REVIEW PAPERS

Standardization for 5G technology and beyond: impact on military communications

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Abstract:

Introduction/purpose: The presented review paper deals with the standardization proces for 5G technology and beyond and its impact on military communications.

Methods: Dominant methods such as analyzes and syntheses were provided for considering the key aspects of the 5G standardization evolution process through presentations of the roles of different Third Generation Partnership Project (3GPP) standard releases and its implementation and usage in military communication networks environment.

Results: The background and key areas in 5G evolution and beyond are presented. Also, 5G standardization and military issues and challenges are discussed.

Conclusion: Standardization for 5G and the emerging 6G landscape is extremely complex and highly innovative with many rapidly evolving industry-driven and societal requirements. Standard development organizations, industry, and academia need to collaborate on standardization to facilitate worldwide interoperability. The paper gives an overview of standardization functionalities and efforts to improve 5G system performance as well as its impact on military communications and services. It analyzes the areas of major enhancements for the existing features and expansion to new use cases and industries as well as to military usage through the 3GPP Releases, starting from Release 15 as 5G Basic, over 16 and 17 as 5G Evolution, up to 18 and 19 as 5G Advanced which precede the upcoming Release 20 and the initial 6G network whose launch is expected by the end of this decade.

Key words: the fifth generation (5G) technology, 5G standardization process releases, 5G functionalities, 5G interoperability.

Introduction

Standardization on a global level is of fundamental importance and even more for wireless networks because of the need for worldwide interoperability (Shafi et al, 2017). First of all, the data rate supported by each generation of mobile networks has significantly increased over time. The advantages of 1G technology included service areas. There was neither roaming between operators of various networks nor a capability of networks to use different frequency bands. The widespread adaption of 1G enabled the introduction of 2G mobile networks, in spite of these shortcomings. 2G networks have a throughput of 9.6 – 236 Kbps. 3G increased this range to 42 Mbps, while 4G further improved it from 100 Mbps to 1 Gbps. 5G has made a leap with of 10 Gbps to 20 Gbps. As for 6G, it is expected to reach 100 Gbps to 1 Tbps. Latency has decreased significantly with each generation. For example, 2G had a latency of 300-1000 ms, 3G reduced it to 100-500 ms, while 4G further decreased this to 30-100 ms. As for 5G, it has lowered latency to 1-10ms. 6G is expected to achieve submilisecond latency. 2G had low spectrum efficiency, while 3G and 4G made significant improvements. 5G has very high spectrum efficiency thanks to Multiple-Input-Multiple-Output (MIMO) and beamforming technologies. For 6G, it is expected to push the limits of spectrum efficiency further using THz frequencies as well as advanced network architectures (Fowdur et al, 2024). Nowadays, there is a focus on wireless regional network standards. Scientific efforts for the fifth generation (5G) specification are going to be finished with the full phase, soon. Also, today there are different studies towards the sixth generation

(6G) standardization. The 3GPP and its first full Release for 5G started with Release 15. Release 15 consists of the Non-Stand Alone and the Stand Alone specifications. Also, Release 15 is recognized as the foundation for network implementation and devices. Release 15 becomes an excellent performance for mobile communication broadband service, that is, data rate, spectral efficiency and latency. The Release 15 performance is recognized as excellent in the Key Performance Indicators. Therefore, Standard Development Organizations and academic society are necessary to cooperate in the standardization process to facilitate interoperability (Abdelkafi et al, 2021).

The evoluton of 5G standard started from Release 15 as 5G Basic, continues with Releases 16, and 17 as 5G Evolution, and achieves Releases from 18 to 21 as 5G Advanced. Next, Release 21 will establish a road map for the 6G standard. Currently, Releases 18 and 19 are open while Releases 20 and 21 are planed.

Key areas in 5G evolution and beyond

It is projected that 5G networks will be widely available all over the world because of some key features such as:

- Data transfer rates on 5G networks are expected to be significiantly higher than those of previous mobile network generations (10 Gbps or more),
- Latency reaching levels are as low as a few miliseconds,
- 5G networks are designed to support a larger number of devices and connections, enabling new applications and services, and
- 5G networks offer improved coverage and reliability.

The first official specification to outline a complete 5G network was Release 15 available in 2018. It includes the specifications for 5G New Radio (NR) (Kim et al, 2019). Representing the current state-of-the-art in cellular network technology, Release 15 forms the basis for the deployment of 5G network all over the world (Bertenyi, 2021).

Releases 16 and 17 respectively belong to the key standardization of the 5G evolution system (Bertenyi, 2021). The specifications for Release 16 were frozen up in the first half of 2020. Next, the Release 17 specification process was underway towards its completion at the end of 2021. The main focus of both Releases 16 and 17 is to expand the ecosystem in order to provide possibilities of different industries to use 5G advantages (Wang et al, 2014). Both releases contain many features in all the key areas of 5G environment, i.e., Industrial Internet of Things, vertical

industries (Ghosh et al, 2019), network deployment and automation, and device evolution.

Releases 15, 16 and 17 unified platforms for innovations in technological advancement of the 5G 3GPP (Lin & Lee, 2021).

The most recent Release 18 named 5G Advanced brings a new wave of innovations especially in the area of Artificial Intelligence and Machine Learning (AI/ML). Further enhancements in AI/ML are expected in the forthcoming Release 19. The first 3GPP standards release for 6G is still several years away, while the work being done today gives the foundation.

Role of Release 16

Additional improvements to the 5G NR air interface brings Release 16 in 2020. In that way, Release 16 complements the full 5G specification which allows for the advanced use cases and applications such as network slicing (NS) and enterprise services (Wijethilaka & Liyanage, 2021). Release 16 expanded on the success of Release 15 conserving consumer and enterprise service field. Two examples of new services and applications it supports are: mission-critical communication as well as the Internet of Things (IoT). Release 16 includes the next main areas such as: massive machine – type communication, ultra – reliable low-latency communication and improved mobile broadband. In order to help cellular networks to continue with progress, additional technical improvements and support for new frequency bands are included in Release 16 (Chen et al, 2021).

The Ultra Reliable Low Latency Communications (URLLC) functionality, critical for Industrial IoT (IIoT) scenarios is completed in Release 16.

Release 16 introduces support for Time Sensitive Communication including integration with Time Sensitive Networking.

Also, Release 16 introduces some significant features which allow NR to use the unlicensed radio spectrum.

Access to the NR-Unlicensed Spectrum (NR-U) provides an important tool to increase capacity for both service providers and private networks. Release 16 NR-U uses the same flexible frame and slot structure, physical layer design, and protocol as NR Release 15 (Milovanovic et al, 2020). In that way, the magnitude of changes to the user equipment compared to the licensed-band operator is limited. The fact that Release 15 provides the basic positioning protocol support is extended in Release 16 to include the capability of locating devices using 5G radio signals themselves leading to an expected accuracy in the order of metrics for a vast majority of users.

The means to reduce operating expenses of running 5G systems enables new application capability for communication service providers. In order to improve the overall separability and automation of network slice deployments, Release 16 is applied. It allows the operator to outsource network slice subscription management to third parties who are using the operator's networks to provide services to their customers. Release 16 introduces network slice-specific authentication and authorization which allows a third party to manage a user's subscription to a particular slice without requiring the operator to be involved in managing transportation. Integrated access and backhaul (IAB) has been introduced in Release 16 as a key enabler for fast and cost-efficient applications, mainly targeting dense mmWave deployments outdoor when using the same spectrum and air interface for access and backhaul, creating a hierarchical wireless multi-hop network between sites. The main purposes for deploying IAB nodes are: to have isolated coverage gaps, to provide backhaul with filter deployment sparse, to enhance system capacity, and to bridge coverage from outdoor to indoor. There are some aspects of 5G standards that directly impact the energy efficiency of devices. Release 16 introduces signaling from the network to the devices enabling the device power consumption to be well optimized during the period of additive transmission and reception.

In Release 16, the 3GPP further expanded the 5G NR frequency spectrum in order to support operation with bands starting from under 1 GHz up to 52.6 GHz with 5 MHz and more channel bandwidth.

Also, Release 16 further enhances the NR support for URLLC services by enabling latency in the range of 0.5 to 1 ms and improved reliability with a target error rate of 10^{-6} in order to provide new use cases, such as factory automation and transport industry as well as to improve use cases such as Augmented Reality (AR)/Virtual Reality (VR) and gaming.

Also, NR Release 16 introduces native positioning support not only for regulatory but also for commercial and other use cases with positioning accuracy down to at least 3 meters and end-to-end latency less than 1 second for commercial use cases.

The improvements due to Release 16 are described in Table 1 (3GPP, 2021).

Table 1 – Areas with the improvements due to Release 16

IMPROVEMENTS	DESCRIPTIONS
Massive MIMO	• Strong management to increase connection stability
	• Enhance coverage at the cell edge
	• Full power uplink for MIMO-capable devices
Enhanced Ultra-Reliable, Low-latency Communication (eURLLC)	• Vertical user cases (industrial automation)
	• High connection dependability provided by improving the 5G URLLC architecture
	• Strict latency restriction
	• Continues communication even if one link is temporally blocked
Power saving	• Low power optimization
	• Overhead reduction
	• Better power control techniques
Integrated Access and Backhaul (IAB)	• Combine access and backhaul to reduce the cost of mm Wave densification
	• Allows a single base station to serve as a wireless access point for end devices and a backhaul node
	• Operators may add more base stations on the fly without having to deploy extra fibers for more backhaul capacity
	• More adaptable densification plan
Unlicensed spectrum (NR-U)	• Enabling 5G service in unlicensed bands
	• Cellular technology can operate "standalone" in unlicensed spectrum
Time-Sensitive Networking (TSN)	• Introduced support for TSN which can guarantee time-deterministic delivery of data pockets
Cellular-Vehicle-to Everything (CV2X)	• Prioritizes the use of 5G to improve automotive safety

Role of Release 17

Release 17 was published in March 2022. It refers to further enhancements and improvements to the 5G NR air interface. The Release 17 development is the result of evolving needs and requirements of the mobile industry. The first stage decade's technological evolution area concluded with Release 17. The 3GPP is part of the Release 16 and Release 17 specifications. These enable 5G media streaming and enhancements edge processing, analytics and event presentation as well as extended reality (XR) experiences.

Enhancements to IAB in Release 17 will improve the options for multiplexing concerning links of an IAB node. Also, increased flexibility and robustness in the network topology will be improved.

In both Releases 15 and 16, the design of 5G NR allows the network to operate in the conventional cellular radio spectrum and the mmWave spectrum up to 52.2 GHz.

The 3GPP makes effort to provide new bands together with band communications for 5G implementation (Zong et al, 2019).

The main goal was to recognize demands of network operators worldwide.

The major step in Release 17 in this domain is the introduction of support for 5G NR in the 52-71 GHz frequency range.

Release 17 scales the existing 5G NR design to expand the mmWave spectrum range from 24.25—52.6 GHz to up to 71 GHz in order to cover the original 60 GHz band (57-66 GHz) as well as the 66-71 GHz frequency band together with 5 MHz and more channel bandwidth.

Also, Release 17 scales down the wideband 5G NR design (i.e., 100 MHz bandwidth) to 20 MHz/100 MHz in the sub-7/mmWave to efficiently support lower complexity IoT devices.

In the focus of Release 17 is power saving for devices in order to improve the battery life (Milovanovic & Bojkovic, 2020).

Release 17 seeks to provide time-sensitive communication (TSC), offering in that way enhanced specific tools for the 5G system in order to support TSC in the application domain.

In that way it is possible to allow the implementation of private wider area networks (WANs).

Release 17 private network support is being further extended in order to support neural host models where the network owner and the service provider need not to belong to the same entity. This provides accessing private networks together with public network operators.

Release 17 offers support of the IoT by NR, in order to support optimal operational device type's characteristic for the IIoT network services.

Next, Release 17 has potential to enhance NR to address the following use cases in the Industrial IoT and other verticals:

- Industrial wireless sensors with 99.99% availability, latency less than 100ms in general and 5-10ms for safety-related sensors, and a medium data rate (<2 Mbps), and a battery life of a few years,
- Video transmission with 99%-99.9% reliability, latency less than 500ms, and a medium to high data rate (2-25 Mbps), and
- Wearables with a high data rate (up to 150 Mbps for downlink and up to 50 Mbps for uplink) with a long battery life (up to 1-2 weeks).

In order to support enhanced positioning in Release 17, the study item focuses on more high-accuracy positioning targeting commercial IoT use cases such as location of assets and moving objects within factories, with sub-meter-lever accuracy and end-to-end latency less than 100 ms.

Release 17 supports a wide but key range of military services, Enhanced Mobile Broadband (eMBB), URLLC, and Massive Machine-Type Communications (mMTC). The description of the improvements due to Release 17 are presented in Table 2 (3GPP, 2022).

Table 2 – Capabilities for primary use cases in Release 17

CAPABILITIES	DESCRIPTION
eMBB	• Support for 5G NR from 52.6 MHz to 71GHz frequency range
	• Thanks to the expansion of the NR frequency range, more spectrum up to and including the unlicensed 60 GHz is available
	• Multicast and broadcast services such as vehicle-to-vehicle (V2X) public safety, IP multicast, software delivery, and IoT are the primary targets
	• Allows the network notification and the avoidance of paging collisions when the user equipment changes networks
	• Support for non-terrestrial networks
	• Through the use of high-altitude platforms, better coverage can be achieved in remote places
	• Sidelink relaying including single hop, User Equipment (UE) to UE and UE to network relaying
URLLC	• Enhanced physical layer feedback for manufacturing automation
	• Positioning, reduced latency, especially for IoT applications
	• Sidelink, V2X, public safety, resource allocation enhancement
	• Continuity mechanisms for ultra-radio access technology
	• UE can quickly read the cell that provides the desired slice
	• Anything reality (XR) evaluations
	• Help for a wide variety of XR applications
mMTC	• Small data transmission in the inactive state
	• Sensors benefit from lower connection establishment overhead
	• Support of reduced-capabilities NR devices
	• Useful for transmitting data over machines

Role of Release 18

Release 18 refers more to 5G Advanced, which is represented in industry and technology that comes between 5G and 6G (Lin & Lee, 2021). It has started in the second quarter of 2022 as the first standard which will witness a greater emphasis on AI, ML and extended reality (XR). Also, it should be noted that there will be a greater focus on sustainability initiatives. The initial freeze data for this standard package was planned in December 2023. After that time, vendors will start integrating the approved changes into commercial equipment. 5G Advanced with XR applications such as video streaming, remote sensing, etc. will create financial improvement in the consumer enterprise market. In order to encourage mass market adoption, 3GPP working groups are going to enhance XR-specifies traffic performance and power consumption. AI/ML is also becoming of great interest for future networks. As for generators, they need to save system-level energy in order to reduce deployment costs and maintain network performance for a range of use cases (Lin, 2022).

The key features in Release 18 involve the 20-MHz or 5-MHz bandwidth (in Frequency Range 1), full duplex/half duplex and time division signal duplication, 64-level QAM (256 optional), and 10 Mbits/sec maximum data speeds (Downlink and Uplink).

Also, Release 18 includes enhancements to the 5G NR technology that enables lower latency, down to less than 0.5 ms in some cases. These enhancements include improvements to the scheduling algorithms and support for low-latency services such as URLLC.

Next, Release 18 has included advancements in spectrum operation utilization for 5G NR, important for networks which require mission critical communications. In order to achieve this, the 3GPP has introduced operation in a narrowband spectrum with channels smaller than 5 MHz, i.e., it specified a new channel bandwidth of 3 MHz, as well as a new synchronization raster (600 KHz) and the technique of SSB (Synchronization Signal Block) puncturing.

The 3GPP radio access network (RAN) approved a work package for its Release 18. It represents a major emulation in the first release of 5G-Advanced. The work package includes diverse study and work items which will significantly contribute to a variety of new use cases. The works conducted in 5G Advanced will shape the evaluation of wireless networks on the path to 6G. In Release 18, the standardization sidelink (SL) communication was extended to the unlicensed spectrum, while the SL positioning is standardized with the licensed spectrum (Lin, 2022). The notable changes and description of the capabilities from Release 18 as well as future research are given in Table 3 (3GPP, 2023).

Table 3 – Description of the capabilities offered by Release 18 and further research

CAPABIITIES	DESCRIPTION AND FURTHER RESEARCH
Network energy saving	• A slicing on network energy has to be correctly done for NR. Also, new methods for maximizing network energy efficiency are welcome
Mobility support	• Mobility focuses on improving conditional handover support
	• UE gets a handover command with a condition from the network
MIMO evaluation	• Support for antenna ports in the uplink and simultaneous multipanel uplink
	• Better support advanced UEs such us customer premise equipment
	• Fixed wireless access devices and vehicular UEs
Multicast and broadcast	• Increase resources efficiency in RAN sharing scenarios and extend multicast support to UEs
	• Make enhancements to allow UEs in connected state to receive broadcast service and unicast services simultaneously
Improved positioning	• Accuracy, integrity, and power efficiency along with positioning

Role of Release 19

Release 19 is the second release of 5G Advanced. Not only is it a continuation of Release 18, but it also represents a bridge towards 6G technology of new capabilities and efficiency. As for the specifications, they are expected to be finalized and frozen in March 2025. What has emerged, for example, is a set of features which will offer services such as extended reality.

In Release 19, at least for the 7-24 GHz spectrum, the 3GPP will validate its existing channel models and if necessary, adopt them to take into account spatial non-stationarity. As the second Release of 5G Advanced, Release 19 will focus primarily on the commercial deployment needs by further enhancing performance, evolving network topology, improving energy efficiency and utilizing AI/ML. Here the innovation work carried out will provide the baseline for 6G standardization.

The 3GPP 5G Work Plan for Release 19 deals with the problems such as: support frequencies up to THz, advanced radio interface including full duplex, joint sensing and communication, energy harvesting and passive IoT, and cognitive access to wireless technologies cellular satellite WiFi (Chen et al, 2023).

Current expectations

Release 20 workshop in July 2024 defined the scope of technology foundation for the next generation innovation platform going towards its finalization in September 2026. The current expectations are that the official specification work on 6G standards will start around 2025. Anticipating supporting use cases requirements in 2030 and beyond, the first 6G standard Release 21 will need to be completed and redefined by early 2028.

5G standardization - military issues and challenges

5G technologies are important in the military environment because it supports various applications. 5G can be implemented for different purposes from the traditional ones such as Intelligence, Surveillance, and Reconnaissance (ISR) systems capabilities for decision making in command and control (*C2*), over training, maintenance, logistics, up to autonomous vehicles, AI, augmented and virtual reality (Miličević & Bojković, 2024).

Also, 5G wireless technology brings significant benefits for military forces. Some of them are (Maris, 2024):

1. Enhanced Communication, Control and Operational Efficiency: The high data rate, ultra-reliable and low latency of 5G enable more efficient communication and information exchange technology in the battlefield, improving command and control capabilities.

Command and Control (C2) which is now expanding to incorporate computers, intelligence, surveillance, target acquisition, reconnaissance and cyber (C5ISTAR) technologies is incorporating all domains of traditional warfare theatre which involve air, land, sea and space for combat operations. To be important in the military domain, C2 has necessity to follow modern technology advancements in order to respond to the challenges and requests of modern warfare in combat fields. In line with this, 5G plays an important role in the optimization and transmission of leading military C2 applications.

From the military perspective, 5G with its main characteristics has huge potential to be vital for effective C2 communication systems in order to provide secure and resilient information exchange between units and commands as well as for intelligence collaboration in the battlefield, coupled with real-time data that are processed in different combat networks.

5G provides enhanced C2 by real-time data transmission with ultra-reliability and low latency and in that way it allows Real-time situational

awareness and Distributed Command and Control for military purposes. In Real-time situational awareness, combat staff have possibility of faster decision making upon receiving critical information from the battlefield (video stream, sensor data, and etc.) On the other hand, by Distributed Command and Control, units operate independently while staying connected to the central command and can use for this purpose a 5G robust, high-speed network.

The ability to run secure C2 applications on 5G ensures that both superiors and subordinates in chain of command can see, monitor and track the same combat or non-combat activities at the same time as well as use C2 services which must be able to share and access data at any time from any location.

2. Real-time Data Processing and Support for ISR systems: 5G allows for the ultra-rapid processing and sharing of large volumes of data, crucial and critical for ISR operations.

5G can enhance Intelligence, Surveillance, and Reconnaissance (ISR) capabilities for military matters by high-bandwidth data rate transmission and edge computing. High-bandwidth data rate transmission has potential to provide transmission of HD (high-definition) and beyond for imagery and video formats from different surveillance platforms (drones and others). Also, implemented support for 5G edge computing has purpose to process data closer to the source and in that way reduces latency and allows for faster analysis and response.

3. Autonomous and Remote Operations Capabilities: The reliable and fast connectivity of 5G supports the deployment of different kinds of modern autonomous systems which are increasingly becoming integral and important to modern warfare.

5G is a technology platform which provides reliable communication links important to ensuring uninterrupted connectivity for remote control and autonomous operations as well as high-speed data transfer which enables real-time video streaming and sensor data transmission for navigation and mission implementation. Both mentioned characteristics provided by 5G are important for the operation of autonomous vehicles and drones.

Autonomous transportation and Remotely Operated Vehicles (ROVs) enabled by high capacity, low latency wireless 5G technology are developed to execute high-risk combat missions without endangering soldier lives, different navigation tasks in hazardous environments, as well as special tasks like reconnaissance and explosive disposal.

Also, they can be used to ensure timely delivery of supplies, provide real-time intelligence, and support decision making.

Generally, in 5G, anything can be user equipment, not only traditional cell phones, but also different types of assets like aircraft, ships, as well as combat and non–combat vehicles.

Equipped with 5G for long-haul communication systems, these vehicles can use the 5G network to enable communications, high-data-rate video conferencing, and Internet of Things sensors to become self-driving or autonomous vehicles in order to remove, for example, soldiers from some missions, regadless of the fact that someone is required on board to oversee the vehicle performance.

Also, different vehicles, from base-contained vehicles to field and combat vehicles equipped with radar, lidar, and sensing techniques to identify and understand their surroundings, which use artificial intelligence and machine learning to sort through, process, and act on this information, can use the potential of 5G to connect all this information.

4. Augmented Reality (AR)/Virtual Reality (VR)/Extended Reality (XR)/Artificial Intelligence (AI) enabled simulations and training.

Simulations and training are essential for military units combat readiness and exactly 5G networks are improving military training capabilities by implementing advanced AR, VR, XR, and AI technologies. In the process of implementing military training, simulations are increasingly used so that accurately reflect real combat scenarios. Precisely speaking, 5G networks, thanks to their high bandwidth and ultra-low latency in real time, can provide support for the modern training process.

The 5G communications capabilities, together with AR for military training, provide a multi-participant training process by an experienced trainer in order to provide military personnel with remote access to the best possible training staff for different specialist jobs as well as to simplify access to cutting-edge programs and platforms for training, regardless of where they are stationed, installed or deployed.

5G enables training and simulation in such a way that military staff can engage in realistic training scenarios using AR/VR as well as in mission operation planning by AR/VR in order to visualize mission conditions and plan operations in a virtual environment.

Also, the high bandwidth and ultra-low latency of 5G ensure real-time, immersive simulations that mirror actual combat scenarios with precision. Soldiers benefit from interactive environments where AR

overlays critical information, and VR and XR offer dynamic, scenario-based exercises.

5. Improved Network-Centric Warfare and Interoperability Concept: 5G's ability to connect numerous devices and systems in such a manner to support the concept of network-centric warfare, enhancing interoperability among different military forces in operations.

For example, 5G has capacity and flexibility to provide military tactical networks well known as Mobile Ad Hoc Networks (MANets). MANets represent some kind of a nomad type of networks that has possibility of self-configuring (reconfiguring) in order to provide connectivity between deployed military commands/units without necessity to build fixed infrastructure in the area of operation, for enabling for users real-time data sharing, coordination and security in dynamic military operational environment. Above all, 5G MANets could enhance situational awareness and have huge impact on a quicker decision-making process in order to improving operational efficiency by providing rapid deployment and reconfiguration in response to changing battlefield conditions.

5G for tactical communications increased flexibility for use cases from enhanced mobile broadband to ultra-reliable low-latency and massive machine-type communications, as well as increased security. Also, 5G tactical networks can provide augmented/virtual reality in combat situations and training, telesurgery on the battlefield, tactical self-driving vehicles, ad hoc secure communications, and the interconnection of different battlefield assets.

Also, the 5G tactical network can be used in different combat/exercise scenarios, for example, to transfer high-speed, secure and reliable data from different sensor platforms over the C2 system or Command Information Systems (CIS) to the command post, for example to choose targets, and from the command post over the C2 system or CIS to artillery units that use this data for calculations and after that for acting on targets in a short period of time in order to eliminate threats on the field. The positive characteristic of the previous scenario is a possiblity to fast deploy eMBB, URLLC and mMTC 5G tactical networks with a smaller propagation footprint for a reliable and resilient communication data flow in order to plan and solve military tasks. On the other hand, the negative characteristic will be a possbility of jamming, intercepting and interupting 5G tactical network communication by enemy electonic warfare systems.

6. Cybersecurity Challenges and Resilient Communications: With rapidly increasing cyber threats, 5G's advanced security features are essential

to answer to them by protecting sensitive military communications and ensuring resilient networks.

The advanced key security features that are implemented in 5G networks for protection against cyber threats are: network slicing and AI-driven security. Network slicing can enhance security and performance by creation of separate network segments for different applications. On the other hand, AI algorithms have a possibility to detect and respond to threats in real time, promising the integrity of military communications.

7. Improving military logistics and supply chain management.

5G supports automated inventory management by applied IoT devices connected via 5G to monitor and manage inventory in real-time enabling. Also, 5G supports enhanced tracking and delivery in order to track in real time supplies, assets, and equipment thus ensuring timely delivery on the location of interest and reducing the risk of shortages, especially those of critical supplies.

5G can enhance logistics military operations through:

- Enhanced communication with 5G - integrating 5G in logistics enables providing a high bandwidth that offers speedy data movement to multiple systems in real time and allows in that way devices and systems to interact and share critical information for logistic operations.
- 5G IoT application in logistics - is suitable for real-time tracking that helps transmit real-time data across long/short distances in order to improve supply chain visibility for command staff with possibility to track and monitor assets shipment status.
- 5G network for smart warehouses – through effective, reliable and faster data transmission for devices in smart warehouses via 5G technology, it can be possible to establish smart inventory tracking and a smart shelves system, because IoT sensors can detect and alert if any product in the inventory is getting out of stock and needs to be restocked.
- Autonomous vehicles for logistics – applying 5G technology allows autonomous vehicles to self-regulate themselves reliably, accurately and safely with its high-speed data transmission, bandwidth and granular data. These self-driven autonomous vehicles are confined to warehouses but can also move onto public roads or off-roads.
- Optimizing transport routes – optimized routes are important to save expenses, fuel usage, and environmental damage. Still, in emergencies situation, it is necessary to change routes immediately to avoid any disruptions and delays. 5G technology has potential to take action and optimize new and better routes.

- Augmented Reality and Virtual Reality training in logistics – 5G, with its robust technology, higher bandwidth, and fast speed, can help boost applying augmented reality and virtual reality as technologies that can be used to train logistic staff to make them more skilled in their jobs by offering a virtually simulated environment for education in logistics.

8. 5G transforms medical care for military personnel.

The 5G-enabled AR training platform which could provide warfighters with more quality military care by enabling 5G AR telemonitoring for medical procedures, which would allow streamlined communication between centrally located medical specialists and their patients in remote locations.

It means that 5G enables a new application that promises to transform medical care for military personnel: robotic surgery. With robotic surgery, military doctors could quickly perform operations from a distance using robotic arms and cameras. Housing such equipment on medical vehicles would eliminate the need to transport patients elsewhere to begin treatment.

From the military point of view, Spectrum, 5G New Radio, 5G Core Network, Proximity Services, and Non-Terrestrial Networks (NTNs) (Bastos et al, 2021) are recognized as 5G technology enablers which have interesting potential and opportunities to be in connection with 5G Releases 15, 16 and 17, respectively.

One of important 5G technology enablers for military applications is the available radio-frequency spectrum. A significant amount of the spectrum for military usage which is arranged in multiple bands from high or mmWaves bands (above 6 GHz), over medium bands (between 1.5 and 6 GHz) to low bands (below 1 GHz) will be targeting bands for implementing 5G military technology in order to provide trade-off between capacity and coverage as well as mobility. The implementation of 5G in different sub-bands of the spectrum assigned to the military can provide cost-effective capabilities for 5G military systems.

Next, an important enabler for the military ecosystem is the 5G New Radio (NR) concept because it offers most prominent features from supporting several significant frequency ranges (from 410 MHz up to 7 GHz and from 24 GHz up to 52 GHz), over psychical layer design (using Orthogonal Frequency Multiplexing modulation (OFDM), providing Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) modes, as well as using a massive Multiple Input Multiple Output (MIMO) concept of active antennas which allow beam forming and steering in order

to reduce self and external interference and contribute the lower probability of interception as well as improve the link budget) to Integrated Access Backhaul (allowing 5G NR base stations to communicate mutually over the 5G NR air interface without the need to be connected on the backbone network and offer various opportunities to rapid deployment of sustainable 5G networks in the battlefield).

Also, 5G Core Network can play a significant role to support military usage requirements through network slicing (possibility to define the subsets of the main network (slices) which can be optimized for particular military service and performances required of the available network). Also, together with virtualization, it offers new opportunities to the military. On the other hand, Mobile Edge Computing (cloud computing can be distributed to the edge of the network (close to the Radio Access Network (RAN)) in order to provide low latency and independent operation of 5G clusters).

5G Proximity services (i.e. D2D technology as 5G Sidelink) have significant potential to provide reliable and secure communication between 5G military user equipment, especially in some military critical scenarios without necessity to use 5G RAN and core network infrastructure.

Finally, Non-Terrestrial Networks (provided by 5G satellites, aircraft or any other airborne vehicles) can extend 5G NR technology in order to provide military services with a lower propagation delay in the locations where terrestrial networks are not available. In that way, Non-Terrestrial Networks (NTNs) create opportunities to extend tactical communications and application services. Non-terrestrial networking is shown in Figure 1.

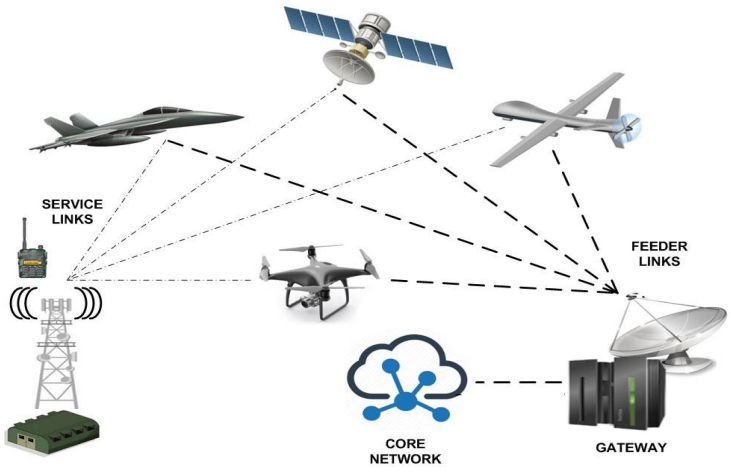

Figure 1 – Non-terrestrial networking presentation

Also, some of interesting 5G device-to-device use cases for the military are vehicle-to-everything communication (V2X) and soldier safety. The block scheme of the V2X communication modes is presented in Figure 2.

Figure 2 shows the basic concept of V2X communication modes where in some combat scenarios the combat and command vehicle as the main 5G station is interconnected with other combat vehicles by the Vehicle-to-Vehicle (V2V) mode, with soldiers by the Vehicle-to-Soldier (V2S) mode, with field command posts by the Vehicle-to-Network (V2N) mode, and with stationary command posts by the Vehicle-to-Infrastructure (V2I) mode using 5G communication infrastructure.

Wherever the network coverage is available, V2X (Vehicle-to-Vehicle, Vehicle-to-Infrastructure, Vehicle-to-Soldier and Vehicle-to-Network) can be supported via the stations using the URLLC functionality of NR together with edge computing to deliver low latencies. To support military safety applications, enhancement to the side link and proximity services are introduced. An example of the usage is when sidebank power saving features are introduced for handheld or manpack devices which are also used as position devices designed to communicate directly with combat vehicles in order to provide soldier safety.

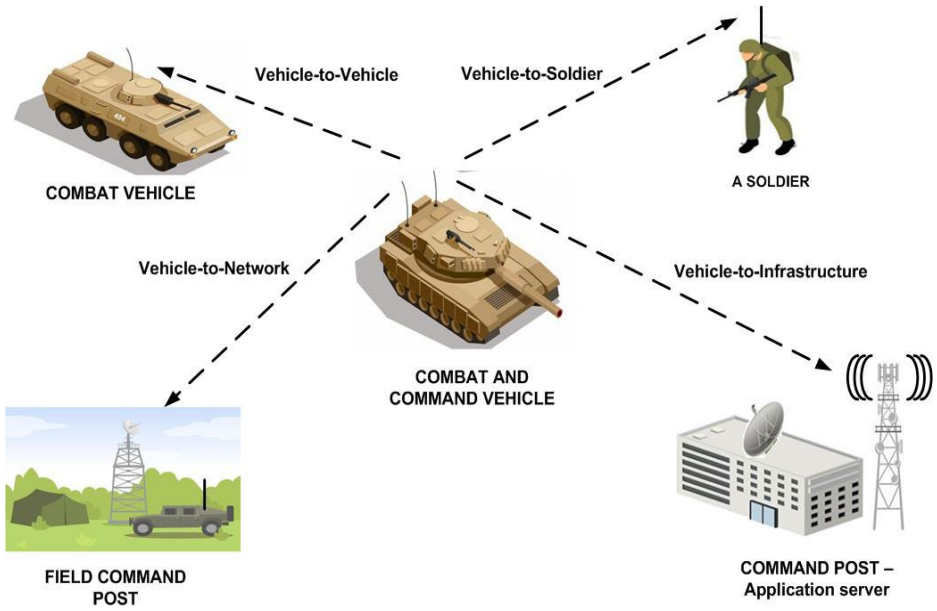

Figure 2 – V2X communication modes

Next, in the available literature, there are elaborated examples of different scenarios in several 5G military application domains which refer to deployable Communication and Information Systems (CISs), land tactical operations, maritime operations, and static communications (Bastos et al, 2021).

From the military point of view, Releases 18 and 19 are interesting because of their focus on AI/ML. Different forms of artificial intelligence incorporated in 5G communications can support military operations in order to provide operational success in various situations and scenarios as well as asset survivability through, first of all, faster situational awareness based on efficient data sharing together with effective collaborative decision making. Also, in 5G, the military's network AI will apply different techniques to provide an appropriate level of intelligence to connect different domain architectures and perform dynamic reconfigurations of the network topology at the edge in order to increase node and data security and to be more resilient to attack. The ML and heuristics as forms of AI will enable automation in the process of tracking and predicting the position of military units and resources, using the weather forecast systems, detecting different obstacles, rapidly rebuilding parts of the infrastructure, and expanding or contracting the network as needed. AI can support deploying swarms of drones in order to form autonomous, adaptive 5G cellular relays stations, which can continually adjust their positions to optimize network communications for mobile combatants and military equipment. For AI, data collection and processing is necessary to be performed between network edge devices and clouds or data centers. 5G and AI together can better support combatants, improve equipment survivability, and contribute to mission operational success in the battlefield.

Finally, different international organizations including NATO bodies and the European Defense Agency (EDA) have considered models of usage of 5G technology for military operations. Generally, they recognized 5G usage potential and benefits for defense reasons especially in the areas of deployed facilities, support, and battle zones (Zmysłowski et al, 2023).

Conclusion

One of the main ways to represent slicing as a powerful tool is to apply this technology in 5G and beyond to mobile communication systems. On the other hand, an important feature of the 3GPP Releases 15 and 16 is

that they pave the way for the introduction of 5G and 5G Advanced as well as for further development.

In the next period, it will be enabled for use cases to increase mobile broadbands. This is the time of industrial productivity resulting from the introduction of Release 16 and Release 17. The initial 6G networks will start with basic research. Network slicing is one of the types in 3GPP Release 16 and further addressed in Release 17 which were in progress in 2021 and 2022, respectively. This motivates an integration of security aspects in network slicing. Also, Release 18 which represents the first release named 5G Advanced puts the main focus on AI, ML and XR. Release 19 as the second release of 5G Advanced with its new capabilities and efficiency such as a set of features which will offer services based on extended reality as well as enhancements in AI/ML will be the next step towards 6G technology.

Next, Release 20 as one more step closer to 6G is expected in the near future.

It is evident that the 5G and emerging 6G landscapes are extremely complex with many complementary technologies and standardization effects, spectrum usage models, and industry-driven consortium developments. In the next period, in no more than five years, it will be evident that 5G and beyond networks will enable different use cases and mobile broadbands to increase. This relates, first of all, to the 3GPP features to be provided with Release 16 and 17. The end of the decade will witness the appearance of the initial 6G networks, already in development.

The standardization process for 5G different functionalities and capabilities contained in 5G Releases up to now as well as in the near future are recognized as the key enablers suitable for implementations in the military environment in modern warfare in order to provide: support for enhanced communication; control and operational efficiency; real-time data processing and support for ISR; autonomous and remote operations capabilities; improved network-centric warfare as well as the interoperability concept and cybersecurity challenges and resilient communications.

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Estandarización para la tecnología 5G y más allá: impacto en las comunicaciones militares

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CAMPO: telecomunicaciones
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: El presente artículo de revisión trata sobre el proceso de estandarización de la tecnología 5G y más allá y su impacto en las comunicaciones militares.

Métodos: Se proporcionaron métodos dominantes como análisis y síntesis para considerar los aspectos clave del proceso de evolución de la estandarización 5G a través de presentaciones de los roles de diferentes lanzamientos de estándares del Proyecto de Asociación de Tercera Generación (3GPP) y su implementación y uso en el entorno de redes de comunicación militar.

Resultados: Se presentan los antecedentes y las áreas clave en la evolución de 5G y más allá. Además, se discuten la estandarización de 5G y los problemas y desafíos militares.

Conclusión: La estandarización para 5G y el panorama emergente 6G es extremadamente compleja y altamente innovadora con muchos requisitos impulsados por la industria y la sociedad en rápida evolución. Las organizaciones de desarrollo de estándares, la industria y el mundo académico necesitan colaborar en la estandarización para facilitar la interoperabilidad mundial. El documento ofrece una descripción general de las funcionalidades de estandarización y los esfuerzos para mejorar el rendimiento del sistema 5G, así como su impacto en las comunicaciones y servicios militares. Analiza las áreas de mejoras principales para las

características existentes y la expansión a nuevos casos de uso e industrias, así como al uso militar a través de las versiones 3GPP, comenzando con la versión 15 como 5G Basic, pasando por la 16 y 17 como 5G Evolution, hasta la 18 y 19 como 5G Advanced que preceden a la próxima versión 20 y la red 6G inicial cuyo lanzamiento se espera para fines de esta década.

Palabras claves: la tecnología de quinta generación (5G), lanzamientos del proceso de estandarización 5G, funcionalidades 5G, interoperabilidad 5G.

Стандартизация технологии 5G и не только: влияние на военные коммуникации

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РУБРИКА ГРНТИ: 49.33.29 Сети связи
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Представленная обзорная статья посвящена процессам стандартизации технологии 5G и последующих технологий, а также ее влиянию на военные коммуникации.

Методы: На рассмотрение были вынесены доминирующие методы, такие как анализ и синтез ключевых аспектов процесса развития стандартизации 5G посредством презентации ролей различных выпусков стандартов Проекта партнерства третьего поколения (3GPP), а также его внедрения и использования в среде военных сетей связи.

Результаты: В статье представлены предыстория, ключевые и прочие области развития 5G. Также обсуждаются проблемы стандартизации 5G, военные вопросы и вызовы.

Выводы: Стандартизация 5G и формирующегося рынка 6G является чрезвычайно сложной и инновационной деятельностью, поскольку многие требования, предъявляемые промышленностью и социумом в целом, скоротечно меняются. В данной связи организациям, занимающимся разработкой стандартов, промышленным предприятиям и научному сообществу необходимо сотрудничать в области стандартизации для того, чтобы

обеспечить совместимость во всем мире. В статье представлен обзор функциональных возможностей стандартизации и усилий по повышению производительности системы 5G, а также ее влияния на военную связь и услуги. Также в статье анализируются области главных улучшений существующих функций и их распространения на новые варианты использованияв разных отраслях промышленности, в том числе в военном применении с помощью выпусков 3GPP, начиная с 15-го выпуска под названием 5G Basic, продолжая 16-м и 17-м под названием 5G Evolution и заканчивая выпуском 18-м и 19-м под названием 5G Advanced, которые предшествуют предстоящему 20-му выпуску и первой 6G сети, запуск которой ожидается в конце этого десятилетия.

Ключевые слова: технология пятого поколения (5Г), выпуски процесса стандартизации 5Г, функциональные возможности 5Г, совместимость 5Г.

Стандардизација за 5Г технологију: утицај на војне комуникације и остале области

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ОБЛАСТ: телекомуникације
ВРСТА ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Овај прегледни рад бави се процесом стандардизације за технологију пете генерације (5Г) и њеним утицајем на војне комуникације и остале области.

Методе: Доминантне методе као што су анализа и синтеза коришћене су за разматрање кључних аспеката процеса еволуције стандардизације 5Г кроз презентације улога различитих стандардних издања Пројекта партнерства треће генерације (3ГПП) и његове имплементације и употребе у окружењу војних комуникационих мрежа.

Резултати: Представљене су позадина и кључне области у еволуцији 5Г. Такође, дискутује се о стандардизацији 5Г и војним питањима и изазовима.

Закључак: Стандардизација за 5Г и 6Г окружење у настајању изузетно је сложена и веома иновативна и мора задовољити многе

захтеве индустрије и друштва који се брзо развијају. Организације за развој стандарда, индустрија и академска заједница морају да сарађују на стандардизацији како би се олакшала интероперабилност широм света. У раду су наведене функционалности стандардизације и настојања да се побољшају перформансе 5Г система, као и његов утицај на војне комуникације и услуге. Анализиране су области великих побољшања за постојеће функције и проширења на нове случајеве употребе у индустрији, као и за војну употребу кроз издања 3ГПП, почевши од издања 15 као 5Г Основа, преко 16 и 17 као 5Г Развој, па навише до 18 и 19 као 5Г Напредни који претходе предстојећем издању 20 и почетној 6Г мрежи чије се лансирање очекује до краја ове деценије.

Кључне речи: технологија пете генерације (5Г), издања процеса стандардизације 5Г, 5Г функционалности, 5Г интероперабилност.

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