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Implications and Considerations of 5th Generation Mobile Networks (5G) for the US Department of Defense

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Fifth generation (5G) mobile communications began with switchboard operators (0G). Then, in the 1980s, Long Term Evolution (LTE) originated with the first generation of cellular (1G), introducing the world to mobile voice calling capability, but it was still analog and the race was on to miniaturize clunky devices. In the 1990s, 2G combined digital technology to produce text messaging, but the fears about band width constraints were already a concern. In 2001, the mobile phone—with video, data, and voice—defined 3G. It was fast enough (14Kb/s-16Kb/s) for web browsing, but mobile applications (apps) were limited by bandwidth (3-6 GHz) constraints. The growth of bandwidth-intensive applications drove development of the fourth generation of mobile telecommunications (4G). 4G provides mobile data speeds fast enough for digital voice and video. As the number of devices continues to increase dramatically, standards bodies and commercial providers are now working on the next generation of mobile communications—5G.

Similarly, computing is coming upon its fifth generation.[1] Computing went from mainframes (1G), to PCs (2G), to internet-connected computers (3G), to mobile and cloud (4G). The fifth generation will be composed of ubiquitous computing, huge volumes of data, and connectivity made possible by 5G mobility. The coming 5G mobile telecommunications will enable a larger variety of use cases than ever before, while providing significant improvements in data transfer speeds.

4G/5G Comparison

Key Measurement	4G (IMT-Advanced)	5G (IMT-2020)
Peak data rate (downlink)	1Gbps	20Gbps
User-experienced data rate	10Mbps	100Mbps
Latency	10ms	1ms*
Mobility	350km/h	500km/h
Connection density	100,000 devices/sq km	1,000,000 devices/sq km
Energy efficiency	1x	100x
Spectrum efficiency	1x	3x
Area traffic capacity	0.1Mbps/sq m	10Mbps/sq m

Source: Zdnet.com (https://www.zdnet.com/article/5g-a-transformation-in-progress/)

Early Telecommunications

While 5G mobility promises a huge advance in mobile technology, in reality, 5G represents a number of separate but interrelated advances that provide new capabilities to further the progress made in increasing network speeds.[2] 5G will enable vast increases in the number and types of connected devices (both low and high power) and new types of networks with varying requirements (e.g., vehicle-to-vehicle networks, virtual reality over mobile, and mobile industrial automation networks). But 5G also enables new exploitation scenarios from adversaries leveraging the Internet of Things (IoT).

The United States (U.S.) was a dominant voice in the development of 4G. However, the terrorist event of September 11, 2001, shifted U.S. focus away from mobile communications to global events. The current epicenter of 5G development lies outside the U.S. Our adversaries have taken the lead in development and have captured much of the 5G component market.

The Two Sides of 5G—New Radio and 5G Core

5G can be broken down into two primary sets of technologies: New Radio (NR) and the 5G Core. NR brings advances in latency reduction and increased throughput between mobile devices and base stations. 5G Core technology advances are on the wired side of the base station that connect the wireless networks to the data centers (for edge computing) and the internet. While most of the attention has been on NR, 5G Core technologies are just as important in making possible critical communications like ultra-low latency and high reliability use cases. 5G Core is also where many of the subtle changes will occur, shifting computational paradigms (e.g., increased use of edge computing) that will impact the Department of Defense (DoD).

NR Technologies

Five key technologies underpinning 5G NR are millimeter wave spectrum, small cells, massive multiple input multiple output (massive MIMO) base station antennae, beamforming, and full duplex communications.[3]

While 5G will be backward-compatible and allow for refarming (repurposing) of 4G frequency bands to 5G uses, 5G will have the ability to also use frequencies at the top of radio spectrum.[4] These high frequencies are referred to as the *millimeter wave spectrum*. Higher frequencies have shorter wavelengths, which are able to carry much more data. But higher frequencies attenuate (fade) very rapidly. Some of the highest 5G frequencies—those offering the highest data speeds—attenuate at only a few hundred meters rather than several kilometers of the lower (longer wavelength) 4G frequencies.[5] This implies that base stations leveraging the highest frequencies of 5G are likely to be in urban or specialized rural (e.g., factory, military, farm) locations. Additionally, higher frequencies do not go through walls and attenuate in rain, so even in urban environments, these frequencies require rethinking how cellular services are deployed.

One of the ways to address both the significant attenuation of millimeter wave frequencies and the anticipated increase in connected devices is to increase the number of cellular base stations. These are likely to take the form of small cell technology (e.g., femtocells, picocells, microcells). Small cells are "low-powered radio access nodes that … can work in either licensed or unlicensed spectrum, and have a range between 10 meters and two kilometers."[6] Small cells connect to the rest of the cellular network either through wireless or physical (e.g., fiber optic) backhaul. The ever-increasing number of cells allows for more devices to connect in a given area and simultaneously allows for spectrum to be reused many times over, as the same spectrum can be used within other cells. However, these small cells require additional capital investment and are unlikely to be as necessary in rural or remote areas.

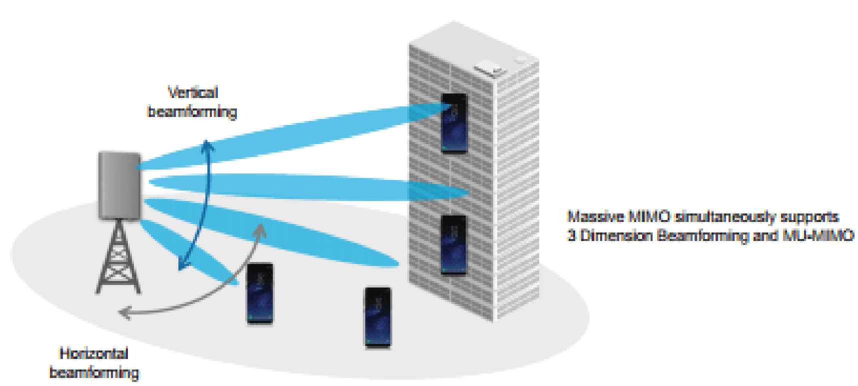
To accommodate the increase in new devices, additional antennae must be installed on each base station. Massive MIMO technology currently increases the number of antenna per base station from 12 to about 100. This is almost a tenfold increase in the number of devices that can be handled per base station. The opportunity for signal interference grows as the number of new devices and base stations increases.

For this reason, the technology of beamforming is critical to 5G's long term success. Beamforming uses various technologies to transmit radio waves directionally, rather than omni-directionally. This means that the signal strength is higher for the recipient it is directed at, but much lower for others not in the path (or paths) to the recipient. By limiting the spread of radio waves, beamforming further enables the reuse of limited spectrum.

The last of the major 5G technologies is full duplex transmission. Traditional radios can only either transmit or receive at any given point in time, much like a walkie-talkie. Leveraging multiple technological advances, 5G radios will be able to simultaneously send and receive from the same antenna using the same frequency. This achieves even more efficient use of spectrum (i.e., faster data transfer).

The key technologies discussed above, combined with carrier aggregation, significantly increase data transfer speeds. Carrier aggregation was introduced in 4G (Long Term Evolution (LTE)-Advanced) radios and is not new to

Beamforming and Massive MIMO



Source: Samsung.

5G. It allows a device to use multiple carriers (frequency bands) at the same time to increase the effective data transfer speed.[7]

5G Core Technologies

NR and other 5G radio technologies are only part of what makes 5G superior. Much of the improvements associated with 5G comes from a new core. The 5G Core (5GC) is a service-based architecture. This brings a level of modularity, adaptability, and resilience not seen in prior versions of the core. Services are associated with service data flows (SDFs), which can have quality of service (QoS) requirements assigned to them to ensure that services are properly differentiated and performance guarantees can be met.

Another key 5GC feature is network slicing. This allows 5GC to look like multiple separate networks, each with different capabilities. "...[A]n operator may deploy multiple network slices with exactly the same system features, capabilities and services, but dedicated to different business segments and therefore each possibly providing different capacity for number of [user equipment] UEs and data traffic. … [T]here can be differentiation between network slices also by the provided system features, capabilities and services. The [machine-to-machine] M2M network slice could, for example, offer UE battery power saving features unsuitable for smartphone slices, as those features imply latencies not acceptable for typical smart phone usages."[8] Network splicing is enabled by network function virtualization (NFV), which allows for virtualization of network functionality like routing and firewalls.

To meet the highest performance requirements, such as ultra-low latencies, 5GC requires the use of edge computing with services collocated with the base stations or very near to them. This enables faster transit times from data source to destination. It also minimizes the amount of data that must transit the internet—a consideration for data intensive applications.[9]

The Transition to 5G

Some aspects of 5G require a serious investment of capital and labor, so many existing carriers are likely to take an evolutionary approach (i.e., implementing select 5G technologies in an incremental manner). This means that not all 5G technologies will be leveraged in all cases. Instead, 5G features will be based on specific use cases. Implementation will most likely begin with updates to radios followed by upgrades to backhaul communications to create end-to-end 5G. The Federal Communications Commission (FCC) recently put in place new rules for some aspects of 5G base station deployment to limit the costs and speed the time of deployment for new base stations.[10]

The 3rd Generation Partnership Project (3GPP), the body responsible for much of the 5G-related standards, released a set of architecture options for various evolutions from 4G to 5G in their Release 15 standard (the first of the 5G standards).

There are two categories of architectures. Standalone architectures have only one radio access technology, while non-standalone architectures have both NR and LTE radios. Option 3 is a non-standalone architecture. It combines 5G NR with the 4G LTE Radio and 4G Core networking technology, "thus making the new 5G-based radio technology available without network replacement. In this configuration, only 4G services are supported, but enjoying the capacities offered by 5G Radio (lower latency, etc.)."[11] The non-standalone architecture uses 5G Radio Access Network (RAN), also known as 5G NR, in conjunction with the existing LTE and EPC infrastructure Core Network (respectively 4G Radio and 4G Core) to make the new 5G-based radio technology available without network replacement. The non-standalone architecture is also known as "E-UTRA-NR Dual Connectivity (EN-DC)" or "Architecture Option 3". The box below shows the EGPP 5G architecture options. EPC is the 4G Core and NGC is the 5G Core. LTE eNB is the 4G Radio and gNB is the 5G NR. Note that, in some cases, the 4G and 4G radios can act in a master/slave relationship with one radio communicating with the other, which in turn communicates with the core.

Telecommunications provider BT Group, Plc suggested they plan to migrate first to Option 3 (non-standalone architecture) and then to Option 7 (non-standalone architecture), probably 7a. This is likely to be a path other major carriers will follow.[12] In Option 7 (both alternatives), the architecture consists of a 5G core and both LTE and NR radio access. Migration considerations are discussed in great detail in a document from the GSM Association (GSMA).[13] Full implementation of the 5G feature set is expected with 3GPP Release 16.[14]

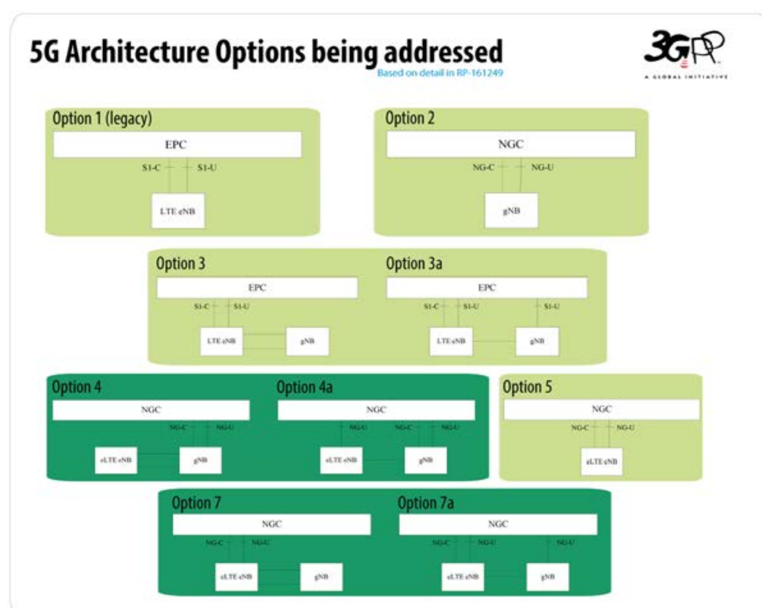
5G Use Cases

There is no single use case that is 5G. Consumer cellular is just one use case among many. Release 15 identifies the following use cases, with example performance parameters:

- *Enhanced Mobile Broadband (eMBB):* "[H]igh data rates, higher traffic or connection density, high user mobility, and the requirements related to various deployment and coverage scenarios. The scenarios address different service areas (e.g., indoor/outdoor, urban and rural areas, office and home, local and wide areas connectivity), and special deployments (e.g., massive gatherings, broadcast, residential, and high-speed vehicles). … For instance, for the downlink, experienced data rates of up to 50 Mbps are expected outdoor and 1 Gbps indoor (5GLAN), and half of these values for the uplink. For services to an airplane, a bitrate of 1–2 Gbps is expected per plane."
- *Critical Communications (CC) and Ultra Reliable and Low Latency Communications (URLLC):* "[S]upport of very low latency and very high communications service availability. These are driven by the new services such as industrial automation. The overall service latency depends on the delay on the radio interface, transmission within the 5G system, transmission to a server which may be outside the 5G system, and data processing. Some of these factors depend directly on the 5G system itself, whereas for others the impact can be reduced by suitable interconnections between the 5G system and services or servers outside of the 5G system, for example, to allow local hosting of the services. … For instance, in the context of remote control for process automation, a reliability of 99.9999% is expected, with a user experienced data rate up to 100 Mbps and an end-to-end latency of 50 ms. This is provided in particular through the Edge Computing capability…."
- *Massive Internet of Things (mIoT):* "[S]upport very high traffic densities of devices. The [mIoT] requirements include the operational aspects that apply to the wide range of IoT devices and services anticipated in the 5G timeframe."
- *Flexible network operations:* "Covers aspects such as network slicing, network capability exposure, scalability, and diverse mobility, security, efficient content delivery, and migration and interworking."

Differences in 5G use cases reflect changes in more than just the radio or a few details of the core. Behind the scenes, 5G supports a service-based architecture. This modernizes the cellular network's architecture while providing capabilities, such as collocating storage and compute near aggregation sites close to base stations, to provide access to services at ultra-low latencies. NFV enables this architecture and provides additional robustness within the core of the 5G network, enabling the dynamic rerouting of application data as required.

While this might seem like more complexity than is necessary, ultra-low latency and high reliability is necessary for use cases such as factory floors, virtual reality, and applications involving tactile feedback. Users with these types of demands will need to either build custom-made 5G networks themselves or collaborate closely with a 5G provider to ensure storage and compute collocation and NFV are implemented in a way that meets the specific requirements of the application. It is important to note that, rather than using regular NR, IoT devices are likely to use narrowband (NB)-IoT or LTE-M for low power wide area (LPWA) radio



Source: 3GPP. Release 15.

communications.[15] These technologies predate Release 15 but continue to evolve with it.

The choice of 5G technologies depends on the use case. For example, in a rural area, the highest frequencies attenuate very quickly (e.g., 300 m), so it might be prohibitively expensive to have high density of small cells with the exception of tailored uses (e.g., around a farm, in a factory, at a military Base/Post/Camp/Station). Collocation of compute and storage will be necessary for critical applications with strict performance requirements, but many traditional applications can continue to operate in their current architectures.

Positioning, Navigation, and Timing (PNT)

One interesting aspect of 5G with direct applicability to the military is the interaction of new positioning and beamforming features. Beamforming and smaller cells enable more accurate relative location determination, even in the absence of global positioning satellite system (GPS) signal availability. Beamforming also provides some resilience against jamming attempts. This could be leveraged for enhanced PNT in electronic warfare-degraded environments.[16,17]

The Market and Supply Chain Landscape

Suppliers for computing and telecommunication technology come from across the globe. Every device sold in the market place is built from components that are manufactured in different countries. For example, the U.S. has off-shored much of its chip set manufacturing and many of today's computing and telecommunication devices (e.g., laptops, smartphones, IoT appliances) contain chips manufactured in China.

The supply chain landscape is intensely competitive and rapidly taking on an East-versus-West appearance. Because the major market subsectors each require hundreds of unique components, there are easy opportunities for some component makers to quickly establish a monopoly or near-monopoly for their specific components. Keysight, a U.S.-based company, provides 5G test equipment for all of the major 5G companies, including Qualcomm (U.S.), Huawei (China), and Samsung (Korea).

Component makers have organized into partnerships with each other and some of the larger equipment vendors. There are a small number of clusters of companies that form options for a vertical slice of 5G implementation. For example, Ericsson partnered with Qualcomm, Juniper, and Cisco to provide an end-to-end solution set for 5G. This group can then partner with a regional telecommunications provider, such as Vodafone, to deploy an integrated platform. HP, Samsung, and Intel are making similar moves for 5G data centers.

Because of its ability to centrally plan its economy, China can organize its 5G verticals much more easily than the ad hoc organizations of more capitalist Western nations. This has created a marketplace for large numbers of acquisitions to prepare the corporate battlefield for 5G, and this is expected to continue for the next several years. Companies that do not rapidly establish market

Dell Inspiron 600m Notebook: Key Components and Suppliers (2005)

Component	Supplier or Potential Suppliers
Intel Microprocessor	US-owned factory in the Philippines, Costa Rica, Malaysia, or China *(Intel)*
Memory	South Korea *(Samsung)*, Taiwan *(Nanya)*, Germany *(Infineon)*, or Japan *(Elpida)*
Graphics Card	China *(Foxconn)*, or Taiwanese-owned factory in China *(MSI)*
Cooling fan	Taiwan *(CCI and Auras)*
Motherboard	Taiwan *(Compal and Wistron)*, Taiwanese-owned factory in China *(Quanta)*, or South Korean-owned factory in China *(Samsung)*
Keyboard	Japanese company in China *(Alps)*, or Taiwanese-owned factory in China *(Sunrex and Darfon)*
LCD	South Korea *(Samsung, LG.Philips LCD)*, Japan *(Toshiba or Sharp)*, or Taiwan *(Chi Mei Optoelectronics, Hannstar Display, or AU Optronics)*
Wireless Card	Taiwan *(Askey or Gemtek)*, American-owned factory in China *(Agere)* or Malaysia *(Arrow)*, or Taiwanese-owned factory in China *(USI)*
Modem	China *(Foxconn)*, or Taiwanese company in China *(Asustek or Liteon)*
Battery	American-owned factory in Malaysia *(Motorola)*, Japanese company in Mexico, Malaysia, or China *(Sanyo)*, or South Korean or Taiwanese factory *(SDI and Simplo)*
Hard Disk Drive	American-owned factory in Singapore *(Seagate)*, Japanese-owned company in Thailand *(Hitachi or Fujitsu)*, or Japanese-owned company in the Philippines *(Toshiba)*
CD/DVD	South Korean company with factories in Indonesia and Philippines *(Samsung)*, Japanese-owned factory in China or Malaysia *(NEC)*, Japanese-owned factory in Indonesia, China, or Malaysia *(Teac)*, or Japanese-owned factory in China *(Sony)*
Notebook Carrying Bag	Irish company in China *(Tenba)*, or American company in China *(Targus, Samsonite, and Pacific Design)*
Power Adapter	Thailand *(Delta)*, or Taiwanese-, South Korean-, or American-owned factory in China *(Liteon, Samsung, and Mobility)*
Power Cord	British company with factories in China, Malaysia, and India *(Volex)*
Removable Memory Stick	Israel *(M-System)*, or American company with factory in Malaysia *(Smart Modular)*

Source: Friedman, Thomas. The World Is Flat: A Brief History of the Twenty-first Century. Farrar, Straus and Giroux. 2005.

dominance or relevance will be left behind.

The rough outlines of the separate 5G providers appears to be coalescing with China on one side and the United States (U.S.) and Southeast Asia on the other. The market battle grounds include Europe (including Russia and the post-Soviet states), India, South America, and Africa. A key group of Western companies includes those led by Ericsson, the non-Chinese global leader in 5G. While Ericsson cannot by itself produce a 5G end-to-end offering, it will be able to do so with the help of its partners. Unfortunately, there is no U.S. equivalent to a market leader like Ericsson, leaving the U.S. with diminished influence in the development and evolution of 5G.

Security Considerations for 5G

The international nature of the 5G supply chain exacerbates the security issues related to transporting data. While the U.S. Federal Government has the ability to avoid foreign components in some of its technologies, this is unlikely to be the case with the coming 5G networks. Instead, it will need to determine appropriate mitigation strategies for the risks from 5G technologies. In some cases, the best strategy might be to avoid 5G technologies.

These risks can be broken down into the traditional security categories of confidentiality, integrity, and availability. In many cases, confidentiality and integrity are straightforward to handle. Using end-to-end encryption and authentication technologies, one can ensure that data is not compromised in route. However, there are likely to be some scenarios in which cryptographic overhead is impractical. This could be for a variety of reasons, including the additional processing or power requirements for cryptographic computations or the latency it may add. Some legacy equipment might only support outdated, insecure ciphers. In these cases, critical data should be isolated from 5G networks that are not trusted. In cases in which cryptography and use of trusted 5G systems are both impossible, the risks must be documented and plans put in place to address the risks associated with compromise.

Availability is less straightforward. Cryptography cannot easily address issues like a maliciously configured component dropping legitimate traffic or routing it improperly. For systems that rely on untrusted components for critical 5G operations, procedures should be in place to operate in a degraded mode using an alternate, trusted communications channel.

The component supply chain is just one of the 5G concerns. 5G is heavily dependent on software for networking and security, and flaws or malware in software could prove more catastrophic than in prior network generations. 5G providers will need to directly address software quality and integrity in ways they have not before. 5G protocol flaws have already resulted in the publication of potential weaknesses that could lead to loss of confidentiality, integrity, or availability. For these reasons, even a trusted hardware supply chain is not a sufficient security strategy by itself.

DoD Way Forward

DoD needs to evaluate which applications are likely to require specific 5G technologies outlined above. In particular, critical communications such as ultra-reliable and low latency communications; mobile IoT, vehicle to vehicle (including UAV), and airplane to ground (Release 15) communications; and satellite (Release 16) communications are some of the communications types that are most likely to be impacted. Network splicing will allow DoD to separate military communications from commercial communications or to separate latency-tolerant communications from low latency ones. However, current security practices favor using separate hardware for federal government data storage and processing, so NFV and network slicing must be approached with caution.

Implementation of 5G brings massive changes and will cause ripple effects through the entire information technology sector with implications for supply chain security. DoD should ensure a trusted supply chain for 5G integrated circuits, base station equipment, core networking equipment (e.g., routing, NFV, compute, storage), and handset/end user equipment.

DoD should be cognizant of the key suppliers of intellectual property, integrated circuits, 5G subsystems, and other 5G-related technologies and services—many of which are based in countries not aligned with U.S. interests. While there are means to secure the supply chain of U.S. telecommunications providers, international DoD communications rely upon foreign providers that might have compromised supply chains. Any standards should address how to meet security requirements in these potentially degraded environments.

Further, DoD, with assistance from the National Security Agency and Defense Information Systems Agency

(DISA), should take steps to ensure that military communications are sufficiently encrypted for confidentiality and that network slicing ensures availability and preserves confidentiality.

DoD might wish to use a specific subset of 5G technologies for its own uses based on needs. These decisions should be requirements-based, since there is no "one size fits all" 5G. DoD should study the effect of 5G for use in weapons platforms, on military installations for traditional communications and IoT, and for general purpose communications (e.g., commercial cellular in buildings with significant attenuation issues like the Pentagon).

Because of the new 5GC technologies and impending need for edge computing architectures, DoD should work closely with partners like the Department of Homeland Security (DHS), the Intelligence Community (IC), the National Institute of Standards and Technology (NIST), and the General Services Administration (GSA) (e.g., FedRAMP Program Management Office) to adopt standards that ensure 5G applications are delivered with appropriate security controls.

For DoD-operated systems, DoD should ensure basic 5G cyber hygiene guidance is created and promulgated. This is easier in systems that DoD owns and operates (e.g., weapons platforms). In cases where DoD is purchasing 5G service, DoD should familiarize itself with 5G security standards and best practices, such as 3GPP Specification 33.501 that documents security procedures for 5G systems. Adherence with these standards should be incentivized and deviations from the standards discouraged through contractual means. Like any other technology, people and processes can undermine security.

DoD should ensure that its equities are fully represented in relevant standards, as well as in interagency groups like the DHS Information and Communications Technology Supply Chain Risk Management Task Force. DoD should also coordinate with other agency groups like the FCC Communications Security, Reliability and Interoperability Council to ensure that threat information is shared with DoD and threat-based evaluations of suppliers and services are performed in a manner consistent with DoD needs.

While there have been some efforts in the past to address 5G security at the highest levels of the federal government, there is currently a lack of clarity on the approach. As executive-level plans for addressing this concern solidify, DoD should work at the inter-agency level and look inwards to create requirements and shape relevant policy.

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14. ABSTRACT

While 5G mobility promises a huge advance in mobile technology, in reality, 5G represents a number of separate but interrelated advances that provide new capabilities to further the progress made in increasing network speeds. Five key technologies underpinning 5G NR are millimeter wave spectrum, small cells, massive multiple input multiple output (massive MIMO) base station antennae, beamforming, and full duplex communications.

5G will enable vast increases in the number and types of connected devices (both low and high power) and new types of networks with varying requirements (e.g., vehicle-to-vehicle networks, virtual reality over mobile, and mobile industrial automation networks). But 5G also enables new exploitation scenarios from adversaries leveraging the Internet of Things (IoT).

15. SUBJECT TERMS

5G, Fifth Generation, MIMO, Beamforming, Milimeter wave, Mobile base station

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