Potential of 5G technologies for military application

Working paper, 15 Sep 2020 |

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***Abstract*–5G specifications and technologies implementing the International Telecommunications Union (ITU) IMT-2020 vision represent a paradigm shift in International Mobile Telecommunication (IMT) standards compared to previous IMT generations. 5G is poised to push the technology limits in many areas, particularly at the radio interface level. With the first 5G network rollouts taking place, a lot of attention to 5G is being given by many actors, including the military. As with any technological breakthrough, 5G is prone to significant hype and misconceptions. This paper provides an overview of 5G technologies and identifies key 5G technology enabling features for military applications. It then proposes a number of initial reference 5G military scenarios where the use of 5G systems or technologies could bring significant benefits to military users, either as private 5G implementations or as use of public 5G infrastructure. It then provides conclusions and recommendations to military communications stakeholders. Detailed rationales will be made available in a technical report. The authors intend to submit a revised revision of this paper to an IEEE conference.**

Keywords*–*5G; IMT-2020; Transmission Systems; Expeditionary Operations; Deployable CIS; Tactical Communications; Maritime Communications; Static Communications; Public Safety.

I. Introduction

In support of the NATO Headquarters C3 Staff (NHQC3S) Programme of Work for Communications Interoperability and Spectrum, NCI Agency conducted a technical assessment of 5G technologies and of their potential for military application. Owing to the complexity of the topic and to the evolving nature of 5G standardization and development, the project team developed products in an incremental manner, starting with a technical presentation [1] to collect initial findings and support discussions with NHQC3S sponsors. The work then progressed towards developing a technical report [2] to be published in Oct 2020 and aimed at: a) Providing informed technical inputs and advice to NATO stakeholders; b) Identifying opportunities in 5G technologies and 5G infrastructure for military application; c) Developing initial reference 5G military scenarios with supporting rationales; and d) Providing conclusions and recommendations for follow-on discussions with stakeholders. This working paper conveys an overview of the technical report [2] ahead of its publication. It follows its structure but addresses some topics superficially, especially the rationales associated with the proposed reference 5G military scenarios.

II. Background and Context of 5G

A. IMT-2020 Vision & Usage Scenarios

The vision for the future of International Mobile Telecommunication (IMT) generation of standards, *IMT for 2020 and beyond*, was developed by the International Telecommunications Union Radiocommunication Sector (ITU-R) in [3]. It developed the (communications) **usage scenarios** and (user) **applications** that are represented in Fig. 1.

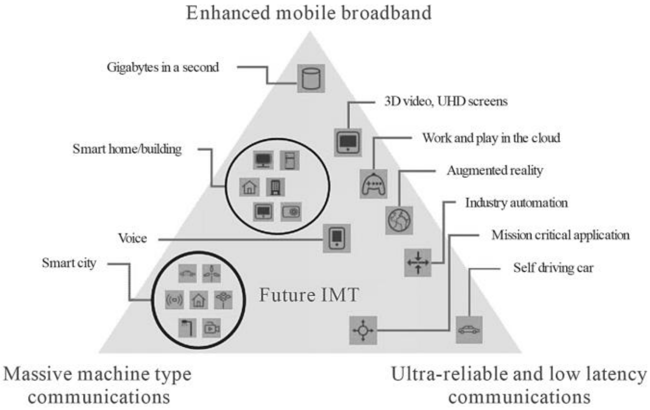

Fig. 1. Usage scenarios and applications for IMT-2020 and beyond [3].

The IMT-2020 **usage scenarios** are as follows:

- **Enhanced mobile broadband (eMBB)**. This is 'traditional' IMT services: human-centric services requiring high traffic bandwidth, high density of users with low to medium mobility, i.e., enhanced 4G data services. A particular case is Fixed Wireless Access (FWA) service providing last-mile fixed connectivity to areas underserved by cabled access infrastructure.
- **Ultra-reliable and low latency communications (URLLC)**. This communications service provides limited throughput but low latency and high availability data services to applications not requiring high throughput but requiring high connectivity in mobile scenarios. Application examples include near-real-time human-machine (or machine-machine) interfacing, such as remote control or industrial applications.
- **Massive machine type communications (mMTC)**. These communications services address the Internet of Things (IoT) applications in which a very large number of connected devices with disadvantaged radio connections require low throughput and intermittent low-volume of non-delay-sensitive data.

ITU-R also conveyed two important key messages:

- IMT-2020 technology footprint will be extended to vertical business areas that had not been considered in previous IMT generations.
- The different requirements of each usage scenario are not compatible with 'one-size-fits-all' technology approaches, as no single design can cope with such disjoint requirements.

In the IMT-2020 context, ***usage scenarios*** address the features and services of the underlying communications layers; ***applications*** refer to the upper layers of the Open Systems Interconnection (OSI) model that use the communications services provided by the 5G networks and systems.

B. Standardization of IMT-2020

The 3rd Generation Partnership Project (3GPP) is the most influential specification body working on IMT technologies and specifications aimed at meeting the IMT-2020 requirements. 3GPP aligned its work plan with IMT-2020 standardization schedule and, from Release 15 [4] onwards, 3GPP technologies are labelled "5G" (5th Generation). 5G is comprised of both evolution of previous generations of cellular mobile technologies (e.g., Long Term Evolution (LTE)) and brand-new technology.

In 2018, 3GPP submitted Release 15 to ITU for evaluation as a candidate IMT-2020 technology. This submission comprises both 4G LTE (evolved radio interface) and 5G New Radio (5G NR), a totally new radio interface, complemented by a new core network. According to ITU-R, submissions were under evaluation in June 2020. Since 5G follows the principle of interworking with existing LTE technologies, particularly the Radio Access Network (RAN) and Evolved Packet Core (EPC) main system components, 3GPP implemented a specification strategy based on two phases:

- **5G Phase 1**. Consists of Release 15 and defines a new radio interface (5G NR) and improvements to 4G LTE. Phase 1 addresses eMBB usage scenarios from 2020 onwards only, for which the most significant customer base already exists. This approach allows a smooth transition and sustained life extension of LTE technologies for mobile network operators (MNOs), while providing users with IMT-2020 capabilities.

- **5G Phase 2**. Release 16 and beyond – it comprises the necessary technology enablers of the three IMT-2020 usage scenarios (eMBB, URLLC and mMTC).

Considering the maturity level of 3GPP releases, it is worth noting that MNOs are marketing the rollout of 5G based solely on Release 15, which has limited scope in terms of usage scenarios (eMBB only). As a result, initial 5G rollouts are mostly providing improved 4G data services to mobile or fixed (via FWA services) users.

III. Main 3GPP System Components and Key Foundations of 5G

Fig. 2 represents a very simplistic view of the 3GPP System Concept for 5G, according to 3GPP's submission of Release 15 as IMT-2020 candidate technology. It shows the main system components of cellular 5G networks, as well as the main technical foundations of 5G (in the two balloons).

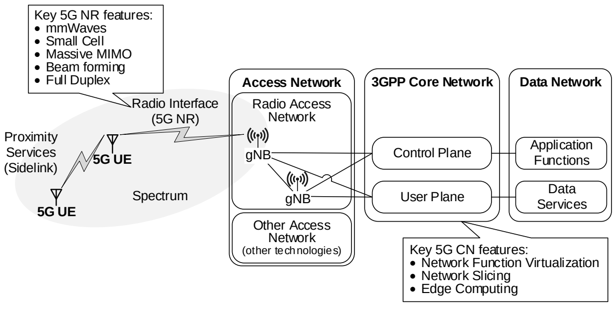

Fig. 2. Main system components of 5G networks (per 3GPP Release 15) & key foundations of 5G (per IMT-2020 Vision).

The 5G system is composed of the following components:

- The **User Equipment** (UE) is the generic name of mobile devices, which can take the form of several instantiations (smart personal devices, terminals, vehicles, things, etc.). Proximity Services (ProSe) through direct communication between devices are allowed and encouraged.

- The **Access Network** is completely new and can accommodate several access technologies such as 3GPP and non-3GPP radio interfaces and fixed interfaces (e.g., LTE, WiMAX, cdma2000, Wi-Fi, etc.). Its main component is the 3GPP 5G NR Radio Access Network, which is composed of 5G NR base stations (gNB).

- The **5G Core Network** provides a clear separation between control and user planes: the control plane controls 5G services (e.g., authorization and mobility management); the user plane provides user data carriage services (e.g., data forwarding, QoS).

- The **Data Network** hosts application functions (services trusted by the operator) and user applications. The data network can be the Internet or any other network.

There are **5 key foundations of 5G New Radio**, per IMT-2020 Vision: a) **Millimetre Waves** (mmWaves), to allow extreme spectrum bandwidth; b) **Small Cell**, to allow small footprint, high-density base stations; c) **Massive MIMO**, to allow multiple simultaneous data streams (making use of the multipath propagation nature of mobile communications); d) **Beam forming**, to allow steerable data streams, improved radio links and reduced interference; e) **Full Duplex**, to allow simultaneous transmission and reception at the same frequency.

There are **3 key foundations of 5G Core Network**: a) **Network Function Virtualization**, to allow a fully virtualized architecture; b) **Network Slicing**, to allow logical end-to-end networks tailored to usage/customer needs; c) **Edge Computing**, to allow resources where they are needed, i.e., close to the access network.

Most of the '5G hype' occurs while addressing 5G NR technologies, as many technologies identified in IMT-2020 Vision are not available in 3GPP Release 15 and are only planned for specification in later releases (or not even planned, like Full Duplex). Therefore, informed discussions on 5G need to be aware of the status of 3GPP releases to understand what exactly is (or may be) available for deployment. Additional details are available in [2].

IV. Key 5G Technology Enablers for Military Applications

We identified 5 main 5G technology enablers that collectively or separately may bring significant opportunities for military applications. They are: **Spectrum, 5G New Radio, 5G Core Network, Proximity Services**, and **Non-Terrestrial Networks (NTNs)**. They are addressed below.

A. Spectrum

5G uses radio-frequency spectrum from previous IMT generations but also brings new frequency bands to the IMT service, most notably frequency bands above 6 GHz. Frequency bands available for IMT-2020 are grouped using a rationale for trading coverage with capacity. They are as follows:

- **Bands above 6 GHz (high bands or mmWaves)**. High bands allow large assignments of contiguous spectrum (up to 800 MHz). Propagation in mmWave ranges is subject to rain attenuation, high propagation loss, and quasi-optical behaviour requiring line-of-sight condition, as addressed in [5].

- **Bands between 1.5 and 6 GHz (medium bands)**. Medium bands provide sufficiently large assignments of contiguous spectrum (up to 100 MHz) which enables eMBB scenarios. They offer immunity to rain attenuation and a good trade-off between coverage and capacity, allowing MNOs to deploy 5G systems co-located with LTE radio sites.

- **Bands below 1 GHz (low bands)**. Low bands provide macro coverage features to 5G, but not eMBB capacity, due to intrinsic low spectrum availability and to only narrow bands being available for IMT service. These bands provide coverage but not capacity, and are therefore suited for low traffic density areas.

Significant IMT spectrum harmonization has occurred in the medium and high IMT bands. 3GPP Release 15 defines 5G frequency bands in a different way, as **Frequency Range 1** (FR1 – 410 to 7,125 MHz) and **Frequency Range 2** (FR2 – 24.25 to 52.60 GHz).

5G technologies are also targeted to make use of different types of spectrum, either by traditional access or through spectrum aggregation: licensed, shared, and unlicensed.

B. 5G New Radio (NR)

5G NR addresses the interface between the core network and the user equipment (including mobility management and other functions) and is the focus of technology developments in the 5G ecosystem. 5G Radio Access Network (RAN) is composed of LTE base stations (eNBs) and 5G NR base stations (gNBs). The most prominent features are:

- **Support of two frequency ranges**. 5G NR supports both FR1 and FR2 ranges and allows the use up to 100 and 400 MHz of spectrum per 'carrier' bandwidths, respectively. Different spectrum use approaches are enabled by carrier aggregation techniques or by Multi-Radio Access Technology (multi-RAT).

- **Physical Layer Design**. Both 4G LTE and 5G NR use Orthogonal Frequency Division Multiplexing (OFDM) modulations for multiple access and radio resource allocation. 5G NR provides both frequency division duplexing (FDD) and time division duplexing (TDD), with mmWave only working in TDD mode. 5G NR further extends the use of Multiple Input Multiple Output (MIMO) to massive MIMO and introduces the concept of active antennas in IMT, allowing beam forming and beam steering. Beam forming contributes to significantly reduce self-interference and improved link budgets.

- **Integrated Access Backhaul (IAB)**. IAB consists in using part of gNB radio resources for backhaul purposes, allowing gNBs to communicate with one another over the 5G NR air interface [6]. It facilitates the deployment of dense cellular networks without the need to cable all gNBs to the backbone network.

C. 5G Core Network (CN)

5G eMBB, URLLC and mMTC usage scenarios have mutually exclusive requirements. As cost efficiency and scalability are drivers for 5G development, 5G CN provides a scalable network solution that is flexible enough to support the different usage requirements. Most noteworthy 5G CN technical features are:

- **Network Slicing**. It is a network orchestration technique that allows MNOs to define subsets of the main network (a slice), each of which can be optimized for a particular service and performance target and/or to a specific customer. Network slices are cross-layer abstractions that include the RAN and where resources can be assigned flexibly. It is an end-to-end technology requiring specific functionality from the user equipment, radio access network, and core network. Slicing is expected from 3GPP Release 17 onwards.

- **Mobile Edge Computing (MEC)**. As 5G's virtualization approach allows advanced concepts such as mobile cloud computing (MCC), the resource pool can be de-centralized (distributed MCC) to the edge (the RAN). This enables low latency at the application level and autonomous operation of 5G clusters (with no backhaul connection), by running a fully independent 5G NC and a small RAN using an MCC cluster.

D. Proximity Services (ProSe)

In 3GPP, ProSe address communications between user equipment (UE) without the intervention of the 5G RAN or 5G CN. Previously, ProSe were enabled by device-to-device (D2D) communications. D2D was first introduced in 3GPP's Release 12 (as LTE technology), had limited use cases, and was eventually not implemented by industry. In 5G, 3GPP refers to D2D technology as **5G Sidelink**, which is now seen as attractive for cell coverage extension, emergency/public safety, and machine-to-machine interaction. 5G Sidelink is naturally limited in range (link budgets are disadvantaged) but offers potential for specific stress scenarios.

E. Non-Terrestrial Networks (NTNs)

5G NTNs extend the scope of 5G NR technology and associated benefits to non-terrestrial platforms. An airborne 5G NR architecture allows MNOs to provide 5G-based services in locations where terrestrial networks are not available using the 5G NR radio interface, thus not requiring any intermediate protocol or technology conversion. 5G NTNs can be provided by satellites, high-altitude platform stations (HAPS) or any other airborne vehicle able to carry the NTN payload. Low Earth Orbit (LEO) satellites and aircraft are the most promising vehicles, due to the associated lower propagation delay. 5G NTN technology solutions are under evaluation in Release 16 work, whereas specifications are expected for 3GPP Release 17.

V. Opportunities in 5G Technology for Military Applications

Many of the features and technologies associated with the 5G technology enablers identified in the previous section provide opportunities for beneficial application to military capabilities in different military scenarios. Noting that military capability development involving new technologies and concepts is a recursive and long-lead process (a workflow based on sequential concept development, system development & prototyping, experimentation & testing, and analysis

& discussion with stakeholders), we identify the following opportunities of 5G technologies for military contexts:

*1) **Implementation of 5G NR in different types of spectrum and in multiple bands enables the implementation of cost-effective militarized private 5G systems**.*

5G will be implemented in different types of spectrum (licensed, unlicensed and shared) and in new frequency bands – in mmWave frequencies (providing high-capacity line-of-sight applications) and in low frequency bands (facilitating highly mobile tactical scenarios, for instance). Also, the fact that 5G will be implemented in different frequency sub-bands for different regions/countries, opens the door to cost-effective implementations of military capabilities in frequency bands of military interest.

For instance, 5G will be massively implemented in the 3.5 GHz frequency band(s) in Europe, but there are implementations in the 4.5-4.9 GHz band foreseen in Japan. The latter falls within the NATO Tactical Relay 4.4-5.0 GHz frequency band, which is ideal for tactical use, making it likely that a military communications vendor may have easy access to key enabling building blocks (e.g., chipsets and antenna systems).

*2) **5G NR in mmWaves opens the door to sophisticated high-capacity and electromagnetically discreet military systems**.*

In a military context, the propagation challenges of mmWaves can be regarded as enabler of relatively covert radio systems. The discretion potential of mmWaves is augmented by 5G NR technologies, such as beam forming. The study of mmWave 5G NR in military scenarios is deemed of high interest.

*3) **5G NR massive MIMO and beam forming create opportunities for high-capacity tactical wireless systems**.*

The advent of very large MIMO antenna arrays (massive MIMO) combined with beam forming significantly increases the performance of 5G NR vs 'classic' radio technologies including LTE, in turn paving the way for high-performance and cost-effective tactical radio systems subject to challenging antenna alignment conditions.

For example, beam forming provides an opportunity for the rapid deployment of self-pointing antennas in the battlefield (e.g., no need to point antennas deployed on tactical masts). Beam forming may also contribute to reduce external interference and lower the probability of interception.

*4) **5G Proximity Services (ProSe) and Integrated Access Backhaul (IAB) are attractive for 5G-based multi-tiered and/or meshed tactical applications**.*

ProSe (or 5G Sidelink, for UE-UE radio links) and 5G IAB (for gNB-gNB radio links) facilitates a number of 'infrastructure-less' tactical scenarios where multi-tier and/or meshed arrangements of wireless systems are desired.

Particularly, IAB offers interesting opportunities to rapid deployment of autonomous 5G clusters in the battlefield (without backbone connections to ground infrastructure) and to meshed maritime networks, especially in case of long-range requirements under challenging propagation conditions.

*5) **Virtualization and slicing offers new opportunities (and associated challenges) to the military**.*

Virtualization of the 5G core and access network components and network slicing offer an array of new opportunities to the military, including associated technical and security challenges.

For instance, it allows the military to use a slice of public 5G infrastructure as a dedicated private-like infrastructure in hosting territory, 'pizza box-type' solutions of private military systems for tactical use (system-in-a-box solutions), or multi-use private 5G systems for tactical use (e.g., providing both eMBB and URLLC features in the same private tactical 5G system to support both multimedia communication and blue-force tracking or logistics applications).

*6) **5G NTNs may create new application opportunities in the tactical domain**.*

The specification of 5G NTN technology architectures is not a priority in 5G standardization and is far from being a reality. However, it may create opportunities to extend tactical communications and application services to a naturally deprived joint operations area (in terms of supporting communications infrastructure), by means or airborne or satellite-based 5G systems.

For instance, airborne 5G NTN systems could illuminate a tactical joint operations area, providing broadband communications and other applications (e.g., force tracking, intelligence, etc.) to mobile troops on the ground and reach-back connectivity to distant parent tactical HQs.

VI. Initial Reference 5G Military Scenarios

A. Approach

The identified opportunities brought by 5G standards and technologies with the potential to overcome previous technologies shortcomings and address several operational challenges motivated the discussion and development of ***initial reference 5G military scenarios***. The aim of these initial scenarios is to help foster follow-on discussions with the different stakeholders, including NATO scientists, military users, policy makers, capability developers, industry and academia, noting that the topic is evolving continuously. As discussions progress, scenarios will be refined, further developed and/or augmented.

The approach for scenario development addressed 5G mainly as a wireless communications system, rather than a platform of applications and services which are part of the 5G ecosystem. Therefore, the scenario descriptions focus on the underlying communications layers of 5G (ISO layer 4 and below) and their improved services to the applications layers above, which is a topic for subsequent analyses.

A total of **ten scenarios** in **four different 5G military application domains** were developed and are described in [2] in detail, addressing the operational use case, the 5G-based technical concept, the key 5G technology enablers, the operational benefits to military users, and the challenges of the concept itself and of its development and implementation (by military communications industry). For each scenario (and 5G system in each scenario), it also provides a table listing key scenario features, key 5G enablers, key operational benefits, and challenges, for reference. An additional six 5G scenarios were listed in [2] but not described in detail, as they require further consideration and discussion. The four **5G military application domains** are: a) Deployable CIS for Expeditionary Operations, b) Land Tactical Operations, c) Maritime Operations, and d) Static Communications. They are succinctly described in the following sub-sections. Details on key scenario features, key 5G enablers (for each scenario), key operational benefits, and associated challenges, as well as additional rationales, are provided in [2].

B. Deployable CIS (DCIS)

The two DCIS scenarios are represented in Fig. 3 and Fig. 4 and address **Large Operational Deployable Headquarters (DHQs)** and **Small Operational DHQs**. They deal with expeditionary operations and the operational level of command (for command & control (C2)), and consider the use of high-performance 5G systems to provide wireless connectivity inside the DHQ, as enabler of quick DHQ setup and tear-down.

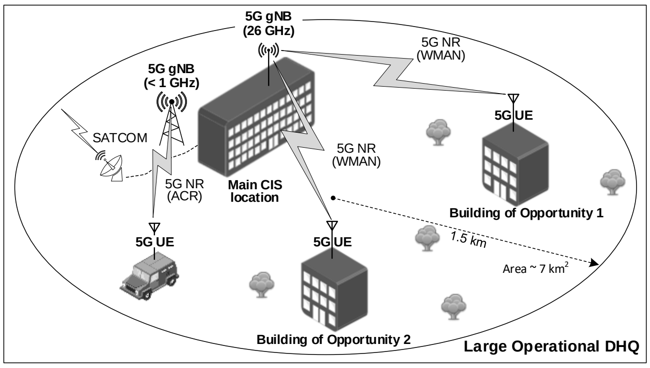

Fig. 3. Large Operational DHQs in a Deployable CIS scenario.

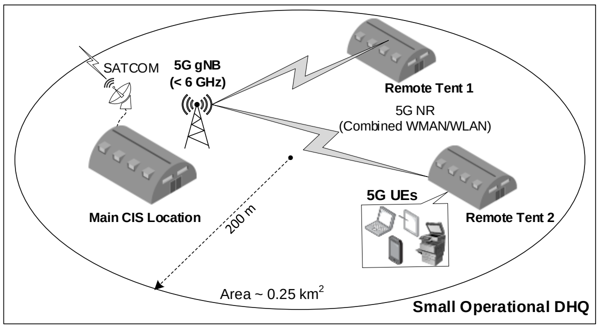

Fig. 4. Small Operational DHQs in a Deployable CIS scenario.

For the Large Operational DHQ scenario (Fig. 3), private 5G implementations are proposed to provide both Wireless Metropolitan Area Network (WMAN) distribution and Area Coverage Radio (ACR) transmission services. In this concept, a high-capacity WMAN private 5G cell operating in mmWave frequencies is deployed as a fixed wireless access (FWA) point-to-multipoint (PTMP) system operating in the 26 GHz band (a NATO harmonized frequency band). For the ACR system, the concept is predicated on implementing a multimedia macro coverage cell illuminating the full DHQ area and beyond, via the implementation of a private 5G cell in low band (below 1 GHz), ideally in the NATO 225-400 MHz UHF band. Such system could provide augmented capacity and multimedia services (video, messaging, broadband data and other applications) to mobile users around the DHQ.

For the Small Operational DHQ scenario (Fig. 4), a private single-tier high-capacity 5G system provides combined WMAN and Wireless Local Area Network (WLAN) connectivity in the 5G Sub-6-GHz (mid) frequency band, ideally in the 4.4-5.0 GHz band (often referred to as NATO Band IV), providing both capacity and flexibility. In this concept, single 5G base station could provide both high capacity (i.e., up to a total system capacity of up to ~1 Gb/s over a 100 MHz [1] wideband radio channel) and mobility around the small DHQ, as the tents are mostly transparent to radio frequencies. Users could use this infrastructure to carry all application services (real-time and non-real-time traffic, etc.)[2]. Using the 4.4-5.0 GHz band, while not ideal for mobile communications but desirable for spectrum management aspects, is compensated by the high-performance features of 5G NR, such as beam forming and massive MIMO, and by the electromagnetic transparency of tents.

C. Land Tactical Operations

A typical Land Tactical Operations scenario is represented in Fig. 5 and Fig. 6 below (two variants of the same scenario) and addresses **multinational land tactical operations**. These use cases refer to land operations at Brigade (Bgde) and below levels, and address the use of 5G systems to provide augmented wireless connectivity at tactical levels, as a practical solution for interoperable broadband tactical communications in mostly benign situations.

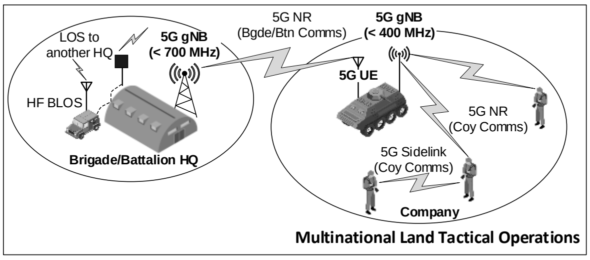

Fig. 5. Terrestrial networking in Land Tactical Operations scenario.

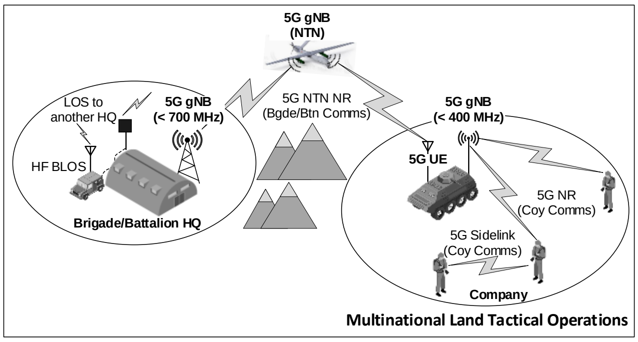

Fig. 6. Non-terrestrial networking in Land Tactical Operations scenario.

Tactical waveforms are designed to cope with moderate to high electronic warfare (EW) threat scenarios and have high system gain factors and low electromagnetic signatures, resulting in limited data rates. 5G technologies are less robust but have very high spectral efficiency and bandwidth, and could be considered as cost-effective and practical augmentation systems for tactical operations, particularly when EW threat scenarios are unlikely.

In this concept, private 5G implementations are considered as augmentation systems to nominal Combat Net Radio (CNR) network capabilities in support of land tactical operations, with two variants for the first tier. In the terrestrial variant (Fig. 5), a Sub-1-GHz terrestrial 5G macro cell is deployed at a Bgde/Battalion (Btn) HQ and would provide augmented tactical reach-back connectivity from Company (Coy) units to the parent Bgde/Btn HQ. In the non-terrestrial variant (Fig. 6), the tactical reach-back connectivity is

[1] Considering a 10 b/s/Hz spectral efficiency, which assumes the use of massive MIMO and beamforming.

[2] For instance, computer laptops and/or thin clients would feature embedded 5G network cards/modems.

provided by an airborne 5G non-terrestrial network (NTN), which would overcome severely disadvantaged terrain conditions (or longer separation distances between Bgde/Btn HQs and Coy units).

For the second tier providing Company communications, a 5G Sub-1-GHz tactical 5G cell (in the upper end of NATO's UHF band, 400 MHz) is deployed on a mobile Coy command post providing augmented tactical communications and other services to mobile troops equipped with tactical 5G mobile terminals featuring 5G Sidelink mode. Such augmentation services would complement CNR networks in benign EW conditions, enhancing situational awareness and functional services down to the dismounted soldier.

D. Maritime Operations

Maritime scenarios are represented in Fig. 7, Fig. 8 and Fig. 9 and address three different maritime scenarios: **Naval Task Force**, **Coastal/Harbour Communications** and **Amphibious Communications**. Maritime scenarios deal with close-proximity naval communications in radio line-of-sight (LOS) condition, and consider the use of high-performance 5G systems to enhance ship-ship, ship-amphibious and ship-shore connectivity, providing low latency and high capacity augmentation communications systems to nominal tactical satellite (TACSAT), CNR and subnet-relay nominal maritime communications.

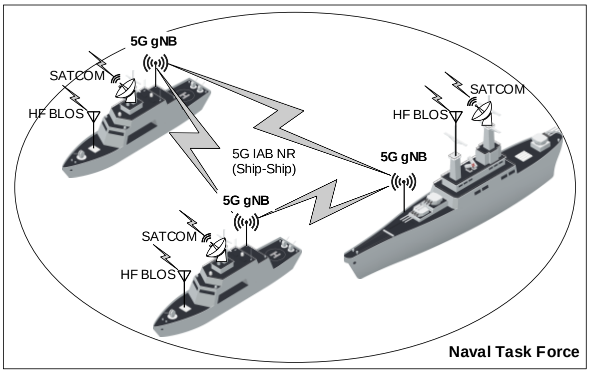

Fig. 7. Naval Task Force scenario.

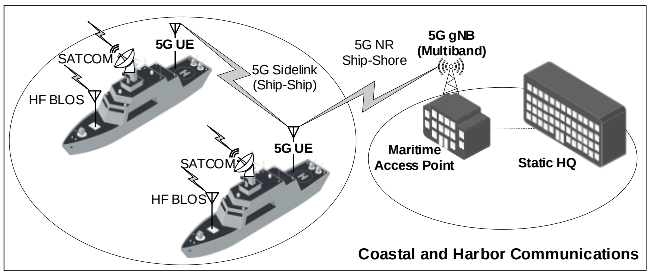

Fig. 8. Coastal/Harbour Communications scenario.

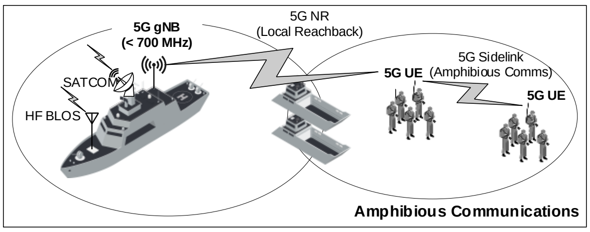

Fig. 9. Amphibious Communications scenario.

For the Naval Task Force scenario (Fig. 7), a 5G system based on IAB technology is proposed to provide ship-ship communications in the Sub-6-GHz (mid and low) frequency bands. In this concept, IAB-enabled gNBs are deployed on each ship, forming a meshed LOS network. Such a meshed network would provide high throughput and low latency ship-ship communications, as IAB takes advantage of gNB antenna and radio characteristics.

For the Costal/Harbour Communications scenario (Fig. 8), a shore-based public or private 5G macro cell provides ship-shore connectivity, offloading and/or complementing satellite communications. This concept could be implemented either through network slicing of a public 5G network, or through the deployment of a private coastal-based 5G military communications network. A combination of coastal-based cellular coverage and Sidelink is also considered for multi-hop range extension.

For the Amphibious Communications scenario (Fig. 9), a shipborne 5G private cell is proposed to augment local amphibious reach-back communications. In this concept, a Sub-1-GHz 5G cell (in the 700 MHz band), deployed at an amphibious assault ship, along with Sidelink-enabled 5G terminals, provides high data rate local reach-back connectivity to mobile amphibious units, augmenting CNR and TACSAT capabilities.

E. Static Communications

Static Communications scenarios are represented in Fig. 10 and Fig. 11 and address two different scenarios: **Internal IT Infrastructure** and **Fall-Back WAN Connectivity**. Both deal with static infrastructure and address the use of high-performance 5G systems to provide wireless connectivity between static site and inside military campuses/HQs, as enabler of high throughput and high assurance wireless connectivity.

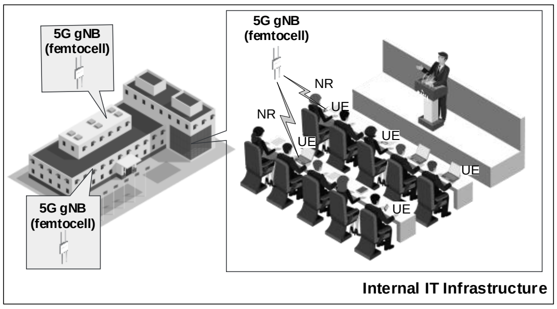

Fig. 10. Internal IT Infrastructure scenario.

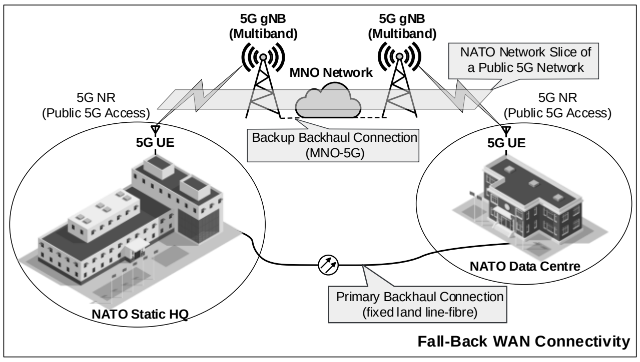

Fig. 11. Fall-Back WAN Connectivity scenario.

For the Internal IT Infrastructure scenario (Fig. 10), private 5G infrastructure is proposed to provide WLAN distribution in military static locations. In this concept, a high-capacity 5G-based WLAN system in the unlicensed frequency bands, ideally in the 5.0 GHz unlicensed sub-bands (regulations vary by country), is used as the baseline technology to provide corporate WLAN connectivity to all wirelessly connected network devices in a NATO static HQ. Such QoS-rich WLAN solution would provide high-quality fixed and mobile connectivity to all wirelessly connected network and user terminals, providing a high-quality user experience and very high flexibility to both users and facilities managers.

For the Fall-Back WAN Connectivity scenario (Fig. 11), the use of public 5G infrastructure is proposed to provide fall-back wide area network (WAN) connectivity to static NATO headquarters, in case nominal connectivity is momentarily unavailable. In this concept, a network slice of a 5G MNO is used to provide fall-back WAN connectivity to the Internet when nominal WAN connectivity is unavailable and for high-priority traffic during those periods.

VII. Conclusions

Based on the findings obtained so far, the authors draw the following conclusions:

*1) **5G is a complex topic that is moving very fast**.*

The 5G ecosystem caters for multiple usage scenarios (eMBB, URLLC, and mMTC) and different applications from the outset. It also pushes the limits of technology in several areas in both access and core networks, with the ambition to develop specifications likely to encounter significant implementation challenges. In addition, its standardization and development efforts are moving very fast, with intensive research and development (R&D) and testing being conducted at multiple venues. Many key features of 5G (and enablers of many military applications) are still to be specified (in 3GPP Releases 16 and 17) and implemented. Credible analyses in this topic area, particularly addressing the identified challenges, require significant effort.

*2) **There is significant misinformation regarding 5G**.*

Available information on 5G is plagued by marketing hype promoted by many commercial stakeholders, providing misleading information to stakeholders including the military. For instance, current 5G implementations are based on 3GPP Release 15, which only addresses the eMBB usage scenario, offering improved 4G data services to the current customer base. Touted applications like IoT, machine-type communications, remote control, telemedicine over 5G networks, etc. require blanket deployments of 5G cellular networks supporting URLLC and mMTC usage scenarios. Although technically possible, it is not taken for granted that new 5G features and associated benefits will be available in the near future, due to technical and economic factors.

*3) **3GPP is the most prominent requirements and specifications development body**.*

The future of 5G technologies is decided at 3GPP, which is influenced by civil commercial industry. Participation by military stakeholders at 3GPP is key to report new developments to the military community, to influence the introduction of military requirements in future 5G specifications and to develop key 5G enabling features such as 5G Sidelink and IAB. This aspect is also discussed in [7].

*4) **5G offers opportunities and challenges for military applications in different military application domains and utilization concepts**.*

Section V identified a number of opportunities and challenges brought by a number of 5G technologies, including spectrum for military applications. The scenarios identified in [2] and succinctly described in section VI above also show that 5G has significant potential to provide augmentation communications and application services to military users in different scenarios in different **5G military application domains** (DCIS for Expeditionary Applications, Tactical Operations, Maritime Operations, and Static Communications) and using different **5G utilization concepts** (Use of private 5G systems, Use of public 5G networks by military users, Use of select 5G technologies in private/bespoke military systems). These opportunities also present a number of challenges to both military users and military communications industry and need to be further discussed and assessed.

*5) **5G implementations and deployments are at early stages, but intensive R&D is ongoing**.*

With rare exceptions, initial deployments of 5G networks will be extensions of 4G LTE networks (i.e., non-standalone mode) and address eMBB usage scenarios only. Yet, many developers and operators are conducting intensive R&D activities not only at technical level but also at application level (industry verticals). It is essential that military stakeholders engage with these players to assess findings and consider them in concept development activities for military capability development using 5G technologies.

*6) **There are many unknowns in 5G development**.*

As said before, 5G pushes many technology limits in terms of specification (which is ongoing), development, and implementation. For instance, the use of mmWaves for mobile communications will require massive deployments of 5G base stations (micro or pico cells), which may prove to be challenging with current regulatory and administrative paradigms and/or not commercially viable. Also, the actual propagation characteristics of mmWave frequencies in the context of mobile communications is not well known yet.

*7) **Lack of MOTS implementations limits assessments of military usage**.*

Focus of mobile industry is on civil public applications (with the exception for industrial private solutions) and, despite widespread interest in the military, there is limited (if any) implementation of military grade/military off-the-shelf (MOTS) systems based on 5G technologies that can be assessed. Therefore, it is fundamental to engage with military stakeholders and military communications industry to identify and explore scenarios of interest.

VIII. Recommendations

Based on the conclusions above, we recommend military communications stakeholders at NATO and nations the following:

*1) **Organize a workshop with military communications stakeholders on 5G to discuss ideas, collect inputs, and synchronize findings**.*

Different communities and teams across the military communities are looking at the potential and challenges of 5G from different angles. In this context, it is pertinent to organize an informal discussion to synchronize views and collect inputs to discuss interim results, identified opportunities, initial reference 5G military scenarios, and collect additional inputs, to prepare follow-on engagements with other stakeholders including industry. In this discussion, it is also critical to involve multiple communities of interest (i.e., Cyber, Intelligence, Command and Control and Core Services).

*2) **Conduct comprehensive assessments of 5G for military application**.*

Given the complexity of the topic (see Conclusion 1), the evolving standardization activities, the different potential implementation domains and variables, and the immaturity of some 5G features, the credible investigation of 5G and related technologies for military application requires a significant and stable effort to be conducted by a technical team, which is only possible with a robust and relatively long-term involvement.

*3) **Engage with the military communications industry to assess the state of the art in 5G developments and discuss implementation challenges in military scenarios**.*

The initial reference 5G military scenarios highlighted in this paper have identified a myriad of implementation challenges (in [2]) for the associated technical concepts on the use of private or public 5G systems in NATO/military scenarios. In ad-hoc contacts with 5G industry and operators, the authors also noted a number of ongoing R&D activities in different laboratories to assess experimental 5G technologies and applications. Therefore, it highly recommended that military representatives and scientists engage with these communities to obtain first-hand feedback on the implementation challenges associated with some reference military 5G scenarios[3].

*4) **Publish a technical paper in a credible military communications conference**.*

In order to facilitate informed dialogues with stakeholders on military applications/use of 5G technologies and systems, as well as to raise awareness to the potential and associated implementation challenges of some concepts, it is key to bring awareness to the topic and to communicate it to a wide audience. Publishing a concept paper on the initial opportunities and challenges of military applications of 5G technologies in the form of a credible technical paper facilitates this effort and contributes to informed discussions with a large audience.

*5) **In assessing the potential of 5G, assess also the potential of related wireless technologies**.*

5G is highly related to other technologies both at the Radio Access Network (RAN) and at the Data Network levels. Specifically, the 5G RAN has an open architecture to include the integration with other wireless access technologies (e.g., LTE Advanced, WLAN technologies, NTN-based 5G). In turn, some these non-5G wireless technologies[4] may bring significant benefits to some military applications and should be also addressed.

*6) **Invest in monitoring, participating and contributing to 3GPP's work plan**.*

As per stated in Conclusion 3, 3GPP is the forum where 5G requirements and specifications are discussed and agreed. Having military representatives participating at 3GPP would ensure that military interests are better represented and would provide the informed inputs to civil participants interested in military/public safety applications. NATO scientists could play this role and represent NATO/military interests at 3GPP.

*7) **Consider developing a multi-stakeholder effort to exploit the potential of 5G and other civil high-performance wireless technologies in support of military applications**.*

Given the need to conduct significant work to effectively assess the potential of 5G and related technologies for effective military applications, it is recommended that NATO and national stakeholders concert efforts to achieve tangible results in the field of military applications of 5G that can be shared between NATO and national military communities. Many of the initial reference 5G military scenarios described in this paper deal with NATO and/or national capability development (5G-based private military systems to support operations), interoperability (5G augmentation systems for cost-effective communications interoperability in select scenarios), IT Infrastructure for NATO/national military users, and/or the use of public 5G (civil) telecommunications networks by the military. Combining R&D efforts in this area would achieve critical mass in the effort in a cost-effective approach aligned with Smart Defence concepts.

IX. Acknowledgments

This work was sponsored by NATO International Military Staff (IMS) C3 Programme of Work in support of Communications Interoperability and Spectrum managed by the NATO Headquarters C3 Staff.

X. References

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[3] For instance, the performance assessment of 26 GHz FWA prototype implementations.

[4] For example, Wi-Gig (Gigabit WLAN in mmWaves), Li-Fi (light-based WLAN), LoRA (for efficient IoT applications), etc.