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Mapping of 5G Technologies and Use Cases to DHS S&T Customer Components

Department of Homeland Security (DHS)
Science and Technology Directorate (S&T)
Office for Interoperability and Compatibility Tech Center (OIC-TC)

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EXECUTIVE SUMMARY

The Johns Hopkins Applied Physics Laboratory (APL) has developed this report to provide the Department of Homeland Security (DHS) Science & Technology Directorate (S&T) Office of Interoperability and Compatibility Technology Center (OIC-TC) a current look at 5G technological trends, specifically those that will most significantly impact the DHS customer components' missions. This report discusses 5G deployment rollout and how the plans for current and upcoming 3rd Generation Partnership Project (3GPP) releases can benefit DHS operations. It presents a set of research strategies that would aid OIC-TC and facilitate preparation of its customer components for operational adoption of 5G technologies.

This report represents an initial update to the "5G Research and Development Plan Recommendations" report APL developed for OIC-TC in February 2020, and initiates the first three phases of the 5G research and development plan:

1. Environmental Scan and Analysis of the 5G Impact to the DHS S&T Customer Components (Subsection 7.1 in February 2020 Report)
2. Adapt/Develop Use Cases that Demonstrate Adaption and Integration of 5G Technologies Relevant to DHS S&T Customer Components (Subsection 7.2 in February 2020 Report)
3. Map 5G efforts to DHS S&T Operational Components' Requirement (Subsection 7.3 in February 2020 Report)

The fifth generation cellular technology, which is referred to as "5G," is focused around design improvements and technology enablers to meet three foundational pillar use cases: enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC), and massive machine type communications (mMTC). In order to meet the performance goals for enhanced service and end-user experience, the 5G industry is developing, adapting, and adopting a wide variety of new technologies.

OIC-TC is uniquely positioned to orient and prepare the customer components because of their mission focus to enable and promote interoperability and compatibility. APL studied the missions of Customs and Border Protection (CBP), Federal Emergency Management Agency (FEMA), and first responders' communications technology needs. APL developed use cases to investigate the impacts of 5G technologies mapped to these missions. As 5G technologies are rolled out, customer components can leverage and benefit from the diverse set of 5G technologies for use in a wide range of environments and mission types. To reach an end state that fully leverages the spectrum of 5G technologies, adherence to standards and common interfaces will be key to enable interoperability and compatibility among customer component end users. The end result of the examining customer component operational needs and 5G's ability to enhance those provides: 1) innovative solutions and adaptations of 5G technology and 2) opportunities to potentially influence 5G standards development.

The 3GPP is the primary Standards Development Organization (SDO) for all radio access, Core Network (CN), and service capabilities of 5G, but is comprised of collection of other standard development organizations and industry partners who scope and define specification releases for mobile telecommunications technologies. Due to 5G's extensive vision of use cases and market applicability, it is considered an ecosystem of many advanced radio and network technologies and services. Carriers have already begun rolling out versions of 5G to the public, but the features offered and specific 5G architecture implemented throughout the Nation is non-uniform.

As 3GPP releases are developed, which provide the specifications of the architecture and protocols that govern the underlying 5G technologies, the equipment manufacturers, carriers, and handset manufacturers make decisions on what specific technologies they will implement. This report thus provides an overview of the current state and outlook of 5G deployment relevant to DHS customer component uses of 5G technologies.

As DHS S&T OIC-TC prepares for the continued growth in and deployment of 5G technologies and capabilities, there are many research and development (R&D) opportunities. These activities include exploration of research ideas through experimentation, development of prototype solutions or proof of concept demonstrations, and examination of advanced concepts through research publications. Because 5G is comprised of many technologies and different enablers, and the potential use cases are so broad, a stepwise approach to R&D is encouraged, focusing on single technologies and use cases at a time. The outcomes could impact standards development work items for DHS S&T OIC-TC in its mission to address DHS S&T and interoperability and compatibility needs and to provide the DHS customer components with the information required to successfully adopt 5G technology into their missions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

5G has been deployed throughout the world over the last few years. The vision for 5G from telecommunication practitioners and researchers was a technology that would represent a paradigm-shifting advancement beyond even the remarkable accomplishments of 4G/Long-Term Evolution (LTE) cellular technology. The three main 5G use case categories are 1) Enhanced Mobile Broadband (eMBB) - downlink peak data rate of 20 Gbps and uplink peak data rate of 10 Gbps, 2) Ultra-Reliable and Low-Latency Communications (URLLC) - latency of 1ms in user contexts, and 3) massive machine type communications (mMTC) - connection density of 1 million devices/km^2 [1]. The 5G usage scenarios are depicted in Figure 1-1.

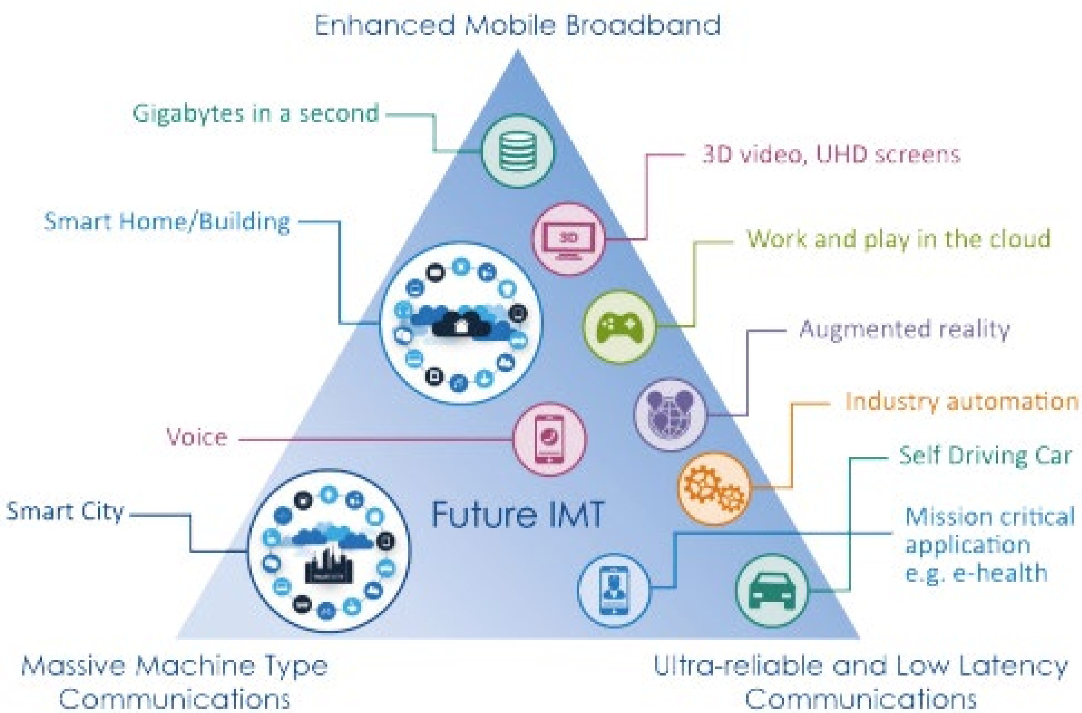

Figure 1-1: 5G Usage Scenarios[2]

There are many stakeholders from industry, government, and academia who are impacting and are impacted by the development, implementation, and evolution of 5G technology. While there are specifications for 5G defined by entities that are a part of the 3rd Generation Partnership Project (3GPP), the 5G technologies that are implemented and deployed are largely dependent on decisions made by telecommunications carriers and handset manufacturers. Furthermore, 5G's forward-looking growth and evolution are being developed and tested by the research community. Therefore, 5G is a

[1] https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf
[2] https://www.itu.int/dms_pub/itu-d/opb/pref/D-PREF-BB.5G_01-2018-PDF-E.pdf

technology whose features and capabilities will be deployed incrementally based on the decisions made by industry and the advancements and achievements of the research community. These decisions and achievements will greatly impact the day-to-day missions of end-users of this 5G technology, which includes the Department of Homeland Security (DHS) Science & Technology Directorate (S&T) operational customer components.

APL has developed this report for the DHS S&T Office of Interoperability and Compatibility Technology Center (OIC-TC), as a follow-on to the "5G Research and Development Plan Recommendations" developed in February 2020. This update includes a current look at 5G technological trends, specifically those that will most significantly impact the DHS customer components' missions and use cases examined herein.

This report is organized as follows:

- Section 2 presents the motivation for development of this report as an update to the previously published 5G R&D plan report (Reference [1]).
- Section 3 discusses relevant 5G industry trends and technologies.
- Section 4 examines the missions of selected DHS customer components and performs a mapping between technologies and specific use cases.
- Section 5 provides a current assessment of 5G technology roll-out and its impact on DHS operations.
- Section 6 summarizes the report and briefly discusses some future R&D activities pertaining to customer component adoption of 5G technology.

2. MOTIVATION

The previous report presented DHS S&T's focus as it pertained to 5G summarized by the following 5G Impact Focus Areas (Reference [1]):

"DHS S&T continually strives to develop and implement technology solutions that address our nation's most pressing homeland security challenges, therefore, S&T will focus on the following six (6) 5G Impact Focus Areas:

1. ***Networks** – Examples: Mission Critical Service, Data Rate, Latency, Capacity, Private Networks, Slicing etc.*
2. ***Hardware** – Examples: UE, VR, CBRN and Physio Sensors, IOT Devices, Drones, Small Cells, etc.*
3. ***Software** – Examples: Public Safety Applications (Leveraging Real-time, high-bandwidth capabilities), 4K video, etc.*
4. ***Data** – Examples: Fusion, Analytics, Visualization, etc.*
5. ***Interoperability** – Examples: Audio/Video Communications, Data, Sharing, etc., with Verticals and Mutual Aid Agencies (Federal, State, Local, Tribes, and Territories)*
6. ***Security** – Examples: Cyber, People, Supply Chain, Facilities, etc."*

The relationships among these focus areas are depicted in the diagram developed in Figure 2-1 (Reference [1]).

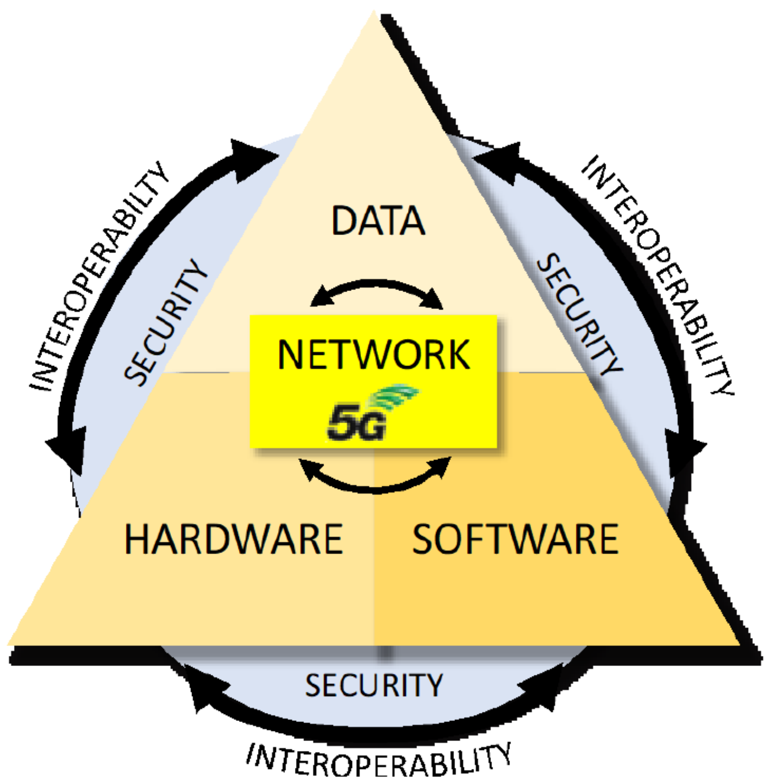

Figure 2-1: 5G S&T Focus Area Relationships

Information included in this section is referenced and extracted from Section 7 of (Reference [1]), which focused on developing the framework for the DHS S&T 5G Research and Development Plan.

"The following seven (7) sections provide an initial high-level description of the proposed phased approach with recommendations and considerations. This should not be considered a final plan, as it is acknowledged that additional discussions are needed with DHS S&T Program Priority representatives, subject matter experts and key stakeholders."

All seven phases/subsections are listed here with the first three in bold indicating the areas discussed in this report.

1. **Environmental Scan and Analysis of the 5G Impact to the DHS S&T Customer Components**
2. **Adapt/Develop Use Cases that Demonstrate Adaption and Integration of 5G Technologies Relevant to DHS S&T Customer Components**
3. **Map 5G efforts to DHS S&T Operational Components' Requirement**
4. Leverage Existing Efforts to Contribute to Optimization and Deployment
5. Leverage Opportunities for Standards Contribution
6. Support Testing and Evaluation Efforts and Provide Recommendations and Feedback from the End-User Communities
7. Support Transition for Operational Deployment

A mapping between the first three subsections from Section 7 in (Reference [1]) to areas where incremental updates and execution plans are discussed in this report is provided in Table 2-1.

Table 2-1: Mapping from Previous 5G R&D Plan to Updates Herein

Subsection from [1]	Description	Updates in this Report
7.1: Environmental Scan and Analysis of the 5G Impact to the DHS S&T Customer Components	**RATIONALE:** Baseline 5G (and beyond) capabilities and features that will be available from a short-term, mid-term and long-term vantage point to help develop the strategic technology investment plan. This may include, but not limited, to the following; • Assess current research, prototypes, proof-of-concepts • Review and understand standards from 3GPP and other standards organizations (e.g., IEEE) that may impact the public safety community • Review relevant 5G tests and reports from industry, government and institutions • Review First Responder Network Authority Roadmap (if available) • Review Industry Roadmaps (if available)	**Section 3** (5G Technology Trends) and **Section 5** (5G Deployment and Rollout)
7.2: Adapt/Develop Use Cases that Demonstrate Adaption and Integration of 5G Technologies Relevant to DHS S&T Customer Components	**RATIONALE:** Leverage existing use cases (NPSTC, 3GPP and others) and adapt as needed to validate 5G (and beyond) baseline capabilities and features that will help to fill critical needs for DHS S&T customers. This may include, but not limited, to the following; • Seek direct customer use case feedback on critical needs and requirements to identify the gaps and how 5G features and capability can be used to enhance capabilities. • Review 5G use cases developed by industry and investigate their applicability to public safety use cases • Leverage the National Public Safety Telecommunications Council (NPSTC) June 2019 "Public Safety Internet of Things (IoT) Use Case Report and Attributes"	**Section 3** (5G Technology Trends), **Section 4** (DHS Customer Components), and **Section 5** (5G Deployment and Rollout)
7.3: Map 5G efforts to DHS S&T Operational Components' Requirements	**RATIONALE:** Using the use-cases, as described in the previous phase (See Section 7.2), and linking it to the DHS S&T Five Mission Areas as part of developing 5G relevant baseline requirements ensures that DHS S&T not only addresses end user needs, but also uses departmental priorities to guide the overall investment plans and encourages cross-agency collaboration. These should also be mapped to the program priorities (Table 2) to ensure each customer component impacted by 5G is considered.	**Section 4** (DHS Customer Components)

3. 5G Technology Trends

The development of 5G technology focuses on design improvements and technology enablers to meet its foundational pillar use cases: eMBB, URLLC, and mMTC. In order to implement these pillars and deliver enhanced service for end-user experience, the 5G industry is developing a wide variety of new technologies. The original IMT-2020 vision for 5G technology capabilities and performance along several key metrics is depicted in Figure 3-1. This includes an order of magnitude improvement in peak data rate, latency, spectrum efficiency, and connection density, and two orders of magnitude improvement in area traffic capacity and network energy efficiency. This means more capacity (tens of gigabits), more users (10^6 per km^2), and sub millisecond latency. This section discusses a selected set of current 5G technologies that would be of interest to DHS customer component operations[3]. The subsequent section discusses customer component missions and operations in greater detail and references the technologies described here.

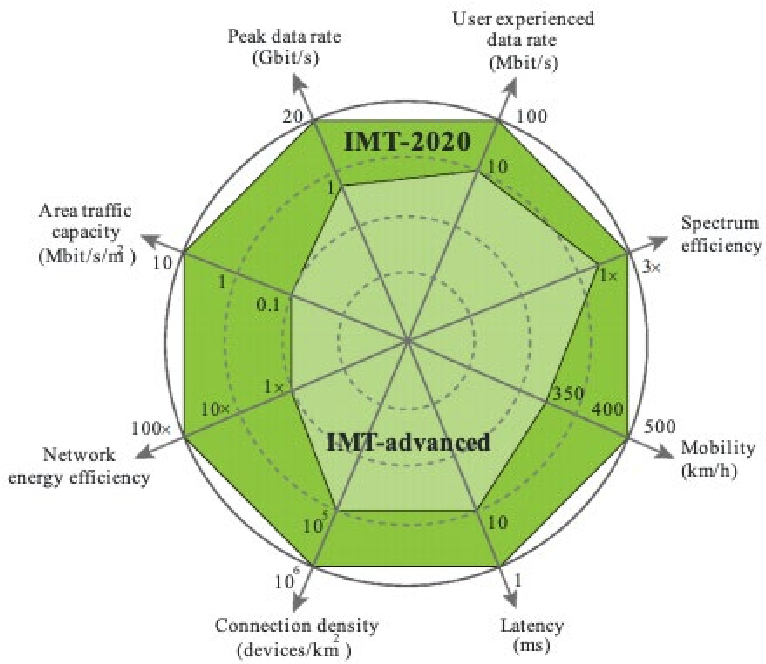

Figure 3-1: IMT-Advanced to IMT-2020 Performance Capabilities[4]

[3] As 5G is an evolving technology, new advancements and technology enablers are developed and deployed incrementally. This section is meant to describe a selected set of 5G technologies relevant to the DHS customer components, based on the APL team's engineering judgment at the time of this writing in May 2021.
[4] https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

3.1 Flexible New Radio (NR)

In order to achieve the multi-faceted vision of performance capabilities laid out in IMT-2020, 5G's radio interface, referred to as New Radio (NR), is developed in a versatile and flexible manner. This includes several key features such as spectrum versatility, scalable Orthogonal Frequency-Division Multiplexing (OFDM) numerology, massive Multiple Input Multiple Output (MIMO), and beamforming and beam-tracking[5].

3.1.1 Spectrum Versatility

5G technology offers spectrum versatility to address its wide range of use cases. 5G spectrum can be divided into low-bands, mid-bands, and high-bands (mmWave) and a selected set (non-comprehensive) list of bands are discussed here. The low-bands are the sub-1 GHz bands that support widespread coverage, but the lowest capacity experience among the band regions. The mid-bands, which include the 2.5 to 2.6 GHz range and the 3-4 GHz range offer a balance between coverage and capacity. Lastly, the high-bands in the mmWave part of the spectrum (26/28/40/66-71 GHz) provide the ultra-high broadband capacity experience at the cost of communications range/coverage[6]. Each of these bands has its own role to play in different scenarios and contexts[7]. In addition to these licensed bands, unlicensed spectrum in the 5 GHz and 6 GHz bands has been made available for 5G deployments, which is referred to as 5G NR-Unlicensed (NR-U). This offers flexibility for organizations to deploy their own 5G networks similar to how organizations may set up Wi-Fi networks[8]. These various frequency bands also map to sub-carrier spacing ranges such as 1 MHz in the low-bands, 100 MHz in the mid-bands, and even 400 MHz in the high-bands. This will be discussed further in Subsection 3.1.2.

3.1.2 OFDM Numerology

OFDM is the scheme by which the 5G protocols manage spectrum allocation among multiple users. It is based on the principle of assigning orthogonal subcarriers to each user to mitigate interference and permit multiple users to occupy a subdivided frequency band. As mentioned in Subsection 3.1.1, 5G operates in multiple frequency bands and ranges. In order to accommodate this spectrum versatility and the massive bandwidths at high-band, OFDM numerology is the scheme which implements scalability in spacing between sub-carriers depending on the band in which the network is operating. Figure 3-2 provides a depiction of how this concept works with the various ranges of sub-carrier spacing.

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[5] https://www.qualcomm.com/media/documents/files/making-5g-nr-a-commercial-reality.pdf
[6] https://www.qualcomm.com/media/documents/files/spectrum-for-4g-and-5g.pdf
[7] https://www.gsma.com/spectrum/wp-content/uploads/2021/03/5G-Spectrum-Positions.pdf
[8] https://www.metaswitch.com/knowledge-center/reference/what-is-5g-new-radio-unlicensed-nr-u

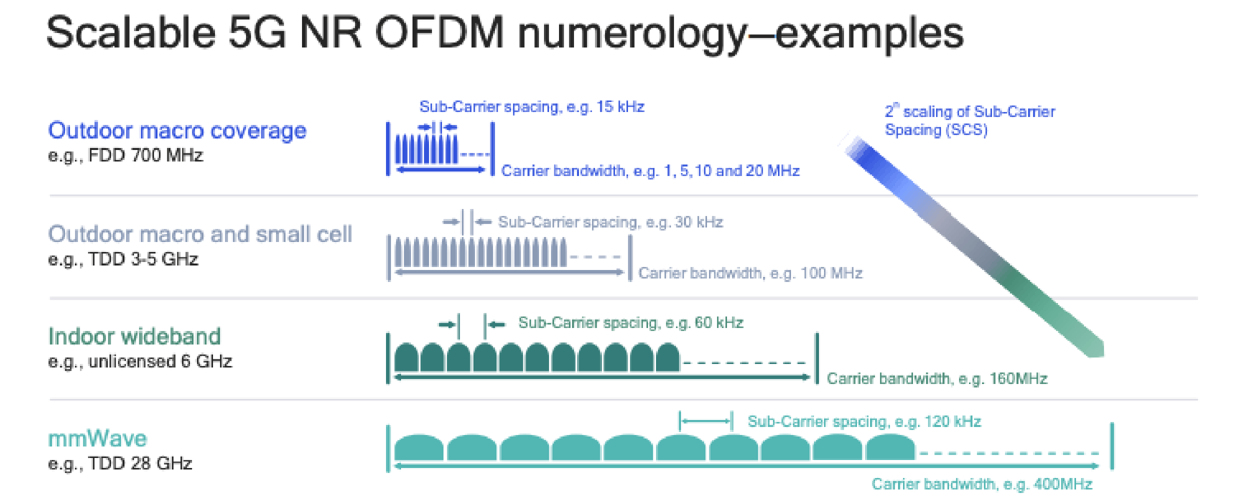

Figure 3-2: OFDM Numerology[9]

3.1.3 Massive MIMO and Multi-User (MIMO)

Multiple-input multiple-output (MIMO) technology enables the use of multiple antennas at a sender and receiver to separate data streams and create virtual pipelines onto individual antennas. This technical approach is to exploit a multipath propagation environment to enhance the throughput between sender and receiver. The concept of Massive MIMO refers to 5G base stations being deployed with 10s-100s of antenna elements to enable greater throughput enhancement to meet 5G performance visions via MIMO technology. This data stream separation is referred to as spatial multiplexing and a pictorial representation is provided in Figure 3-3. Each of the different colored paths represents an individual data stream from the base station to the phone. Each stream takes a different path (multipath propagation environment) based on the complex environment depicted in the diagram.

[9] https://www.qualcomm.com/media/documents/files/making-5g-nr-a-commercial-reality.pdf

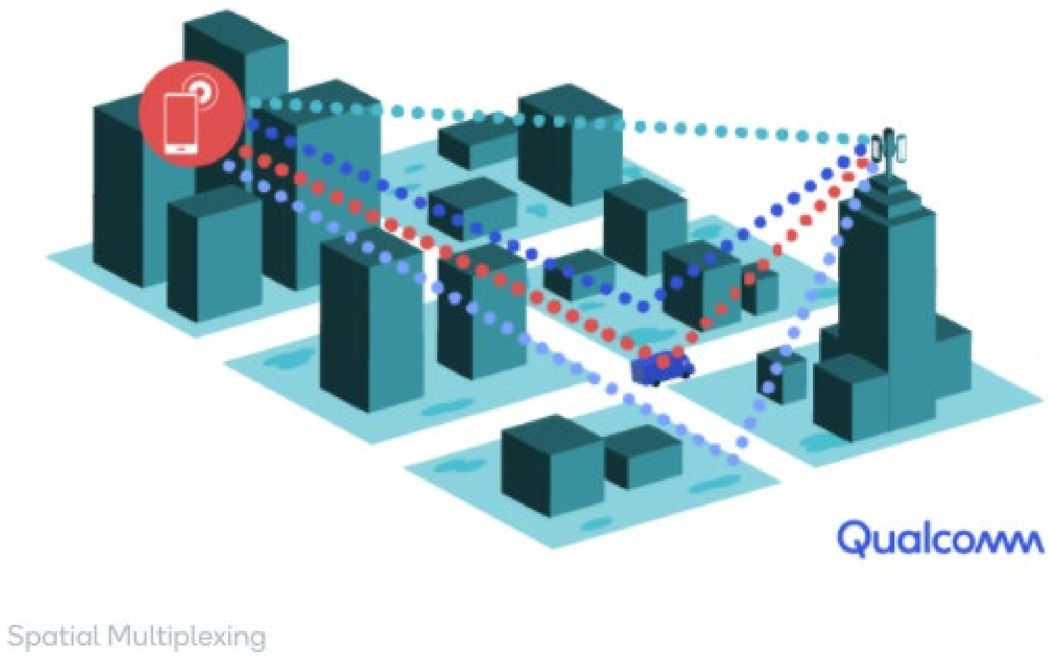

Figure 3-3: Spatial Multiplexing Representation[10]

In multi-user MIMO (MU-MIMO) network efficiency is enhanced by packaging information for multiple users on individual data streams and ensuring each user only receives the information intended for it.

3.1.4 Beamforming and Beam-steering

In addition to enabling massive MIMO technology, the deployment of a massive number of antenna elements on a base station presents opportunities to leverage multiple antennas to transmit a single data stream, in a manner which focuses energy directivity and enhances antenna gain and antenna radiation control. This technology is discussed in greater detail in the context of IAB technology in Subsection 3.6.

[10] https://www.qualcomm.com/news/onq/2019/06/20/how-5g-massive-mimo-transforms-your-mobile-experiences

3.2 VIRTUALIZATION

Virtualization of services and network functions has grown in popularity over the past decade in cloud computing and enterprise environments to ensure high availability through self-deployment, self-scaling, and self-healing of services. This is especially true in 5G mobile broadband networks where 5G core architecture, transport networks, and even radio access technologies are being virtualized to run on shared infrastructure. This virtualization allows for a flexible environment where services can be deployed in disparate geographic locations and instantiated dynamically to combat load within the system.

3.2.1 VIRTUALIZED CORE

5G brings a transformational change to its core architecture and introduces a new virtualized Service-Based Architecture (SBA) with common Service-Based Interfaces (SBI), as illustrated in Figure 3-4, that defines all new network functions (NFs) offering their services over common standardized interfaces. These network functions follow a common micro-services architecture where each is self-isolated and provides a specific function to the network as a whole and together comprise the 5G system. The 5G SBA is further split into a logical Control Plane (CP), shown in the top of Figure 3-4 and a User Plane (UP), shown in the bottom of Figure 3-4. This CP/UP split leverages virtualization concepts to support flexible and dynamic on-demand deployments at geographically dispersed locations. The UP functions can now be placed very close to the user allowing for optimal traffic steering and thus improved quality of service and quality of experience. This architecture along with the virtualized RAN described in the next subsection play a major role in enabling many of the novel features of 5G.

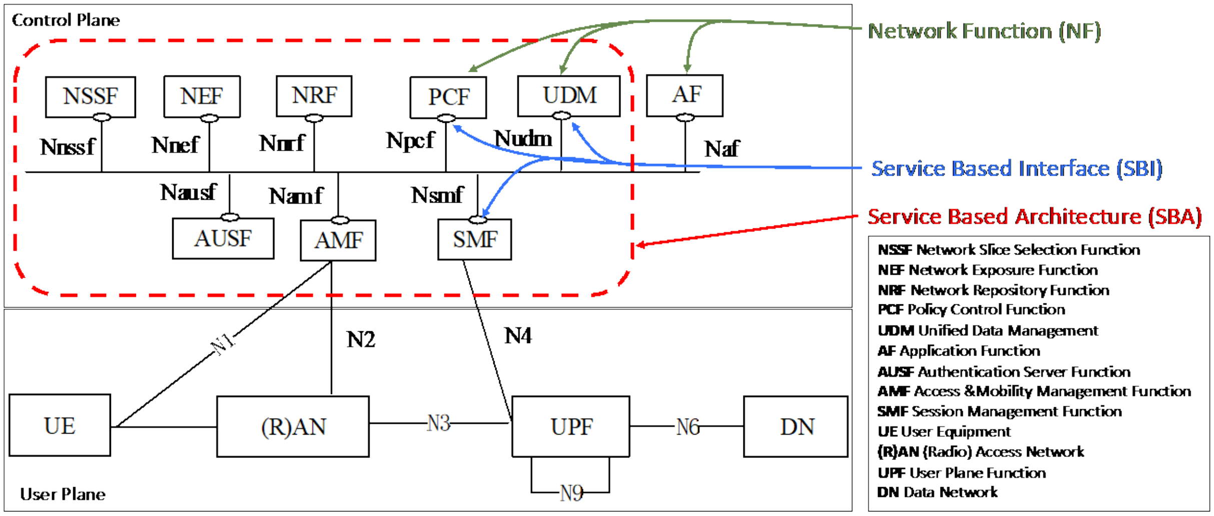

Figure 3-4: Virtualized Core - User Plane and Control Plane (Reference [2])

3.2.2 VIRTUALIZED RAN (VRAN)

In order to provide eMBB and URLCC to 5G end-users, the 5G technology community decided an architectural shift in cellular infrastructure needed to be adopted through a disaggregation of the cellular radio access network (RAN) implementation and functionality. One key area of this shift was the disaggregation of baseband unit (BBU) functionality, the portion of cellular infrastructure which processes the digitized versions of the data on the uplink and downlink. What was typically seen as one functional block in 4G systems, a BBU, is now separated into a Distributed Unit (DU) and a Central Unit (CU) to respectively address lower layer and higher layer communications functionality. Furthermore, to provide eMBB services, it is anticipated that many more 5G towers must be deployed beyond what was previously deployed for 4G. DUs handle more real-time baseband processing functionality as they are closer to the Remote Radio Units (RRUs) and antennas [sometimes integrated into what is known as an Active Antenna Unit (AAU) at the base station]. For less time-sensitive traffic, processing can take place at CUs in a centralized manner. This enables the processing to be pooled together and executed at centralized data centers on general purpose processors rather than specialized hardware. This virtualizes parts of the Radio Access Network (RAN) architecture, a capability called vRAN[11]. This virtualization enables the disaggregation of the RAN functionality. Furthermore, this alleviates Size, Weight, and Power (SWAP) related concerns at the cell site itself.

What this disaggregation of RAN functionality has now created is a new transport interface in the uplink/downlink traffic processing chain: the midhaul between DUs and CUs as seen in Figure 3-5[12] [13]. A representative diagram of the 5G disaggregated RAN architecture compared to that of 4G is presented in Figure 3-5.

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[11] https://www.samsung.com/global/business/networks/insights/blog/realizing-the-benefits-of-virtualized-ran/
[12] https://medium.com/@miccowang/5g-c-ran-and-the-required-technology-breakthrough-a1b2babf774
[13] https://www.ciena.com/insights/articles/spotlight-on-5g-midhaul-networks.html

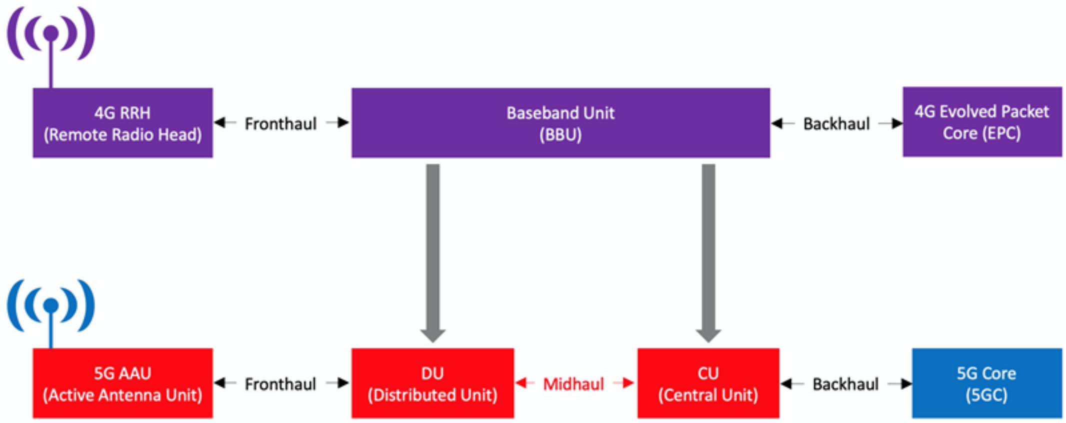

Figure 3-5: 5G Disaggregated RAN Architecture [14]

With regards to 5G RAN, there are several terms that are commonly used where clarification would be beneficial as part of a 5G strategy. In addition to vRAN, some other common RAN-related terms are OpenRAN and O-RAN[15]. OpenRAN refers to a disaggregated RAN functionality where the interfaces between modules are open. These modules and functionality can be built agnostic to vendor hardware or software technology. O-RAN is a specification group focused on next generation RAN architectures[16].

3.2.3 Software-Defined Networking

In order to tie together these various disaggregated core and RAN components, 5G is embracing various Software-Defined Networking (SDN) components. This allows for custom traffic flow rules to be pushed into the network to support optimal traffic steering and load balancing. This is especially true for user plane traffic that connects the DU, CU, and 5G Core in both the midhaul and backhaul portions of the network. Essentially, users will experience customized transport to meet their specific needs rather than a one-size-fits-all view where all traffic is tunneled from the RAN to the core for processing.

3.2.4 Management and Orchestration of Virtual Network Functions

In order to enable effective and efficient automation and zero-touch deployments envisioned within 5G networks, the virtualization and software defined radio and transport networks must be remotely monitored, managed, and orchestrated. This is accomplished through various centralized controllers and Management and Orchestration (MANO) functions. For SDN applications, this has long been accomplished via often complex SDN Controllers which expose a set of common north- and south-bound interfaces where users, applications, and physical networking infrastructure can trigger policies and procedures within the network to influence routing and switching. Common open source SDN controllers include Open Daylight[17] and ONOS[18]. A new trend involves programming the software defined logic and behaviors directly in the firmware of network architecture switches, interface cards,

[14] https://www.ciena.com/insights/articles/spotlight-on-5g-midhaul-networks.html.
[15] https://www.o-ran.org/
[16] https://mavenir.com/blog/what-is-the-difference-between-openran-o-ran-and-vran/
[17] https://www.opendaylight.org/
[18] https://opennetworking.org/onos/

routers, and network appliances. This is achieved using the common Protocol-independent Packet Processors (P4) language[19].

The orchestration of Virtual Network Functions (VNFs) such as the 5G Core SBA and RAN is accomplished via MANO applications. The generic MANO architecture as illustrated in Figure 3-6 is being standardized by the European Telecommunications Standard Institute (ETSI)[20] and includes all logical functional blocks for "element management" of individual VNFs, as well as oversight and control of the underlying Network Function Virtual Infrastructure (NFVI). The network services and functions, along with configuration templates are all stored in the NS and VNF catalogs respectively. The health and state of deployed VNF is tracked in the Network Function Virtualization (NFV) instances repository. Similarly, the health and state of all physical infrastructure is tracked in the NFVI resources data store. The standardized interfaces between each functional component allows for a very flexible environment of orchestration. Some common open source vendors of MANO include the Open network Automation Platform (ONAP)[21] and Open Source MANO (OSM)[22]. Additionally, commercial vendors such as Cisco [23] and Juniper[24], among others, are looking to play a major role in this arena.

[19] https://p4.org/
[20] https://www.etsi.org/technologies/nfv
[21] https://www.onap.org/
[22] https://osm.etsi.org/
[23] https://www.cisco.com/c/en/us/products/cloud-systems-management/network-services-orchestrator/index.html
[24] https://www.juniper.net/us/en/products-services/sdn/contrail/

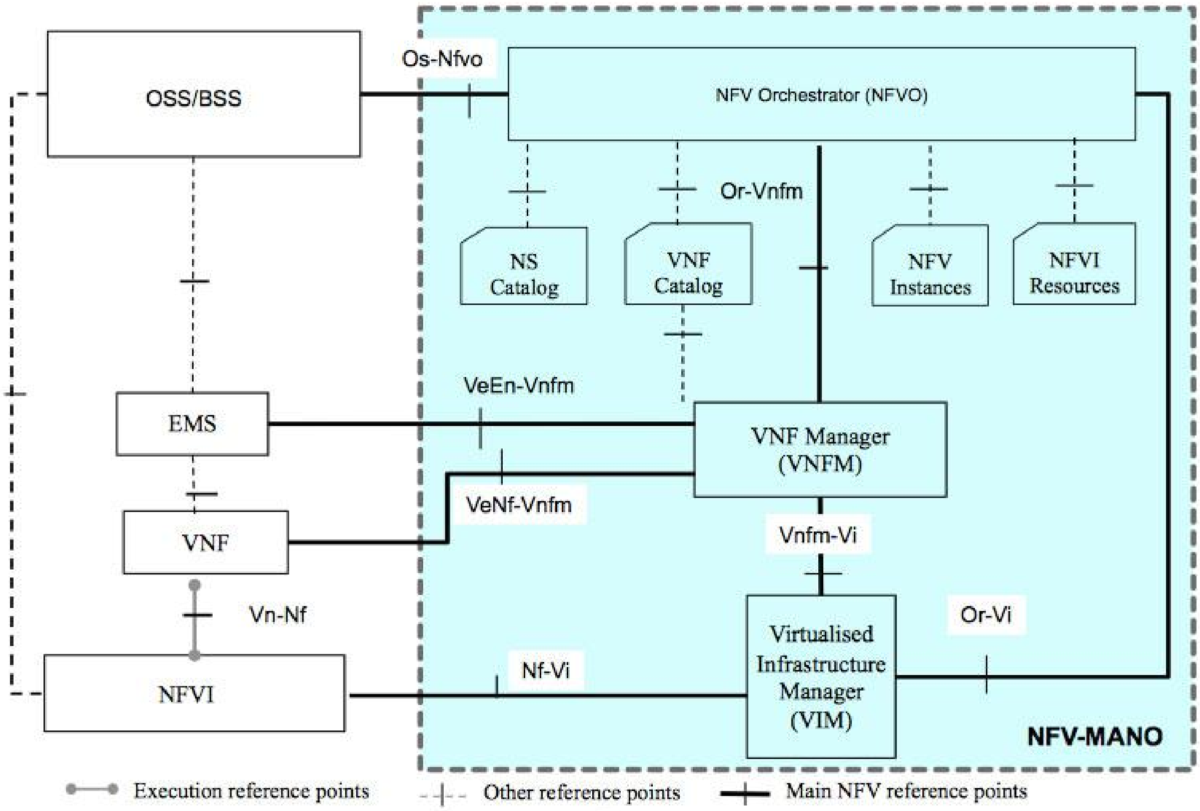

Figure 3-6: ETSI NFV/MANO Architectural Framework (Reference [3])

ETSI is further developing concepts and frameworks to enable Zero-touch Network and Service Management (ZSM)[25]. The end-goal is to enable full end-to-end automation of network and service management deployment supporting self-configuration, self-monitoring, self-healing and self-optimization without further human intervention. ZSM of all systems, both virtual and physical are accomplished using many of the concepts developed for NFV and MANO.

3.2.5 Operations Support Systems / Business Support Systems

The final piece of enabling the virtualized 5G infrastructure is achieved through the business application and business enablement layer as illustrated in Figure 3-7. These functions will be exposed through the various Operations Support Systems / Business Support Systems (OSS/BSS) which provides input to the MANO architecture and enables the administrator or end user to specify the expected behavior of the operational systems or business services enabled within the network. This allows the overall 5G network to be driven by business service level objectives and promotes the very flexible, robust, and resilient end-to-end network. Together, virtualization, centralized management and control, and the business driven intent offers a wide range of new capabilities for 5G networks that will likely bring new features and function well into the future.

[25] https://www.etsi.org/technologies/zero-touch-network-service-management

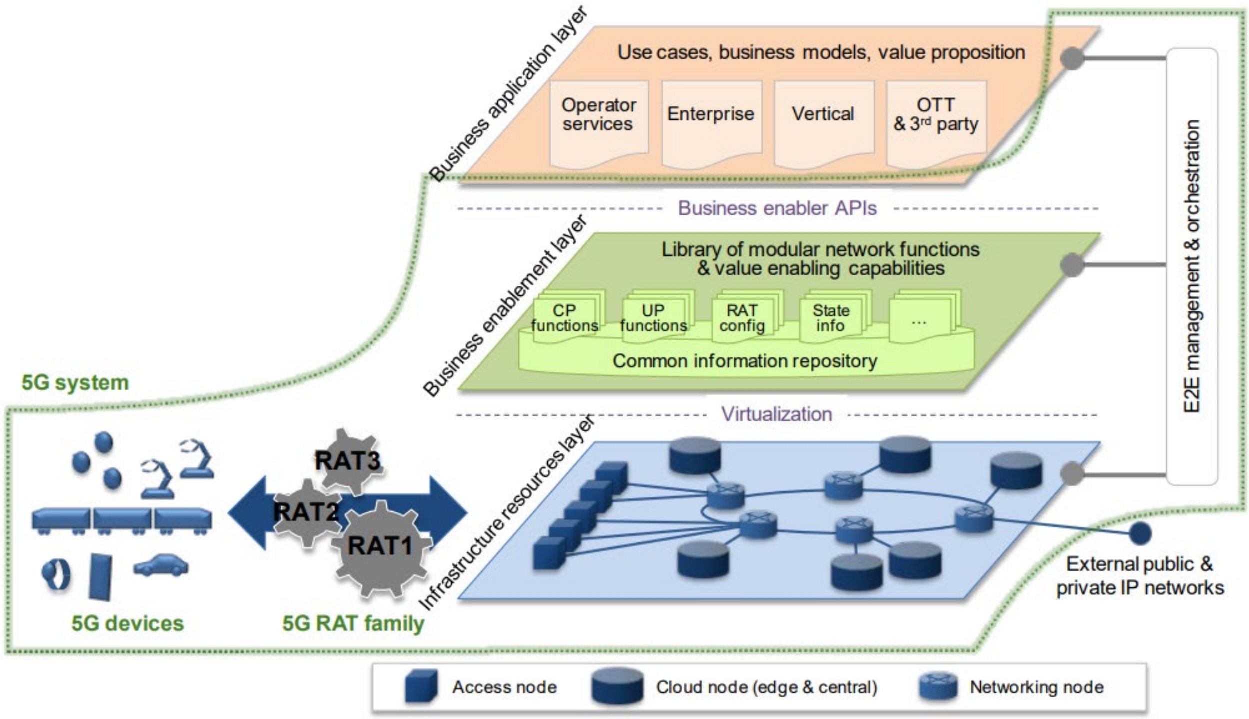

Figure 3-7: Business Driven 5G Architecture [26]

3.3 MULTI-ACCESS EDGE COMPUTE

Carriers and cloud computing services companies are now partnering to provide enhanced capabilities and services to enterprises seeking to take advantage of what 5G technology has to offer. These capabilities fall under a technology referred to as Multi-Access Edge Computing (MEC). The 5G networks have been architected from the start to support advanced routing and traffic steering to connect end users optimally to the closest edge computing resource available.

The Amazon Web Services (AWS) Wavelength project is an example where AWS computing and storage infrastructure (referred to as Wavelength Zones) are deployed within "communications service providers' datacenters at the edge of the 5G network"[27] What this is trying to accomplish is to minimize the number of hops application traffic from 5G devices must travel to application servers. If the application servers reside in Wavelength Zones, then the application traffic does not have to leave the telecommunications network[27]. This is to enable URLLC capabilities for 5G users. A pictorial representation of this setup is provided in Figure 3-8.

[26] "NGMN 5G White Paper", Next Generation Mobile Networks (NGMN), 17-February-2015 https://www.ngmn.org/wp-content/uploads/NGMN_5G_White_Paper_V1_0.pdf
[27] https://aws.amazon.com/wavelength/

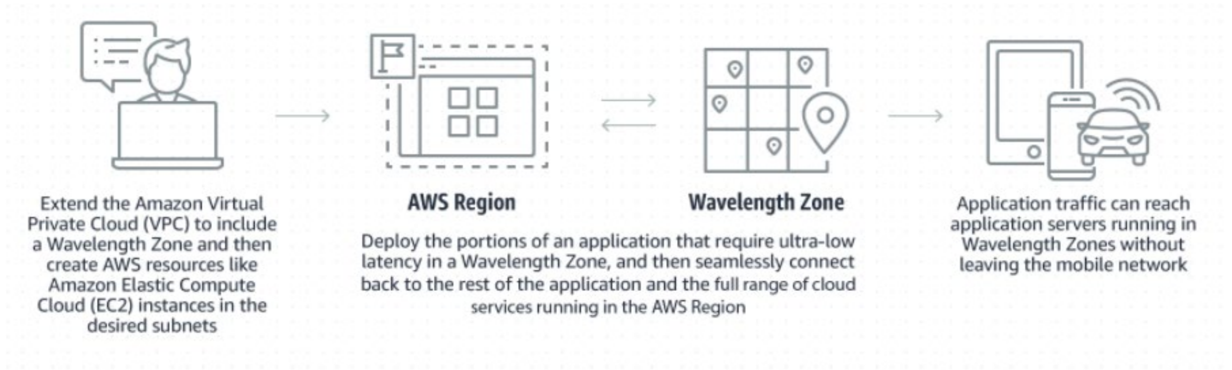

Figure 3-8: AWS Wavelength[27]

The focus of this system integration is to provide a mechanism for developers to build next-generation applications that demand high-capacity and low-latency experiences for end-users. The compute and storage architecture enables next-generation applications that seek to leverage advanced technologies such as machine learning inference and augmented and virtual reality (AR/VR). This opens up opportunities for next-generation applications that can address DHS customer component operational needs[27].

Similarly, Microsoft offers what are called Azure Edge Zones, where Azure cloud computing and storage resources are embedded at the edge of 5G networks for application deployment. Applications include local data processing, real-time IoT and AI analytics, and high-intensity applications where high-density graphics and real-time operations are required[28]. A pictorial representation of Azure Edge Zone setups is presented in Figure ***3-9***.

[28] https://azure.microsoft.com/en-us/solutions/low-latency-edge-computing/#edge-zones

***Figure* 3-9*: Microsoft Azure Edge Zones*[29]**

3.4 INTERNET OF THINGS/SMART CITIES

The deployment of 5G technology throughout communities presents opportunities for densely-connected Internet-of-Things (IoT) solutions addressing the use case of mMTC. As sensors collect information and transfer that information to their necessary recipients, an underlying communications technology that can support this information flow will enable organizations to increase their sensor deployments perhaps by orders of magnitude. This will further enable them to collect valuable situational awareness (SA) and information for advanced analytics purposes, and to address dynamic behavior in the environment and end-user needs. The vision is that this cellular connectivity will not be limited to simply an end-user's smartphone or smartwatch, but potentially dozens of connected devices per end-user. An IoT-enabled smart city setup is illustrated in Figure 3-10.

[29] https://azure.microsoft.com/en-us/solutions/low-latency-edge-computing/#edge-zones

***Figure 3-10: IoT Enabled Smart City*[30]**

One avenue through which the major carriers are enhancing 5G/IoT solutions is through work with Smart City initiatives. Smart City initiatives like those in Aurora, IL focus on building modernized and next-generation infrastructure as a fundamental pillar of their implementation. The Smart Aurora initiative also focuses on public safety modernization, cybersecurity improvements, and Information Technology (IT) infrastructure, which are all critical for supporting a robust 5G-based IoT network deployment.

In addition to Smart City applications, on-premise, Non-Public Network (NPN) 5G is being applied to IoT as it pertains to manufacturing, production, and supply chains. These are commonly referred to as "private networks". Mobile networks can be deployed for factory floor automation, automated warehousing, logistics, and other industrial applications enabled by implementation of 5G URLCC technologies as well as mMTC technologies[31].

[30] https://digital-strategy.ec.europa.eu/en/library/why-eu-betting-big-5g-researcheu-focus-magazine
[31] https://www.gsma.com/iot/wp-content/uploads/2020/10/2020-10-GSMA-5G-IoT-Private-and-Dedicated-Networks-for-Industry-4.0.pdf

3.5 PROXIMITY-BASED SERVICES

Proximity-based services (ProSe) in 5G enable what is called a sidelink channel (as opposed to the downlink or uplink channels) for direct UE-UE communications. Sidelink channel capabilities for device-to-device (D2D) communications were specified in earlier LTE releases, but saw limited adoption. The commercial interests in vehicle-to-everything (V2X) services may convince handset manufacturers and carriers to more widely implement these sidelink channel capabilities. Enhanced sidelink channel capabilities present some compelling options for DHS customer component operators whose areas of responsibility may lack sufficient coverage from 5G base stations[32]. Sidelink channel capabilities offered by ProSe can provide coverage extension options; for example, by UE-network relays or UE-UE relays (circled) depicted in Figure 3-11.

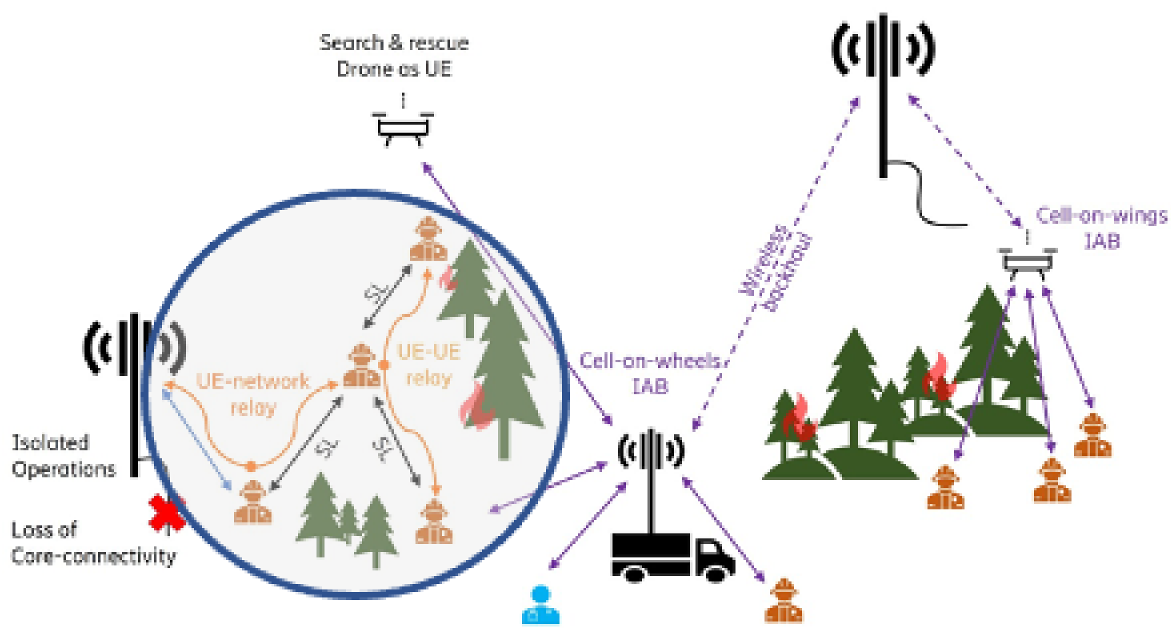

Figure 3-11: Notional Public Safety Diagram from Ericsson (ProSe Focus)[33]

3.6 INTEGRATED ACCESS AND BACKHAUL

As discussed in the notional scenario in the subsection on ProSe, operators may conduct their work in areas lacking 5G cellular coverage. Another technology that could be beneficial to operations in such environments is Integrated Access and Backhaul (IAB). This provides a multi-hop wireless access and backhaul capability for end-users lacking convenient access to 5G base station

[32] https://www.ericsson.com/en/blog/2020/5/how-5g-for-public-safety-could-save-lives
[33] https://www.ericsson.com/en/blog/2020/5/how-5g-for-public-safety-could-save-lives

infrastructure. Furthermore, the spectrum versatility and antenna beam steering technologies implemented in 5G enable frequency-band separation among the access and backhaul links for IAB implementation. IAB deployments are anticipated to operate in mmWave bands for the backhaul links and the same (inband operation) or lower bands (out-of-band operation) for the backhaul links[34]. To mitigate mmWave propagation loss (which is directly proportional to frequency), multi-element antenna arrays in both base stations and UE can be used to provide higher antenna gain capabilities on the uplink and downlink. Moreover, sophisticated beam steering techniques with these antenna arrays address the mobility challenges that could be encountered with mmWave operations, enabling UEs to steer the high gain lobes of their directional antenna patterns to maximize link quality and strength to the IAB deployment[35]. Note that beam steering is an option for bands lower than mmWave as well. The same notional picture from Ericsson is presented in Figure ***3-12*** with the IAB components circled.

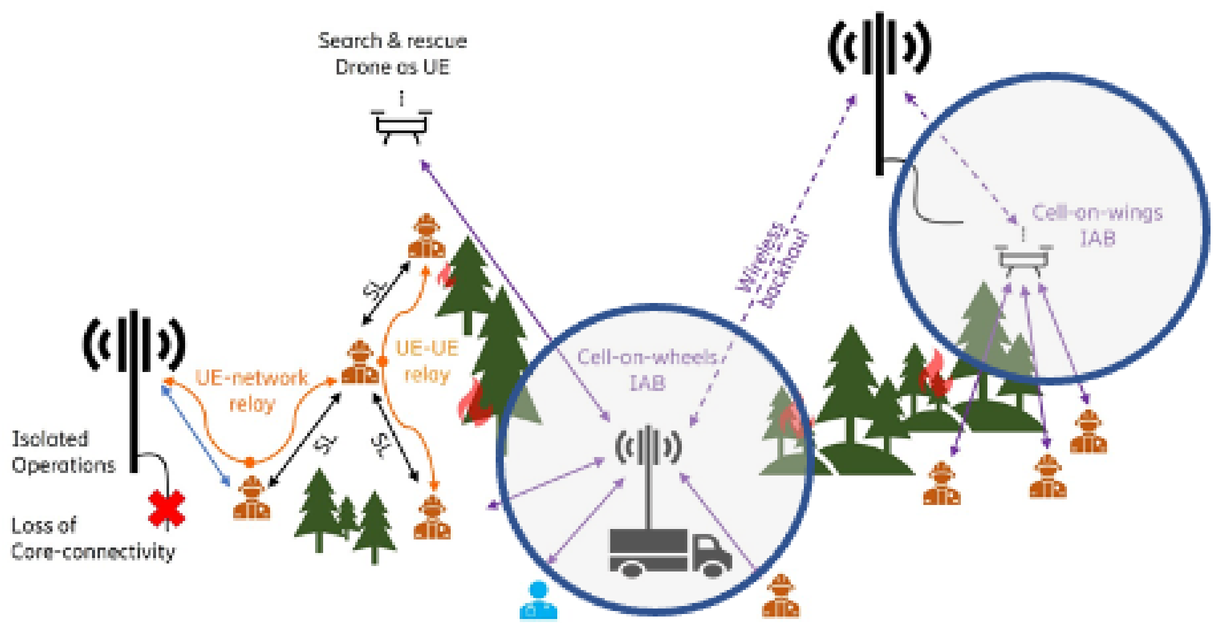

Figure** 3-12**: Notional Public Safety Diagram from Ericsson (IAB Focus)[36]

In this notional scenario, IAB capabilities are provided by both a vehicle (cell-on-wheels) and a UAV (cell-on-wings). This technology option extends the possibilities for 5G access to end-users/operators in remote or rural environments lacking sufficient cellular network infrastructure.

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[34] https://www.5gamericas.org/wp-content/uploads/2020/06/Innovations-in-5G-Backhaul-Technologies-WP-PDF.pdf

[35] https://www.qualcomm.com/media/documents/files/5g-nr-mmwave-deployment-strategy-presentation.pdf
[36] https://www.ericsson.com/en/blog/2020/5/how-5g-for-public-safety-could-save-lives

3.7 MISSION-CRITICAL SERVICES

The National Public Safety Telecommunications Council (NPSTC) defines mission critical as "an expectation that system coverage and availability is not lost and that limited data losses do not impact mission critical systems." It further defines mission critical data communications system as a system that "must not suffer loss of service availability due to single point failures" (Reference [4])

5G technology is being designed with standards to support mission-critical services, defined by 3GPP as:

"Communication service providing enabling capabilities for Mission Critical Applications that are provided to end users from Mission Critical Organizations or other businesses and organizations (e.g., utilities, railways)." (Reference [5])

The traditional communications applications with mission-critical characteristics are considered to be push-to-talk voice (MCPTT), real-time video (MCVideo) and real-time data (MCData)[37]. Telecommunications carriers are implementing technologies to enable these mission-critical applications, which could be leveraged by DHS customer components to address their dynamic and diverse mission needs.

3.8 NON-TERRESTRIAL NETWORKS

5G Non-Terrestrial Networks (NTN) comprise airborne or spaceborne platforms operating as networks or network segments. Examples of airborne platforms include unmanned aerial systems and in general High-Altitude Platform Systems (HAPS), while spaceborne platforms refer to satellite communication systems including Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geostationary Earth Orbit (GEO), and Highly Elliptical Orbit (HEO) systems. These added 5G network platform tiers enable wide-ranging infrastructure deployments especially to areas where terrestrial coverage may be challenging or saturated[38].

[37] https://www.etsi.org/deliver/etsi_ts/122200_122299/122280/16.08.00_60/ts_122280v160800p.pdf
[38] https://www.3gpp.org/news-events/1933-sat

4. DHS CUSTOMER COMPONENTS

OIC-TC's mission to address DHS S&T and interoperability and compatibility needs presents an important opportunity to provide the DHS customer components (the DHS operational entities) with the information required to adopt 5G technology into its missions. This section discusses the various DHS customer components, their missions, how 5G technology can enhance the missions in a broad sense, and then will examine 3 selected customer components via a use case for each to explore more deeply how 5G technologies could be applied.

Table 4-1 provides a summary of the 12 identified DHS customer components including their mission statements. It is anticipated that all 5G foundational use cases (eMBB, URLLC, mMTC) will be applicable to each customer component and that there is a core set of technologies that will be valuable to each of them.

Table 4-1: DHS Customer Component Summary

Operational Component	Acronym	Mission Statement	Source
Customs and Border Protection	CBP	Protect the American people, safeguard our borders, and enhance the nation's economic prosperity.	https://www.cbp.gov/about
United States Coast Guard	USCG	The Coast Guard manages six major operational mission programs: 1) Maritime Law Enforcement, 2) Maritime Response, 3) Maritime Prevention, 4) Maritime Transportation System Management, 5) Maritime Security Operations, 6) Defense Operations	https://www.uscg.mil/About/Missions/
Immigration and Customs Enforcement	ICE	With a workforce numbering approximately 20,000 including deportation officers, special agents, analysts, and professional staff, ICE stands at the forefront of our nation's efforts to strengthen border security and prevent the illegal movement of people, goods, and funds into, within, and out of the United States. The agency's broad investigative authorities are directly related to our country's ongoing efforts to combat terrorism at home and abroad. HSI and ERO are recognized as essential law enforcement partners domestically and abroad, and either lead or participate in multiple interagency task forces that aim to target and prevent terrorism and transnational crime.	https://www.ice.gov/mission
United States Citizenship and Immigration Services	USCIS	U.S. Citizenship and Immigration Services administers the nation's lawful immigration system, safeguarding its integrity and promise by efficiently and fairly adjudicating requests for immigration benefits while protecting Americans, securing the homeland, and honoring our values.	https://www.uscis.gov/about-us/mission-and-core-values
Countering Weapons of Mass Destruction Office	CWMD	The Countering Weapons of Mass Destruction Office (CWMD) leads DHS efforts and coordinates with domestic and international partners to safeguard the United States against CBRN and health security threats.	https://www.dhs.gov/countering-weapons-mass-destruction-office

Operational Component	Acronym	Mission Statement	Source
Federal Emergency Management Agency	FEMA	FEMA's mission is helping people before, during and after disasters, and our guiding principles help us achieve it.	https://www.fema.gov/about
Federal Law Enforcement Training Center	FLET	The Federal Law Enforcement Training Centers, through strategic partnerships, prepares the federal law enforcement community to safeguard the American people, our homeland, and our values.	https://www.fletc.gov/our-mission-vision-and-values
First Responders Public Safety	FIRST RESPONDERS	First responders are often the primary line of defense for U.S. communities, responding to an evolving spectrum of natural and man-made threats. The Department of Homeland Security Science and Technology Directorate (S&T) works closely with first responders across jurisdictions and disciplines to improve their safety and effectiveness.	https://www.dhs.gov/science-and-technology/first-responders
Cybersecurity and Infrastructure Agency	CISA	Lead the National effort to understand and manage cyber and physical risk to our critical infrastructure.	https://www.cisa.gov/about-cisa
Transportation Security Administration	TSA	Protect the nation's transportation systems to ensure freedom of movement for people and commerce.	https://www.tsa.gov/about/tsa-mission
Office of Intelligence and Analysis	I&A	The Office of Intelligence & Analysis (I&A) is a unique member of the U.S. Intelligence Community (IC). I&A is the only IC element statutorily charged with delivering intelligence to our State, Local, Tribal and Territorial (SLTT) and private sector partners, and developing intelligence from those partners for the Department and the IC.	https://www.dhs.gov/office-intelligence-and-analysis
United States Secret Service	USSS	We have an integrated mission of protection and financial investigations to ensure the safety and security of our protectees, key locations, and events of national significance. We also protect the integrity of our currency, and investigate crimes against the U.S. financial system committed by criminals around the world and in cyberspace.	https://www.secretservice.gov/about/overview

According to the Industry Guide[39], published by S&T to provide information to industry, the priority R&D needs identified were:

- Securing Aviation
- Securing Borders
- Preventing Terrorism
- Protecting from Terrorist Attacks
- Securing Cyberspace
- Managing Incidents

It can be seen that there are a broad range of areas DHS S&T has prioritized for R&D that would certainly span across all of the DHS customer components. Moreover, 5G and its enabling technologies span a wide range of areas and can be considered in addressing each of these priorities.

Below is a summary table with information extracted from the Industry Guide[39]. The table includes discussion of how areas of 5G technology can address these needs:

Table 4-2: DHS S&T Subset of Priority R&D Needs

Priority Need	Specific Areas	5G Applicability
Securing Aviation	• High-throughput cargo screening • Cost-effective electronic imaging for bulk air cargo • Passenger identification and vetting • Rapid detection and alarming of explosives • Distinguishing threats from non-threats on passengers • Efficient and accurate detection of complex threat concealment on passengers and carried property	Dense deployments of sensors, including technologies: - mMTC, NB-IoT, Cat1M[40] - Edge Analytics Directional networking technologies for targeting users and systems - Massive MIMO - Beam steering
Securing Borders	• Cross-border tunnel detection, surveillance, and forensics • Infrastructure tunnel surveillance • Integrated and improved sensors, systems, and data	Dense deployments of sensors, including technologies: - mMTC, NB-IoT, Cat1M - Edge Analytics Coverage enhancement - IAB

[39] https://www.dhs.gov/sites/default/files/publications/st_industry_guide.pdf
[40] NB-IoT and Cat1M technology descriptions can be found here: https://www.ericsson.com/en/blog/2019/2/difference-between-nb-iot-cat-m1

Priority Need	Specific Areas	5G Applicability
	• Actionable intelligence gathering and sharing • Dark aircraft and vessel detection, tracking, and interdiction • Expedited people screening • Maritime surveillance and communications in remote environments	- NTN - ProSe Utilization of next-generation applications - Multi-Access Edge Compute
Securing Cyberspace	• Distributed cloud-based communications and monitoring • Industrial control systems, cyber sensors, analytics, and prevention • Metrics for cybersecurity effectiveness, severity, and comparison • Data capture of networked devices for forensic examination	Cloud computing capabilities - Multi-Access Edge Compute - Industrial IoT - Open architecture (open RAN, NFV enabled core functions, etc) - Common interfaces for collecting stats, metrics, KPIs, at all points of networks (RAN, Edge, Transport, Core)
Preventing Terrorism	• Organic explosive compound and homemade explosives detection • Improvised explosive device-related anomaly detection • Automated machine learning	Dense deployment of sensors with next-gen applications - Edge Analytics - AI/ML
Protecting from Terrorist Attacks	• Personal protective equipment for all CBRNE hazards • Modeling and predictive analytics for decision making • Disease and biological threat detection, identification, and classification in field operational environments • Biological attack verification	Sensor data collection, fusion, dissemination with use of next-gen applications - Edge Analytics - AI/ML -Mission-critical services for emergency responders and senior leaders

Priority Need	Specific Areas	5G Applicability
Managing Incidents	**Situational Awareness** • Access, integration, sharing, and display of incident scene images and video • Indoor and outdoor geolocation of responders • Threat and hazard detection and identification • Map generation of indoor and outdoor locations • Real-time merging and synthesis of disparate data sources • Identification of potential cascading effects that impact incident response and/or the surrounding community • Creation and maintenance of bird's-eye views of incident scenes **Communications** • Effective communication in the presence of loud ambient noise • Multiple jurisdiction and agency coordination of dispatch • Multi-disciplinary communication channel and frequency facilitation and management Information sharing among agencies and disciplines **Intelligence & Investigation** • Capture, processing, integration, management	Situational Awareness: - Network slicing - Business-driven policies -Edge analytics - IoT/Smart City technologies Communications: - eMBB for increased capacity - mMTC for integrated sensors at massive scale - URLLC for augmented reality, autonomous vehicles and drones, telehealth -Mission-critical and interoperable communications e.g, FirstNet Intelligence & Investigation: - Processing and fusion of raw and digital information collected from mobile apps such as social media apps

Priority Need	Specific Areas	5G Applicability
	of raw and digital information • Creation of actionable intelligence based on multi-source data and information • Monitoring of social media and other non-traditional intelligence sources for warnings and indications of planned activities or violence • Isolation and extraction of critical information from social media feeds and electronic communications	

This section will focus on use cases and 5G applicability for three customer components: 1) Customs and Border Protection (CBP), 2) Federal Emergency Management Agency (FEMA), and 3) First Responders/Public Safety. It is important to note, though, that the 5G technologies and research problems discussed in this section could apply to all customer components.

4.1 Customs and Border Protection

The United States Border Patrol (USBP) is an operational component of Customs and Border Protection (CBP), which is a DHS S&T customer component. USBP is responsible for patrolling the border between legal ports of entry. A recent DHS Office of Inspector General (OIG) report detailed technological challenges encountered along the Southwest border[41]. Its focus was on the employment of a wide variety of sensor systems as a force multiplier in austere physical environments, such as those characterized by rugged terrain or dense foliage. These sensor systems include fixed and mobile surveillance video systems, unmanned aerial systems, and sensor detection equipment. USBP personnel interviewed have said that the technology has enhanced their operations. However, there are some interoperability challenges both at the system/device level and the inter-station level, where information between non-integrated systems cannot be shared or coalesced, and information cannot be easily transferred between stations during real-time operations. Furthermore, it was discussed that several USBP sectors were challenged with slow network speeds preventing the ability for agents deployed out in the field to "access and process information."

The eMBB and mMTC usage scenarios are directly applicable to this scenario. For eMBB, deploying links with increased capacity from sensors out in the field to agents and to headquarters will enable

[41] https://www.oig.dhs.gov/sites/default/files/assets/2021-02/OIG-21-21-Feb21.pdf

enhanced information flow such as high-quality video feeds. For mMTC, sensor densification-enabling technologies such as power-saving modes, low-frequency, and low-bandwidth communications via waveforms to meet low throughput needs in rural scenarios will be applicable for this context.

Table 4-3 provides an exploration of how 5G technology could be applied to enhance the effectiveness of the sensor system deployments at the Southwest border.

Table 4-3: 5G Mapping to CBP Use Case

Exemplar Use Case	Mission Needs addressed by 5G Technologies and Enablers	Operational Impact (Advantages/Challenges)
Employment of sensor systems providing situational awareness at Southwest Border	Access to sensor information in rural, austere physical environments • **Non-terrestrial Networks (NTN):** Deployment of UAVs or high altitude platform systems (HAPS) with communications payloads or leveraging SATCOM technology • **mMTC Capabilities:** Waveforms, battery saving mechanisms for fixed sensors, implementation of shorter/smaller messages[42] • **Spectrum Versatility:** Addressing possible contention in the EM environment Integrated access and coordination among sensors, systems, and end-users • **Proximity-based Services (ProSe):** Sidelink channel for sensor – sensor, sensor-agent, or agent-agent connection • **Integrated Access and Backhaul (IAB):** Enabling 5G connectivity access for remotely deployed sensors and agents combined with backhaul connectivity • **Tactical Private Network Solutions:** Subset of 5G network infrastructure provided in a manpack or vehicular form	**Advantages:** Real-time information to deployed field agents; option to deploy higher density of lower-cost sensors with mMTC; enhanced connectivity and coverage for sensors and agents **Challenges:** Assessment of operational capability of 5G sidelink technology; IAB implementations on diverse platforms; network support for wide variety of sensor types; information overload; more complicated network architecture and IT infrastructure may be required to support sensors i.e., need end-to-end infrastructure enhancement

[42] Some envisioned energy efficiency practices are discussed here: https://www.ericsson.com/en/blog/2020/3/5g-network-energy-efficiency

The mission needs previously identified can be further summarized as follows:

1. Access to sensor information in rural, austere physical environments:

   As discussed in the OIG report[43], areas along the Southwest border are austere physical and geographical environments with rugged terrain and dense foliage, often in rural (sparsely-populated) environments. This presents communications connectivity challenges both from an electromagnetic wave propagation standpoint (terrain/foliage) as well as an underlying communications infrastructure availability (rural environment) standpoint. In order to mitigate these challenges, tailored applications of 5G technologies will need to be applied such as the use of altitude in the aerial or space tier via non-terrestrial networks. Additionally, to ensure longevity of effectiveness of these remotely-deployed sensors, mMTC capabilities will need to be implemented. Lastly, the spectrum versatility of 5G could be effectively employed in the event of adversarial activity in operating frequency bands along the border.

2. Integrated access and coordination among sensors, systems, and end-users:

   Real-time integrated coordination of information along all connected devices deployed along the Southwest Border can enhance the comprehensive view for agents in the field and back at headquarters. The use of 5G sidelink channels to connect disparate systems could enable otherwise stovepiped systems to interact. In addition to sidelink channels, deployment of IAB systems could provide hubs for disparate systems to interoperate through their 5G access. Integration could also be enabled or enhanced if agents in vehicles or remote monitoring towers were deployed with private 5G networks set up in these remote and rural areas.

Research and Development Challenges and Open Questions

In order to leverage 5G in a manner that enhance CBP/USBP's operations at the Southwest border, some research and development challenges must be addressed and some open questions must be answered. Below are a few identified and presented per the information captured in Table 4-3.

- Implementation of 5G sidelink (device-to-device) channels to enable sensor-to-sensor or sensor-to-UE communications and information transfer and sharing
  - Can mesh networking capabilities for sidelink channels be implemented along with multi-hop sidelink channel paths?
  - How many devices can sidelink and at what altitudes?
  - What is the range of sidelink channels and is it impacted by terrain, weather, and other environmental conditions?
- Implementation of IAB solutions such as on vehicles or UAVs to support operations in remote and geographically-challenging areas
  - Investigation of cell-on-wheels' and cell-on-wings' IABs' abilities to form richly-connected mobile ad hoc networks to implement path redundancy

[43] https://www.oig.dhs.gov/sites/default/files/assets/2021-02/OIG-21-21-Feb21.pdf

  - How resilient are these IAB deployments in contested electromagnetic environments?
- Access and broad RAN/Network support for a wide variety of sensor types, with disparate information requirements; Ability to support ultra-dense sensor deployments in the coming decade based on the prospects of 5G mMTC capabilities
  - Can 5G technologies play a role in improving information flow, processing, and sharing from the current set of disparate sensor types at the Southwest Border?
  - Will 5G advancements be able to support the complex operations and missions involving potential ultra-dense sensor deployments in the future? What, if any, will be the limiting factors?
- Leverage flexible and virtualized 5G infrastructure solution to support next-generation application deployments and sensor fusion through the network
  - Assessment of the 5G network's capability to transfer information in a timely manner providing a rich SA picture enabling automated decision-making
  - Automation that intelligently prioritizes, filters, and processes SA information

4.2 FEMA

The Federal Emergency Management Authority (FEMA) has a diverse set of responsibilities as a DHS customer component. One of its major responsibilities rests within the Office of Response and Recovery, which "provides guidance leadership and oversight to build, sustain and improve the coordination and delivery of support to citizens and state, local, tribal and territorial governments to save lives, reduce suffering, protect property and recover from all hazard."[44] Within this office is the capability to support disaster responses by providing "emergency communications through six geographically dispersed Mobile Emergency Response Support detachments and a pre-positioned fleet of Mobile Communications Office Vehicles."[45] Providing such a capability to a community that has sustained a disaster can serve as a pathway towards preserving and stabilizing community lifelines, which are: Safety and Security; Food, Water, Shelter; Health and Medical; Energy (Power & Fuel); Communications; Transportation; and Hazardous Material[46].

When Mobile Emergency Response Support (MERS) detachments are deployed along with Mobile Communications Office Vehicles (MCOVs) for disaster response, coordination takes place at multiple levels of government along with Non-Governmental Organizations (NGOs). At a specific staging site, multiple communications trucks from various organizations may have their own communication systems for reach-back to their respective headquarters. However, these trucks may not be able to directly communicate with each other through their individual communication systems. Furthermore, there may be a diverse set of platforms connecting to a network such as handsets, vehicles, UAVs etc. based on the response needs.

Furthermore, each MERS has a supporting MERS Operations Center (MOC). If a MERS-based private 5G network is deployed (discussed further in this use case), the MERS can trunk back to the MOC, which provides a connection to public networks (i.e., "the rest of the world"). Typically a MOC has normal

[44] https://www.fema.gov/about/offices/response-recovery
[45] https://www.fema.gov/about/offices/field-operations/disaster-emergency-communications
[46] https://www.fema.gov/sites/default/files/2020-04/NRF_FINALApproved_2011028.pdf

(non-degraded) communications capabilities. The MOC can serve a collection and fusion point for all the incoming data from various deployed private 5G networks that are part of the disaster response. Further, the MOC can serve as a central location for enabling the management and orchestration of deployed MERS-based private networks. It can help automate the connections and configuration of new users and systems such as the nearby supporting NGOs.

Since the software applications and traffic or information type can vary widely for every disaster, interoperability to coordinate the response is a major concern. Voice communications is usually the highest priority, but integrated voice, video, data (e.g., broadband services) will be highly valuable for disaster response. Technology that could serve as a force multiplier from lack of personnel would be highly valuable. From an eMBB perspective, enhanced capacity will be valuable to FEMA to broaden the scope of information transferred over cellular networks. URLCC capabilities could provide real-time and updated information at every phase of a disaster response. mMTC principles could apply when considering interaction with smart city communities where information from smart city sensors and monitoring devices could be helpful for preparedness and response.

Table 4-4 provides an exploration of how 5G technology could be applied to enhance MERS disaster response capabilities to stabilize community lifelines.

Table 4-4: 5G Mapping to FEMA Use Case

Exemplar Use Case	Mission Needs addressed by 5G Technologies and Enablers	Operational Impact (Advantages/Challenges)
Enhancement of MERS capabilities during disaster response to help stabilize community lifelines	Rapid deployment and automated setup and configuration of MERS communications infrastructure at disaster response site • **Virtualization:** vRAN and vCore capabilities to ensure dedicated and flexible, configurable 5G infrastructure implementation • **Management and Orchestration (MANO):** Enable effective and efficient automation and zero-touch deployments of 5G MERS infrastructure • **Non-terrestrial Networks (NTN):** Enhance SATCOM capabilities MERS currently has Access and interoperability with adjacent operational components, including multi-jurisdiction, multi-agency, and NGOs • **Private (non-public) Network Infrastructure with On-Prem Edge capabilities:** Implementing 5G access and network coverage with private edge to core network setup[47] • **Integrated Access and Backhaul (IAB):** Providing 5G access capabilities to a wide variety of government and NGO stakeholders involved in disaster response beyond private network infrastructure • **Multi-Access and Authentication:** Leveraging the 5G Non-3GPP Interworking Function (N3IWF) to enable authentication capabilities for entities/devices that may be connected by diverse access methods e.g., WiFi, LMR, etc.	**Advantages:** Enhance MERS and MCOV capability to accommodate more users in an affected community and provide better coordination among multiple responding agencies **Challenges:** Temporary nature of the infrastructure could cause a confusing cellular network disruption to the community; operators would need to be trained in how to configure the 5G networks to most suit the disaster area's needs, unless configuration properly automated; implementation of diverse IAB solutions to support wide range of adjacent agencies/entities

[47] https://www.ericsson.com/en/portfolio/iot-and-new-business/dedicated-networks/private-networks

The mission needs previously identified can be further summarized as follows:

1. Rapid deployment and automated setup and configuration:

   Deploying a MERS to a disaster response staging site requires the ability to support the mission as rapidly and seamlessly as possible, often by operators with limited technical expertise. As is evidenced by the discussions herein, 5G comprises a wide array of technologies, so automated setup and configuration of appropriate 5G network infrastructure is of paramount importance regardless of operator or practitioner technical experience level. In order to support this, virtualization such as vRAN and vCore technologies could be incorporated. Management and orchestration techniques could be applicable to ensure minimal manual deployment and configuration efforts. NTN setups to enhance 5G backhaul capabilities or complement legacy SATCOM systems could also be implemented to ensure reliable MERS communications.

2. Access and interoperability:

   One of the key tenets to disaster response is the coordination and interaction of agencies at multiple jurisdiction levels. Typically, each agency arrives at a disaster response site with its own communications infrastructure, limiting communications and data interoperability among the multiple entities. MERS deployments with private 5G network capabilities can provide a cellular network infrastructure for these entities. Furthermore, IAB components can provide access to devices and systems that may be deployed in more remote parts of a community where disaster response attention is required. Lastly, the non-cellular systems e.g., WiFi or LMR technologies that the various agencies arrive with at a site play their own unique roles, so the ability to implement multi-access and authentication in a centralized way for devices along all of these access technologies will enable greater interoperability.

Research and Development Challenges and Open Questions

In order to enable 5G to enhance FEMA's employment of MERS during disaster responses, some research and development challenges must be addressed and some open questions must be answered. Below are a few identified and presented per the information captured in Table 4-4.

- Leveraging Automation, Orchestration, and Virtualization of RAN, Edge, and Core network functions
  - How automated and seamless can 5G network configuration be to enable rapid setup of MERS communications-providing capabilities that may be stored in a private cloud?
  - How will FEMA define the services they require?

- Exploration of 5G Non-Terrestrial Network (NTN) applications to complement or enhance current SATCOM backhaul capabilities
    - Can relationships with commercial low earth orbit (LEO) satellite communications providers be established to enable NTN solutions for unified interagency backhaul capabilities?
- 5G Private Network Setup
    - What is the level of coordination required and automation available to enable other entities to connect to a 5G Private Network setup on a MERS? Are there limits on users, capacity, coverage?
    - What are the requirements for interoperability between a private and commercial network or between two private networks?
- Implementation of IAB solutions on MERS to support community lifeline stability during degraded cellular communications services post-disaster
    - What is the capacity and spectrum versatility that can be supported by a MERS deployment and how robust to dynamically-changing needs will they be?

4.3 First Responders/Public Safety

First responders are trained to operate in a wide variety of scenarios and situations to protect and preserve our communities. They interact with the community on a daily basis and encounter incidents where a coordination of a variety of personnel and information is required. In order to provide real-time situational awareness to all relevant operators, communications technologies must be reliable and resilient.

In the near future, 5G networks will become prevalent and Smart Cities will include sensors of all types and be located at all locations. This includes sensors for public infrastructure including roads and streetlights, sensors for tracking traffic patterns and monitoring for threats, sensors on vehicles and drones for communicating and coordination actions, and various wearable sensors for interacting with the world or monitoring biometrics. These sensors will generate varying degrees of information including periodic formatted messages to high quality real time streaming of video.

While many of these sensors and systems will initially be deployed and utilized by the public, they have the potential to offer profound impacts to the public safety community as well. 5G technologies have the potential to enhance situational awareness, which consequently can improve decision making. Some situational awareness needs extracted from the DHS Industry Guide are[48]:

- *Access, integration, sharing, and display of incident scene images and video*
- *Indoor and outdoor geolocation of responders*
- *Threat and hazard detection and identification*
- *Map generation of indoor and outdoor locations*
- *Real-time merging and synthesis of disparate data sources*

[48] https://www.dhs.gov/sites/default/files/publications/st_industry_guide.pdf

- *Identification of potential cascading effects that impact incident response and/or the surrounding community*
- *Creation and maintenance of bird's-eye views of incident scenes*

There are numerous efforts which each seek to ensure interoperability at all levels of government, ensuring multi-agency and multi-entity planning and coordination leveraging shared situational awareness[49] [50] [51].

Table 4-5 below provides an exploration of how 5G technology could be applied to enhance real-time situational awareness capabilities during public safety incidents, where integration of information from Smart City/IoT infrastructure, first responder devices, and private citizen devices would be powerful.

[49] https://www.dhs.gov/science-and-technology/ngfr
[50] https://www.cisa.gov/necp
[51] https://www.cisa.gov/safecom

Table 4-5: 5G Mapping to First Responder Use Case

Exemplar Use Case	Mission Needs addressed by 5G Technologies and Enablers	Operational Impact (Advantages/Challenges)
Enhanced situational awareness during public safety incident in a Smart City environment	Connectivity for dense deployment of sensors of disparate types with varying information characteristics and performance requirements[52] • Flexible New Radio and vRAN solutions enabling all use cases (eMBB, mMTC, URLLC) • Spectrum versatility • mmWave and Beam steering for tracking mobile users and vehicles • Proximity-based Services and V2X for extending reach indoor or below ground • Integrated Access and Backhaul (IAB) for extending coverage along busy urban streets A communications platform that enables edge analytics, advanced routing, and interoperable applications solutions • MEC • Virtualized and disaggregated RAN and Core • Business driven services and automated deployments • Network Slicing	**Advantages:** Access to information would greatly improve situational awareness for public safety community leading to improved decision-making and can save lives and resources. Events in the environment could trigger response without direct reports from the public, mission critical services will enable the first responder consistent quality of experience regardless of the threat. **Challenges:** Complexity of communications environment and supporting systems, information overload, trust of automated systems and business driven policies, interoperability among those in the public safety community, and general access to public and private information with an emphasis on security and privacy. Many new applications and policy for improved decisions support will be required.

[52] Note: connectivity of vast number of these sensors are not a concern of the public safety community, however the 5G technologies will enable access and thus serve as a means to leverage these information sources.

Exemplar Use Case	Mission Needs addressed by 5G Technologies and Enablers	Operational Impact (Advantages/Challenges)
Enhanced situational awareness during public safety incident in a Smart City environment	Access to public, private, and public safety community sensor data as well as in-band network telemetry or over-the-air RF transmissions[53] • Business driven enablement • Traffic steering, SDN, and Network Slicing for moving public data to proxy enforcing unidirectional access by public safety community • MEC for hosting cross domain solutions • Access to 5G RAN, Edge, Transport, and Core KPIs • vRAN solutions and disaggregated architecture to enable RF and environmental sensing from common infrastructure Mission critical services in both day-to-day operations and incidents facing congested, contested, or degraded environments • Mission critical services as defined in 5G • Network Slicing for guaranteed SLAs • Virtualized and disaggregated RAN and Core • Business driven policies and controls	See above

[53] This is less of a technical challenge and more of a policy problem – however 5G solutions can likely help

The mission needs previously identified can be further summarized as follows:

1. Connectivity for dense deployment of sensors of disparate types with varying information characteristics and performance requirements:

   An ultra-dense urban environment with envisioned smart city deployments will be one of the first places where mMTC requirement for 1e6 device/km^2 is likely to occur. Combining this with the need for mobility at speeds ranging from a human walking to a high speed train and the disparate types of information the sensors will generate, there is a need for a very complex network with flexible radio access technologies, advanced routing and transport, and intelligent control. The 5G networks offer a multitude of new technologies including Flexible NR, mmWave, Beam Steering, and spectrum versatility that will provide consistent access to these sensors and support the ultra-dense deployments. Furthermore, 5G networks are leveraging novel fronthaul, midhaul, and backhaul technologies such as IAB and ProSe to extend the network into buildings or underground with limited permanent infrastructure.

2. A communications platform that enables edge analytics, advanced routing, and interoperable applications solutions:

   In order to enable sensors and information sources in a Smart City environment, it will be necessary that the mobile broadband network seamlessly integrate with cloud computing environments and fully embrace virtualization and the disaggregated RAN and Core architecture that support traffic steering and host the compute and storage capability to enable information fusing, processing and dissemination, as well as perform advanced analytics. The 5G MEC cloud environment will need to host various applications for interoperability within both the commercial and public safety community and support automated deployment and lifecycle operations via business driven service orchestration. Advanced routing and network slicing will be essential to ensure efficient, optimal, and resilient communication ensuring networks are not inadvertently overloaded and that the right information is moved to the right place at the right time. It is likely that the public safety community will host many of their solutions for shared situational awareness and interoperability within the cloud and attached to the 5G networks.

3. Access to public, private, and public safety community sensor data:

   Access to this plethora of new information will be challenging as much of it will be owned by the city, critical infrastructure organizations such as gas, water, and power, or even private information owned by citizens or private organizations such as wearables, vehicle sensors, or security cameras. Access to this information is much less of a technical challenge and far more of a policy concern, regarding how the public safety community could leverage the information sources without abuse or access to private information. This is beyond the scope of 5G communications however, elements of 5G can be leveraged to help. There will need to be strict policies and control which restrict how and when information can be access. These could be installed within a 5G network and managed via existing business driven service orchestration. This will be enabled by dynamic formation of services triggered by critical events and supported by advanced routing such as SDN and filtering of traffic including network slicing. The 5G MEC applications can serve as proxy solutions to collect, filter, scrub, and disseminate information to the public safety community with unidirectional access and protection of privacy content.

Another avenue to sources of information will be through the 5G network itself. The public safety community could leverage the network for monitoring of emerging threats or incidents which have not been reported, quick assessments of infrastructure degradation after any large scale event, or even terrorist or other threat activities. In order to enable an efficient and flexible network, 5G SDOs are exposing common interfaces throughout the network which includes the virtualized RAN, edge, transport, and core. These interfaces will provide carriers and potentially application developers or public safety community the ability to view information in real time such as number of connected devices, transport characteristics, flow information, spectrum utilization, and sensed RF environment, among others. There is also the possibility to use virtualized RAN (vRAN) technologies to leverage common deployed infrastructure to monitor over the air transmissions to detect anomalies or monitor for large-scale threats and events.

4. Mission critical services in both day-to-day operations and incidents facing congested, contested, or degraded environments:

Mission critical services for voice, video, and other data will be crucial to enable the public safety community as they leverage 5G communications. This will be necessary in both day-to-day operations as well as during response to incidents that could involve highly congested scenarios or other events where networks are naturally degraded or contested and under attack. The 5G network and SDOs are taking a proactive approach to define the expectations, requirements, and architecture for mission critical services. Additionally, many of the features of 5G networks including virtualization, disaggregated architecture, network slicing, and flexible new RAN will enable robust and resilience services ultimately improving the quality of service and quality of experience for all. The public safety community thus has a tremendous set of options when approaching 5G technologies and influencing the standards to ensure mission dependent, mission critical services are offered and delivered as expected.

Research and Development Challenges and Open Questions

In order to use 5G to enhance situational awareness capabilities to address public safety incidents in (sub)urban environments, research and development challenges must be addressed and open questions must be answered. Below are a few identified and presented per the information captured in Table 4-5.

- Development of next-generation interoperability applications that can rapidly ingest diverse traffic types from diverse sources to synthesize and disseminate meaningful SA information
  - Can these applications run solely on the UEs or do they need multi-access edge computing capabilities to provide the computing power to synthesize this information?
  - How can information be properly marked and appropriate users identified and authenticated to ensure access is restricted but available to the right people?
- Develop technical solutions, procedures, and policies to enable the public safety users to leverage ubiquitous deployment of disparate 5G solutions such as disaggregated RAN, mmWave base stations, IAB, device-to-device ProSe communications, IoT sensor nets, and NPN
  - How can public safety users securely access these networks while protecting the public's privacy and security?
  - How to ensure public safety user information and identity is not leaked onto these networks and used by an adversary?
  - How to ensure access to mission critical services once connected?
- Research into advanced routing and intelligent service orchestration to move the right information to the right place at the right time
  - Is network slicing able to offer this granular level of information delivery securely among the public safety community?
  - Can mission critical services be offered along the end-to-end path of transmission?
  - What trigger conditions and rules should exist to initiate and filter information dissemination?
  - Which algorithms are needed to facilitate this process including the dynamic placement of virtualized network functions?

4.4 Customer Component Opportunities

The 5G technologies discussed in the exploration of these customer component use cases all addressed highly dynamic or flexible needs often in austere or dense/diverse user environments, where the operators may experience challenges in robust and reliable cellular network access. A diverse set of 5G technologies provides capability enhancements for customer components and addresses a wide variety of operational challenges that a typical commercial end-user may not encounter.

Implementation of these capabilities in a manner that enables interoperability and compatibility among customer component end-users will only be a reality by adherence to standards and common interfaces. The output of the research examining customer component operational needs and 5G's ability to enhance those capabilities addressing those needs provides: 1) innovative solutions and adaptations of 5G technology and 2) opportunities to potentially influence 5G standards development.

5. 5G DEPLOYMENT AND ROLLOUT

5G technology deployment has begun and will continue as an incremental process[54]. As 3GPP releases are developed, providing the guides for specifications of the protocols and standards that govern the underlying 5G technologies, the equipment manufacturers, carriers, and handset manufacturers make decisions on what specific technologies they will implement. This implementation process is depicted in Figure 5-1.

Figure 5-1: 5G Technology Rollout Process (Reference [1])

This section provides an overview of the current state and outlook of 5G deployment relevant to DHS customer component use of the technologies. For a high-level understanding of how 5G technology is performing in the recent past (Q1 and Q2 CY2021), the assessment by the organization OpenSignal provides an independent look along with Key Performance metrics[55].

5.1 CARRIER SURVEY

This subsection provides a brief carrier technology deployment survey from relevant information collected from online sources. The relevant areas that would be of interest to DHS customer components include: 5G Non-Stand Alone (NSA) implementation status (integration of 5G RAN with 4G Core functionality) vs. 5G Stand Alone (SA) (integration of both 5G RAN and Core), spectrum usage, carrier interest in vRAN/OpenRAN technology, and demonstration of IAB technology. These are summarized in Table 5-1.

[54] Note that this section was developed for informational purposes and is based on content that was found in the public domain. It is not meant to be an exhaustive or necessarily authoritative representation of the state of 5G deployment and rollout. The information is provided as an initial glimpse into what technologies the carriers are offering.
[55] https://www.opensignal.com/reports/2021/04/usa/mobile-network-experience-5g

Table 5-1: Carrier Key Technology Survey

	Verizon	AT&T	T-Mobile
Deployed NSA 5G	Yes[56]	Yes[57]	Yes[58]
Deployed SA 5G	No (planned for 2021)[59]	No (planned for 2021)[60]	Yes[61]
Spectrum Usage[62]	Low Band: 850 MHz mmWave: 28 GHz	Low Band: 850 MHz mmWave: 39 GHz	Low Band: 600 MHz Mid Band: 2.5 GHz (from Sprint) mmWave: 28 GHz and 39 GHz
Interest in vRAN/OpenRAN	Yes[63]	Yes[64]	No (not planned yet)[65]
Demonstrated IAB	Yes[66]	Some mention of testing in 2020 and wider use in 2021[67]	Not mentioned explicitly

5.2 Edge-to-Core Implementation Snapshot

Figure 5-2 from the organization netmanias depicts a 2020 snapshot of the intricate relationship between the Mobile Network Operators (MNOs) providing cellular services to end-users, the cloud computing companies hosting the Multi-access Edge Computing resources, virtualized 5G Core network functions, and virtualized 5G RAN functions, and the various 5G Core and RAN vendors on the right[68]. As can be seen in the figure, cloud computing enables many aspects of the 5G systems architecture and services offered through the networks. These partnerships among the MNOs, cloud computing companies, and Core/RAN vendors will be key to establishing a robust network to meet the envisioned 5G pillar use cases.

[56] https://www.telecompetitor.com/verizon-readies-5g-standalone-core-to-support-slicing-and-more/
[57] https://www.sdxcentral.com/articles/news/att-5g-standalone-core-deployment-set-for-mid-2021/2020/09/
[58] https://www.sdxcentral.com/articles/news/att-5g-standalone-core-deployment-set-for-mid-2021/2020/09/
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[65] https://www.lightreading.com/open-ran/t-mobiles-network-chief-pours-cool-but-not-cold-water-on-o-ran/d/d-id/765518
[66] https://www.rrmediagroup.com/Features/FeaturesDetails/FID/1008#:~:text=Verizon%20announced%20a%20successful%20test,to%20public%20safety%20through%20deployables
[67] https://www.fiercewireless.com/wireless/at-t-expects-to-test-iab-2020-use-it-more-widely-2021

[68] https://www.netmanias.com/en/?m=view&id=oneshot&no=14881

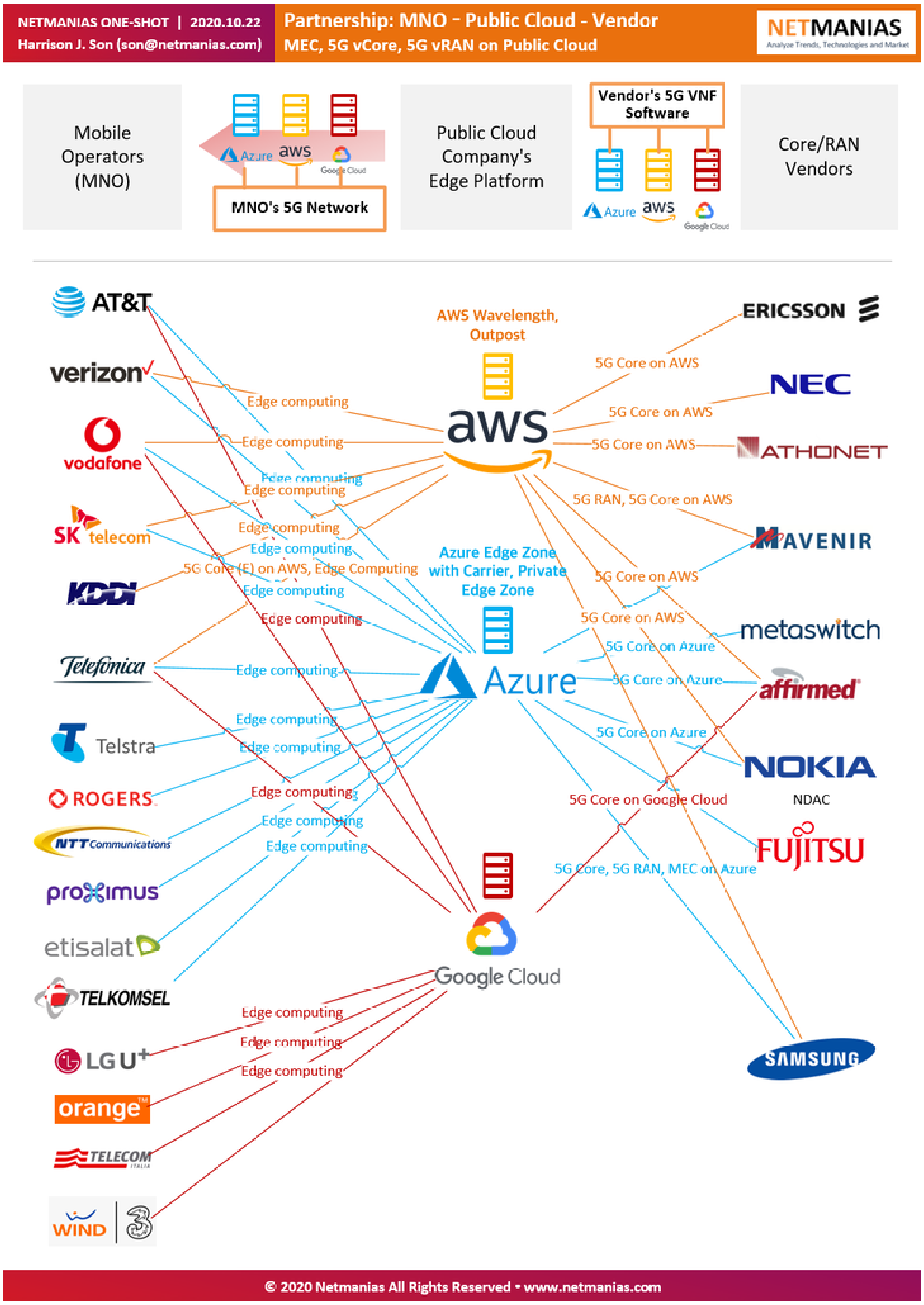

Figure 5-2: Implementation from Edge to Core

5.3 FirstNet

The First Responder Network Authority is responsible for the deployment of the National Public Safety Broadband Network (NPSBN). The NPSBN is powered by AT&T and was developed as a 4G/LTE-based cellular network. The network itself is often referred to as FirstNet. As 5G networks begin to be deployed, it is essential to understand in what ways FirstNet will be impacted by these deployments.

AT&T claims it is adopting a first responder-centric approach to incorporating 5G capabilities into FirstNet that "will be ideal for IoT and video intelligence solutions"[69]. Adoption of 5G into FirstNet will take a phased approach. This includes first upgrading the FirstNet core to be 5G compliant, thereby providing first responder access to (5G+) mmWave spectrum, while preserving its always-on and preemption capabilities on LTE public safety (Band 14). What this means with respect to broadband services, is that first responders will maintain priority and preemption-based voice communications on LTE, while data traffic routing will be optimally-selected through either 5G or LTE spectrum based on network service conditions[69].

FirstNet's adoption of 5G technologies will also impact DHS customer component use of 5G. In FirstNet's 2020 roadmap[70], adoption of 5G is mentioned in several different contexts. This includes:

- *Core and RAN updates as the technologies are deployed and made available to FirstNet*
- *Focus on priority and preemption on 5G*
- *Implementation of mission critical applications such as Mission Critical Push-to-Talk (MCPTT) and Mission Critical Video (MCVideo), and Mission Critical Data (MCData)*
- *Implement standards-based systems and features providing cybersecurity to public safety users on 5G in support of the network security requirements.*

The FirstNet roadmap has also included consideration and feedback from the user community about what specific aspects of 5G are most desirable. The ability to enhance situational awareness capabilities using the anticipated number of IoT devices to be available along with other data sources is one of the key areas of interest as it pertains to 5G. Furthermore, having the proper tools to process, analyze, and synthesize this data for decision-making purposes is a priority for the end-user community, which FirstNet recognizes.

5.4 Release Version-Based Timeline

All 5G technologies and capabilities deployed operationally by carriers and enterprises will ultimately trace back to standards developed in 3GPP and other organizations. The carrier deployments however, tend to lag behind the standards process by up to several years, and further, not all solutions and architectures presented in the standards will be implemented. The 3GPP release timeline provides some insights into what would be the absolute earliest certain technologies would be seen. This subsection provides timeline and technology information on Releases 15, 16, and 17, the current releases defining

[69] https://about.att.com/story/2021/fn_5g.html
[70] https://firstnet.gov/system/tdf/Roadmap_2020_nocompress.pdf?file=1&type=node&id=1612

5G technology, to inform the approximate time when key technologies of interest to DHS customer components could be expected to be available.

5.4.1 Release 15

Release 15 evolved[71] over the course of 2018 with some activity in mid-2019. It included some of the first set of technologies for 5G as depicted in the timeline in Figure 5-3. Note that networks that are Release 15-compliant are only now being deployed in early 2021. Many commercial products, software solutions, and even open-source solutions are only Release 15-compliant.

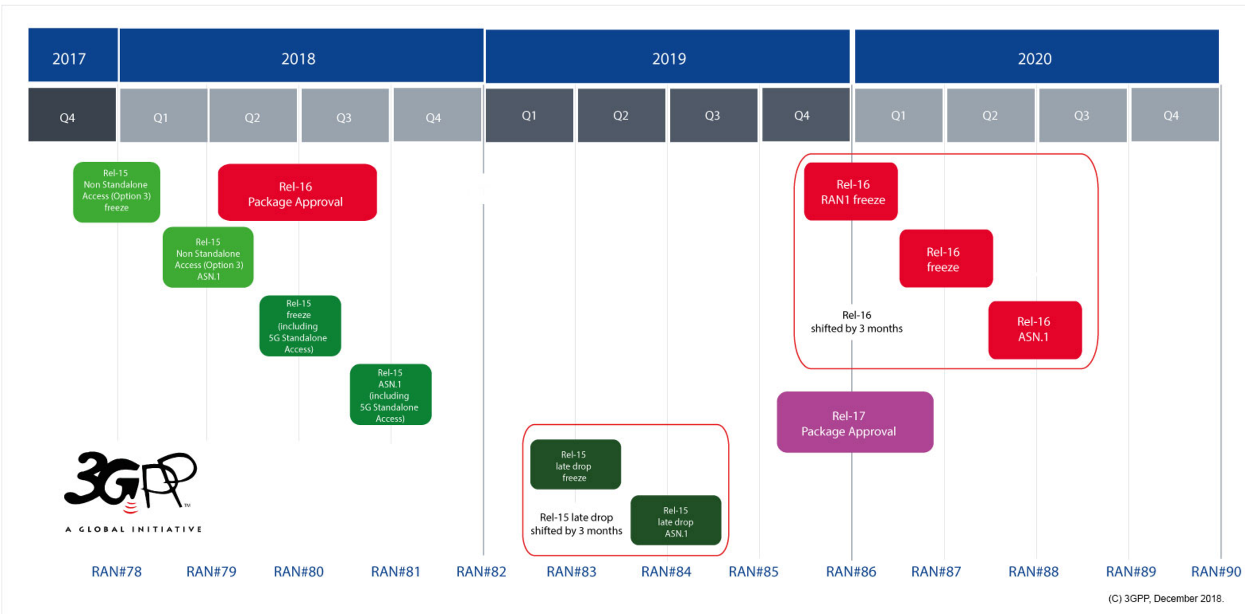

Figure 5-3: Release 15 Timeline

Key technologies of interest (depicted in Figure 5-4) include:

- New Radio (NR) defining functionality for the RAN
- Massive MTC and Internet of Things (IoT)
- Mission Critical interworking with legacy systems
- Service Based Architecture (SBA)

[71] https://www.3gpp.org/release-15

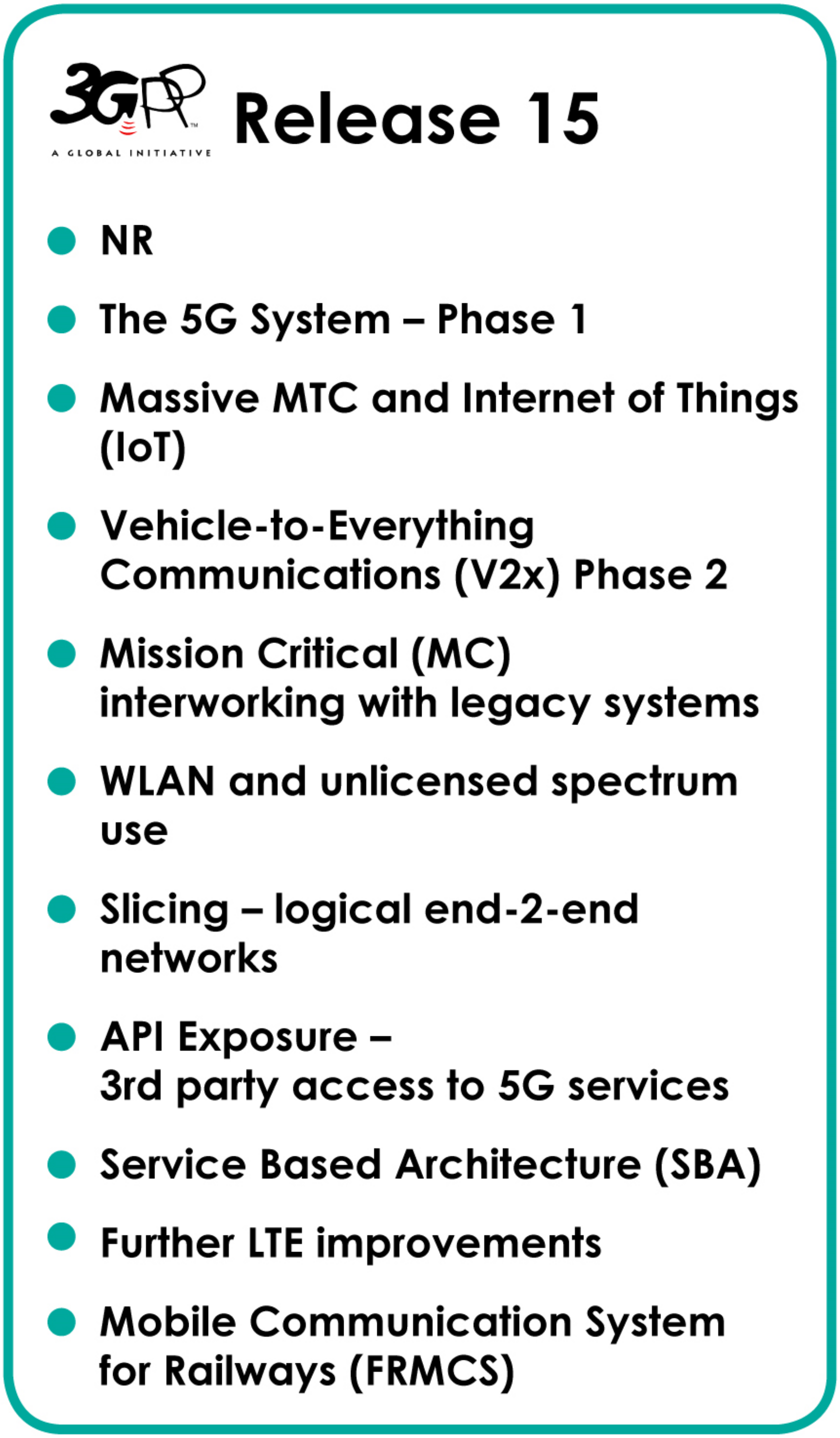

Figure 5-4: Release 15 Technologies[72]

[72] https://www.3gpp.org/images/articleimages/Releases/R15.jpg

5.4.2 RELEASE 16

Release 16 efforts[73] continued until the end of 2020 as depicted in Figure 5-5.

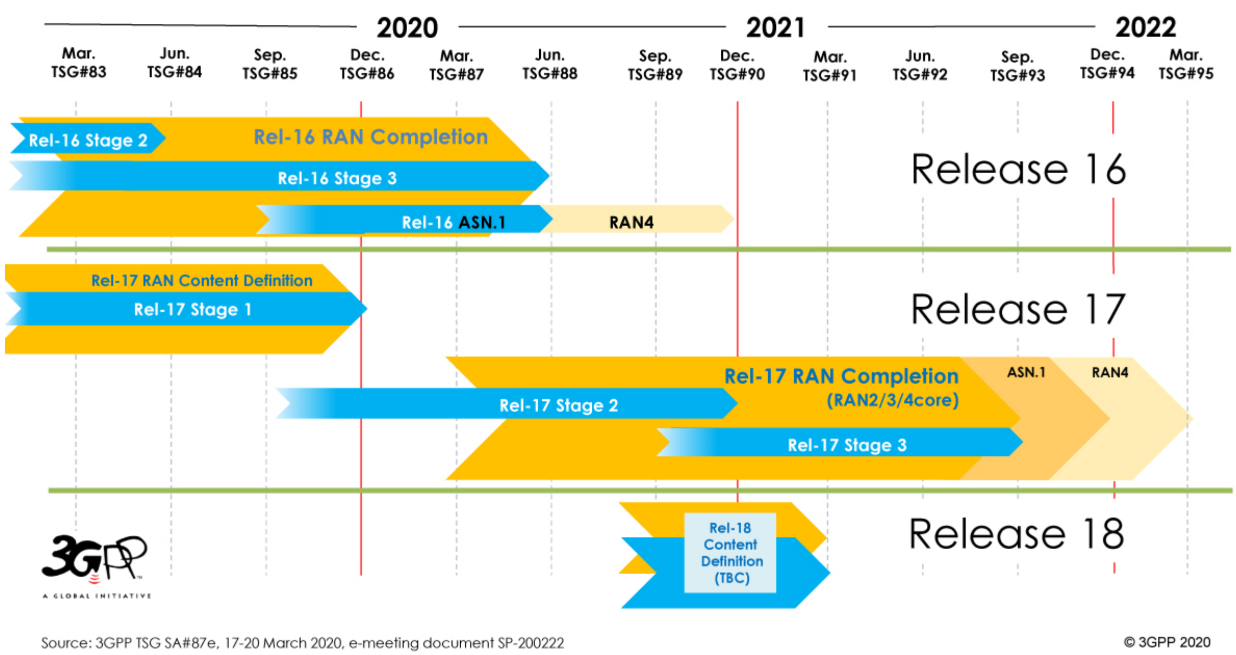

Figure 5-5: Release 16 Timeline

The major relevant technologies from Release 16 (summarized in

Figure 5-6) are:

- Industrial IoT
- URLLC enhancements
- NR-U
- 5G Efficiency
- IAB
- Satellite Access in 5G

[73] https://www.3gpp.org/release-16

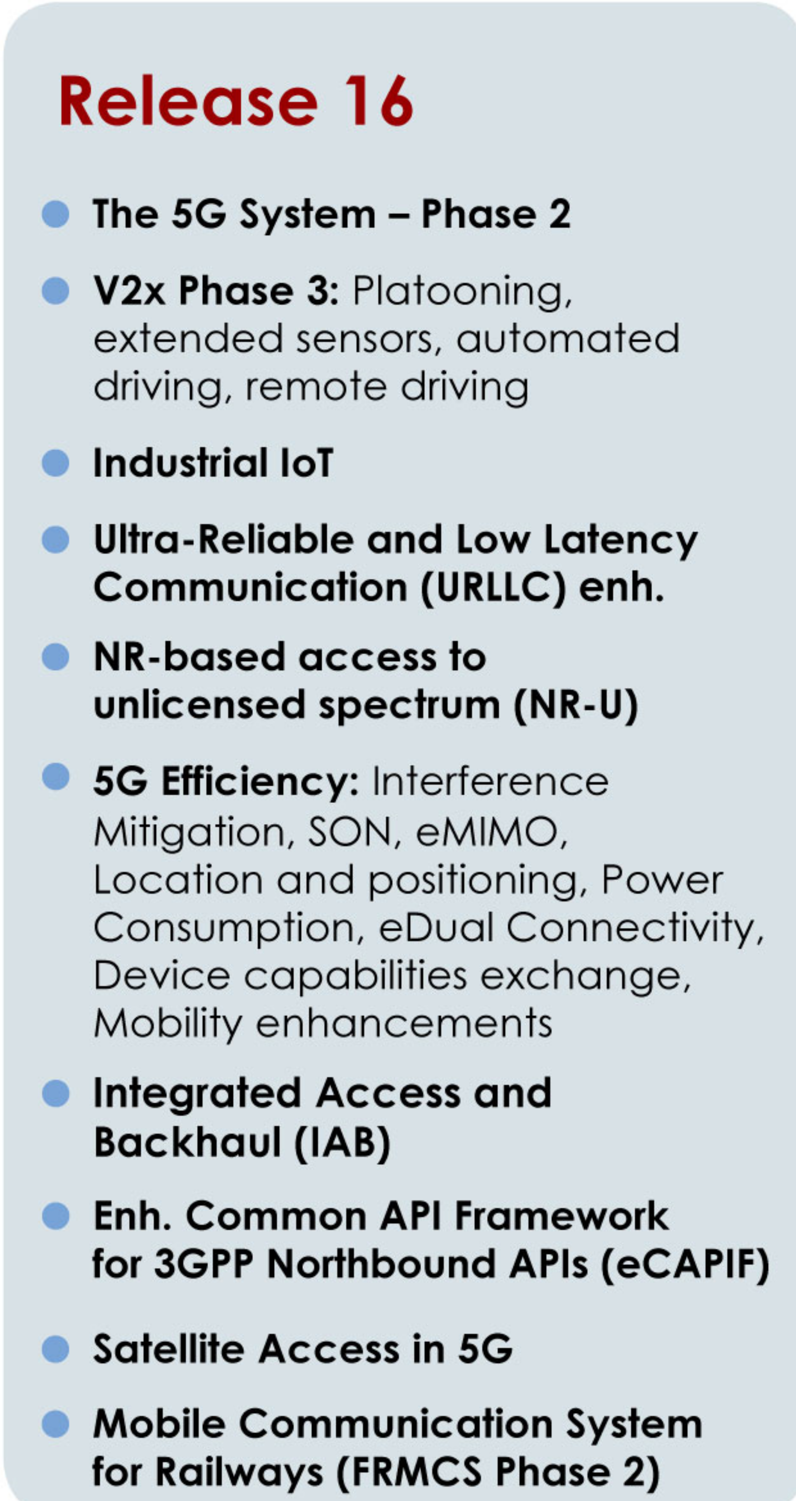

Figure 5-6: Release 16 Technologies[74]

[74] https://www.3gpp.org/images/articleimages/Rel16-highlights.jpg

5.4.3 Release 17

Release 17 will be completed in mid-2022 according to Figure 5-7 provided by 3GPP[75].

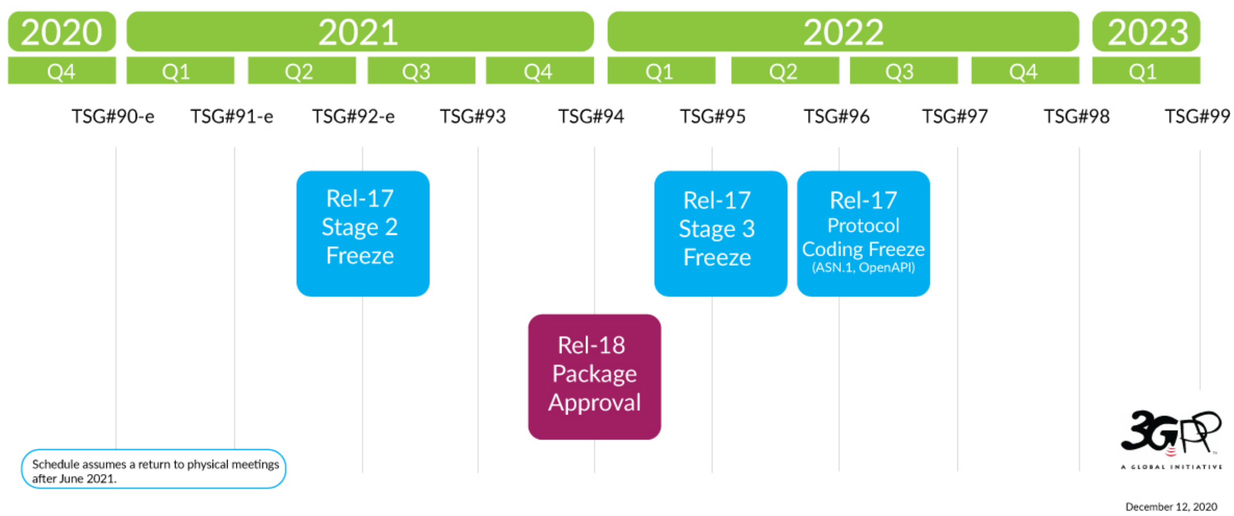

Figure 5-7: Release 17 Timeline

The major relevant technologies (fully summarized in Figure 5-8) mapped to what has been discussed herein are:

- NR Sidelink enhancements
- Industrial IoT/URLLC enhancements
- NR over Non Terrestrial Network (NTN)
- Power saving
- NR coverage enhancements
- IAB enhancements
- NR Sidelink relay
- RAN Slicing
- Satellite components in the 5G architecture
- UAS
- UPF enhancement for control and 5G SBA

[75]https://www.3gpp.org/release-17

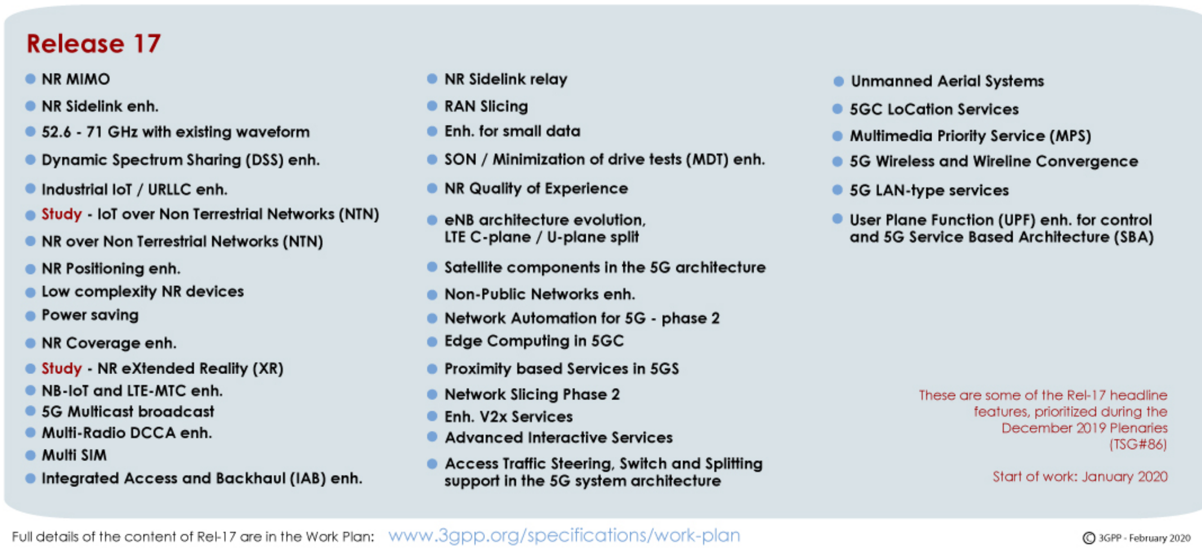

Figure 5-8: Release 17 Technologies

5.4.4 Release Summary

Table 5-2 provides a summary of the collected release information, relevant technologies, and what DHS customer components could be enhanced. Note that as depicted in Figure 5-8, there are several steps between a release being completed by 3GPP and the technology being available for the end-user.

Table 5-2: Release Schedule, Technologies, and Enhanced Capabilities

Release	Completion Date	Relevant Featured Technologies	Capabilities Enhanced
15	Mid 2019	New Radio (NR) defining functionality for the RAN Massive MTC and Internet of Things (IoT) Mission Critical interworking with legacy systems Service Based Architecture (SBA)	Throughput and situational awareness capabilities Infrastructure for next-generation applications
16	End 2020	Industrial IoT URLLC enhancements NR-U 5G Efficiency IAB Satellite Access in 5G	Densification of sensor deployments for real-time monitoring IAB and NTN technologies for coverage enhancement in austere or degraded environments
17	Mid 2022	NR Sidelink enhancements Industrial IoT/URLLC enhancements NR over Non Terrestrial Network (NTN) Power saving NR coverage enhancements IAB enhancements NR Sidelink relay RAN Slicing Satellite components in the 5G architecture UAS UPF enhancement for control and 5G SBA	UE-Network relay capabilities Improvements in ability to support densification of sensor deployments Coverage enhancements with improved IAB and NTN technology Virtualized Core and RAN capabilities

5.5 DEPLOYMENT AND ROLLOUT SUMMARY

There are several 5G technologies defined in current release specifications which have the potential to provide customer components with opportunities to fundamentally enhance their operations. It is important to note, though, that these technologies are being defined incrementally as each new 3GPP release is published. Moreover, there are many steps in the technology development process between development of a definition or specification and actual implementation of technology for end-user experience. An understanding of what is being discussed in organizations like 3GPP does provide an opportunity to properly prepare for new capabilities and make decisions on how to ensure efficient and effective adoption of new technologies as they become available.

6. SUMMARY

This report presented an updated view of the impact 5G technology can play on DHS customer component operations. It focused on three specific areas identified in (Reference [1]):

1. Environmental Scan and Analysis of the 5G Impact to the DHS S&T Customer Components
2. Adapt/Develop Use Cases that Demonstrate Adaption and Integration of 5G Technologies Relevant to DHS S&T Customer Components
3. Map 5G efforts to DHS S&T Operational Components' Requirement

The applicability of 5G technologies was explored through the development of customer component use cases, specifically for CBP, FEMA, and First Responders. While focused on these three, the mapping of use cases to technologies provides a glimpse of how all customer component operations can be enhanced through adoption of 5G technologies. The key for adoption of this technology is preparing and anticipating individual customer component needs and mapping to specific 5G technologies and enablers. Once mapped, technologies can be further adapted for customized and specialized use.

Moving forward as DHS S&T/OIC prepares for the continued growth in availability of 5G technologies and capabilities, the full seven steps for the DHS S&T 5G R&D Plan referenced in Section 2 can be pursued. Activities could include coordination, integration, and development of customer component test and evaluation efforts experimenting on testbeds hosted and operated in government, academia, and/or industry. Furthermore, R&D activities could include development of prototype solutions or proof-of-concept demonstrations. Because 5G is comprised of many technologies and different enablers, and the potential use cases are so broad, a stepwise approach to R&D is encouraged, focusing on single technologies and use cases at a time. In addition, exploration of research ideas should be documented in white papers or reports serving as inputs to standards development work items. Staying on top of 5G developments and trends in both industry and academia will be key as DHS S&T/OIC-TC executes its mission to address DHS S&T and interoperability and compatibility needs and to provide the DHS customer components with the information required to adopt 5G technology into their missions.

7. Acronyms

3GPP	3rd Generation Partnership Project
AAU	Active Antenna Unit
AWS	Amazon Web Services
AR/VR	Augmented and Virtual Reality
CBP	Customs and Border Protection
CP	Control Plane
CU	Central Unit
DHS S&T	Department of Homeland Security Science & Technology Directorate
DHS S&T OIC-TC	Department of Homeland Security Science & Technology Directorate Office of Interoperability and Compatibility Technology Center
DU	Distributed Unit
eMBB	Enhanced Mobile Broadband
ETSI	European Telecommunications Standard Institute
FEMA	Federal Emergency Management Agency
HAPS	High-Altitude Platform Systems
HEO	Highly Elliptical Orbit
GEO	Geostationary Earth Orbit
IAB	Integrated Access and Backhaul
IT	Information Technology
IoT	Internet-of-Thing
JHU/APL	Johns Hopkins Applied Physics Laboratory
LEO	Low Earth OrbitV
LTE	Long-Term Evolution
MANO	Management and Orchestration
MCData	Mission Critical Data
MCPTT	Mission Critical Push-to-Talk
MCVideo	Mission Critical Video

MEO	Medium Earth Orbit
MEC	Multi-Access Edge Computing
MIMO	Multiple Input Multiple Output
MNO	Mobile Network Operators
NFVI	Network Function Virtual Infrastructure
NGO	Non-Governmental Organizations
NPSTC	National Public Safety Telecommunications Council
NPN	Non-Public Network (NPN)
NTN	Non-Terrestrial Networks
OFDM	Orthogonal Frequency-Division Multiplexing
OSM	Open Source MANO
P4	Packet Processors
RRU	Remote Radio Unit
SBA	Service-Based Architecture
SDN	Software-Defined Networking
UP	User Plane
URLLC	Utra-Reliable and Low-Latency Communications
V2X	Vehicle-to-Everything
VNF	Virtual Network Function
vRAN	Virtual Radio Access Network
ZSM	Zero-touch network and Service Management

8. REFERENCES

[1] Department of Homeland Security (DHS) Science and Technology Directorate (S&T) Office for Interoperability and Compatibility Technology Center (OIC-TC), "5G Research and Development Plan Recommendations DRAFT Version 1.3," 25 February 2020

[2] 3GPP TS 23.501, System Architecture for the 5G System; Stage 2," Release 15, Version 15.7.0, September 2019

[3] European Telecommunications Standards Institute, "Network Function Virtualization (NFV); Management and Orchestration, NFV-MAN 001 v.1.1.1," 2014.

[4] Defining Public Safety Grade Systems and Facilities. Littleton: NPSTC; 2014:24

[5] TS23.280 Common functional architecture to support mission critical services; Stage 2 (Rel 16 2019)