5G WIRELESS CONNECTIVITY: THE NEXT STEP

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I. INTRODUCTION

Wireless communication technology is about to enter a new era: 5G networks. "5G" stands for "fifth generation," the next step up from the currently mainstream 4G networks.[1] From 2014 levels, mobile traffic is expected to increase by 1000 times by 2024.[2] The next generation of wireless network, known as the 5G network, must be able to support this massive increase.[3] This paper will define 5G networks, explain the technologies that underly its creation and feasibility, and explore the network's potential applications.

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[1] *What is 5G?*, VERIZON, https://www.verizon.com/about/our-company/5g/what-5g (Oct. 27, 2019) [https://perma.cc/7BBH-SAL3].

[2] Qian Clara Li et al., *5G Network Capacity: Key Elements and Technologies*, IEEE VEHICULAR TECH. MAG. 71 (2014), https://ieeexplore.ieee.org/document/6730679 [https://perma.cc/XX2N-3VZ7].

[3] *Id.*

II. 5G DEFINED

The 5G network is the fifth generation of wireless technology. The first generation, capable of transmitting wireless phone calls, emerged with the invention of cell phones.[4] The second generation paved the way for text messaging and voicemails.[5] 3G brought web browsing to mobile devices, and 4G brought deep web functionality to those devices.[6]

Many people are familiar with the term "4G LTE." LTE stands for "long term evolution," an industry standard for 4G wireless technology that allowed for greater speed on 4G networks over its 3G predecessor.[7] The equivalent of LTE for 5G wireless networks is "NR," or "new radio," a standard that allows for 5G technology to scale as needed.[8] Think of the jump from 4G LTE to 5G NR as analogous to the jump from Blu-ray to Netflix; "it's the way it is built rather than just the speed that makes it different."[9] The 3rd Generation Partnership Project (3GPP), a group of telecom organizations that create standards for wireless technology, set the 4G LTE and 5G NR standards.[10]

Wireless networks connect devices by utilizing a spectrum of radio frequency waves transmitted through the air to send and receive messages.[11] As smart phones and tablets have risen in popularity, existing cellular networks are expected to have a capacity shortage in the coming years.[12] In order to fight this shortage, 5G networks seek to expand the frequency spectrum that devices use to communicate.[13] Millimeter wave technology

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[4] *What is 5G?*, *supra* note 1.
[5] *Id.*
[6] *Id.*
[7] *In re Qualcomm Antitrust Litigation*, 292 F. Supp. 3d 948, 955 (N.D. Ca. 2017).
[8] Simon Rockman, *Why 5G Isn't Just Faster 4G*, FORBES (May 25, 2019, 5:12 PM), https://www.forbes.com/sites/simonrockman1/2019/05/25/why-5g-isnt-just-faster-4g/#361e45f143a6 [https://perma.cc/P54Y-4YE5].
[9] *Id.*
[10] *About 3GPP Home*, 3GPP, https://www.3gpp.org/about-3gpp/about-3gpp (accessed Oct. 27, 2019) [https://perma.cc/2SB2-F7GP].
[11] Maruerite Reardon, *Wireless Spectrum: What It Is, and Why You Should Care*, CNET (Aug. 13, 2012, 12:01 AM), https://www.cnet.com/g00/news/wireless-spectrum-what-it-is-and-why-you-should-care/?i10c.ua=4&i10c.encReferrer=aHR0cHM6Ly9wZXJtYS5jYy9ZWjJXLU02UVA%3d [https://perma.cc/YZ2W-M6QP].
[12] Kei Sakaguichi et al., *Millimeter-Wave Evolution for 5G Cellular Networks*, E98-B IEICE TRANSACTIONS ON COMM. 388 (2015), http://home.deib.polimi.it/capone/papers/IEICE2015.pdf [https://perma.cc/5T7K-Y2MH].
[13] *Id.*

utilizes previously unused radio frequencies to transmit wireless signals.[14] Previous generations of wireless networks used frequencies below 6 GHz, whereas millimeter waves broadcast between 30 and 300 GHz, meaning that 5G networks use waves that are much smaller compared to their 4G predecessors.[15] By using previously untapped frequencies, 5G networks lower the traffic on the old networks, as well as open the door for low-traffic communications on the new networks. Millimeter waves have several other advantages as well. For example, millimeter waves reduce interference between neighboring connections.[16] Additionally, utilizing millimeter waves could improve energy efficiency in wireless networks.[17] Millimeter waves, however, have a glaring flaw; they can only travel short distances and are highly susceptible to interference from weather and physical obstacles.[18]

5G aims to not only improve network speeds and capacity, but also to improve spectrum efficiency. Spectrum efficiency measures how effectively the wireless frequency system is utilized, measured in bits per second per Hertz.[19] Essentially, spectrum efficiency is transferring as much information as possible while utilizing the minimum amount of the spectrum necessary to do so.[20] By using less of the spectrum to send the same amount of information, spectrum efficiency frees up space on the network to send more information. Thus, 5G networks will be able to better support the large number of wireless devices projected to come into the market in the coming years.

III. 5G ENABLING TECHNOLOGIES

5G is often referred to as a single technology, but in reality, it is an amalgam of several different technologies which comprise the network. Some of those technologies are small cells, Massive MIMO, beamforming, and Full Duplex.[21]

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[14] Amy Nordrum et al., *Everything You Need to Know About 5G*, IEEE SPECTRUM (Jan. 27, 2017, 7:00 PM), https://spectrum.ieee.org/video/telecom/wireless/everything-you-need-to-know-about-5g [https://perma.cc/KS6Z-3Q7A].

[15] Broadband Div, Fed. Comm. Comm'n, *Millimeter Wave 70/80/90 GHz Service*, FCC.GOV, https://www.fcc.gov/wireless/bureau-divisions/broadband-division/microwave-services/millimeter-wave-708090-ghz-service [https://perma.cc/B4S6-T7YS].

[16] Sakaguchi et al., *supra* note 12.

[17] *Id.*

[18] Margaret Rouse, *5G*, SEARCHNETWORKING, https://searchnetworking.techtarget.com/definition/5G (accessed Oct. 20, 2019) [https://perma.cc/M2LP-QNJQ].

[19] Hong et al., *Cognitive Radio in 5G: A Perspective on Energy-Spectral Efficiency Trade-off*, 52 IEEE COMM. MAG. 46, 48 (July 2014), https://ieeexplore.ieee.org/document/6852082 [https://perma.cc/5B86-3TX5].

[20] FED. COMM. COMM'N, SPECTRUM POLICY TASK FORCE: REPORT OF THE SPECTRUM EFFICIENCY WORKING GROUP 5 (2002).

[21] Nordrum et al., *supra* note 14.

A. Small Cells

Small cells are 5G wireless signal base stations that are placed around an area in large numbers.[22] Small cells are necessary to make millimeter waves technology viable, as they can be more easily placed in a wide range of places around cities than traditional cell towers.[23] This solves two issues posed by utilizing millimeter waves. First, by having a greater number of access points, devices are less likely to experience interference from weather and physical objects. Second, it increases the network's efficiency by allowing the spectrum to be reused in the various cells.[24] However, the large number of small cells needed and the short distances between them pose two new problems: first, that it will be difficult to set up 5G networks in rural areas, and second, that it will require a significantly larger amount of antennas at base stations than current networks use.

B. Massive MIMO

Massive multiple-input, multiple-output (Massive MIMO) is central to the evolution of 5G networks due to its ability to boost spectral efficiency.[25] MIMO technology allows a network to transmit and receive multiple data signals over a singular frequency, thus multiplying the capacity of the network without having to expand the frequency band.[26] Put more simply, "If spectrum is a highway, then MIMO doesn't just add more lanes; it adds levels, creating multiple-decker highways that vastly increase the capacity of the network."[27] Current 4G base stations already implement MIMO technology, but they only have about twelve ports for antennas, whereas 5G base stations with massive MIMO can support a hundred ports.[28] Thus, implementing massive MIMO

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[22] CHRIS D. LINEBAUGH, CONG. RESEARCH SERV., LSB10265, OVERVIEW OF LEGAL CHALLENGES TO THE FCC'S 5G ORDER ON SMALL CELL SITING (Feb. 25, 2019), https://crsreports.congress.gov/product/pdf/LSB/LSB10265 [https://perma.cc/H2C9-4NGT].
[23] *Id*.
[24] Theodore S. Rappaport et al., *Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless Networks—With a Focus on Propagation Models*, 65 IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION 6213, 6214–15 (2017), https://ieeexplore.ieee.org/document/7999294 [https://perma.cc/D2BL-UGK6].
[25] Xiaochen Xia et al., *A 5G-Enabling Technology: Benefits, Feasibility, and Limitations of In-Band Full-Duplex mMIMO*, IEEE VEHICULAR TECH. MAG. 81, 82 (Sept. 2018), https://ieeexplore.ieee.org/abstract/document/8396262 [https://perma.cc/FU6A-3U2U].
[26] Jon Mundy & Kevin Thomas, *What is Massive MIMO Technology?* 5G.CO.UK, https://5g.co.uk/guides/what-is-massive-mimo-technology (accessed Nov. 18, 2019) [https://perma.cc/9NAZ-MWAB].
[27] *A Closer Look at Massive MIMO*, SPRINT BUS. (Nov. 7, 2018), https://business.sprint.com/blog/massive-mimo/ [https://perma.cc/AD5X-K9KM].
[28] Xia et al., *supra* note 25.

over MIMO in 5G base stations causes considerable gains in network efficiency by lowering the workload of each antenna. Unfortunately, however, the massive number of antennas in close proximity can cause significant interference in the network when the signals crash into one another.[29]

C. Beamforming

Beamforming is a traffic-signaling system that reduces the interference inherent in Massive MIMO base stations.[30] Essentially, beamforming shapes a radio frequency signal in order to send that signal along the most efficient pathway to the wireless device.[31] This allows for the network to control interference and more equitably allocate network resources by shaping the signal around objects and other signals.[32] Due to the signal crashing that occurs with massive MIMO, beamforming is necessary to make sure the signals are shaped in such a way that they do not interfere with one another. Beamforming also assists millimeter waves in avoiding signal-blocking obstacles that normally interfere with smaller radio waves.[33]

D. Full Duplex

Full Duplex is another technology used to increase efficiency on 5G networks. Current wireless networks require base stations and phones to take turns transmitting and receiving on the network.[34] Full Duplex allows transceivers on base stations and cell phones to simultaneously transmit and receive data on the same frequency.[35] It does so by utilizing silicon transistors which can act as switches on the frequency, temporarily rerouting signals to avoid a crash between two signals traveling on the same frequency.[36] Thus, Full Duplex technology can theoretically double the capacity of wireless networks.

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[29] Nordrum et al., *supra* note 14.
[30] *Id.*
[31] *Id.*
[32] Faezeh Alavi et al., *Beamforming Techniques for Nonorthogonal Multiple Access in 5G Cellular Networks*, 67 IEEE TRANSACTIONS ON VEHICULAR TECH. 9474 (2018), https://ieeexplore.ieee.org/document/8411153 [https://perma.cc/WW7C-Q4ZS].
[33] *Id.*
[34] Xia et al., *supra* note 25.
[35] Nordrum et al., *supra* note 14.
[36] Amy Nordrum et al., *5G Bytes: Full Duplex Explained*, IEEE SPECTRUM (Apr. 1, 2017 2:21 PM), https://spectrum.ieee.org/video/telecom/wireless/5g-bytes-full-duplex-explained [https://perma.cc/WWF6-7L36].

IV. BENEFITS OF 5G

5G NR technology boasts increased data transfer speeds, increased capacity, and decreased latency over its 4G LTE predecessor.[37] This means more devices will be able to download more information at greater speeds, with less lag time. According to Samsung, 5G will be around 100 times faster than current 4G networks,[38] and others claim that some parts of the 5G network will support up to a million devices per square kilometer.[39]

Low latency is a key improvement of 5G networks that could enable applications that were impossible over 4G networks. Latency is the time it takes for data to be sent from a device until it reaches a receiver.[40] This is distinct from network speed, which is the amount of information that can be transmitted in a certain amount of time.[41] Part of the reason that 5G networks will be able to handle all these new technologies is a feature called network slicing.[42] Network slicing allows operators to create multiple networks embedded within the larger network, tailoring each device's connection to meet its specific needs.[43] For example, an autonomous vehicle may need a faster connection than a smart light bulb; network slicing can allocate the car a faster connection than the bulb.[44] This optimizes the network by making sure that the lower-usage devices are not eating up the bandwidth required to run higher-usage devices.

V. APPLICATIONS OF 5G

Some technologies that were initially developed for 4G networks were not viable for the mass market because of 4G's drawbacks. 5G networks' high speed, high capacity, and low latency characteristics allow it to improve technologies such as remote healthcare, autonomous vehicles, virtual reality, and the Internet of Things.[45]

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[37] Rouse, *supra* note 18.
[38] *How Fast Is 5G?* SAMSUNG, https://www.samsung.com/global/galaxy/what-is/5g-speeds/ [https://perma.cc/8FTG-T685].
[39] Rockman, *supra* note 8.
[40] *Id.*
[41] *Id.*
[42] Rouse, *supra* note 18.
[43] *Id.*
[44] *Id.*
[45] Nordrum et al., *supra* note 14.

The reliable, low latency connections provided by 5G networks will help improve technology in industries such as healthcare services.[46] Two applications for 5G networks in healthcare are bio-connectivity and remote robotic surgery.[47] Bio-connectivity allows for the decentralization of hospitals so that medical care can be provided in a patient's home or in an emergency vehicle by providing access to electronic medical records, data analysis for predictive healthcare, and pharmaceutical analysis.[48] 5G networks in this context can allow the information to travel more quickly and efficiently, potentially saving lives. Remote interventions allow for complex medical interventions and surgeries using special equipment over an internet connection.[49] This can help doctors provide these services to people in areas where healthcare is less accessible.[50]

Autonomous vehicles are another use case for 5G networks. Many of the devices necessary for operating an autonomous vehicle require low latency and high reliability.[51] A low latency 5G network is required to ensure minimal communication times between the sensors and the car's computer to be as low as possible, which can allow the car to react quickly to dangerous situations.[52] Additionally, autonomous vehicles must transfer an extremely large amount of data, which requires faster speeds than 4G networks.[53]

5G networks also will help push media and entertainment technology forward. Recent trends in the entertainment industry have caused users to demand a more immersive experience.[54] 5G can allow for higher quality live and streamed content, offer live audiences an enhanced experience, and allow for faster information sharing within media production.[55] The gaming industry, in particular, could benefit from a 5G network. Virtual and Augmented Reality (VR and AR, respectively) is a growing trend in the gaming industry designed to enhance immersive experience.[56] VR allows

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[46] Abdul Ahad et al., *5G-Based Smart Healthcare Network: Architecture, Taxonomy, Challenges and Future Research Directions*, 7 IEEE ACCESS 100747, 100752–53 (2019), https://ieeexplore.ieee.org/document/8769822 [https://perma.cc/V4PU-G665].

[47] Maria A. Lema et al., *Business Case and Technology Analysis for 5G Low Latency Applications*, 5 IEEE ACCESS 5917, 5919 (2017), https://arxiv.org/pdf/1703.09434.pdf [https://perma.cc/TN22-V8J8].

[48] *Id.*

[49] *Id.*

[50] *Id.*

[51] *Id.* at 5920.

[52] Ralf Llanasas, *5G's Important Role in Autonomous Car Technology*, MACHINEDESIGN (Mar. 11, 2019), https://www.machinedesign.com/motion-control/5g-s-important-role-autonomous-car-technology [https://perma.cc/QC78-YYLZ].

[53] *Id.*

[54] Lema, *supra* note 47, at 5920.

[55] *Id.*

[56] *Id.*

users to enter a virtual world, whereas AR adds virtual elements to the real world.[57] Low latency is fundamentally necessary for VR and AR technologies to provide a truly immerse experience.[58] VR gaming is also demanding from a capacity standpoint,[59] and 5G increased bandwidth makes it more suitable for such applications.

5G networks can also help improve the capabilities of the Internet of Things. The Internet of Things is a network infrastructure that configures itself using standard communication protocols between devices, allowing for greater compatibility of connections across devices.[60] The information stream allows for easier automation for everyday tasks.[61] For example, a connected alarm clock could check the traffic report before a morning commute, adjust the alarm accordingly, and also adjust the connected coffee maker's timing.[62] The Internet of Things could also be useful in the a manufacturing context, where the connectivity of sensors and robots could lead to improvements in factory or warehouse maintenance.[63] This network requires a large number of network-connected devices, and 5G has the capacity to support significantly more devices than its predecessor 4G LTE networks.[64] Latency in 4G LTE networks have also limited Internet of Things technologies in the past, and 5G's low latency can help push past those limitations.[65]

VI. CONCLUSION

4G LTE changed the way we live our everyday lives. It allowed us to access a previously untapped wealth of information, all from devices small enough to fit in our pocket. 5G wireless networks are the next step in that evolution. It is unclear at this early stage exactly how it will change our lives, but there is little doubt that these new technologies will have a profound impact on our history.

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[57] ßBrian Cooley, *AR and VR made simple*, CNET (Aug. 6, 2018, 5:00 AM), https://www.cnet.com/how-to/ar-and-vr-made-simple/ [https://perma.cc/ZA2Z-MFZE].
[58] Lema, *supra* note 47, at 5920–21.
[59] *Id.* at 5921
[60] Ahad, *supra* note 46, at 100748.
[61] *Id.*
[62] *Id.*
[63] Hatem Zeine, *What the Future of IoT and 5G May Look Like*, FORBES (Nov. 1, 2018, 7:45 AM), https://www.forbes.com/sites/forbestechcouncil/2018/11/01/what-the-future-of-iot-and-5g-may-look-like/#6cb33251629b [https://perma.cc/8HCJ-9H3C].
[64] Nicholas Shields, *Here's How 5G Will Revolutionize the Internet of Things*, BUS. INSIDER (June 15, 2017, 10:15 AM), https://www.businessinsider.com/how-5g-will-revolutionize-the-internet-of-things-2017-6 [https://perma.cc/KF6Q-K9YG].
[65] *Id.*