

Propagation challenges in 5G millimeter wave implementation

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ABSTRACT

With current technology advances, implementing millimeter wave in real life had became more promising and demanding. However, before millimeter wave can be deployed, there were several challenges in terms of technical, path loss and shadowing. This paper provides review on the challenges that might occurs when implementing 5G millimeter wave. An overview of LTE-Advanced and millimeter wave is made to provide further understanding. A critical analysis was also made to identify the problem especially in rain and haze attenuation, if addressed, will help mobile service provider to overcome the problem.

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1. INTRODUCTION

Nowadays, it is quite challenging for mobile service provider in order to meet the expectation for faster wireless data services. Modern wireless network such as Long Term Evolution (LTE) was introduced to the public to meet customers need on wireless network. As stated by 3rd Generation Partnership Project (3GPP), the Universal Mobile Telecommunications System (UMTS) Long Term Evolution (LTE) Release 8 can provide data rates up to 300 Mbps on downlinks and 75 Mbps on uplinks. Based on the requirement from International Mobile Telecommunications-Advanced (IMT-A), few improvements have been studied to provide improvements to current LTE Release 8. These improvements are considered as part of LTE-Advanced [1-2].

Due to technology advances, the usage of mobile data growth have rapidly increase at over 50% and is expected to expand even more for the next coming decade [3-5]. However, the growth of mobile traffic have been challenging to the wireless service provider in order to overcome a global bandwidth shortage [6-8]. Thus, the LTE-Advanced is actively researching fifth generation (5G) mobile communication system to cope with current demand. Figure 1 illustrates the evolution of mobile communication system towards 5G.

The fifth generation or 5G has been highlighted to be the next era for mobile communication system. Although many technological advances has been implemented in fourth generation (4G) system such as orthogonal frequency-division multiplexing (OFDM), multiple-input multiple-output (MIMO) and etc. It is expected that the surging demand mobile data in the next decade can no longer accommodate the user data usage and latency requirement [8-9]. Thus, the development 5G network is introduces a promising frequency spectrum around 3–300 GHz better known as millimeter wave bands with wavelength range between 1 to 100 mm. This spectrum is currently underutilized by mobile service provider. Figure 2 shows the frequency spectrum for both super high frequency (SHF) with a range of 3-30 GHz and 30-300 GHz spectrum for extremely high frequency (EHF).

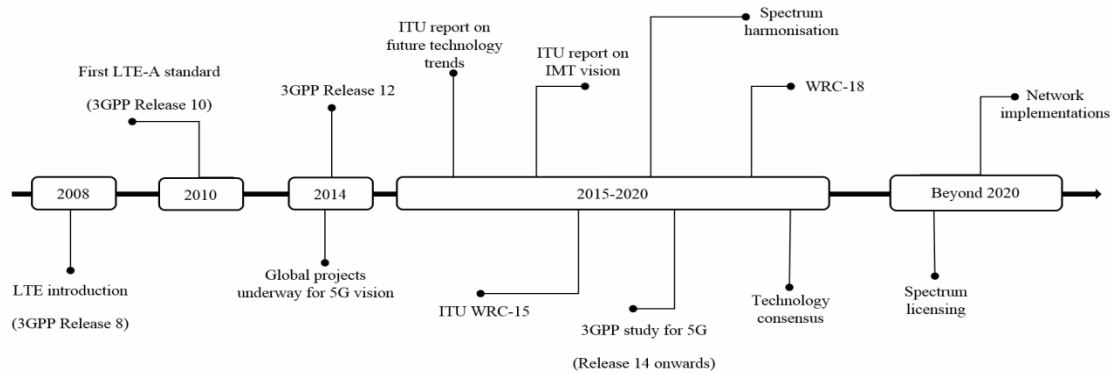


Figure 1. Timeline and the development towards 5G [10]

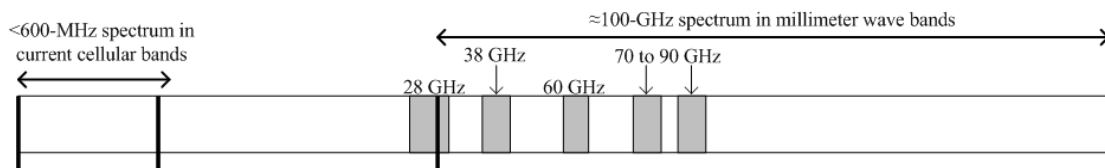


Figure 2. Frequency spectrum from 300 MHz – 300 GHz

Millimeter wave historically has been considered expensive to be utilized thus only selected authorities such as governmental bodies to broadcast in this spectrum. Nowadays with current semiconductor technology advances, the cost has been greatly reduced which gives an opportunity for this spectrum to be broadly used commercially.

However, the usage of millimeter wave have experience some challenges to be broadcast by mobile network operators. Millimeter wave path loss and shadowing are greatly impeded due to the reflection in building as well as absorption and scattering made by rain, haze and fog compared to the standard 4G spectrum bands (2-8 GHz). Besides that, researchers also found few technical difficulties in order to implement millimeter wave. Although, many researchers have made breakthroughs to ensure the functionalities of the 5G millimeter wave communication system but none of them were actually been deployed to be used commercially. Most of the equipment was used for research purpose only. This paper will review the following key contributions in terms of channel propagation, antenna technology and also path loss and shadowing in urban and suburban area.

The rest of the paper is organized as follow. Section 2 will explained the technical challenges in order to implement 5G millimeter wave. Section 3 consist of challenges in terms of path loss and shadowing in 5G millimeter wave. Section 4 discussed on the rain and haze attenuation by comparing previous works. And finally Section 5 concluded this paper and suggested future work.

2. TECHNICAL CHALLENGES IN IMPLEMENTING 5G MILLIMETER WAVE

Implementing millimeter wave is always considered challenging by researchers. Until these days, millimeter wave have been primarily been used by military. To overcome the expected limitation of 4G networks, researchers have proposed the broadcast in millimeter wave spectrum. As aforementioned, implementation of millimeter wave in 5G are met with various challenges, this section provide a brief review on the technical challenges.

2.1. Channel Propagation

Currently, there are lots of effort in researching the channel measurement and modelling for 5GHz Wireless Local Area Network (WLAN) band [11-13] and 3-10GHz Ultra-wideband (UWB) band [14-17]. However research on the channel modulation of frequency above 60 GHz is still limited. The authors in [18] stated that frequency above 60 GHz have severe path loss that can limit the functionality of the system. This findings were echoed by researchers in [19-21]. Even though, there are solutions to this problem by the use of relays or regenerative repeaters. However, currently there is no specific channel that

can address the 60 GHz which required spatial properties and can detect the effect of human movement. Current technology approaches only measured the angle of arrival of the received signal in corridor and desktop environment by using antenna array [22] and rotational directive antenna [23]. But the result may vary thus it required in-depth research on characterize and validation of these results.

Paper [18] also stated that all the channel models currently available are only for radio channel which making it hard due to its dependency on the antenna which only can be used for particular setup of an antenna. This paper suggested a research on propagation channel which excluded the effect of antenna [24] and explore the effect of a different type of antenna setups with different gain/bandwidth especially frequency at 60 GHz and above. Referring to [25], it said that high gain antenna can greatly reduce the delay spread of the radio channel when both transmitter (Tx) and receiver (Rx) antennas are aligned. But, any minor error on the main lobe of the antenna may affect the direction of arrival of the signal [26-27]. Moreover, [18] also mention the effects of multipath suppression using circular polarization over linear polarization demonstrated on [28], needed more accurate measurement to produce a promising result for 60GHz frequency and above.

Referring to [29], it is mentioned that current research need to be more efficient and produce realistic measurement data because it was needed in the future for modification or extensions for available channel propagations. It also stated that the measurement approach should base on various frequency, spatial consistency, 3D, spherical waves, small cell communications and also new communication paradigms (e.g. Device-to-Device (D2D) or Machine-to-Machine (M2M)). The data need to be tested in millimeter wave especially frequency above 60 GHz. The data measurement should considered real life events such as vehicle-to-vehicle and crowded areas. It also emphasized that the data should be carried out for both indoor and outdoor situations.

Another notable mentions from [30] is the usage of large-scale antenna for directive communication and millimeter wave communication to be implemented on the 5G systems. Current channel models essentially need few improvement primarily in angular resolution and sub-path amplitude distribution. [30] proclaimed that large-scale antenna should use spherical wave instead of plane wave approximation. Therefore, millimeter wave especially at 60GHz is proposed to attain spectrum and spatial multiplexing gain but some the features like highly resolved angular properties and non-line-of-sight (NLOS) path loss require deeper understanding.

2.2. Antenna Technology

One of the main components that need to be analyzed in developing millimeter wave system is the antenna. Although, there are many type of antennas that had been developed and used, however, none of them are designed specifically for millimeter wave due to the requirements to be low cost, small in size, light weight and high gain. As stated by [18], 60 GHz antennas were required to be operated with constant gain and high efficiency for wider frequency range which are 55-67 GHz. It also discussed on the beamforming of 60 GHz can be accomplish using switched beam array or phase array. Both researchers of [31-32] proved that beam steering antenna can produced result around 14 dBi with 20° half power beam width (HPBW) meanwhile 4-element planar array have an average conversion loss less than 10.6 dB for all four channels. However, current antenna that had been developed are using larger phase array that can dispute other technical challenges meanwhile initial proposed requirement are small size, low cost, light weight and high gain which can only be achieve by thorough research.

3. PATH LOSS AND SHADOWING IN 5G MILLIMETER WAV

Path loss and shadowing are example of major challenges in implementing millimeter wave as stated by [33]. The free space path loss is highly dependence on the carrier frequencies, f_c . As the carrier frequencies increase, the free space path loss will also increase [33-34]. Shadowing can degrade the millimeter wave for example brick and human body can attenuate the signals around 40-80 dB and 20-35 dB respectively [8], [19], [35-38]. Besides that, according to [76], millimeter wave can severely attenuated can also be caused by rain, haze and fog through absorption and scattering.

3.1. Urban and Suburban

For the past few years, many researches had been conducted for various measurement of mm bands [3], [39-44] in order to evaluate path loss through different materials and buildings. The research made on [35] had experimented the reflection and path loss around building in urban area in New York City using 28 GHz. The authors used frequency at 28 GHz due to it was underutilized [45] and have low atmospheric absorption and similar free space path loss with 1-2 GHz cellular bands compare to 60GHz [7]. This paper also mentions that the research was made for both indoor and outdoor to investigate the value of reflections

coefficients on several type of materials. The experiments used directional antenna whereas the distance between Tx and Rx was 5m and also used broadband sliding correlator channel sounder that also been done in [45-48]. The authors stated that the path loss at outside environment shows higher path loss than indoor making it harder to utilized 28 GHz spectrum for indoor-to-outdoor penetration.

Next, the authors in [49] had conducted an experiments to measure the line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios in urban microcellular area at New York City and Austin, Texas. This paper majorly focusing on finding new suitable path loss model by referring the previous path loss model for frequencies spectrum at 28 GHz and 38 GHz. This research used steerable antennas for Tx and Rx with different heights and gains for both frequencies. Besides that, the authors also used sliding correlator channel sounder in order to present conceive measurement results. It also mentions that the new path loss was distance dependence and it had been created by referring to the linear regression fits. The authors suggested to use higher gain antennas to compensate the additional path loss.

In [50], the authors focused on comparing the previous rural microcell (RMA) propagation models and current RMA path loss models which was introduced by the 3GPP for frequencies around 0.5 until 30 GHz. Thus, by comparing both of the results, the authors had developed new RMA path loss model which was more accurate and easier to be applied for different height of the transmitter antenna. The research also stated that it can be used for frequency from 0.5 until 100 GHz. RMA path loss model can only be used for transmitter above 35 meters as stated in [51-52] but for 73 GHz RMA was designed to overcome the limitation for the previous RMA. Based on the research made in [50], it designed CIH path loss model by referring the previous CI path loss model considering the model was designed for several conditions. This paper concluded that the RMA that had been introduce by the 3GPP does not have any existing evidence. Below shows the mathematical form for CIH model which is same with the CIF model [53] and given here for $d_0 = 1 m$:

$$\begin{aligned}
 PL^{CIH}(f_c, d, h_{BS})[dB] &= FSPL(f_c, 1 m)[dB] \\
 &+ 10n \left(1 + b_{tx} \left(\frac{h_{BS} - h_{B0}}{h_{B0}} \right) \right) \log_{10}(d) + \chi_{\sigma}; \quad (1)
 \end{aligned}$$

where $d \geq 1 m$

Where

- h_{BS} = RMA base station antenna height (m)
- h_{B0} = Default base station height
- n = Distance dependence of path loss is denoted
- b_{tx} = Model parameter
- χ_{σ} = Standard deviation
- d = Distance

3.2. Rain

An attenuation caused by rain had become dominant fade mechanism on fixed links that operate above 10 GHz. In this paper [54], new joint rain fade simulation tool; GINSIM, was developed to compare the simulation results with ITU-R model and real radio links which covered United Kingdom and European area. This simulation tool was developed to replace the previous Hull Rain Fade Network Simulator (HRFNS) which include several upgrade in fade mechanism and etc. hydrometeors (raindrops, ice pellets, hail and complex mixed phase particles) can caused scattering and absorption at the radio links especially above 10GHz due to the size of the raindrop was the same with EHF band. Scattering can be divided into two which were Rayleigh scattering and Mie scattering. Rayleigh scattering can only be used when the particles is smaller than wavelength meanwhile Mie scattering is used when particles size were similar with the wavelength. However, this paper suggested to use Rayleigh scattering model which suitable for detecting rain scattering on microwave links. The author stated that specific attenuation using the power law Recommendation ITU-R P. 838-3 [55] will increase as the frequency and rain rate increase. Therefore, Nimrod data had been introduced with finer-scale spatial variation using multiscaling exponents

The rain rate is one of the main factor in determine the rain attenuation in microwave link. [76] agreed that rain can affect losses in transmission line for frequency above 10 GHz due to scattering and absorption. In [56], the paper focused in analyzing rain attenuation and rain data for three years (2013-2015) in South Korea. The authors tested the experiments using six channel models which were ITU-R P. 530-16 [57], Da Silva Mello model [58], Moupfouma's model [59], Abdulrahman et. al [60], Lin model [61] and differential equation approach [62] by referring to the local environment and comparing all of the results. Usually, ITU-R P.530-16 was the most focuses models in many previous researches for example in [63-67]. Among all of six models ITU-R P. 530-16 showed a promising results because it had the closer estimation on

rain attenuation on rain for both 38 GHz and 75 GHz frequencies. However, De Silva Mello and Abdulrahman et. al models also produced closer results but due to the time consumed, ITU-R P. 530-16 was chosen. This occurred in both frequencies.

Currently, most of the study on path loss due to rain attenuation were made in temperate location, this can be seen in [6], [47], [68-70]. Tropical location received more rain due to heavy rainfall and caused rain attenuation. Therefore, paper in [71] conducted simulation on to test the channel model for rain attenuation in tropical location specifically in Kalkota and Spina d'Adda for 28 GHz and 28 GHz frequencies by using time series of rain rate prediction as shown in [72]. Method in [72] separated all rain rate data into three segments; constant (C), down (D) and up (U). As known to many, tropical locations received more rainfall than temperate and the author also agreed that rain attenuation is slightly higher there based on the research that had been made. Tropical showed higher attenuation which was 10 to 12 dB for every 200 m meanwhile temperate locations only produced 3.5 dB. The authors emphasized on finding a channel model suitable for tropical locations.

3.3. Haze

Current air quality throughout the world had declined rapidly. This is the results from open burning, industrial emissions and others. This phenomenon may cause attenuation especially on millimeter wave and had been proved in this paper [73]. In [73], it has provided a mathematical calculation and simulations to prove that haze and fog can also cause attenuation. The characteristics of haze particles as mentioned by authors were it has diameters between 0.001~10 μm , particle concentrations between 103~10 cm^{-3} and particles mass concentrations between 29.3~166.3 $\mu\text{g}/\text{m}^3$ [74]. As stated in [75], haze particles can be categories into six which are soluble particles, sea salt particles, sulfate particles, insoluble particles, soot and dust particles.

Dust and soot played major roles in causing haze attenuation. It can impact the millimeter wave transmission due to scattering. As mentions before, scattering can be divided into two which are Rayleigh scattering and Mie scattering. The authors suggested that Mie scattering theory can be used to estimate the attenuation coefficient. Mie scattering equation can be seen in (2).

$$\alpha_m = 169.2 X \frac{\mu D^3}{\rho \lambda^4} \left| \frac{\varepsilon - 1}{\varepsilon + 2} \right|^2 \quad (2)$$

Where:

- α_m = Attenuation coefficient
- μ = Material density
- D = Particles diameter
- ρ = Particles density
- ε = Relative complex dielectric constant
- λ = Frequency wavelength

This calculation had proven the author's theory on haze can be one of the main impacts and also it can caused attenuation in millimeter wave transmission link.

4. DISCUSSION

Path loss and shadowing are the challenges in implementing millimeter wave. However, this part will only discussing on the impact on rain and haze attenuation. This is because all of the environmental attenuations can happen in both urban and suburban area.

Based on the reviewed papers, we can see that there are already many research discussed on the impact of rain attenuation in millimeter wave. The researches made already covered most of the frequency spectrum for millimeter wave for example 38 GHz and 75 GHz. Both of the frequencies had proven that rain attenuation can occurs in both frequencies but more severe as the frequency getting higher. Moreover, some of the researcher also had been focusing on rain attenuation in both temperate and tropical regions.

However, only one paper did mentions the effect of haze in millimeter wave transmission link. But, there is no concrete evidence to verify the result since there was not further research been made on this paper. Research on haze attenuation is important for many countries especially in South East Asia and China whereas haze is one of the major environmental phenomenon that happening every year. By implementing 5G millimeter wave without taking haze attenuation into consideration may cause major problem for mobile service provider in the future. Besides, the paper only provide theory on haze scattering and mathematical

modelling to prove that it can caused attenuation. Currently, there are no channel model had been developed that can withstand haze attenuation in millimeter wave.

5. CONCLUSION

In conclusion, few challenges on implementing 5G millimeter wave have been reviewed. Communication system using 5G millimeter wave have a promising future but some challenges in technical as well as path loss and shadowing need to address thoroughly. Further research on environmental attenuation especially haze attenuation is crucial to overcome the limitations on millimeter wave. Moreover, further enhancement on current millimeter wave channel model is essential in order to develop a channel model that can encounter haze attenuation issue.

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