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Naval Use Cases of 5G Technology

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ABSTRACT: Fifth-generation (5G) technology is currently developing in mobile networks. The civilian 3rd Generation Partnership Project (3GPP) standard is the basis for this implementation. Higher throughput, network capacity, user density, and lower latency are the main advantages offered by 5G over Long Term Evolution (LTE) and older standards. For this reason, these advantages are increasingly recognized in critical mission and military solutions. However, the 5G technology utilization in military equipment requires a deep analysis of the 3GPP standard, especially regarding technological gaps, security, and use cases. This is particularly important in using communication equipment during armed conflicts. Such equipment must be characterized by greater security and reliability than civilian equipment. Currently, work and analyses in this area are realized by the European Defence Agency (EDA), North Atlantic Treaty Organization (NATO) Communications and Information Agency (NCIA), Allied Command Transformation (ACT), and NATO Science and Technology Organization (STO). In the Information Systems Technology (IST) Panel of the NATO STO, the research task group (RTG) "IST-187-RTG on 5G Technologies Application to NATO Operations" is working on this topic. This paper presents exemplary 5G use cases in the navy. We indicate potential advantages, problems, and technological gaps that should be solved before implementing 5G technology in naval systems.

1 INTRODUCTION

Long-Term Evolution (LTE) as a fourth-generation (4G) standard significantly improved the quality of services (QoS) offered in mobile networks compared to the previous ones: second (2G) and third-generation (3G) standards, i.e., Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS), respectively. However, the improvement of transmission speed and the commonness of data transmission-based services using the Internet Protocol (IP) significantly impacted it. As a result, new services became popular, and older ones, such as voice and video transmission, are implemented using optimized technologies, i.e., voice over LTE (VoLTE) and video over LTE (ViLTE), respectively [1,2].

Currently, LTE is a widely used standard in mobile networks around the world. At the same time, for several years, we have been observing the dissemination of the recently developed fifth-generation (5G) standard called New Radio (NR), also known as IMT-2020, i.e., International Mobile Telecommunications (IMT) for 2020 and beyond [3]. As a result, most mobile network operators (MNOs) are also withdrawing support for older 2G and 3G technologies and using the released radio resources for the needs of 4G and 5G standards. Thanks to this, newer, more spectrally efficient radio and network technologies allow throughput and number of user increasing also QoS improvement [4,5].

5G NR is the next evolution of digital mobile networks. For 5G, there is often talk of a telecommunications revolution because 5G is referred not only to mobile networks but also to other communication standards, including wired, fiber optic, satellite, radio link, wireless Wi-Fi networks, etc. To emphasize the importance of the changes introduced in 5G, many radio and network technologies are mentioned that ensure the high performance of the new standard. The 5G standard, like the standards of previous generations, is developed by the 3rd Generation Partnership Project (3GPP). 3GPP is an international initiative bringing together many standardization organizations, national telecommunications regulators, MNOs, telecommunications equipment vendors, universities, and research and development (R&D) centers. Developing new telecommunications standards, particularly protocols, is the 3GPP goal and mission. Currently, 3GPP is working on a sixth-generation (6G) standard [6].

5G NR is a civilian standard considering the operation specificity of telecommunications systems in peacetime. By design, MNOs and communication system users adhere to the telecommunications law applicable in a given country in peacetime. These regulations, particularly those concerning the radio spectrum, consider the arrangements made during the World Radiocommunication Conference.

Direct use of civilian standards in military systems is not possible because of several premises. Firstly, military communication systems, by definition, are dedicated to wartime, when telecommunications law may be violated. This is mainly related to using radio system jamming, which is prohibited in peacetime. Therefore, military communication systems must be highly reliable and resilient to intentional interference. On the other hand, the transmission of sensitive information enforces increased system security.

The attractiveness of 5G technologies and the high efficiency of 5G NR mobile systems make it necessary to consider the implementation of civil standards in military systems [7–10]. Therefore, considering the above conditions, the civilian 5G standard is currently being analyzed regarding its usefulness in military applications. For several years, work in this field has been carried out by the European Defense Agency (EDA) and various bodies of the North Atlantic Treaty Organization (NATO), i.a., NATO Communications and Information Agency (NCIA), NATO Industrial Advisory Group (NIAG), NATO Allied Command Transformation (ACT), NATO Science and Technology Organization (STO), NATO Cooperative Cyber Defence Centre of Excellence (CCDCOE), and NATO Headquarters C3 Staff (NHQC3S). Furthermore, in the Information Systems Technology (IST) Panel of the NATO STO, the research task group (RTG) IST-187-RTG on '5G Technologies Application to NATO Operations' is working on this topic.

This paper aims to present aspects of the work carried out within EDA, NATO STO, and NCIA. Mainly, we focus on potential 5G use cases in the navy. We are based, i.a., on the works of IST-187-RTG and NCIA. Simultaneously, we highlight the Polish context concerning civil and military 5G.

The rest of the paper is organized as follows. Section 2 describes the 5G NR in terms of advantages, 5G technologies, and usage scenarios. A summary of the EDA and NATO STO works is included in Section 3. Section 4 presents 5G use cases in the navy. Finally, conclusions are provided in Section 5.

2 5G NR STANDARD

The 5G NR standard, similar to the 2G/3G/4G earlier, is developed under the auspices of 3GPP. 3GPP regularly issues technical specifications (TSs) and technical reports (TRs) that define new or update existing general specifications for cellular systems. The specifications are grouped into releases (Rel), allowing the system to be built per the standard. In this way, the possibility of cooperation between base station devices and user equipment (UE) is ensured for different vendors, operators, and countries [11].

2.1 *3GPP Releases*

The LTE system and major enhancements, LTE Advanced (LTE-A) and LTE-A Pro, were developed under Rel 8–14 specifications. LTE-A Pro is sometimes called the Pre-5G standard. The 5G standard is being developed in Rel 15-21. Rel-15 describes the so-called 5G Basic, Rel-16, and 17 – 5G Evolution, while Rel 18-21 – 5G Advanced. Rel-21 will already introduce the 6G standard (6G Basic). This is illustrated in Figure 1 [12]. Currently, Rel 18 and 19 are open while Rel 20 and 21 are planned, Rel 8-17 are frozen, and older Releases are closed [11]. Figure 2 shows the main technologies developed in Rel 15–18+ [13].

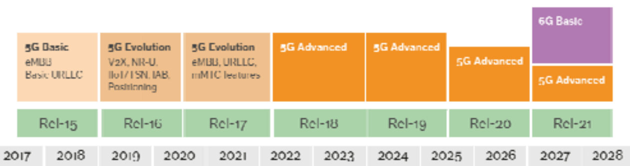

Figure 1. Evolution of 5G (source: [12]).

2.2 *Advantages*

Most works focused on 5G technologies, networks, and systems indicate significant benefits from their implementation. The most important benefits include [1,14–17]:

- throughput up to 20 or 10 Gb/s for downlink and uplink, respectively, when using the extremely high frequency (EHF) band;
- throughput of tens of Mb/s per tens of thousands of users;
- data throughput of 100 Mb/s for metropolitan areas;
- throughput of 1 Gb/s for each employee on the same office floor;
- greater network capacity - up to 10,000 times greater than today (and in laboratory conditions, even 30,000 times greater);

- up to a 1,000-fold increase in data volume per geographical area, reaching the target value of 10 Mb/s/m2 (in the case of a hotspot in indoor conditions);
- ability to support several hundred thousand simultaneous connections of wireless sensors (i.e., ultra-dense network (UDN));
- spectral efficiency significantly increased compared to 4G (peaks of 30 or 15 bit/s/Hz for downlink and uplink, respectively);
- latency significantly reduced compared to LTE (up to 1 ms);
- increased range;
- improved signaling efficiency;
- maximum mobility: 500 km/h.

However, it should be noted that the benefits outlined above are not met simultaneously for each of the considered use cases described in Section 2.4.

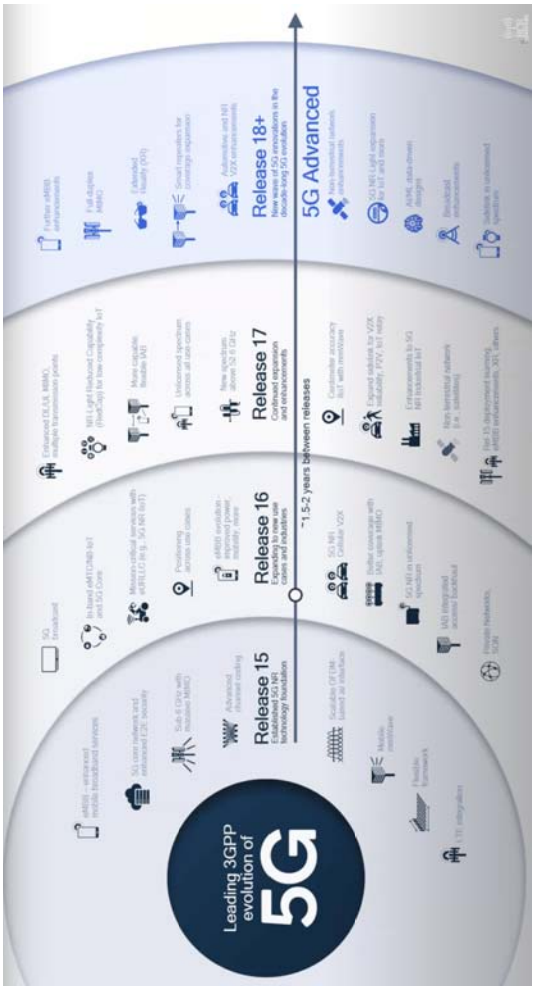

Figure 2. Main 5G releases (source: Qualcomm, via [13]).

2.3 *5G technologies*

Behind the success of the 5G standard are several radio and network technologies that are implemented in mobile networks. Among the crucial technologies, we can distinguish, e.g., [1,14–17]:

- beamforming and massive multiple-input-multiple-output (MIMO);
- millimeter waves (mmWaves);
- software-defined network (SDN), network functions virtualization (NFV);
- self-organizing network (SON), multi-access edge computing (MEC);
- network slicing;
- cloud, fog, and edge computing;
- cloud radio access network (C-RAN);
- flexible physical layer (PHY) design, integrated access and backhaul (IAB);
- Internet of Things (IoT), massive IoT, UDN;
- full duplex, machine-to-machine (M2M), device-to-device (D2D), vehicle-to-everything (V2X), and energy harvesting (EH) communications;
- radio resource management (RRM), dynamic spectrum access (DSA),
- interference mitigation;
- visible light communication (VLC);
- big data and data mining;
- artificial intelligence (AI) algorithms and methods, including machine learning (ML) and deep learning (DL);
- augmentation reality (AR) and virtual reality (VR), mixed reality (MR), extended reality, or multisensory extended reality (XR).

Implementing the new technologies in 5G networks made it possible to achieve the vision of the so-called smart car, smart home, smart city, smart health, smart grid, etc., which are inextricably linked to the 5G concept.

In 5G, various multiple access techniques will be used, including orthogonal frequency-division multiplexing (OFDM), filtered OFDM (FOFDM), pattern division multiple access (PDMA), multi-user shared access (MUSA), interleave division multiple access (IDMA), sparse code multiple access (SCMA), non-orthogonal multiple access (NOMA), new coding and modulation techniques, e.g., filter bank multi-carrier modulation (FBMC), frequency and quadrature amplitude modulation (FQAM), low density spreading (LDS). In addition, depending on the frequency ranges used (i.e., radio bands), 5G mobile networks will use a time division duplex (TDD) or frequency division duplex (FDD) as a technique for accessing the radio network.

It is worth noting that many of these technologies have been developed much longer than the 5G standard, e.g., SDN, NFV, or OFDM. Moreover, massive MIMO can also be an example of the technology already being developed in LTE-A Pro under full-dimension MIMO (FD-MIMO) [18,19]. Despite this, the abovementioned technologies have been collectively called '5G technologies'.

2.4 *Usage scenarios*

One of the first coherent visions of the 5G system is presented in the recommendation of the International Telecommunication Union (ITU) no. ITU-R M.2083 [3]. In this case, three main 5G use cases are defined:

- enhanced mobile broadband (eMBB) – a scenario that takes into account the use of high bandwidth, which is required, for example, by AR/VR/MR/XR technologies;
- ultra-reliable and low latency communications (URLLC) – a scenario for mission-critical applications that require a guaranteed connection and low latency;

– massive machine type communications (mMTC) – a scenario that considers using a huge number of devices (massive IoT, UDN).

Figure 3 presents the main three use cases for 5G technologies presented at the vertices of the triangle and other use scenarios whose location inside the triangle illustrates the need for adequate bandwidth (eMBB), low latency (URLLC), or connecting a large number of devices (mMTC) [3].

Individual use cases differ in crucial capabilities, including network energy and spectrum efficiencies, peak and user-experienced data rates, area traffic capacity, mobility, latency, and connection density. The importance of key capabilities in different 5G usage scenarios is shown in Figure 4 [3]. These key capabilities were also used to compare the effectiveness of 5G (IMT-2020) with LTE (IMT Advanced), as illustrated in Figure 5 [3].

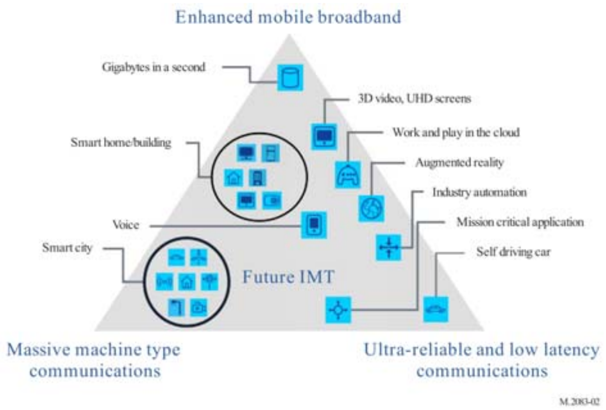

Figure 3. Usage scenarios of 5G (source: [3]).

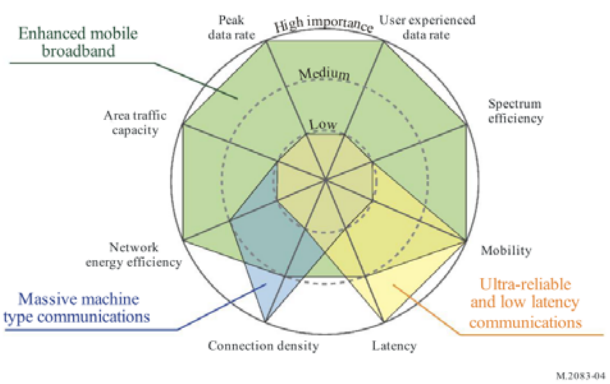

Figure 4. Importance of key capabilities in different 5G use cases (source: [3]).

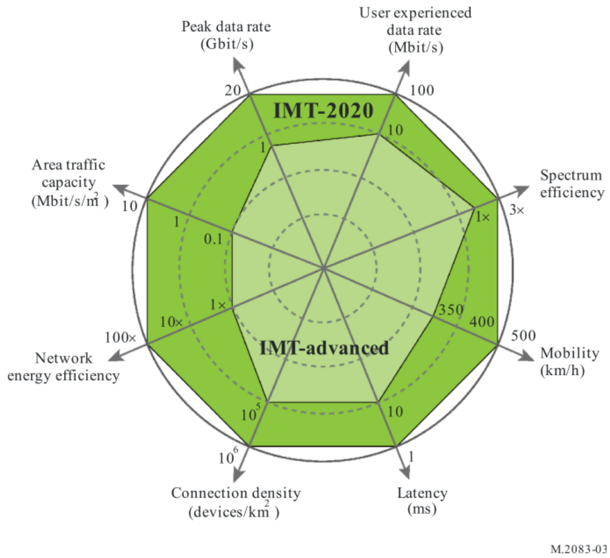

Figure 5. Enhancement of key capabilities from LTE (IMT-Advanced) to 5G (IMT-2020) (source: [3]).

2.5 *5G in Poland*

In 2018, tests and implementation of the 5G system began in Poland. In the same year, the "5G Strategy for Poland" [14] was developed by the Polish Ministry of Digital Affairs. This document indicated the importance of implementing 5G technologies and systems for developing the Polish civil telecommunications market.

In the first stage of implementing the 5G standard, MNOs implement the so-called 5G NR non-standalone (NSA) standard, the network part of which is based on the LTE standard. In the longer term, the 5G NR standalone (SA) standard will be implemented. MNOs offer their users the basic functionalities of 5G systems on LTE bands.

A significant problem in the 5G network development was the lack of allocation of radio resources in the C band (i.e., 3.4÷3.8 GHz). In December 2022, a 5G auction for the aforementioned radio resources was launched [20]. The regulator of the Polish telecommunications market, the Office of Electronic Communications, is also preparing to announce a tender for the 700 and 800 MHz frequency bands to ensure increased coverage with the 5G network.

3 MILITARY ASPECTS OF 5G

The high potential and efficiency of the 5G concerning LTE and older generations of mobile networks gave an impulse to undertake analyses in terms of the use of 5G technologies in military communication systems. The military operation specificity, particularly during armed conflicts, forces the military communication systems to ensure high reliability and resilience to intentional interference, i.e., jamming. Civil telecommunications standards and systems do not offer these features. Therefore, direct implementation of the civilian 3GPP standard into military communication systems is impossible. Thus, the undertaken analyses focus primarily on two aspects. Firstly, an indication of technological gaps in the civilian standard that should be removed before implementation into military systems. In this case, looking for proper ways to close these vulnerabilities will be necessary. Secondly, a significant issue is the designation of specific use cases of 5G technologies. It is worth noting that military use scenarios may differ from civilian ones.

3.1 *EDA workshops on 5G for defense*

In 2019-2020, the EDA Capability Technology (CapTech) Communication Information Systems and Networks (shortly CapTech Information) group organized four workshops on '5G for defense'. Typically, such workshops aim to launch a future EDA project in a given topic area. In this case, the workshop contributed to developing the document "5G technologies for defense" [21].

In this document, 5G usage and benefits for defense have been defined, including, i.a., enhancing soldier experience, improving shared governmental use, and 5G usage in areas of deployed facilities, support, and battle zone.

The authors of [21] see a problem in the production of military communication equipment, which, due to the limited group of recipients, is relatively expensive and small-amount compared to commercial systems and components for the civilian telecommunications market.

However, they point out that ready-made 5G technological building blocks, such as SON, SDN, NFV, MEC, and MIMO, can be used in military systems. On the other hand, the use of mmWaves, beamforming, D2D, and IAB technologies may allow for the reduction of radio emissions and covert transmission. Therefore, many benefits from implementing 5G technology in military systems are noticeable.

In addition, in the civil standard 3GPP, the authors of the white paper [21] diagnosed technology gaps in the following areas:
- cloud support;
- security;
- centralization;
- resilience;
- network integration & interoperability;
- identity management;
- massive MIMO;
- mmWaves;
- Doppler effect;
- IAB;
- D2D communication on the battlefield;
- integration of satellite technology.

Future military 5G projects will also be implemented under the European Defense Fund (EDF) under the auspices of the European Commission (EC), e.g., 5G COMPAD [22].

3.2 *NATO STO RTG on 5G technologies application to NATO operations*

In 2020, IST-187-RTG on '5G technologies application to NATO operations' started work, established under the auspices of the IST Panel of the NATO STO. This RTG will work until 2024, and the result of its work will be the report on "5th Generation International Mobile Telecommunications (5G) Technologies Application to NATO Operations", as well as technology trials and tests. Work at RTG carried out in four Objective Teams (OBJs):
- OBJ 1 - slicing & MEC;
- OBJ 2 - massive MIMO & full duplex;
- OBJ 3 - extreme long-range coverage;
- OBJ 3 - security mechanisms;

that focus on specific technology areas. The work of each OBJ focuses on analyzing the 3GPP standard in terms of technological gaps and assessing the potential of using particular 5G technologies in various usage scenarios (see Figure 6).

The starting point for the work of the IST-187-RTG was the technical report of the exploratory team (ET) IST-ET-096 on 'Expeditionary 5G technology' entitled "5G technologies: A defense perspective" [23] and the document entitled "Potential of 5G technologies for military application" prepared by NCIA employees [24].

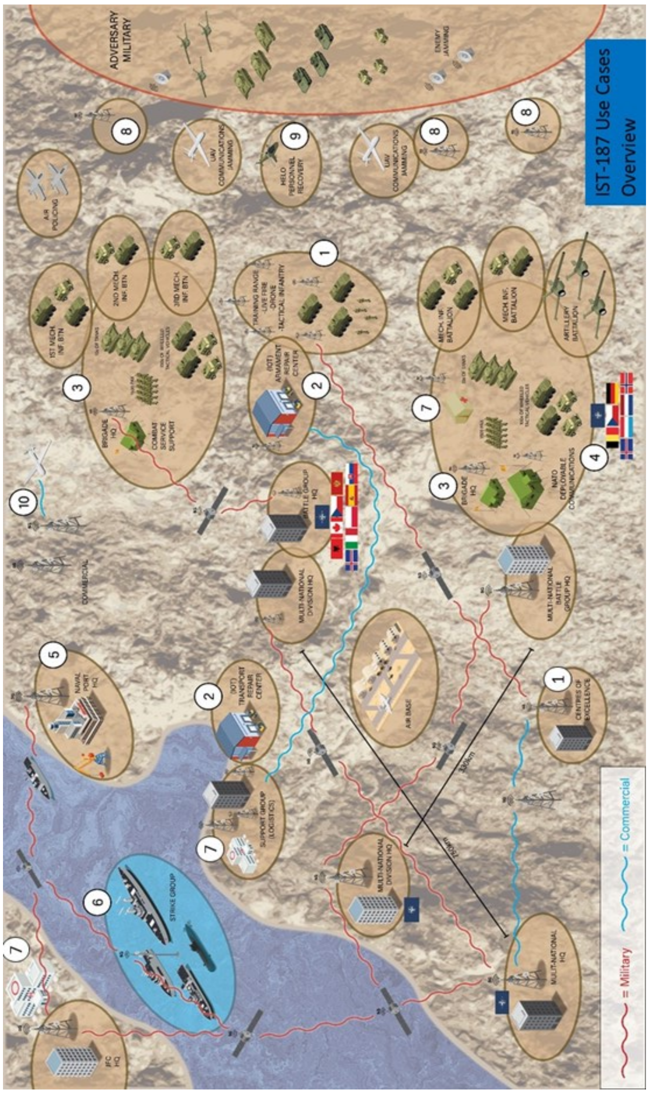

Figure 6. 5G military use cases defined by IST-187-RTG (source: IST-187-RTG).

Other international organizations, including NATO bodies: NCIA, NIAG, ACT, CCDCOE, and NHQC3S, are also analyzing the use of 5G technology for military operations. The 2021 1st Workshop on Securing NATO Military 5G Networks hosted by the ACT and CCDCOE [25], the aforementioned report [24], and the participation of employees of some of these agencies in the works of IST-187-RTG are examples of this.

3.3 *5G in Polish Army*

The potential of using 5G technologies has also been noticed in the Polish Armed Forces. However, the document "5G Strategy for Poland" [14] did not address the military aspects. Therefore, the Chief of the General Staff of the Polish Army appointed a group of experts whose task was to develop the "Concept of using 5G technologies for the needs of the Polish Armed Forces" [26].

Polish universities and companies are also involved in the international activities of EDA CapTech Information and NATO STO. Representatives of the Military University of Technology and ISN company (IS-Wireless) participated in 5G workshops organized by EDA and helped develop [21]. Poland also actively participates in the works of IST-187-RTG. The Military University of Technology, Gdansk University of Technology, Warsaw University of Technology, the Polish branch of Nokia Solutions and Networks, and ISN have representatives in this RTG.

4 NAVAL USE CASES

In [24], three marine scenarios have been defined:
– Scenario 1. Naval task force (see Figure 7);
– Scenario 2. Coastal or harbor communications (see Figure 8);
– Scenario 3. Amphibious communications (see Figure 9).

In maritime scenarios, efficient 5G systems will be used mainly for line-of-sight (LOS) short-range communications, which will be implemented between several ships, ships and other floating objects (e.g., amphibious vehicles), or ships and coastal land infrastructure. Two of these scenarios are also shown in Figure 6, i.e., Scenarios 1 and 2 as ⑥ and ⑤, respectively. The characteristics of these scenarios were presented during the conference:
– 2020 3rd Workshop on 5G Technologies for First Responder and Tactical Networks [27];
– 2021 International Conference on Military Communication and Information Systems (ICMCIS) [28,29];
– 2022 18th Conference on Automation and Exploitation of Control and Communication Systems (ASMOR) [30].

The previous works are the basis for describing the analyzed scenarios. In the final part of Section 4, we additionally address other aspects of using 5G technology in the navy.

4.1 *Scenario 1. Naval task force*

Due to the specificity of maritime operations, naval communication systems are based primarily on long-range communications, i.e., satellite communications (SATCOM) and high frequency (HF) beyond line-of-sight (BLOS) communications. Figure 7 illustrates a grouping of ships carrying out a common combat task (i.e., maritime operation) [24].

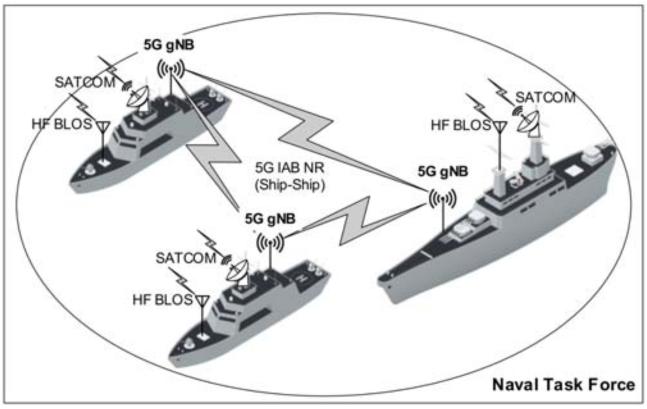

Figure 7. Naval task force scenario (source: [24]).

If the distances between ships provide LOS conditions, then 5G systems can effectively communicate between them. For this purpose, it would be required to install a 5G base station, i.e., next-generation node B (gNB), on each ship. The gNBs arranged in this way form a meshed LOS network. In this case, it is proposed to use IAB technology and the sub-6 GHz band. Such 5G connectivity will provide high throughput and low latency thanks to beamforming backhauls [24,28,29].

4.2 *Scenario 2. Coastal or harbor communications*

Another scenario presented in Figure 8 is related to the use of 5G technology for connectivity between the ship and land [24].

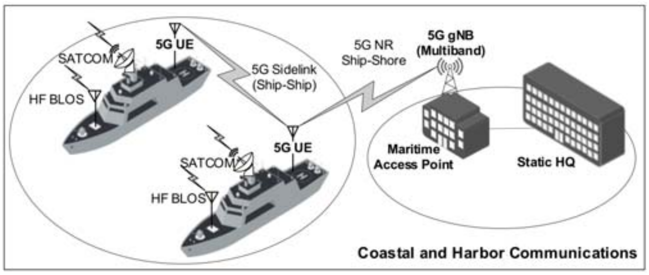

Figure 8. Coastal or harbor communication scenario (source: [24]).

Scenario 2 concerns a situation where the ship is in a harbor or near the shore, which ensures LOS conditions between the ship and the 5G land infrastructure. In this case, 5G technology can communicate with headquarters (HQ), harbor command, etc. Furthermore, communication between land infrastructure elements and the ship (5G NR ship-shore link) can be carried out via land public or private macrocell 5G gNB (e.g., multiband maritime access point) and via gNB of another ship (i.e., 5G sidelink ship-ship) considering multi -hops. In this way, the ship's 5G network is connected to the 5G network on land, which enables the relief of SATCOMs and quick exchange of information, e.g., with HQ [24,28,29].

4.3 *Scenario 3. Amphibious communications*

Figure 9 depicts the use of 5G communication between the ship, amphibious, and land units [24].

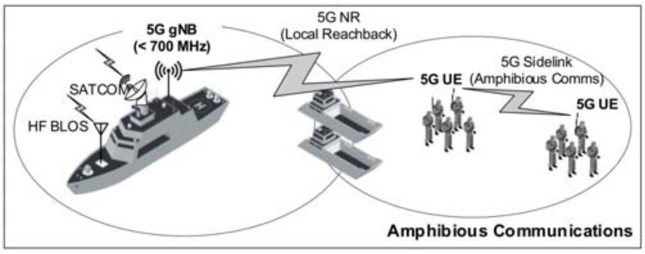

Figure 9. Amphibious communication scenario (source: [24]).

In Scenario 3, the use of lower frequency ranges (e.g., 700 MHz) by 5G gNB on the ship was proposed. Thanks to this, the gNB range is increased (e.g., in relation to the C band or NATO Band IV: 4.4÷5.0 GHz), and the possibility of ensuring connectivity with subdivisions on land (i.e., with their EU), which is essential in landing operations. In this case, using the offshore 5G network is usually impossible. On the other hand, there is the potential for non-LOS (NLOS) conditions to occur. In this way, tactical satellite (TACSAT) and tactical terrestrial communications are relieved [24,29].

4.4 *Other scenarios*

In [28], additional proof of concept requirements for coastal communication scenarios is presented, which consider the following:

- two-tier, point-to-multipoint (PTMP) and meshed architecture;
- multiple band support;
- the minimum coverage range of 15 km from the shore station to maritime platforms and between ships;
- above 10 Mbit/s gross channel capacity, with support of IP data traffic;
- suitable EU and gNB ship-borne equipment;
- low latency access to applications on the edge of the 5G network;
- active mitigation of electromagnetic (EM) interference;
- availability of highly integrated and easy-to-operate systems by unskilled personnel;
- availability of dynamic and flexible network topologies, enabled by sidelink and IAB-based NR communications;
- the optimal choice of operating band (and carrier aggregation schema) for the EM constraints and propagation conditions;
- continuous and reliable operation under intentional interferences;
- active reduction of EM signature;
- fully autonomous mobile networking.

When analyzing the possibilities of 5G technology, it is also worth noting the benefits of using higher radio frequency ranges, i.e., EHF in particular mmWaves, and optical communication, i.e., VLC. Utilizing EHF and optical bands allows for a significant reduction of EM signatures. VLC can be an ideal solution to provide covert communication between ships or between ship and offshore infrastructure, i.e., for Scenarios 1 and 2. In this case, good visibility and a calm sea must be present. The ship's onboard connectivity can be implemented using mmWaves.

Given the nature of military operations, reconnaissance, and electronic warfare (EW) systems are always analyzed with communications systems. EW systems are used to disrupt enemy communications. Currently, work is underway to develop effective jamming methods concerning civil and future military 5G systems [10,31–35]. Jamming systems are essential from the viewpoint of EW ships.

Other aspects of using 5G and 6G technologies in maritime communications, along with using an unmanned aerial vehicle (UAV), were presented, among others, in [36,37]. The development direction of maritime transport indicates that modern civilian vessels and military ships use more and more sensors, also in the form of autonomous unmanned surface (USV) or unmanned underwater vehicles (UUV). From the 5G system viewpoint, modern ships can be treated as smart vessels that will have to provide connectivity for massive IoT [38].

5 CONCLUSIONS

Currently, we are witnessing a revolution taking place in the civil telecommunications market. This is related to introducing the 5G standard in mobile networks. The use of several new telecommunications technologies, 5G technologies, has contributed to a significant increase in the efficiency of provided telecommunications services. Therefore, it is planned to use these advantages in future military communication systems. In this paper, we presented an analysis of the use of 5G standards and technologies in military solutions, particularly concerning naval use cases. We present the potential possibilities of using 5G in several marine scenarios. In addition, we introduced the works carried out by international and national bodies responsible for setting directions for the development of future military systems.

ACKNOWLEDGMENT

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ABBREVIATIONS

2G	second generation
3G	third generation
3GPP	3rd Generation Partnership Project
4G	fourth generation
5G	fifth generation
6G	sixth generation
ACT	Allied Command Transformation
AI	artificial intelligence
AR	augmentation reality
BLOS	beyond line-of-sight
C-RAN	cloud radio access network
C3	consultation, command, and control
CapTech	Capability Technology
CCDCOE	Cooperative Cyber Defence Centre of Excellence
D2D	device-to-device
DL	deep learning
DSA	dynamic spectrum access
EC	European Commission
EDA	European Defence Agency
EDF	European Defence Fund
EH	energy harvesting
EHF	extremely high frequency
EM	electromagnetic
eMBB	enhanced mobile broadband
ET	exploratory team
EW	electronic warfare
FBMC	filter bank multi-carrier modulation
FD-MIMO	full-dimension MIMO
FDD	frequency division duplex
FOFDM	filtered OFDM
FQAM	frequency and quadrature amplitude modulation
gNB	next generation node B (or 5G base station)
GSM	Global System for Mobile Communications
HF	high frequency
HQ	headquarter
IAB	integrated access and backhaul
IDMA	interleave division multiple access
IMT	International Mobile Telecommunications
IMT-2020	IMT for 2020 and beyond
IoT	Internet of Things
IP	Internet Protocol
IST	Information Systems Technology
ITU	International Telecommunication Union
LDS	low density spreading
LOS	line-of-sight
LTE	Long-Term Evolution
LTE-A	LTE Advanced
M2M	machine-to-machine
MEC	multi-access edge computing
MIMO	massive multiple-input-multiple-output
ML	machine learning
mmWaves	millimeter waves
mMTC	massive machine type communications
MNO	mobile network operator
MR	mixed reality
MUSA	multi-user shared access
NATO	North Atlantic Treaty Organization
NCIA	NATO Communications and Information Agency
NFV	network functions virtualization
NHQC3S	NATO Headquarters C3 Staff
NIAG	NATO Industrial Advisory Group
NLOS	non-line-of-sight
NOMA	non-orthogonal multiple access
NR	New Radio
NSA	non-standalone
OFDM	orthogonal frequency-division multiplexing
PDMA	pattern division multiple access
PHY	physical layer
PTMP	point-to-multipoint
QoS	quality of service
RRM	radio resource management
SA	non-standalone
SCMA	sparse code multiple access
SDN	software-defined network
SON	self-organizing network
Rel	release
RRM	radio resource management
RTG	research task group
SATCOM	satellite communications
STO	Science and Technology Organization
TACSAT	tactical satellite
TDD	time division duplex
TR	technical report
TS	technical specification
UAV	unmanned aerial vehicle
UDN	ultra-dense network
UE	user equipment
UMTS	Universal Mobile Telecommunications System
URLLC	ultra-reliable and low latency communications
USV	unmanned surface vehicle
UUV	unmanned underwater vehicle
V2X	vehicular-to-everything
ViLTE	Video over LTE
VLC	visible light communication
VoLTE	Voice over LTE
VR	virtual reality
XR	extended reality (or multisensory extended reality)

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