks. An mm-Wave communication system has very large bandwidth (multiple giga hertz), which can be translated directly to much higher data rate and overwhelming capacity. Millimetre wave generally corresponds to the radio spectrum between 30GHz to 300GHz, with a corresponding wavelength between one and ten millimetres. However, in the context of wireless communication, the term generally corresponds to a few bands of spectrum near 38, 60 and 94 GHz, and more recently to a band between 70 GHz and 90 GHz (also referred to as E-band), that have been allocated for the purpose of wireless communication in the public domain (Adhikari, 2008). With advances in radio frequency (RF) circuits (Wei et al., 2014), the era of operating cellular networks in millimetre-wave (mm-Wave) bands is coming. Recent measurements have confirmed the feasibility of using mm-Wave as a cellular access channel (Rappaport et al., 2013). While considered in wireless applications like backhaul, personal area networking, and wireless local area networks, the millimetre wave spectrum may be the key to providing an order of magnitude increase in the capacity of current cellular system (Bai et al., 2014).

Millimetre wave cellular system will differ from conventional cellular system due to the particular channel characteristic (Rappaport et al., 2013) and hardware constrain at mm-Wave frequencies. System analysis of cellular networks needs to incorporate these features to provide a good characterization of coverage and capacity. Millimetre wave 5G cellular networks are expected to have the main characteristic of highly directional antennas at both wireless devices and base stations, lower link outage probability, extremely high data rate in the widest coverage area, and higher aggregate capacity for many simultaneous users. As a replacement of copper/fiber infrastructure, mm-Wave mesh networks can be used as a wireless backbone for 5G to provide rapid deployment and mesh-like connectivity. The goal of this article is to expose the potentials of mm-Wave for
5G and to propose solutions to the problems militating against effective implementation of millimetre wave (mm-Wave).

Table 1. Evolution of cellular network from 1G to 4G

<table>
<thead>
<tr>
<th>Generation</th>
<th>Primary services</th>
<th>Key differentiator</th>
<th>Weakness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1G</td>
<td>Analogue phone calls</td>
<td>Mobility</td>
<td>Poor spectral efficiency, major security issues</td>
</tr>
<tr>
<td>2G</td>
<td>Digital phone calls and messaging</td>
<td>Secure, mass adoption</td>
<td>Limited data rates difficult to support demand for internet/email</td>
</tr>
<tr>
<td>3G</td>
<td>Digital phone calls, messaging and data</td>
<td>Better internet experience</td>
<td>Real performance failed to match hype, failure of WAP for internet access</td>
</tr>
<tr>
<td>4G</td>
<td>All IP services (including voice, messaging)</td>
<td>Faster broadband internet, lower latency</td>
<td>4G experiencing bandwidth shortage</td>
</tr>
</tbody>
</table>

THE NEED FOR 5G TO RE-ENFORCE OR RE-PLACE 4G

With the introduction of a myriad smart hand held devices, user demands for mobile broadband are undergoing unprecedented rise. The exponential growth of bandwidth-demanding applications such as video streaming and multimedia files sharing are already pushing the limits of current cellular system (4G). In the next decade, envisioned media-rich mobile applications such as tele-presence and 3D holography will require data rates simply not possible with fourth generation (4G) networks. On top of this, people have really high expectations for wireless services. They want a high level of reliability, low levels of latency (delayed uploading or downloading of content) and constant connectivity anytime, anywhere. The internet of things, where new types of devices are connected digitally, as well as the increasing use of mobile technology for health care, smart power grid and vehicular networking create new expectation for wireless, especially when it comes to speed and reliability.

The ever growing demand for higher data rates and capacity, require unconventional thinking for the next generation (5G) cellular system. 5G will have to deliver a huge leap in performance to handle surging mobile network traffic. According to Cisco systems’ most recent visual networking index (VNI) “mobile data traffic will grow 10 fold globally between 2014 and 2020, reaching 24.3 exabytes per month worldwide in 2020” (larry, 2015), (an Exabyte is 1
billion gigabytes). 5G is expected to provide connections 40 times faster and with at least four times more coverage worldwide than the current 4G long term evolution (LTE) wireless communication standard. Even without clear definition of 5G, testing is underway or in the works in places including Finland, Russia and South Korea (Larry, 2015).

**How will 5G differ from 4G?**

One different will be that 5G may move wireless signal to a higher frequency band, operating at millimetre wavelengths between 30 and 300 GHz on the radio spectrum. That is going to open up a huge amount of bandwidth and alleviate concerns about wireless traffic congestion. Rader, satellite and some military systems use this area of spectrum currently (Larry, 2015), but it’s definitely less occupied than the spectrum currently in use. In addition, whereas 4G supports hundreds of megabits-per-second data rate, 5G is promising data rates in the gigabits-per-second range. It may not support those higher rates at all times in all places, but it will lower latency rates overall. Table 2 shows comparison between 4G LTE and 5G.

**COMPARISON OF 5G WITH 4G LTE SYSTEM.**

Table 2. Comparison of 5G with 4G system (Fatimah et al., 2017)

<table>
<thead>
<tr>
<th>Technology</th>
<th>4G LTE</th>
<th>5G network</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Bandwidth</strong></td>
<td>1Gbps</td>
<td>Higher than 1Gbps (1000 times faster)</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td>Wi-Max, Wi-Fi, LTE</td>
<td>WWWWW including all generation of the wireless system. (1G, 2G, 3G, 4G D2D etc.)</td>
</tr>
<tr>
<td><strong>Core network</strong></td>
<td>Packet switching (internet)</td>
<td>Internet</td>
</tr>
<tr>
<td><strong>Multiplexing</strong></td>
<td>CDMA</td>
<td>CDMA</td>
</tr>
<tr>
<td><strong>Switching</strong></td>
<td>All Packet</td>
<td>All Packet</td>
</tr>
<tr>
<td><strong>Primary Service</strong></td>
<td>All-IP Service</td>
<td>High speed, High capacity</td>
</tr>
<tr>
<td><strong>Latency</strong></td>
<td>Lower latency</td>
<td>Extremely low latency</td>
</tr>
<tr>
<td><strong>Deployment</strong></td>
<td>Many network operators already deploy 4G LTE technology</td>
<td>5G technology currently includes pilot project and research purpose design</td>
</tr>
<tr>
<td><strong>Machine type communication</strong></td>
<td>4G is unable to provide raw bandwidth to user on request</td>
<td>5G is intended with features to provide fast and resilient internet access to each user anytime and anywhere.</td>
</tr>
<tr>
<td><strong>Implementation</strong></td>
<td>Presently</td>
<td>? (2020 estimate)</td>
</tr>
<tr>
<td><strong>Handoff</strong></td>
<td>Horizontal &amp; Vertical</td>
<td>Horizontal &amp; Vertical</td>
</tr>
</tbody>
</table>
WHY MILLIMETRE WAVE (mm-Wave) FOR 5G?
One of the most promising potential 5G technologies under consideration is the use of high frequency signals in the millimetre wave frequency band that could allocate more band width to deliver faster, higher-quality video and multimedia content.
Millimetre wave wireless technology presents the potential to offer bandwidth delivery comparable to that of fiber optics, but without the logistic and financial challenges of deploying fiber (adhikari, 2008).

Potentials of Millimetre wave
- The radio spectrum at mm-Wave frequencies is still rather undeveloped, and more bandwidth are available at these frequencies.
- Millimeter wave allow frequency reuse at shorter distances.
- The inherent security and privacy is better at mm-Wave frequencies because of the limited range and the relatively narrow beam widths that can be achieved.
- The spatial resolution is better at mm-Wave frequencies since the small wavelength allows modest size antennas to have a small beam width.
- The physical size of antennas at mm-Wave frequencies becomes so small that it becomes practical to build complex antenna arrays and/or further integrate them on chip or PCB.
- The large bandwidth at 60 GHz can provide unlicensed short-range high speed links for wide personal area network (WPAN) (802.15.3c) and wireless high definition video streaming (wireless HD). Data rates can be several Gbps.
- The 77GHz band of mm-wave is suitable for automotive long-range (100m) autonomous cruise-control radar. The high carrier frequency allows modest-size antennas to have a small beam width and therefore a better angular resolution.
- The 24 GHz band can be used in automotive short-range radar, since the large bandwidth at 24 GHz offers sufficient small distance resolution (5cm)
- The large bandwidth at 71-76GHz, 81-86GHz and 92-96GHz can provide licensed high speed links with data throughput up to
10Gbps. This is more than the sum total of all other licensed spectrum available for wireless communication (adhikari, 2008).

MAJOR CHALLENGES ASSOCIATED WITH mm-Wave

Despite the potential of millimeter wave communication, there are numbers of key challenges that limit the potential of the millimeter wave spectrum.

Propagation Loss

The propagation characteristic of millimeter waves through the atmosphere depends on the atmospheric oxygen, humidity, fog, and rain as shown in table 3.

Table 3: Millimeter signal loss through Atmosphere (Loea Corporation, 2008)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Comment</th>
<th>Signal loss (dB/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>Sea level</td>
<td>0.22</td>
</tr>
<tr>
<td>Humidity</td>
<td>100% at 30 °C</td>
<td>1.8</td>
</tr>
<tr>
<td>Heavy Fog</td>
<td>10°C, 1 gm/m3 (50m visibility)</td>
<td>3.2</td>
</tr>
<tr>
<td>Cloudburst</td>
<td>25 mm/hr rain</td>
<td>18.4</td>
</tr>
</tbody>
</table>

The free space path loss is dependent on the carrier frequency $f_c$. Increasing the carrier frequency will reduce the antenna size. As a result the effective aperture of the antenna scales by a factor of $\frac{\lambda^2}{4\pi}$, while the free space path loss grows with $f_c^2$. Hence, increasing the carrier frequency $f_c$ from 3 to 30 GHz, will correspondingly add a power loss of 20 dB regardless of the transmitter-receiver distance (adhikari, 2008).

- **Line of Sight (LOS):** the transmitter and the receiver must have a line of sight between them, otherwise there will be high attenuation. Microwave signals are less vulnerable to blockages but they fade due to diffraction. In contrast, mm-Wave exposes prismatic propagation and suffers less diffraction than the microwave signals, making them much more susceptible to blockages.

- **Blockage:** Millimeter wave signals are more sensitive to blockage effects than microwave, as certain material such brick walls of buildings cause severe penetration loss (Pi et al, 2011). The isolation effect of walls makes it hard for outdoor base station to cover indoor users. Blockage can add up to 40dB attenuation on top of the path loss (Pi et al, 2011). Mm Wave signals will have weaker diffractions due to the small wavelength. Thus, line of sight (LOS) signal will propagate in free space. On the contrary, while reflections can establish NLOS communication links, even the best
NLOS signals are shown to be much weaker than LOS signals (Rappaport et al., 2013). This indicates a significant difference between LOS and NLOS path loss. In addition, millimeter wave signals suffer from foliage losses, which require a larger margin in the link budget for system design (Rappaport et al., 2013). Figure 2 demonstrate mm-wave signal blockage by buildings.

![Signal blocked by buildings](URL 1)

**Fig. 2 Blockage of millimeter wave signal** (URL 1)

- **Hardware Constraints:** Mm Wave transceivers are subject to a set of practical hardware constraints. For example, mixed signal components like analogue-to-digital converters (ADCS) tend to be of higher power consumption and higher cost relative to microwave solutions. Hence, the traditional approach in microwave transceivers of dedicating a separate RF chain for each antenna is extremely difficult in millimeter wave system (Bai et al., 2014).

**POSSIBLE SOLUTIONS**

- **Beamforming Technology:** This is the application of multiple radiating elements transmitting the same signal at the same wavelength and phase, which combine to create a single antenna with a longer more targeted beam which formed by re-enforcing the waves in a specific direction. Beamforming could be:
Directional Beamforming: Antenna arrays will be used for directional Beamforming in millimeter wave system. Fortunately, realizing large arrays is possible due to the fact that antenna size is inversely proportional to frequency size, so higher frequency signals would require smaller antennas. More antennas could be packed into devices. That enables directional transmission. Directional Beamforming at both transmitters and receivers provides not only directivity gains to compensate for the high path loss but also capability to manipulate interference through more advance beam shaping (Bai et al., 2014). In Beamforming each user’s signal is multiplied by complex weight that adjust the magnitude and phase of the signal to and from each channel. The phases and amplitudes are adjusted to optimize the received signal. This causes the output of the arrays of antenna to form transmit or receive in a particular direction and minimizes the output in other direction. Figure 3 shows how a millimeter wave base station can serve multiple users simultaneously using multiuser techniques (MIMO).

Fig. 3. Directional Beamforming (URL2)
➢ **Steering Beamforming technique:** This technique can provide solution to signal blockage problem. When the line of sight (LOS) link is blocked, the transmitter searches different beam directions, to bypass the obstacles so that the receiver can receive some non-line of sight link signal to be in the acceptable channel quality.

![Steering Beamforming Diagram](URL 3)

Fig. 4. Steering Beamforming (URL 3)

- **Small cells deployment (Ultra dense networks):** There has been a trend toward small cells; often called microcells, femtocells and picocells, depending on their ranges. Millimeter wave can take advantage of these technologies, as they are better suited for transmission over relatively short distances. High-frequency signals can also be reused across short distances by different cells in a network, meaning the available spectrum is used more efficiently. Small cells will reduce path loss and improve coverage.
Fig. 5. Small cells deployment (Niu et al. 2015)

- **Millimeter wave and Microwave Coexistence**: since millimeter wave will be limited in range, there will be coexistence with conventional microwave cellular system for universal coverage. There will be a significant difference in coverage between picocells and microcells station. Microcells may offer high coverage but mostly NLOS connection while picocells can provide LOS coverage. However, both will need to coexist.

- **Relay**: To achieve wider coverage using millimeter wave communication, relays could be deployed to serve as a link between cells or to provide alternative communications link in case of blockage. Figure 3 demonstrate the use of relay to provide alternate link. Alternatively, fiber connectivity may be used between cells to achieve universal coverage.
Fig. 6. Provision of alternate links through relays

- **Indoor and Outdoor Users:** Another issue resulting from blockages is the isolation of indoor and outdoor environment in a millimeter wave network. Due to the high wall penetration loss with certain materials, indoor users are unlikely to be covered by an outdoor base station. The indoor and outdoor cell on the private building may be best operated by a different operator who could then be able to provide roaming for multiple carriers from the different subscriber. While roaming service is commonly used in the current network, millimeter wave roaming service will be a lot faster compared to other network generations.

**CONCLUSION**

In this paper, an overview of the millimeter wave as a promising technology for the 5G cellular system is provided. The main propagation challenges associated with millimeter Wave are presented and potential solutions were discussed. Despite the challenges militating against effective exploitation of the millimeter wave technology, it is concluded that the combination of mm-Wave potentials and available solutions can be regarded as a key technology solution for the 5G mobile communications.

**REFERENCES**


