What is the role of millimeter waves in the success of 5G?

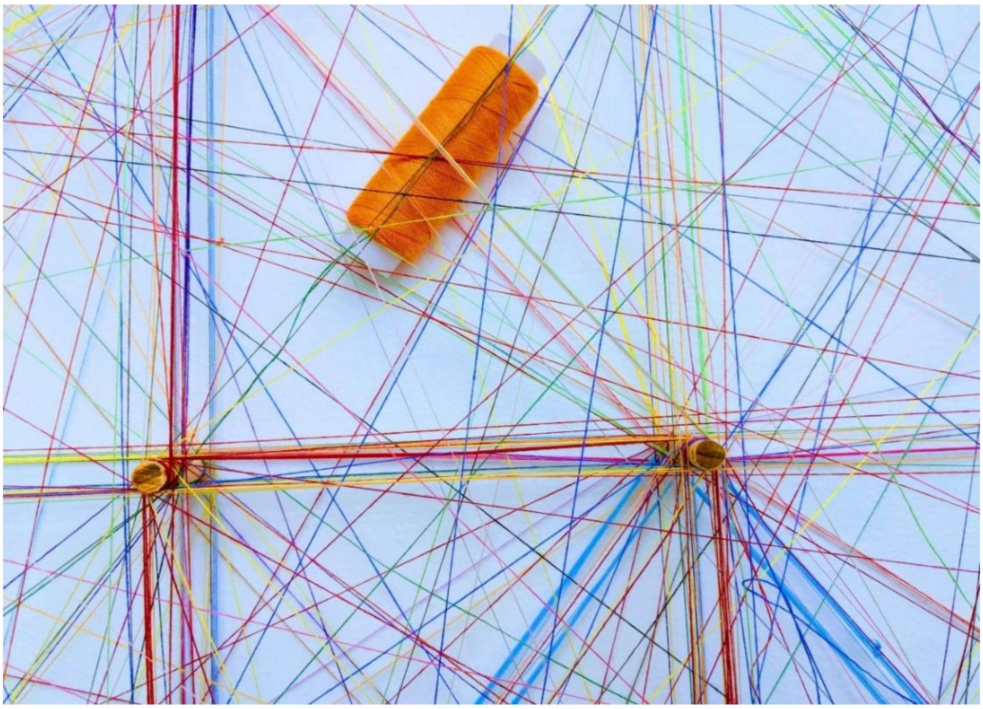


Image Source: Omar Flores

Introduction

Lately, there has been a lot of buzz about how 5G – the new generation communications technology – is going to improve our lives and boost economic growth which is much needed in the post covid world. 5G is to enable connectivity services with abundant availability, very high reliability and low latency. In comparison with 4G, with up to 100x higher data rates and 10x lower latency (the delay between sending and receiving information), it is expected to enable 1,000x higher data volumes and 100x more devices to be simultaneously connected to a network. 5G is touted to make our society more connected and free to stream high-definition video content or engage in AR/VR enhanced real-time online gaming experiences anywhere. This new generation communications technology is proclaimed as a key enabler of new use cases such as smart manufacturing, smart agriculture, smart energy, autonomous driving and logistics to name just a few.

While 5G is early in its lifecycle and is being continuously enhanced and refined with new 3GPP releases, it is important to address and understand what role the mm-wave spectrum will have in enabling 5G to deliver on its promises. This post will describe briefly what millimeter waves are and discuss the importance of the mm-wave spectrum in enhancing broadband services. As its characteristics are still not well understood, we will also present the benefits as well as discuss the challenges associated with transmitting radio waves at very high frequencies.

What is the millimeter wave spectrum?

Millimeter waves are a subset of an electromagnetic spectrum that spans from 30 GHz to 300 GHz [1]. Due to its properties (discussed in subsequent section) it is a frequency band that is increasingly researched, studied and adopted for high-speed wireless communication. As mobile data transfer levels have surpassed those of the wired communication and are projected to increase each year for the foreseeable future, the need for enhanced data performance of networks and bandwidth shortages of sub-7GHz spectrum, make the mm-wave spectrum a very attractive proposition. With the benefits of mm-waves also come the challenges and issues that need to be addressed by researchers and engineers, who are tasked with development and deployment of 5G devices, systems and networks.

5G systems are being implemented to operate below 1 GHz, Sub-7GHz (1-7.1GHz) and mm-wave range, with the most recently finalized by 3GPP Release 16 defining the later as a spectrum between 24.25 and 52.6 GHz. The work continues on Release 17, which will introduce further feature enhancements and is expected to support the spectrum up to 71 GHz [2].

What makes millimeter waves critical in the 5G future success?

Image Source: Frederik Lipfert

The millimeter wave spectrum offers several benefits and opens new opportunities for 5G, which were left untapped by all previous communication technologies. Here are five attributes that the mm-waves enable which are fundamental to 5G realizing it’s potential.

Larger bandwidths

The wireless spectrum is a heavily occupied resource, especially in the low- and mid-band range (up to 7GHz). The high-band (24.25-52.6 GHz) – the 5G mm-wave spectrum – is by contrast a much broader band in absolute terms than the sub-7GHz band. It is also much less crowded and not as heavily used, making a tremendous amounts of bandwidth capacity available for new applications and use cases such as:

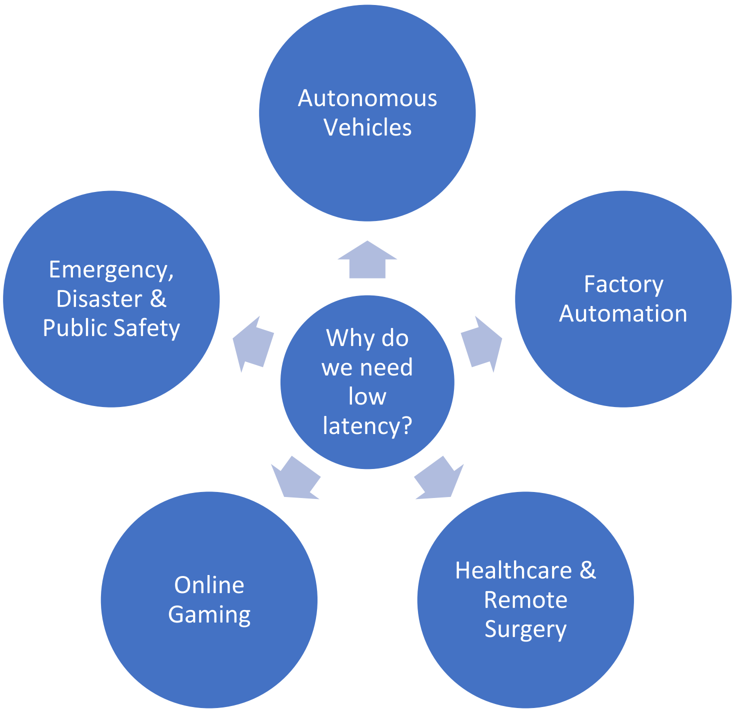
- enhanced mobile broadband (eMBB) enabling broadband everywhere, smart offices, connected vehicles, and enhanced multimedia.
- massive internet of things for smart buildings and cities, agriculture and environment, transport & logistics, and consumer wearables.
- ultra-reliable low latency applications for: mission critical machine type communication, process & factory automation, public safety and disaster recovery, healthcare and remote surgery.

Small antenna form factor

As the radio signal wavelength is inversely proportional to frequency, the mm-wave spectrum allows for deployment of antenna arrays that, although compact in size, are capable of delivering very high far field gains and help overcoming increased propagation losses (further discussed below). For example, an antenna array at 70 GHz would be a ¼ of the size of an antenna designed for 30 GHz.

Low latency

Latency is the time taken for a signal to travel from the source to destination and returns back to the source [4]. One of the promises of 5G is that it is expected to provide latency in an order of milliseconds, ideally achieving even less than 1 mS. This is to be achieved by both a more efficient data transmission protocol as well as by using high frequency millimeter wave signals – the higher the frequency, the lower the theoretical limit of latency. The question remains however: Why do we need low latency?



There are several use cases and real-time applications for which latency, more so than a higher data rates, is much more important. One example are autonomous vehicles that will be moving at high speeds and require real-time information about their surroundings. Another application is factory automation, that with low latency wireless connectivity for all machine types, communication will allow to increase the utility and efficiency of robots [4].

Low latency is fundamental to providing healthcare access to all, even the most remote patients and performing remote surgeries to extend the reach of expert medical personnel and help address staff shortages in the future. In these cases, haptic and video feedback as well as robotic response must be minimized and put a stringent demand on the network with latency demand of lower than 20 mS [5]. Other use cases that require a quick, low latency real-time communications are emergency response, disaster recovery and public safety [3]. Lastly, user experience of online gaming is largely dependent on low latency more so than the sheer download and upload speeds.

Image Source: Roberto Nickson

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High network densification

Due to significantly higher propagation losses, the transmission range of mm-waves is considerably reduced in comparison with sub-7 GHz networks [3]. Providing the required coverage requires a larger number of cells to be deployed as a part of 5G mm-wave networks. This network densification mm-waves are able to provide the higher data rates, capacity and service availability than 4G. Higher network densification comes of course at the increased cost of deployment of a greater number of base stations.

Channel reciprocity

The 5G network relies on Time Division Duplex transmission system, which means that same frequencies are used for both up- as well as downlink communications. This allows the system to perform the communication channel estimation and use it for transmitting and receiving data. Such arrangement saves a significant amount of network resources [3].

What are challenges for millimeter waves the 5G future success?

While there are undisputed benefits of the mm-wave spectrum, it helps to understand the properties of high frequency signal transmission that present several challenges for researchers, designers and engineers who are tasked with making sure that 5G lives up to its expectations.

Free Space Pathloss

Pathloss is a major consideration for any wireless communication system, and due to its frequency dependence character, high frequency signals suffer a higher attenuation relative to low frequency signals, [3]. For instance, a signal at 39 GHz suffers is subject to a 31.6 dB higher free space loss than a signal at 1 GHz - in other words, it's energy at the reception point is lower by almost 1,500 times [3]. Pathloss requires thorough analysis and design of link budget.

Shadowing effects

Additional effects from which the mm-waves suffer more than the sub-7GHz band are signal blockages that are caused by obstacles in the propagation environment. Millimeter waves are much more easily absorbed, reflected and scattered or diffracted than microwaves. These phenomena significantly reduce the signal strength of mm-waves and must be carefully factored-in by careful channel modeling and characterization, and can be counter measured by deployment of high gain antenna arrays that allow for a narrow beam forming.

Penetration Loss

As the millimeter wave signal encounters surfaces and objects that are made of various materials such as glass, concrete, wood and many others, it gets weakened. Penetration loss is a measure of this phenomenon and is defined as a difference in power levels between an unobstructed and obstructed path of signal propagation that is caused by both absorption and reflection [3]. Penetration loss is strongly dependent on the frequency of the signal, material permittivity and its thickness, as well as the angle of transmitted signals and its polarization. While certain materials remain reasonably transparent to mm-wave inducing only marginally higher losses in comparison to microwaves, other materials that are frequently used in constructing outer walls of buildings such as tinted glass, brick and concrete cause severe signal reflections, resulting in extreme penetration losses [3]. Tinted glass is characterized by 6-10 times higher propagation loss than its clear (uncoated) equivalent.
Consequently, millimeter wave signals of 5G cannot be expected to penetrate the building walls in an outside-to-inside communication scenario and vice versa (inside-to-outside). The latter scenario enables a frequency re-use and operation of private indoor networks alongside outdoor public networks with minimal interferences. Indoor millimeter wave 5G coverage cannot however be achieved from the outdoor base stations and one solution is to use repeaters and relays. However, these additional network components increase the cost and complexity of the network.

Foliage loss

Ground level 5G communication is likely to be affected by foliage and vegetation induced losses of leafy plants and trees of various structures. Foliage can completely attenuate millimeter waves. For example, at 57.6 GHz a 5m of foliage adds additional 40 dB to a signal path when compared with a microwave signal at 9.6 GHz [3].

Image Source: Liam Drinan

Human body losses

Human body presents a significant obstacle to mm-waves for which it acts as a reflecting and scattering object and introduces additional losses in the path of a signal propagation. A single person is expected to add between 25 and 40 dB of loss to the signal path [3]. This presents significant challenges with regard to the mobile device designs and beamforming solutions.

Atmospheric loss

Gas molecules that comprise our atmosphere absorb the energy of radio-wave signals at the frequencies at which their resonances occur. There are two dominant sources for atmospheric attenuation: oxygen (O2) and water vapor (H2O), with resonance frequencies located at 60 GHz and 115 GHz for oxygen; and 23 GHz, 180 GHz, and 315 GHz for water vapor, respectively [3]. The effects of oxygen resonance are particularly prominent at 60 GHz for which a wireless communication would incur an additional 13 dB/km attenuation, typically.

Summary

High free space loss and additional sources of mm-wave signal attenuation when compared to sub-7GHz call for short range and line-of-sight (LOS) path type of 5G communication at mm-wave band. While the 5G is being marketed as 100 times better than 4G, it goes without saying that it is proportionally more complex and far more demanding as far as science, research and design and implementation of components, systems and networks is concerned.
While the future of 5G success will not depend on a mm-wave band alone as it will be anchored in the sub-7 GHz range providing a control plane for acquisition, paging and mobility, to meet the expectations for unparalleled mobile data rates, bandwidth availability and latency utilization of mm-wave frequencies is a must. It is only then with a full deployment of a 5G technology that its true benefits can be realized.

The true speed and performance of 5G is still rarely experienced. Current average user time connected to 5G services using millimeter wave band is between 0.5% and 0.8% in US [6]. However, the device availability and deployment of 5G networks is growing much more rapidly than with all previous generations and it is expected that the number of 5G subscriptions and number of IoT connections to reach 3 and 5 billion, respectively [2]. Despite the rapid progress in the deployment of networks the subscribers remain largely unimpressed with the quality of 5G services, with some of the Korean customers expressing a strong interest in filing a class lawsuit against the three major Korean mobile operators [8]. The expectations are very high and 5G networks must employ more and more of the millimeter wave band to ensure that the critical requirements for all the use cases are met to unlock the value for all stakeholders.

Closing Comments

Despite numerous challenges faced by 5G technology operating at millimeter wave spectrum, reliable wireless links can be established by accounting for known losses in device, system and network design and deployment.

Farran has been supporting the research & development of 5G technology since the conceptual works began. We have supplied test & measurement equipment required to perform the early phase studies of path losses and channel sounding. We supported our customers in their efforts to characterize materials, devices and subsystems in an on-wafer, bench-top and over-the-air measurement scenarios. As the 5G technology started taking shape and our customers went from conceptual and early development phase and into volume production we supported them with cost effective and application specific custom solutions that fulfilled their needs in terms of cost, test time and reliability of measurements.

Farran | Millimeter wave solutions, made simple.

Contact us today to discover how we can help you chose a product or a solution that suits your 5G needs. Our knowledgeable and helpful team will be happy to take you through our existing product lines or invite you to a call with our engineering team who will be delighted to advise on a specification and functionality of a custom solution for you.

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