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What Role Will Millimeter Waves Play in 5G Wireless Systems?

5G will bring mobility to mmWave communications as the next-gen wireless network attempts to serve more people and even things with a major expansion of mobile services.

Wireless communications networks have evolved dramatically from their humble beginnings. The first-generation (1G) wireless network, the Advanced Mobile Phone Service (AMPS) cellular communications standard, was based on analog technology from Bell Labs. But users liked the convenience of carrying a communications device such as a telephone wherever they went, and the number of users grew quickly. Subsequently, second-generation (2G) wireless networks saw the adoption of GSM and CDMA technologies as the first digital standards.

Still, users wanted more functions from their cell phones, so third-generation networks eventually arrived as the first mobile broadband wireless systems. With 3G UMTS technology integrated as the high-speed digital standard, they could send e-mails and data as well as make voice calls,. The fourth-generation (4G) wireless network, equipped with Long Term Evolution (LTE) and LTE Advanced digital technologies, was thought to be the last wireless communications network that anyone would ever need—until the need arose for the fifth generation (5G).

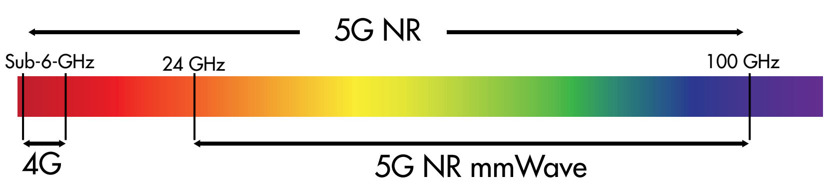
In spite of digital techniques and advanced modulation formats, wireless communications generations 1 through 4 have worked with essentially limited bandwidth, trying to serve a fast growing number of users wanting more services that consume ever-increasing bandwidth.

For example, current 4G LTE wireless network infrastructure equipment in the U.S. operates at 800 MHz, 1900 MHz, 1.7 to 2.1 GHz, and 2.5 to 2.7 GHz. However, it also employs a variety of additional communications technologies, such as wired Ethernet and fiber-optic cables, to transfer data at the highest rates possible. Both fixed and mobile wireless users now expect data rates in excess of 1 Gb/s. With the coming of 5G in approximately two years, data rates are expected to reach 10 Gb/s.

THE MMWAVE BANDWIDTH SOLUTION

Even with the advances of 4G LTE, the network is running out of bandwidth. The solution, as seen by 5G wireless network developers, is to add more bandwidth by using frequency spectrum in the millimeter-wave frequency range *(Fig. 1)*. With hundreds of megahertz of wireless transmission bandwidth available at center frequencies such as 24, 28, and 38 GHz, 5G wireless networks will be capable of almost zero-latency phone calls and extremely high data speeds. Although mmWave frequencies, according to their wavelengths, range from 30 to 300 GHz, 5G innovators such as Qualcomm and other members of the Third Generation Partnership Program (3GPP) working on 5G network solutions typically refer to the mmWave frequency range as starting at about 24 GHz.

People are just one projected part of the many users of 5G networks. Autonomous vehicles will need that 1-ms latency of 5G networks to safely steer through traffic and maintain awareness of the traffic around them by means of vehicle-to-everything (V2X) communications. In addition,



1. The amount of bandwidth available at mmWave frequencies is enormous compared to the amount of frequency spectrum used by 4G and previous wireless network technologies.

potentially billions of Internet of Things (IoT) sensors may be adding their data contributions to 5G networks within the next decade, giving people instant access to information about different things and environments around them. Due to this projected massive bandwidth consumption, developers see mmWave frequencies providing the bandwidth to make 5G possible.

However, there are many reasons why mmWave equipment has remained within astronomy, military, and research applications for so many years, beyond the high cost of the components and the relative scarcity of test equipment for aligning and evaluating the hardware. Electromagnetic (EM) energy at those higher frequencies suffers a great deal of path loss through the air (especially through air with high humidity) compared to lower-frequency signals with longer wavelengths.

2. The infrastructure for 5G wireless networks will employ many more closely spaced base stations than earlier wireless networks, to support the shorter propagation distances of mmWave signals. (Courtesy of Verizon)

Signals at 24 GHz and above can be absorbed by any objects in their propagating path, such as buildings, trees, even the hand of someone holding the smartphone that's sending the mmWave signals to a cell site to connect with a listener. But mmWave frequencies also have benefits, in addition to the generous bandwidths they offer, such as their use of much smaller antennas (to fit those smaller wavelengths) compared to lower frequencies. The small size of these antennas makes it possible to pack many of them together into small form factors to benefit from antenna arrays.

ARCHITECTURALLY SPEAKING…

The architecture of 5G networks will be much different than earlier wireless-network generations, in part because of the use of mmWave frequencies. Smaller antennas will be used in mobile handsets to transmit and receive those higher-frequency signals but, as noted, the propagation distances for mmWave frequencies is less than for signals at the lower frequencies traditionally used in cellular networks.

As a result, 5G network infrastructure must be erected with many more, smaller cell sites or base stations than lower-frequency wireless networks *(Fig. 2)*. In addition, within those smaller cells, many antennas will be used to produce three-dimensional (3D) antenna beams, as part of a process known as beamforming.

It is a technology that has long been in use by the military as part of phased-array radar systems, to create and direct high-energy pulses for reflection from a target. In 5G systems, multiple-element antennas in closely spaced, smaller base stations will use hundreds of antenna elements to form directional beams for transmission and to receive similar 3D beams from adjacent base stations. A user with a mobile handset will have an antenna array with much fewer elements, possibly around 30 within a battery-powered mobile device, to send and receive signals within microwave and mmWave frequency bands.

The actual application of mmWave frequency bands in 5G wireless networks has yet to be determined, although the additional bandwidth they offer is vital to the improved performance promises of 5G networks. The mmWave frequencies, for example, may only be for outdoor use, with indoor cell sites operating at under-6-GHz frequencies and providing indoor and outdoor-to-indoor coverage. The plan for the buildup of 5G New Radio (NR) infrastructure is not to abandon 4G LTE, but to add to the capacity and coverage already provided by 4G LTE networks.

LOOKING AHEAD

Forward-looking companies such as Qualcomm, Skyworks, and Ericsson have been at work on 5G components and subsystems for some time. Qualcomm has worked closely with the 3GPP on developing its 5G NR standard as a means of cost-effectively incorporating mmWave technology into compact 5G base stations and mobile handsets. It will do so using 3D beamforming and multiple-input, multiple-output

(MIMO) antenna techniques.

The company has developed smart, closed-loop algorithms for beam switching, steering, and tracking to maximize the amount of energy transmitted and received between 5G access points at mmWave frequencies. These algorithms look for reflected energy when a mmWave line-of-sight (LOS) signal path is blocked by a building or other obstruction, and combine the signal energy from alternative signal paths into the maximum received signal energy.

In fact, Qualcomm has already successfully demonstrated (November 2015) a 5G system at mmWave frequencies. Along the way, the firm has performed a wide range of simulations and measurements from 22 through 67 GHz, comparing the propagation of the mmWave signals to 2.9 GHz as a lower-frequency reference.

Extensive over-the-air (OTA) testing of prototype 5G NR base station units and mobile devices has been conducted, even within vehicles moving at speeds to 30 mph, and reliable communications at mmWave frequencies were achieved even through the walls of buildings. Qualcomm showed what it calls its 5G NR shared spectrum (SS) approach to managing mmWave signal propagation at the most-recent Mobile World Congress (MWC), using the live demonstration of a prototype circuit board.

The company offers its Snapdragon X50 5G modem as a building block for 5G infrastructure. The modem features an integrated antenna array and RF front end. It's designed for use at 28 GHz, achieving as much as 800 MHz bandwidth through 8 × 100-MHz carrier aggregation. The modem employs the company's adaptive beamforming and beam-tracking techniques as well as MIMO antenna methods to extend the typical LOS range of mmWave frequencies to longer, non-LOS ranges that also support mobile users. Qualcomm recently announced additions to the Snapdragon X50 5G modem family with 5G NR multimode chipsets compliant with the 3GPP 5G NR standard. They also support operation at frequencies below 6 GHz for compatibility with 4G LTE networks as well as earlier 2G and 3G systems. The first commercial products with Snapdragon X50 5G modems are expected in 2019.

In providing components for the expected rapid buildup of 5G infrastructure during the next several years, Skyworks Solutions (www.skyworksinc.com) offers circuits at the RF front end. It has announced its Sky5 product family for 5G networks. The line includes the highly integrated SKY78250 5G NR power-amplifier (PA) module with integrated filtering and dual-path low-noise amplifier (LNA).

For its part in the 5G NR planning, Ericsson (www.ericsson.com) has paid a great deal of attention to concerns about the security of 5G wireless networks. The company now offers a downloadable white paper on its website, "5G Security—Enabling a Trustworthy 5G System," which explains the steps being taken as part of the initial 5G NR 3GPP standard to protect the privacy of future 5G users.

Advances in semiconductor and integrated-circuit (IC) technologies will play major roles in the development of affordable integrated and modular circuit solutions for 5G base stations and mobile devices, especially with the complexity of mmWave antennas and radio circuits. Components for mmWave frequencies, both active and passive, have traditionally been expensive—even the coaxial connectors (depending upon frequency) for hybrid circuits were precision machined and expensive. But the imminent buildup of 5G networks and its expanding contingent of mobile devices has brought a new awareness to the high-frequency industry concerning the need for more cost-effective components, circuit materials, and test instruments for frequencies above 24 GHz.

Moroever, major instrument manufacturers are addressing the coming needs for test equipment that can evaluate 5G systems and their components, at both mmWave frequencies and below 6 GHz. Anritsu Corp., for example, recently announced the expected launch of its MT8000S Radio Communication Test Station for developing chipsets and terminals for 5G wireless networks. The tester has built-in support for the broadband signal processing and beamforming technologies used in 5G in a compact desktop configuration. It will be capable of RF and protocol tests at mmWave frequencies and at 6 GHz and below.

In addition, Keysight Technologies has issued a memorandum of understanding to develop test equipment for 5G NR standards. On the computer simulation side, high-frequency model master Modelithics recently released a new mmWave and 5G library of devices for the popular Advanced Design System (ADS) suite of software circuit and system simulation programs from Keysight. 5G system simulations have also been performed on specialized modeling tools, such as MATLAB from MathWorks.

With this first 5G NR standard as embraced by the 3GPP, it's apparent that development is accelerating for 5G wireless communications networks, with plans to provide sufficient bandwidth to support mobile users as well as cars, IoT devices, and even unmanned drones. The enormous number of devices to be connected by means of 5G wireless network technology may even make that additional bandwidth seem like it's not enough before long. But this initial use of mmWave frequency bands for commercial communications will provide generous frequency spectra through 60 GHz and above, as the high-frequency industry seeks to learn how to cost-effectively produce mmWave components and possibly even test equipment and software in large volumes for the first time.