TECHNICAL NOTE

The 5G Wave

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ABSTRACT

Reliable access to the Internet through a mobile high-speed wireless communications network is an achievement of modern engineering that has changed how people communicate. The advent of a mobile, Internet-enabled economy has created new business models and touched all segments of the business world. Many predict that the deployment of 5G will result in a new wave of changes as the communications backbone for what is referred to as the fourth industrial revolution. This article provides a high-level overview of how 5G relates to previous technologies and the key technical features of 5G that support new applications within different industries. In addition, this article provides insights into the use of advanced antenna techniques, millimeter Wave (mmWave) frequencies, and the security of 5G.

Keywords: 5G, mobile communications, mmWave, IoT

Introduction

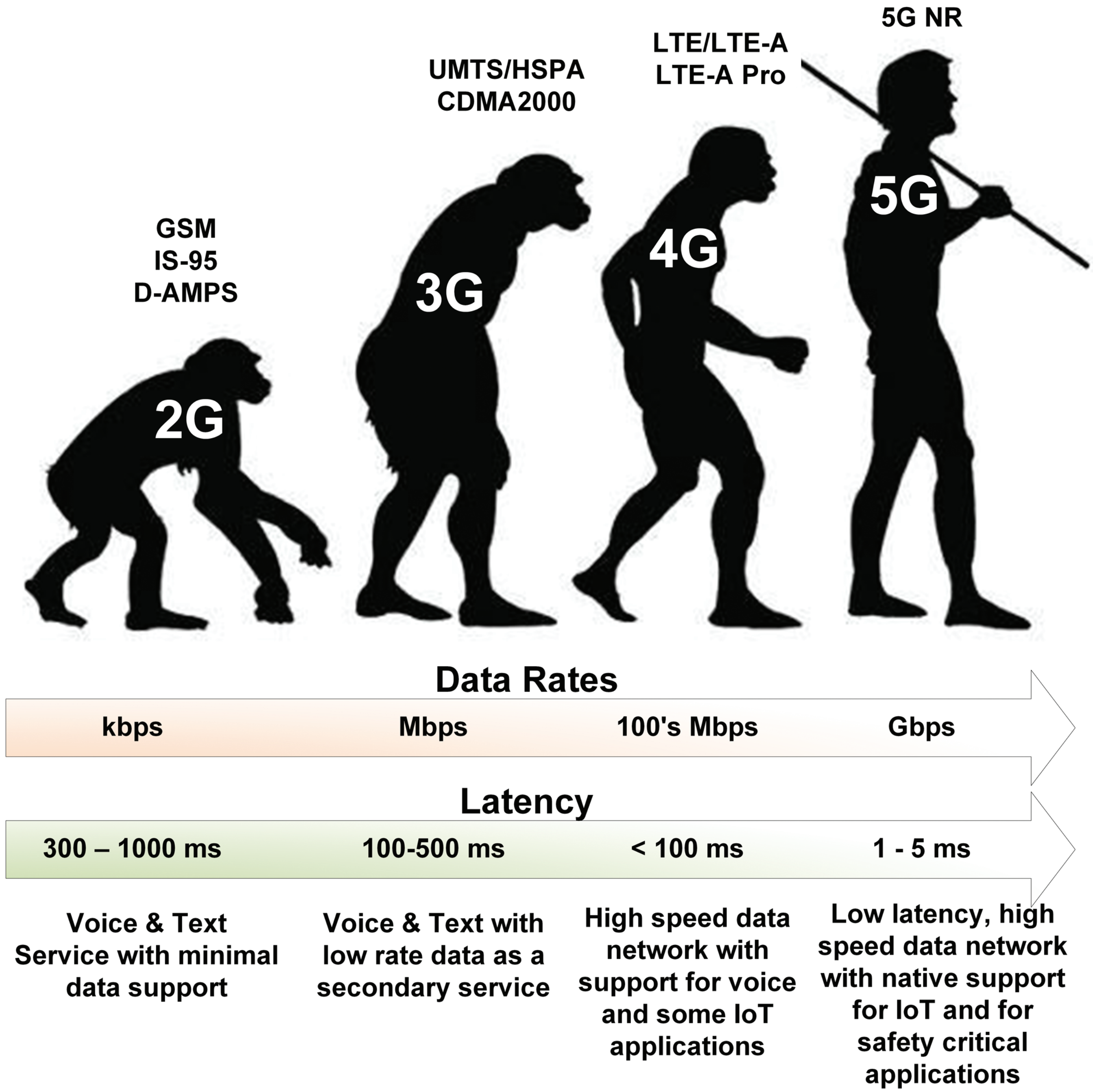
Reliable access to the Internet through a mobile high-speed wireless communications network is an achievement of modern engineering that has changed how people communicate. The advent of a mobile, Internet-enabled economy has created new business models and touched all segments of the business world. Many predict that the deployment of 5G will result in a new wave of changes as the communications backbone for what is referred to as the fourth industrial revolution (cf. Marr, 2018). This wave of changes where the Internet of Things (IoT), virtual reality, artificial intelligence, and other leading-edge technologies work concurrently to increase automation and efficiency has the potential to revolutionize current industries. Maritime ports will be one of the early adopters as they utilize 5G-enabled technologies to improve the efficiency of operations. Indeed, one of major 5G European test sites (cf. Blackman, 2019; Seals, 2017) is located at the Port of Hamburg in Germany. As a communication backbone for the port, the 5G test bed enabled real-time monitoring and active control of traffic flow to improve the movement of people, ships, and goods through the port. New augmented reality applications utilized the 5G network to speed up construction projects and improve maintenance operations. While these are impressive demonstrations, these examples are just the beginning as many new potential applications of 5G for maritime operations are still being imagined. This article provides a high-level overview of how 5G relates to previous technologies and the key technical features of 5G that support new applications within different industries. In addition, this article provides insights into the use of advanced antenna techniques, millimeter Wave (mmWave) frequencies, and the security of 5G.

Generations—How Did We Get Here?

The cellular industry usually markets new technology as providing a faster network in order to differentiate performance for consumers. This reflects the improvements in data speeds and latency that have occurred as new technologies are introduced. While the term *faster* is easy to measure and describe, focusing only on data speed and latency fails to fully capture the changes in network capabilities over time. The term *generation* does a better job of reflecting the evolutionary shifts in capabilities that have occurred when new cellular technologies deploy. This term originated in the late 1990s after the success of GSM (Global System for Mobile) in Europe and IS-95 and digital AMPS in North America. Unlike earlier analog mobile phone systems, these technologies were digital and therefore considered to be a second generation (2G) technology. These 2G technologies were focused on providing better voice and text service over a wider coverage area than the analog systems they replaced. While digital data was possible in 2G, the rates supported were relatively low. As the generations progressed from 2G to 3G to 4G, each generation increased the data rate and decreased the latency, as can be seen in Figure 1. The more significant change over the generations has been the evolution from a voice and text network with some data to today's 4G network

FIGURE 1

Evolution of cellular technology to 5G.

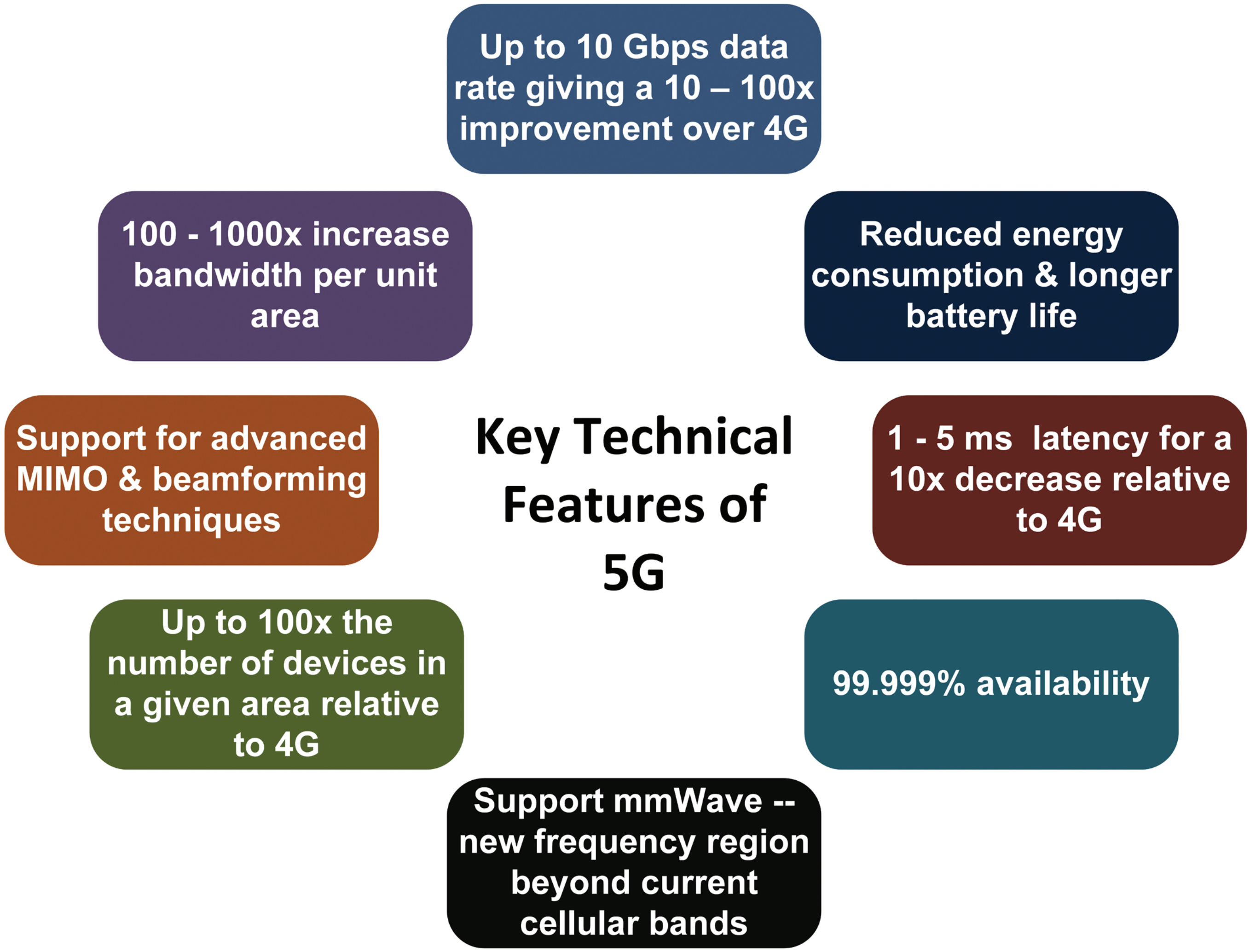


where all traffic, including voice, is treated as packet data.

Naturally, 5G continues cellular evolution by increasing the data rate and reducing the network latency. As Figure 2 shows, 5G can provide from ten to a hundred-fold increase in data speeds and a factor of ten reduction in latency relative to 4G. More significantly, 5G evolves the data network to provide support for a higher density of devices with longer battery life in order to better support IoT applications. Through a combination of technical features, 5G also provides support for safety-critical applications. These safety-critical applications include the remote control of vehicles in a smart transportation network, precision control of

FIGURE 2

Key technical features of 5G compared to 4G.



instruments for remote repair operations, and a communications platform for real-time 3-D monitoring applications. The ability of 5G to aggregate information from many sensors and then provide a network capable of controlling safety-critical applications is essential for other emerging technologies to sense the environment and react in real time. This combination has the potential to revolutionize many aspects of manufacturing, control and optimize traffic flow, and manage energy use not only for maritime port areas but also in many industries.

When Will 5G Arrive?

The mobile industry has not been shy about advertising their current deployments of 5G, and the effort has been effective with consumers. An informal survey (Sherr, 2019) shows that many people believe their current phone is 5G capable and they have seen an improvement in their service due to 5G. The reality is different. There are few devices available today that are truly 5G capable, and 5G coverage, while expanding, is still confined to select areas within a few cities. Moreover, 5G is still in its infancy both as a standard and as a well-defined interoperable technology. Early versions of the specifications have been completed, but key portions of the actual technical specifications won't be completed until 2020 (Bertenyi, 2019). While the current hype over early 5G deployments may be misleading some consumers today, a more mature and more widely deployed 5G is not far in the future. One prediction has over 20% of mobile subscriptions in the world on 5G-capable connections by 2024 (Ericsson, 2019). While 4G will remain the dominant technology in use throughout the world over that time period, it is expected that North America, Western Europe, and Northeast Asia will all have nearly half of their mobile subscriptions on 5G by 2024.

Advanced Multiple-Input Multiple-Output and Beamforming

Even with an increasingly crowded signal environment, each generation of cellular technology has provided higher data rates and supported more users. Signal processing techniques that utilize multiple antennas, higher order modulations, and compression and coding techniques have allowed the radios of each generation to push more data through the available spectrum. 5G continues this trend and, as indicated in Figure 2, supports advanced antenna technologies like advanced multiple-input multiple-output (MIMO) and beamforming. While both MIMO and beamforming are part of 4G, 5G provides better support for these advanced techniques. MIMO uses multiple antenna elements on both transmit and receive to layer multiple signals on the same frequency band using the spatial diversity created by the antennas and the wireless channel to separate the signals at the receiver. The term *massive MIMO* is used when the number of antenna elements greatly exceeds the number of signal layers. These additional elements allow the system designer more degrees of freedom to minimize interference and reduce other degradations. This improves the spectral efficiency (i.e., more bits per hertz), which in turn helps 5G achieve higher data rates. While an in-depth discussion of these technologies is beyond the scope of this article, there are numerous technical articles on 3-D beamforming (cf. Cheng et al., 2014) and massive MIMO (cf. Larsson et al., 2014) that provide a good introduction to these techniques.

Frequency Bands and Bandwidth

Early in the development of 5G, it was recognized that, even with the spectral efficiency improvements available from signal processing techniques, there would not be enough capacity in the existing cellular frequency regions to support the goals of 5G, and that 5G would need a 100× to 1,000× increase in bandwidth available for a given area of service. To achieve this goal, 5G was designed to operate across more frequency regions than earlier generations. The frequencies planned for 5G include the traditional cellular bands below 3 GHz where the majority of 2G, 3G, and 4G systems operate, the emerging bands in the 3- to 7-GHz range, and open for the first time the usage of what is referred to as the mmWave frequencies. The mmWave and near-mmWave bands currently intended for cellular use are in the 20- to 60-GHz range. The mmWave bands are lightly used and offer tremendous bandwidths with individual channel sizes that are 20 times larger than the largest nonaggregated 4G channels. Aggregating multiple frequency channels together allows 5G to achieve the needed increase in bandwidths.

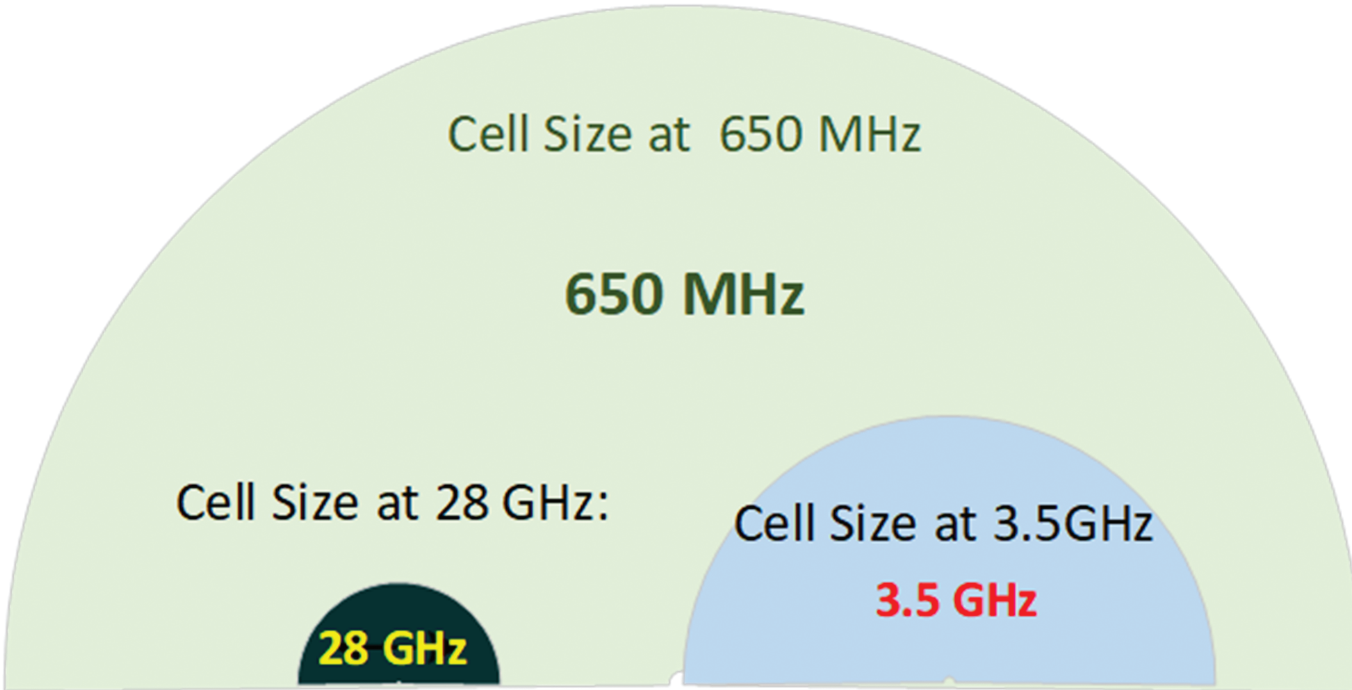
The challenge with using mmWave frequencies for cellular technology is that these frequencies have poor propagation characteristics compared to traditional bands. This leads to much smaller coverage areas and requires a significant increase in the density of cell sites. To illustrate this, Figure 3 shows relative cell sizes for 650 MHz, 3.5 GHz, and 28 GHz using the same transmit power and antenna size. The range of system was estimated based on the ITU's free space propagation model (ITU-R, 2012) and is assumed to be line of sight only. For this idealized comparison, a 28-GHz system would require 45 cells to cover the same region as a cell at 650 MHz. While significant work has gone into improving performance at mmWave frequencies and early testing has shown better range than initially feared, the range achieved by mmWave will always be limited by the physics of radio propagation. As a result, most carriers are planning to use mmWave for very high rates and short-range hot spots while simultaneously using the traditional frequencies below 7 GHz to provide the wider range coverage necessary for true mobility.

Security

As cellular devices are now an integral part of financial and commercial transactions, the security of the cellular network is essential for public acceptance. Each generation has strengthened the security features and addressed identified weaknesses. Because 5G will serve as a backbone for critical automation functions like port and factory operations, security is of even more importance and 5G made several key changes that enhance the security for user data and identity. As a result, the 5G system is robust and will provide state-of-the-art data and identity security.

FIGURE 3

Relative cell sizes for three frequency ranges planned for 5G usage.



Nonetheless, 5G has become a political issue because of security. The political and national security concerns do not arise out of a weakness in the 5G standard itself but rather out of a concern for vulnerabilities that lie outside the standard. The primary concerns are that equipment makers may either intentionally or accidently have an external weakness in their equipment that allows someone other than the network owner to access the data or disable the network for hostile reasons. Developing confidence in the security of the supply chain is a challenging problem because the cellular industry is both large and diverse in the nationalities of the companies involved. This global nature of the network and the providers is a twist to security that is difficult to address. Several efforts are currently under way to study how networks can test and detect vulnerabilities, take automatic and active measures to prevent malicious activity, and design their networks to be robust against any such threats.

Conclusions

The coming wave of 5G cellular deployments will establish a wireless communications system with higher data rates, reduced latency, support for IoT devices, and an ability to provide communications for safety-critical systems. As such, 5G will form a powerful communications infrastructure that, when combined with other emerging smart technologies like machine learning, will enable a new wave of automation. While many of the uses for 5G are yet to be developed, early tests are demonstrating the potential of 5G to enhance maritime port operations. The test bed at the Port of Hamburg has shown that 5G can provide ports with an ability to track cargo, monitor and control traffic flow, and augment repair and construction activities. While the technology is still maturing and there are still important technical challenges, today's early deployments are creating a pathway for a future 5G network that will change and shape many industries in the future.

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