Standards-Based Agile Radio Systems and Tactical Interoperability; the Use of 3GPP Protocols in Tactical Networks

Alex Hamilton, Balazs Bertenyi, Karen Murphy, Philippe Agard, Ken Spruyt and Dave Peterson

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Alex Hamilton
Nokia
Cambridge, UK
alexander.hamilton@nokia.com

Balazs Bertenyi
Nokia
Budapest, HU
balazs.bertenyi@nokia.com

Karen Murphy
Fenix Group Inc.
Chantilly, VA, USA
kmurphy@fenixgroupinc.com

Philippe Agard
Nokia
Paris, FR
philippe.agard@nokia.com

Ken Spruyt
Nokia
Antwerp, BE
ken.spruyt@nokia.com

Dave Peterson
Fenix Group Inc.
Chantilly, VA, USA
dpeterson@fenixgroupinc.com

***Abstract*—In this paper the authors explore the 3GPP communications network architecture and associated standards-based interoperability and how this could provide a robust and reliable communications network to enable Joint All Domain Command and Control (JADC2). The communications stacks of 4G LTE and 5G are explored, evidenced by demonstration activity based on the implementation of a 4G LTE tactical node.**

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***Keywords*— 3GPP, 4G LTE, 5G, JADC2**

I. Introduction

The ability to conduct NATO operations in a deployed environment fundamentally relies on an interoperable, secure, resilient, and robust C4 network architecture.

This architecture in turn relies on communication protocol standardization to enable these architectures, such as Link 16 [1], Link 22 [2], NATO Narrowband Waveform [3], NATO Wideband HF [4], and JANUS [5] to name a few; yet these protocols have limited flexibility and do not always have a clearly defined path to evolve in a timely manner to meet the needs of NATO, or undergo continuous technical scrutiny and evolution via appropriate government and industry experts.

In contrast the civilian telecommunications industry, through the process of 3GPP, has developed and continues to develop a high performance, highly resilient communications network that evolves via regular releases to meet the needs of both Mobile Network Operators (MNOs), as well as industry verticals.

3GPP develops these specifications via proposals that are submitted to the various working groups that undergo scrutiny and assessment by a large community of the mobile telecommunication industry, before being agreed by all members to eventually become part of the next release, and the cycle continues. This cycle of releases can be seen in Figure 1 which shows the release schedule for 5G and 6G releases within 3GPP

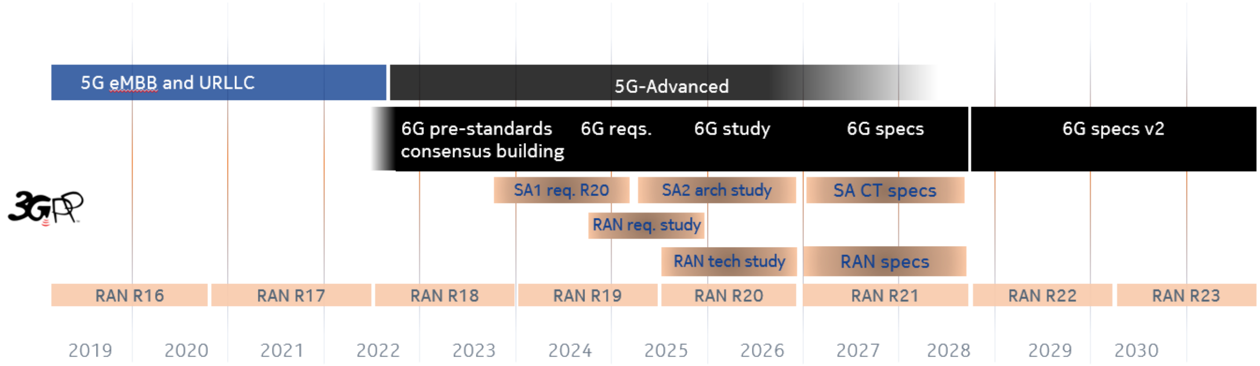

Figure 1 : Release Schedule for 5G, 5G Advanced and 6G

This process ensures that the protocols provide the flexibility and performance demanded by the end users, but also means a significant amount of research is contributed globally to ensuring high performance is achieved; over the last two decades alone Nokia has invested more than €130B on communications R&D (of which the vast majority directly contributed to 3GPP). In contrast for example the UK (as a significant partner in NATO) Communications and Networks Research Programme has a budget of £100M over the period 2022-2027, which if extrapolated to two decades would only be £400M, a significant order of magnitude less.

One of the key drawbacks regarding the utilisation of 3GPP protocols within the tactical battlespace is the centralised nature of cellular communications, relying on a relationship between a central base station and User Equipment (UE). This is in direct contrast to some of the more flat networks currently in use by NATO, such as MANET via NBWF [6]. 3GPP features such as side link (originally part of 4G LTE specifications) go some way to meet this capability requirement, however the UE products are not fully mature, primarily due to a lack of market opportunity from MNOs.

In this paper, the authors introduce 3GPP communications protocols, analyse the performance comparison between 5G New Radio (NR) Physical layer and NATO Narrowband Waveform, and further provide some initial results of the use of a commercial 4G LTE tactical offering. The structure of the paper is depicted in Figure 2.

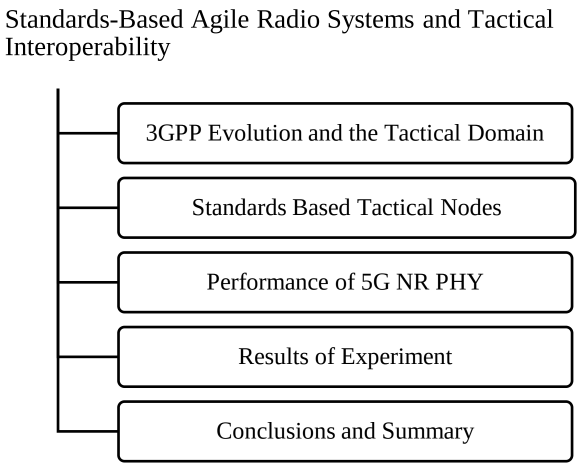

Figure 2: Structure of Paper

II. 3GPP Evolution and the Tactical Domain

3GPP maintains a continual release cycle to meet the emerging and demanding needs of Communications Service Providers (CSPs) and MNOs, yet specific industry verticals exist, such as public safety, rail, manufacturing etc. It is possible to observe defence and security as other industry verticals when utilising 3GPP protocols.

The commercial success of private wireless access, as can be seen in [7], has direct implications for defence. Private LTE and 5G (NSA and SA) cellular networks offer significant bandwidth increases for military forces and solve the previous issue of relying on untrusted, unowned infrastructure. Adoption of this technology was limited in the past due to security concerns, but private wireless access has addressed these issues.

The advancement of 5G NR based slicing promised to resolve infrastructure issues, but the concept of private cellular emerged as a game changer. Private cellular networks, based on commercially available 3GPP Release 15 capabilities, are widely adopted for industrial use cases in Europe, Asia and the US, particularly with the liberalization of spectrum such as CBRS in the US. Some implementations also incorporate Edge-as-a-Service and other novel techniques, though these are not yet standardized by 3GPP.

3GPP's definition of the Non-Public Network (NPN) was established in Release 16 and refined in Release 17, though it remains to be seen how much of these standards will be adopted into Commercial Off-the-Shelf (COTS) product offerings.

It is likely that a mix of public-private integration will exist in the future, as this concept gains more attention. Furthermore, it is important to note that political considerations, both market and national interest driven, also play a role in these technical 3GPP discussions.

The US DOD stated within it’s new "5G strategy implementation plan" [8] that the US must play a lead role in shaping information and communications technology standards. It is expected to be true for NATO and NATO partner nations.

Whilst private wireless can be directly employed in several NATO use cases, such as deployed HQ elements and expeditionary hotspots, it is important to note the slew of features that are being developed under 3GPP that could have direct relevance to the defence and security community. A number of these are introduced below, however please note this is a small selection of features which may be of interest specifically for JADC2.

A. Enhanced Physical Layer Performance

The enhanced physical layer performance of 5G NR represents a significant advancement over previous cellular standards, providing faster speeds, lower latency, and improved reliability. This improvement is achieved through the use of innovative techniques such as massive MIMO, which enables higher spectral efficiency. The physical layer of 5G NR also employs advanced coding and modulation techniques, which improve the efficiency of the wireless link. These enhancements allow 5G NR to support a wide range of new use cases, including enhanced mobile broadband, massive machine-type communications, and ultra-reliable low-latency communications.

B. Non-Terrestrial Networks

Non-Terrestrial Networks (NTN) refer to the use of airborne or satellite-based communication platforms for providing wireless coverage, especially in areas where terrestrial-based networks are not available or are inadequate. Within 5G, NTN represents a significant opportunity to expand the reach of the network and provide connectivity in remote and rural areas, as well as in areas where terrestrial-based networks are unreliable or unavailable. NTN protocols are being developed as part of Release 17 and beyond.

C. Side Link

Side Link is a feature of the 3GPP standards, from 4G LTE onwards, that allows direct communication between two

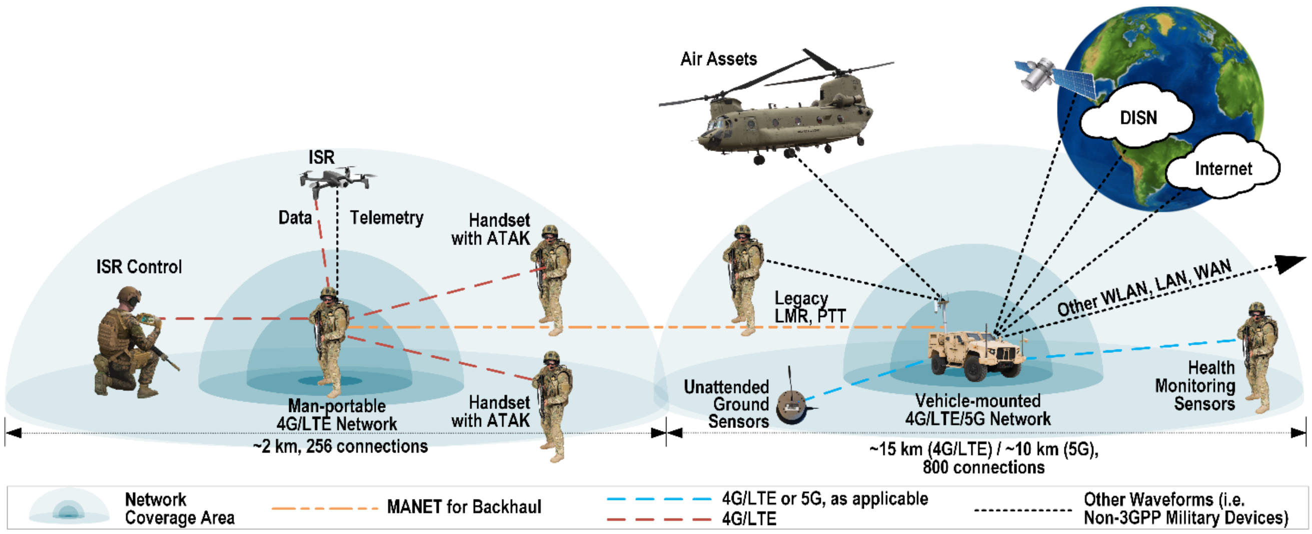

Figure 3 : Operational View – 1: Network of Networks

UE devices without the need for a central base station. This enables communication in situations where the UE devices

are out of range of a base station or when a direct connection is required. Side Link provides a more flexible and decentralized communication solution compared to traditional cellular communication, making it well suited for use in tactical and emergency situations.

D. *Integrated Access and Backhaul*

Integrated Access and Backhaul (IAB) is a key component of 5G networks, providing a seamless and efficient solution for connecting users to the network core and enabling high-speed data transfer between different network segments. IAB combines traditional access and backhaul technologies into a single system, reducing the complexity and cost of deploying and maintaining a 5G network. This integrated approach enables the efficient use of spectrum resources, improves network performance and coverage, and provides a scalable and flexible solution for supporting the growing demand for 5G services and applications.

E. *Low PAPR-Design Waveforms*

Within Release 15 and onwards of 3GPP, there are ongoing work items to reduce the Maximum Power Reduction (MPR) and Peak to Average Power Ratio (PAPR) of the Physical layer of 5G NR. This is in order to enable the base station and UE to transmit at maximum power efficiency for a given radiated power requirement and thus achieve improved coverage.

This PAPR reduction is one of the reasons that military communications systems typically use Continuous Phase Modulation schemes to maintain a constant power envelope whilst operating in or near the non-linear region of a power amplifier. The techniques proposed and being developed for Low PAPR techniques in 5G could be directly applicable to defence and security communications systems.

F. *Agile Radio Systems*

5G NR introduces the concept of a ‘resource grid’ which provides a division of the frequency and time domain into a grid of equally spaced resource elements. This division of the available resources into a grid allows for the efficient allocation of these resources to individual users and services, depending on overall network (or channel) needs.

The resource grid in 5G NR enables an Agile Radio System, which can adapt to the changing demands of the network in real-time, including link degradation to individual UEs (similar to that which may be experienced through jamming). The resource grid provides a flexible framework for the allocation of resources, allowing the system to dynamically allocate resources as needed to meet these demands. The resource grid also provides a scalable and flexible solution for the implementation of new services and applications, as the grid can be easily reconfigured to support new requirements. This enables 5G systems to support a wide range of use cases and applications, including low-latency and high-throughput services, and to effectively address the diverse demands of the user through an Agile Radio System.

G. *Coverage Enhancements*

3GPP is also looking to increase the coverage from a given base station, or minimize bottlenecks in UE uplink performance. This is of particular interest for rural coverage, and range extension.

The techniques 3GPP is developing in 5G NR and beyond are directly applicable to coverage enhancements which are likely to be of interest for defence and security communications systems.

III. Standards Based Tactical Nodes

In the context of an evolving battlefield with the increasing use of uncrewed assets, it is crucial to maintain Multi-Domain Integration (MDI) through JADC2 in order to achieve mission success. To achieve both sovereign and coalition MDI, it is essential to utilise proven, standards-based interoperability.

Figure 3 provides an example of the systems and standards-based interoperability. It illustrates three tactical zones of 3GPP-based communication systems working together to produce a network effect for MDI.

Federated Mission Networking (FMN) is a NATO concept for the interconnection and interoperability of military communication networks. It aims to provide seamless and secure information exchange between different nations and their military forces, even when using different communication systems and technologies. FMN enables more effective and efficient cooperation between NATO members in modern military operations. Yet it does not seek to tackle the underpinning problem of interoperability by design nor does it specify the performance requirements of wireless access devices entering the network.

Standards such as NBWF, Common Data Link (CDL) and WBWF attempt to answer some of these underpinning problems in Physical layer interoperability yet are often not driven to be optimised performance Radio Access Networks, but instead minimum viable options for interoperability across nations. This is in part due to market drivers in the defence community, compared to the vast market opportunities available for commercial cellular communications.

As an alternative and in addition to these existing NATO wireless communications standards, it is further possible to utilise 3GPP-based communications such as 4G LTE and 5G to enable interoperability and to provide enhanced physical layer performance and flexibility. Furthermore, these protocols have significant efforts both in their development and in their performance requirement specifications which ensures that any equipment developed according to these specifications guarantee minimum performance.

Application layer systems, such as Tactical Assault Kit (TAK)[9], are designed to be agnostic to the underlying bearer, which means that they do not depend on the specific technology used for transmitting data. Instead, these systems focus on providing specific functionality and services to the user, regardless of the underlying communication infrastructure. This allows them to be easily adapted to new or changed networks, without requiring changes to the application itself.

For example, a TAK system designed for military communications may use a variety of communication bearers, such as satellite, MANET, or even 5G to transmit data. The TAK system would use the appropriate bearer for a given task or situation, without the need for the user to be aware of the specific technology being used. This makes TAK systems highly flexible and adaptable to changing operational needs and environments.

By being agnostic to the underlying bearer, application layer systems such as TAK provide a higher level of interoperability and ease of use, allowing users to focus on their mission and objectives, without being concerned with the specifics of the communication technology being used.

It is these principles of interoperability at both the application and physical layer that have led to the development of a standards-based interoperability node, known as Banshee Mobile Radio, which will be discussed in section V.

IV. Performance of 5G NR PHY vs NATO NBWF

In order to provide a direct comparison to an existing NATO standard, we wish to compare the spectral efficiency vs SNR, and compare the performance of 5G vs NBWF in an Adaptative White Gaussian Noise (AWGN) Channel.

This enables a direct comparison between the two physical layers and further allows us to understand how many Modulation and Coding Schemes (MCS) enable the system to be adaptive and flexible to channel conditions (including how they may be degraded by non-cooperative noise sources).

It is important to note however, that NBWF will (potentially) have a performance gain due to its narrower band (assuming optimal filtering) corresponding to Equation 1.

$$Gain = 10 \times log10\ (\frac{BW_{5G}}{BW_{NBWF}}) \qquad (1)$$

Currently the minimum BW of 5G NR is fixed at 5 MHz, but as a further example of industry verticals influencing 3GPP to meet their needs, the railway industry requires use of mission critical communications down to 3 MHz due to limited spectrum access from the legacy GSM-R frequency bands dedicated to rail; this is described in RP-213603 [10]. It is crucial to keep in mind that the main limitation of the bandwidth is caused by the Synchronization Signal Block (SSB) from the base station. A narrowband version of SSB is being developed for 3GPP Release 18, as indicated in [9]. However, the UEs are capable of using a much narrower bandwidth of 1 Resource Block (180 kHz, with FR1 and 15 kHz subcarrier spacing).

Therefore, the narrowband gain of NBWF over 5G NR ranges from 23 dB (for 5 MHz 5G BS vs. 25 kHz NBWF modes NR-N4) to 2.3 dB (for 180 kHz 5G UE vs. 50 kHz NBWF modes N5-N6), as demonstrated.

However, to fairly compare the physical layer performance, it is more useful to use a bandwidth-independent metric like Spectral Efficiency, which considers important variables but offers a level playing field between the two physical layers.

In order to compare the performance, results for NBWF were taken from Le Nir et al [11] and for 5G NR the Channel Quality Indication (CQI) mode is utilized. Results are performance results taken from Kovalchukov et al [12].

The CQI table and its associated modulation and coding schemes can be seen in Table 1, which is taken from the 5G Technical Specification [13].

Table 1 : CQI Index and Associated MCS

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

Once the results from [11] and [12] are plotted we can observe Figure 4, which plots the discrete modulation and coding schemes of each MCS from both NBWF and the CQI table of 5G NR.

As can be observed in Figure 4, 5G NR offers much greater flexibility in its choice of MCS for a given channel SNR, specifically if the region between 2.4 and 21 dB SNR is observed; the NBWF only offers 4 discrete MCS for data throughput, whilst 5G offers 10.

This increase in discrete MCS options, allows for much finer granularity of data throughput as channel conditions degrade or improve based on external factors, such as interference and allow the user to maintain the most efficient data throughput available for a given channel condition.

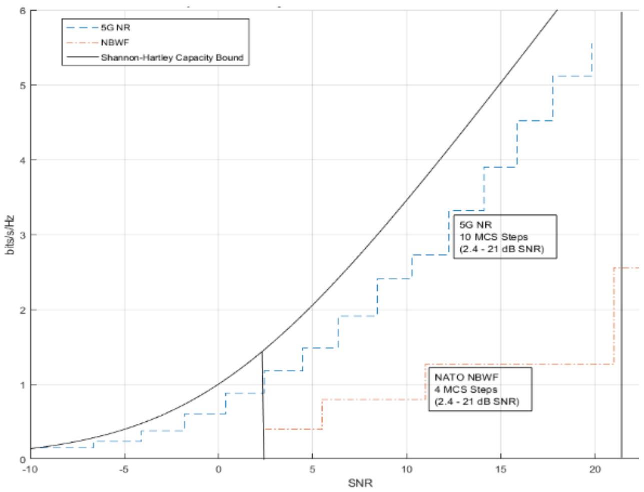

Figure 4 : Performance of Spectral Efficiency vs SNR for 5G NR and NBWF

Within Figure 4 we also include the Continuous-input Continuous-output Memoryless Channel (CCMC) capacity, which is unbounded and defined by Shannon's ubiquitous capacity formula [14], which enables direct comparison with the maximum error free SNR performance for a given spectral efficiency or vice-versa.

Specifically, if the average gap to capacity for all of the modes shown in Figure 4 is calculate for both 5G NR and NBWF it is possible to create a metric to compare both physical layers, this is shown in Table 2.

Table 2: Gap to Shannon Capacity

Average Gap to Capacity	
5G NR	**NBWF**
2.8610 dB	13.6028 dB

The results from this analysis indicate that 5G NR offers significant improvements over NBWF in terms of SNR performance and flexibility, providing a clear indication of its superior capabilities. These results support the notion that the physical layer of 5G NR is a promising technology for improving the performance of military communications systems.

V. EXPERIMENTATION

The Banshee Mobile Radio and Banshee Tactical Radio (3GPP based tactical radio systems) form a private wireless access solution developed by US-based Fenix Group – incorporating a Nokia base station. Banshee radios use a multi-band LTE front end to provide an interoperable network that supports a range of operational needs. The system is a COTS solution for defence private networking. The Banshee system provides secure and reliable wireless connectivity for the tactical use cases. The systems can be observed in Figure 5.

Figure 5: Banshee Tactical and Mobile Radio Systems

The Banshee radio systems have been trialled and demonstrated at several NATO nations' experimentation activities in order to demonstrate the capability that is able to be provided to an end user from a 3GPP based tactical radio system. Furthermore, the Banshee system has been integrated with other bearer systems as part of a Primary, Alternative, Contingency and Emergency (PACE) plan, in a fashion not too dissimilar to Figure 3. Unfortunately results of these experimentation activities cannot be openly published at this time.

Utilising the TAK based edge computing server, it is possible to produce a Radio Environment Map, similar to that explored in NATO IST 146 RTG and discussed in [15] for Spectrum Situational Awareness, this instantiation is known as Soothsayer, an example user interface of this can be seen in Figure 6. This capability enables the user to perform on the fly spectrum management and understand the Electromagnetic Environment for their operational deployment.

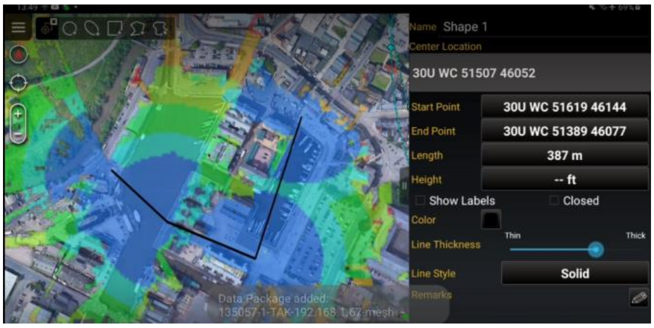

Figure 6:User Interface for Soothsayer

Ultimately, the Banshee equipment capability shows a trial proven system of 3GPP protocols utilising an edge based TAK server to meet the operational needs of NATO partners. This ultimately laying the foundations for 3GPP systems to be utilised to achieve a high performance, flexible, secure and interoperable by design communications network for defence and security users.

VI. Conclusions and Summary

In conclusion, we have analysed the advantages of 3GPP compared to an existing NATO communication physical layer (NATO NBWF). It has been found that 3GPP (4G/5G +) is attractive to defence users due to its interference mitigation capabilities, high-performance physical layer, and specific features that can be utilized by the defence community.

Additionally, it has been identified that 3GPP can serve as a foundation for developing defence communication standards in a specific industry vertical. However, the process for building a "Defence" vertical using 3GPP is not yet clear.

Furthermore, we have shown that there is an operational 4G LTE solution currently available for defence use which has proven its utility in a variety of operational trial activities.

Acknowledgment

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