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April 2026

What role will 5G play for Critical Communications users?

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Contents

Executive Summary 3
Summary of key points raised by this paper: 3
Brief comparison of 4G LTE and 5G technology 5
5G capabilities most relevant to critical communications 8
What role will 5G play for Critical Communications users? 11
Use cases enabled by 4G LTE and further enhanced with 5G 11
New and emerging 5G use cases 12
Expected benefits of 5G to user operations 13
What is the likely market timing and availability of 5G Services? 14
Summary of 3GPP MC Roadmap Developments related to 5G 14
Implementation timeframe for 5G SA services 15
Migration path to 5G 15
Conclusions and recommendations 17
Recommendations for further action: 18
Acknowledgements 19
Acronyms and Abbreviations 19
References 20

Executive Summary

This white paper addresses key questions raised by the critical communications community regarding the importance and role of 5G technology, including:

- How it compares to existing 4G Long-Term Evolution (LTE) technology?
- What are the initial use cases that 5G will address for Public Protection and Disaster Relief (PPDR) organisations?
- What are the expected benefits to and impacts on user operations?

Furthermore, it forecasts the market timing and availability of mission-critical 5G equipment and services, and the supported migration paths from existing 4G LTE systems[1]. The paper concludes with a set of recommendations for consideration by TCCA and the wider critical communications community.

Summary of key points raised by this paper:

- The evolution from mission-critical voice-centric narrowband services to mission-critical information-centric mobile broadband services began with 3GPP Release 12, specifying 4G LTE mobile broadband technology. In addition to information-centric services, a major benefit of adopting 4G LTE and 5G standards for critical communications use is the access to a much larger ecosystem of device manufacturers, solution providers and application developers, when compared to previous technologies.
- 4G LTE has proven to be a capable mission-critical broadband technology: secure, reliable, available and able to offer high performance mobile communications over a wide coverage area. New use cases are now supported, focused on the use of mission-critical video and data, as well as voice, delivering clear user benefits. 4G LTE is widely available today, it will continue to be deployed with a clear path to evolve to the 5G era, delivering the full capabilities of 5G technology.
- Whilst 4G LTE offered a step change in terms of capabilities for critical communication operators and users versus previous technologies, 5G is providing evolutionary enhancements. As mission-critical 4G LTE networks are deployed, and user adoption of these services grows significantly, this is encouraging further innovation and enhancements to 5G and future generations of 3GPP standards.
- 5G technology is essentially delivering improvements to users in two distinct ways: (i) Enhancing use cases initially enabled by 4G LTE e.g., in terms of scaling up these services to more users within a given locality, and (ii) Addressing new and emerging use cases made possible with advancements in technology such as ultra-low latency mobile connectivity. Both will provide important user benefits, ranging from enhanced situational awareness - using advanced video recognition capability, artificial intelligence analysis of data collection and new immersive user applications - to greater use of remote and specialist expert analysis of incident ground environments for first responders.
- 5G networks will provide first responders with fast, robust and high-performance communications. It will give control room dispatchers an accurate view of a situation and allow them to better allocate resources. The information between agencies can be shared more easily via cloud-based application platforms. The net result is that the cooperation between first responders can be more effective and efficient, improving the safety of users and saving the lives of others.
- From a technology perspective, 5G will provide a plethora of new capabilities, most notably enhancing mobile broadband services with ultra-reliable low latency communications and supporting massive machine-type device deployments. Whilst these capabilities will be available across all bands, the benefit of some will be more pronounced at higher frequencies due to correspondingly larger channel bandwidths.
- In 5G networks, the use of a service-based architecture with networking functions built for cloud-native server platforms is allowing operators and users to customise network performance to match specific needs at a specific moment in time, allowing both mission-critical and non-mission-critical applications to share the same infrastructure simultaneously – be that public, private or a hybrid mix.

[1] Interworking considerations between narrowband and broadband systems are outside the scope of this paper.

- 5G covers an array of new capabilities and ways of deploying network services. In general, it is implemented as a complementary add-on to existing LTE networks, termed Non-Standalone (NSA). Over time, these NSA deployments will gradually transition to full 5G Standalone (SA) networks. Therefore, networks are likely to support dual mode 4G-5G equipment, enabling a smooth migration path from 4G LTE to 5G SA, before going to a full 5G SA network and providing access to the full range of 5G capabilities.
- The global 5G ecosystem is driving further standardisation and development of mission-critical services. Industry is also investing in and delivering solutions capable of providing new ways of monitoring network performance and assuring service levels using complementary software technologies such as automation, analytics, and artificial intelligence.
- To build nationwide 5G services, low, mid and high band spectrum will be required. Low band (<1 GHz) provides ideal geographic coverage in rural areas, mid band (1-6 GHz) is suitable for urban and suburban coverage providing a balance between capacity and coverage. The high band (>6 GHz) is ideally suited for significantly boosting capacity in dense urban areas, including in-building coverage.
- Since 2020, commercial 5G operator services have been made available in many countries, however these are mainly deployed in mid and high spectrum bands; notable exceptions include Switzerland which has rolled out relatively quickly 5G-New Radio (NR) in low bands through software updates only.
- 5G technology offers highest throughput and lowest latency in the higher bands, where operators and/or agencies typically have 100+ MHz of channel bandwidth in urban and suburban areas, in comparison to low bands used for wide area coverage. Note, combining low and higher bands can substantially increase the coverage of capacity gains from higher bands – the latter typically deployed within suburban areas.
- To meet PPDR user needs with regard to the availability of nationwide mission-critical broadband services, a range of coverage solutions will be necessary using 4G LTE, 5G or optimally a combination of both. These solutions will typically involve “fixed” wide area macro networks - in many cases relying on the networks of public operators as well as rapidly deployable networks, complemented by User Equipment (UE) with Device-to-Device (D2D) communication capability using the 5G Sidelink feature.
- Applications such as video surveillance and mass rollout of sensors across government and critical infrastructure will have increasing importance for critical communications and are likely to have a profound effect on the provision of future PPDR services. Nevertheless, voice will continue to play an important role in mission-critical communications, hence the driving force behind the porting efforts in 3GPP of mission-critical (MC) services (MCX) from 4G LTE to 5G NR. This together with other factors mentioned throughout this paper forecasts that PPDR 5G SA systems, with a comprehensive suite of mission-critical functionality, are likely to be available in the market by 2027.
- Whilst this paper describes the capabilities and general timing of 5G technology to operators and agencies planning for mission-critical services, the exact implementation and availability of those services will always depend on country-specific conditions.
- Looking beyond, international collaboration on service deployment experiences and sharing of best practice is highly recommended, and TCCA is the ideal organisation in which to discuss this.

Brief comparison of 4G LTE and 5G technology

Before we begin, it is important to define what we mean by '4G LTE' and '5G'. In simple terms, and throughout this white paper, we will define 4G LTE and 5G in relation to the functionality and capability provided by specific Releases of the 3GPP standards. More specifically:

- The set of requirements that need to be fulfilled by a 4G LTE system is defined by the IMT-Advanced specifications. 3GPP implements this in Release 8 through Release 14. It is characterised by the introduction of LTE radio access technology (RAT) and packet-centric network architecture.
- The set of requirements that need to be fulfilled by a 5G system is defined by the IMT-2020 specifications. 3GPP implements this in Release 15 through Release 18 (18 being the latest Release in current development at the time of publication of this white paper). It is characterised by the introduction of NR RAT – as well as continued support for LTE RAT - and a 5G Core (5GC).
- Whilst 4G LTE offers a step change in terms of capabilities for critical communication operators and users versus previous technologies - and provides considerable benefits already to mission-critical users - 5G will provide evolutionary enhancements in terms of performance, greater breadth of use cases and quality of service network controls. Although not discussed in detail, it's worthwhile to understand the key objectives underpinning development of 5G standards, i.e.
- Enhanced Mobile Broadband (eMBB), providing substantially improved throughput performance and capacity.
- Massive Machine-type Communications (mMTC), connecting sensors and physical assets, enriching device ecosystems, enabling additional use cases and improving situational awareness.
- Ultra-Reliable Low Latency Communications (uRLLC), enabling critical machine-type communications (cMTC).

However, it should be observed that Machine-type Communications are already specified in 4G LTE, i.e. NB-IoT and LTE-M are kept. Furthermore, in the initial 3GPP 5G Releases, the IoT functions make use of the LTE IoT radio interface, adding support in 5G SA mode - details discussed later in this section.

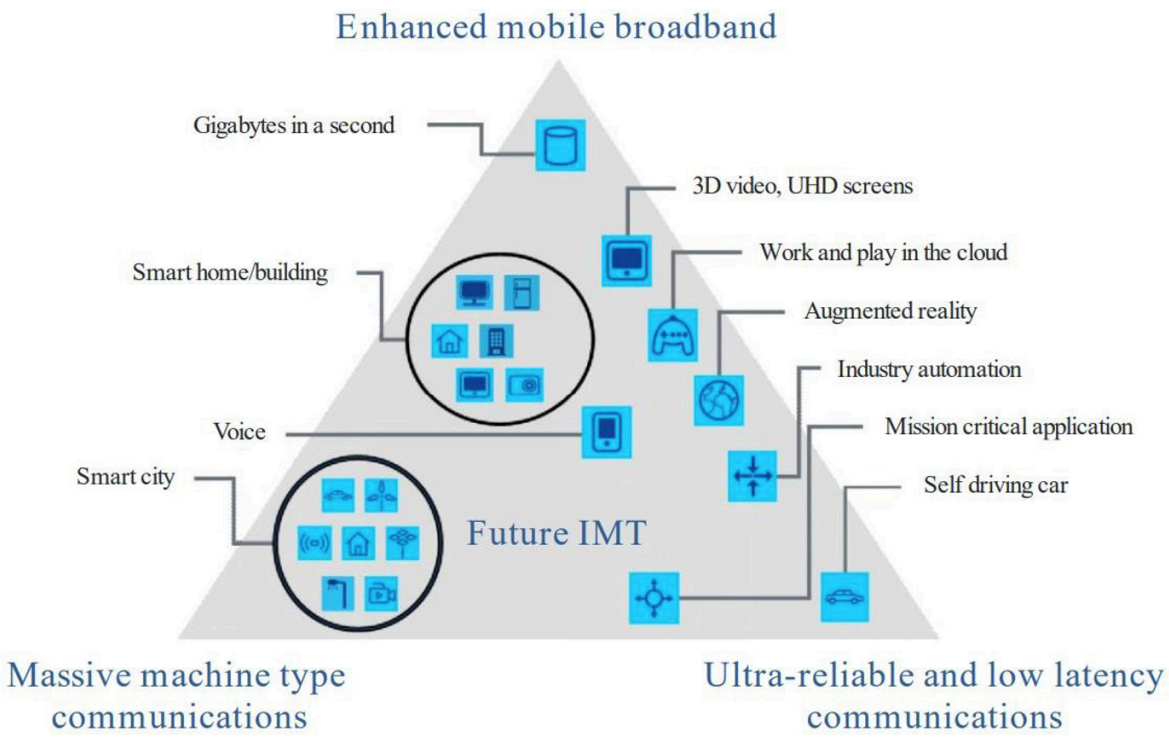


Figure 1 Framework and overall objectives of 5G[2]

[2] Re-printed from Recommendation ITU-R M.2083-0, 'IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond' by ITU-R, 2015, page 12, Figure 2.

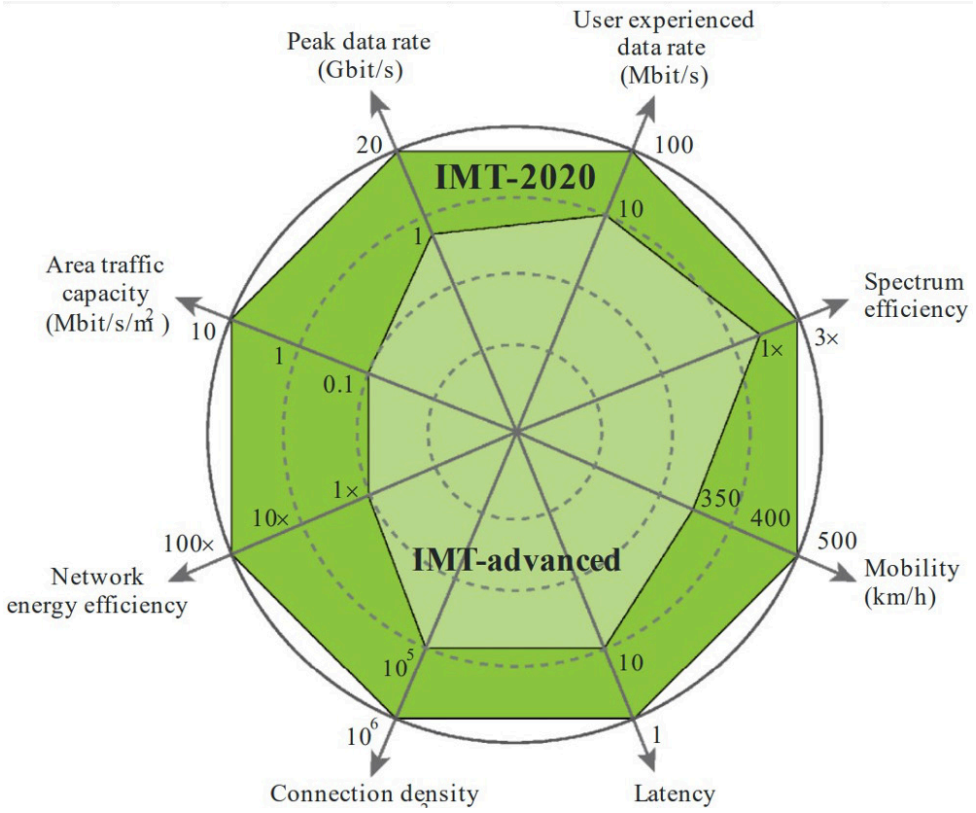


Figure 2 Comparison of key capabilities between 4G LTE ('IMT-Advanced') and 5G NR ('IMT-2020') [3]

1. Support for new spectrum, mainly mid and higher bands delivering Gbps+ data speeds.
2. Extensive use of massive MIMO – up to 64 antenna arrangements.
3. New RF interface techniques combined with edge computing – lowering latency to milliseconds.
4. Enhancements to signalling protocols and antenna diversity – targeting 99.9999% reliability across the radio interface.
5. Adoption of service-based architectures enabling deployment on cloud native platforms – where the cloud environment provides highly scalable and dynamically configurable networks.

The throughput performance of a 5G network very much depends on the spectrum utilised as well as deployment options such as edge computing, minimising transport latency and jitter. Figure 2. shows typical coverage as well as latency targets depending on the frequency bandwidth. By combining multiple carriers, using Dual Connectivity or Carrier Aggregation (CA) features, a combination of good downlink/uplink coverage and high throughput can also be achieved. Note CA involving low and higher bands can substantially increase the coverage of capacity gains from higher bands – typically deployed within suburban areas.

In general, 5G technology is essentially an evolution of 4G LTE. It will be deployed in many different architectural models, which are expected to change over time as the market evolves – see Figure 4 for the two main variants. Critically, however, an evolution path is described within the 5G standard starting from (i) LTE anchored services re-using the existing Evolved Packet Core (EPC) – in what is referred to as NSA architecture – to (ii) a full-blown 5G network with 5G NR as the primary radio access technology and using a service-based 5G Core (5GC) – the latter being referred to as SA architecture.

Given the widespread deployment of 4G LTE networks and services, particularly in the low (coverage) and mid (coverage/capacity) spectrum bands, these networks will evolve from NSA to SA over the long term. Consequently, 4G LTE and 5G (NR) RATs will be tightly integrated, operating in unison and adapting to the varying needs of users and their use cases.

[3] Re-printed from Recommendation ITU-R M.2083-0, 'IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond' by ITU-R, 2015, page 14, Figure 3.

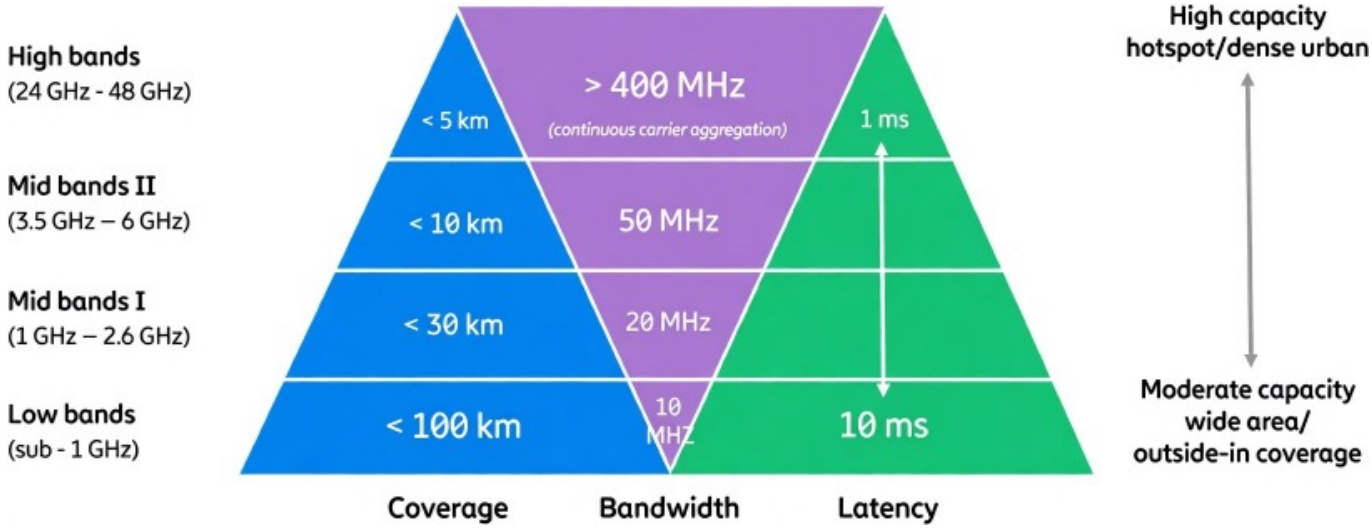


Figure 3 Coverage and latency depending on frequency band [4]

Security has been one of the main considerations in 3GPP standards development, ensuring that the resulting technology is trustworthy. Each generation of 3GPP standards have incorporated security improvements – underpinned by advancements in hardware and software – and against the backdrop of an ever-evolving threat landscape. Hence the security of 5G is a further enhancement over 4G LTE.

5G now permits a single network to offer services and performance similar to a 4G LTE network, whilst at the same time providing a foundation for continuing to offer new services that target very different use cases with often contradictory demands in terms of latency, throughput, battery efficiency and device complexity. This is the embodiment of the 'Network Slicing' concept.

[4] Adapted from Broadband Library, 2019 (https://broadbandlibrary.com/5g-low-latency-requirements/).

5G capabilities most relevant to critical communications

3GPP Releases 15 and 16 have specified functionality and interfaces required to offer 5G networks supporting enhanced Mobile Broadband (eMBB) and Voice-over-New-Radio (VoNR) services. They also laid the foundation for more advanced critical communications services such as massive IoT, critical IoT and MCX over NR.

Furthermore, Release 17 has specified the initial functionality to provide MCX over a 5G SA network. MC functionality is comparable to LTE for unicast services.

In addition, Release 18 (completed in 2024) and Release 19 (completed in2025) focus on 5G Multicast/Broadcast Services as well as various functionality enhancements including edge computing in mission critical networks for low latency applications, extended coverage solutions involving use of Non-Terrestrial Networks communication and/or 5G Sidelink.

5G (3GPP Releases 15-19) contains a myriad of new functional capabilities that could be considered relevant to critical communication users, a summary of the ones with greatest impact are as follows:

MC Services over 5G: Principally the porting of all MCX services to 5G NR.

5G Multicast & Broadcast Services (5MBS): Enabling more efficient and effective usage of spectral resources for group-based communications – consisting of mission-critical voice, data and video services – and support for high concentrations of Public Safety users operating in large groups within a small incident area.

Device-to-Device Communications using Sidelink: Enabling the capability for Proximity Services (5G ProSe[5]) and Vehicle-to-X (V2X) services, addressing device-to-device (D2D) short-range communication use cases in environments with limited or non-existent network coverage. In order to increase the range of the service, NR Sidelink multi-hop functionality now supports two relaying features, multi-hop UE to Network relaying (MU2N) and multi-hop UE-to-UE relay (MU2U).

End-to-End Network Slicing: Providing the ability to slice a single physical network into many virtual 'private' networks with widely differing network service characteristics. Example implementations include network slices allocated within a dedicated core to different PPDR organisations, or alternatively slices allocated and optimised to specific types of end-to-end applications, such as HD video, drone deployments, IoT sensors, etc.

Enhanced Network Security: Further mechanisms to protect the integrity, confidentiality and availability of the network services and user data, including support for Network Slicing and the use of cryptographic algorithms to provide enhanced security.

Isolated Operation for Public Safety (IOPS): Originally introduced in 3GPP Release 13, enhanced and refined in terms of its security and operational deployment capabilities. IOPS over 5G systems was finalised in Release 19.

Advanced Congestion Management (i.e., Unified Access Control): Allows the differentiation of mission-critical users and services during times of peak congestion based on Access Categories and Access Identities.

RedCap (Ambient IoT and integrated sensing): Reduced capability (RedCap) NR devices will allow devices embedded in equipment used or worn by first responders for example to assist in the determination of more accurate location of responders. This could enhance situational awareness.

Network-Controlled Repeaters (NCRs): enhance 5G coverage and reliability, crucial for mission-critical communications in public safety, emergency response, and industrial applications. Unlike passive RF repeaters, NCRs intelligently adjust signal amplification under network control, optimising coverage, reducing interference, and ensuring stable connectivity in tunnels, rural areas, highways, and disaster zones. Their beamforming support and power efficiency improve network resilience, making them vital for ensuring uninterrupted mission-critical operations.

5G VMR (Vehicle-mounted relays) using 5G WAB (Wireless Access Backhauling): this concept is to have a relay capability in a rapidly deployable network e.g. CoW (cell on wheels) that uses a portion of the Radio band for the backhaul, this allows efficient network extension mechanism. (WAB is an evolved concept of the IAB solution, facilitating simpler adoption.)

[5] The protocol stack and QoS model has evolved from the LTE equivalent, catering for robust MCX in D2D operation.

5G Non-Terrestrial Networks (NTN): Expanding coverage solutions to places with no terrestrial coverage or in case of service interruptions, NTNs involve non-terrestrial flying objects such as satellites and unmanned aerial vehicles/drones (UAVs), UAV-based services will dramatically increase support for multiple drone operations, search and rescue operations, and cargo delivery in emergency applications, as well as enhancements in IoT connectivity services served by NTN.

N3IWF & ATSSS: Non-3GPP Interworking Function (N3IWF) allows connectivity of a UE to the 5G core network (e.g., to connect to MC servers) via an untrusted non-3GPP network (e.g., WLAN). Access Traffic Steering, Switching and Splitting (ATSSS) allows the UE to setup a multiple access PDU session, i.e., data traffic can be served to the UE over one or more concurrent access networks (e.g., NR and WLAN). This can be used to improve reliability (steering), provide a seamless handover (switching) or increase throughput by the aggregation of the capacity of the different access networks (splitting).

AI/ML: 3GPP is exploring the use of AI and ML to enhance RAN performance, focusing on areas like position accuracy, beam management, and CSI (Channel State Information) feedback. CSI feedback involves the UE sending channel quality data to the network, enabling optimised resource allocation and signal transmission. AI and ML aim to make this feedback more efficient and adaptive, driving overall improvements in RAN performance.

Mobile Metaverse, Digital Twin, and Extended Reality (XR): focus on seamless connectivity, ultra-low latency, and high reliability. These innovations support immersive virtual environments, real-time simulations, and enhanced XR experiences across industries like gaming, education, healthcare, and industrial automation.

Integrated Sensing and Communication (ISAC): utilises 5G signals for both communication and sensing simultaneously. ISAC enhances capabilities like positioning, object detection, and motion tracking, making it integral to autonomous vehicles, smart cities, Industry 4.0, and security systems. This technology improves network efficiency by seamlessly integrating sensing into existing 5G infrastructure, enabling lower latency and better situational awareness.

Network Exposure: refers to the process of enabling access to specific network functions through standardised interfaces. This allows external applications and services to interact with the network efficiently. Examples include Network Slice Capability Exposure for application enablement, Location Exposure Function (LEF) for location-based services, and QoS Exposure Function for managing Quality of Service requirements.

Non-Public Network (NPN): Network that is intended for the non-public (or private) use. NPNs can be tailored to better suit the needs from Mission Critical Network (MCN) operators independently of public networks. For example, a MCN operator may require providing coverage in area which is not of interest for public operators or serving public needs. 5G specifications support various configurations of NPNs.

Edge Computing: enables the processing and storage of user data closer to end-user operations, reducing reliance on centralised cloud infrastructure. It facilitates low-latency, high-speed processing, supports advanced applications, and optimises network traffic offloading. By leveraging big data analytics and edge computing techniques, it enhances performance for latency-sensitive applications while keeping data local for improved security and efficiency.

Enhancements for Railway Communications: Driven by the Future Rail Mobile Communications System (FRMCS) initiative, it will enable interworking and future migration of existing rail mobile communications from GSM-R and TETRA, and the provision of new broadband-enabled services, e.g., Train Control, Voice Communication, Train Telemetry, Automated train operation (ATO) as well as improved passenger connectivity.

Non-Standalone Architecture (NSA)

NSA was designed to launch 5G services, enabling the use of new 5G spectrum - quickly increasing capacity and throughput - and supporting early adopters of 5G-enabled devices. It can support advanced video streaming, such as AR/VR/XR type of applications, as well as critical IoT use cases. It leverages existing LTE networks, providing mobility management and control signaling, as well as utilizing an enhanced Evolved Packet Core that supports both LTE and 5G NR radio access technologies (RAT).

Standalone Architecture (SA)

SA is the target architecture for 5G networks, enabling simplified RAN and device operations. It uses a cloud-native 5G Core (5GC) and supports advanced network-slicing functions, facilitating a wider range of use cases involving a plethora of new device types, and requiring higher performance levels including ultra-low latency and/or higher throughputs. This option will also enable the pervasive deployment of 5G NR in low spectrum bands with the same coverage footprint as 4G LTE.

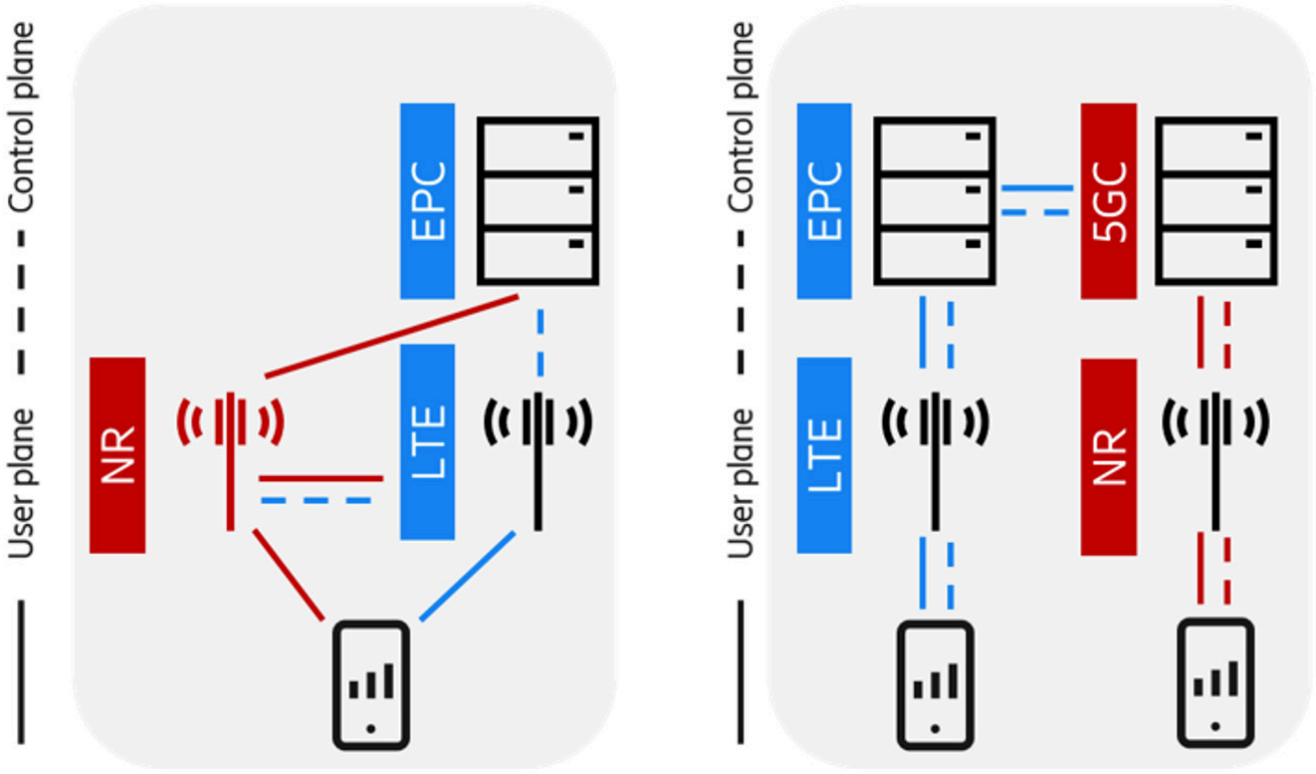


Figure 4 Overview of 4G-5G architectures evolving over time from NSA to SA[6]

[6] Adapted from "5G-Implementation-Guideline-v2.0-July-2019", GSMA, 2019.

What role will 5G play for Critical Communications users?

The evolution from mission-critical voice-centric narrowband technologies to mission-critical information-centric mobile broadband services started with functionality introduced in 3GPP Release 12 ('4G LTE'). The use cases addressed by 4G LTE now include mission-critical voice, data and video.

With the introduction of 5G which has lower latency, higher capacity, and increased bandwidth compared to 4G, the boundary of mobile broadband networking is expanded to new levels, with the obvious potential to increase user operational efficiencies further. New 5G capabilities include not only a further development of mission-critical feature set and services but also new ways of monitoring network performance and providing service assurance, as well as supporting new 'hybrid' network deployment models – the latter aiming to optimise users' experience and adapt to available spectrum/infrastructure, regulation and agencies operational requirements. In summary, these capabilities will deliver improvements in two distinct ways:

- Enhancing use cases currently enabled by 4G LTE
- Create new and emerging use cases, previously not viable with earlier generations

Use cases enabled by 4G LTE and further enhanced with 5G

With mission-critical 4G LTE, many use cases can already be addressed and deployed (or are being deployed). Common examples are listed here and have been widely discussed amongst TCCA stakeholders and the wider community:

- **Situational Awareness:** Being aware of events related to an incident, in time and space, is a key area where the introduction of broadband will play a pivotal role. Combining enhanced X, Y and Z positioning capability together with 10 to 100 times more connected devices per square kilometre will enable the collection and processing of a large amount of data from a wide variety of mobile-connected sources for real-time pattern matching using big data technologies. In practice, this means for example connecting body-worn cameras and cameras in police cars to command centres to identify what is happening at an incident and to gain an overview of the situation as it unfolds. This will ultimately enhance user operations and planning for future emergency response, collecting data and sharing the required processed information to agencies and users in service, while boosting cooperation and enabling more efficient resource management.
- **Video Surveillance and Analytics:** In addition to cameras hosted in and around emergency services vehicles, cameras can also operate on remotely controlled drones or unmanned vehicles for a better awareness of urgent situations occurring in areas that human beings cannot easily access (e.g. wild forest fires). Because 5G focuses on massive broadband, it will allow the number of cameras in specific hotspots to be increased where capacity is currently limited by 4G LTE. In addition, higher resolution 4K, 360° cameras or thermal imaging cameras can be used for more precise visual insights.
- **Remote Control and Monitoring:** 5G NR will bring a number of benefits such as ultra-reliable and low-latency communications which can be used by applications and pave the way to assisted driving and unmanned automated vehicles. This capability will also be important for instance in automating a fleet of high-speed drones with real-time centralised coordination that uses sensors, geo-fencing and/or video analytics to avoid collisions. This can also include asset monitoring/tracking (e.g. providing the immediate operational status of stored equipment).
- **Immersive Applications for First Responders:** The introduction of mobile broadband with low latency combined with edge computing opens new possibilities for deploying command and control capabilities. Usage of augmented reality (AR) and virtual reality (VR) will reduce the amount of desk space used by multiple display screens and allow emergency organisations to equip workers with wearable solutions like smart glasses to access data at the scene of an event.
- **User-Friendly Operations:** Network resource prioritisation, geofencing combined with enhanced parameters for positioning are examples of 5G techniques which can be used by the application layer to automatically connect users in the same area in order to provide more user-friendly operation. This enables more focus on the task at hand and less on the device.
- **eHealth and Telemedicine:** The new level of performance provided by 5G networks will be an important enabler for major eHealth and telemedicine applications. Examples include future healthcare and its transformation in terms of preventative, routine and post-operative care. Furthermore, 5G will empower moving 'connected' ambulances to transmit life-critical data to hospitals, including high-definition video and the outputs of

sophisticated medical equipment. These capabilities, combined with real-time video communication with remote doctors, will make it possible for doctors to diagnose and address problems before patients even arrive at the hospital.

New and emerging 5G use cases

Transformative 5G Use Cases for Public Safety

The integration of mission-critical mobile broadband services in 5G will revolutionise communication and operational efficiency for Public Safety agencies. With enhanced access to real-time, richer information, these agencies can make safer, more effective decisions faster. Specific use cases include (but are not limited to):

1. **Enhanced Situational Awareness and Decision Making**

- Remote Surgery Support: Leveraging data from medical IoT sensors, digital medical images, and electronic health records combined with high-speed video and audio for critical surgeries.
- Crime Prediction and Prevention: Utilizing AI-driven analytics on real-time data from sources like CCTV to predict incidents and provide actionable insights for police forces.

2. **Advanced Authentication and Security**

- Biometric Sensors: Real-time transmission of biometric data (voice recognition, iris recognition, wrist veins, palmprints, heartbeats) for authentication and security purposes, allowing verification against special alert watchlists.

3. **Extensive Coverage and Network Expansion**

- **Deployable Tactical Networks:** Expanding coverage in rural or remote areas using mobile cell systems.
- Wireless Access Backhauling (WAB): Employing 5G's increased capacity and multi-hop backhauling for enhanced coverage deployment.
- **Device-to-Device Communications:** Ensuring communication among critical users even outside network coverage through Sidelink technology.
- **Digital Airspace Communications:** Providing connectivity to flying objects through specialized Air Ground Air networks.

4. **Non-Terrestrial Connectivity**

- Satellite Networks (LEO & GEO): Enabling connectivity for mission-critical operations in areas without terrestrial network availability.
- UAV (Unmanned Aerial Vehicles): Supporting multiple drone operations for search and rescue, and cargo delivery in emergency situations.

5. **Advanced Communication and Collaboration**

- **VR Communication Platforms:** Creating virtual spaces for communication and collaboration accessible from anywhere.
- **Accurate Real-Time Situational Awareness:** Using drones to provide real-time traffic and incident overview, enabling efficient resource allocation and dispatching.

6. **Operational Flexibility and Security**

- **Unified Authentication Framework:** Enhancing security flexibility for cross-network communications and international cooperation.
- **Semi-Autonomous Vehicles:** Utilising semi-autonomous UAVs and ground vehicles for interventions in hostile environments.

7. **Immersive and Real-Time Application**s

- **Augmented Reality for First Responders:** Equipping firefighters with AR-enhanced helmets for better navigation and situational awareness in zero-visibility environments.
- **VR and AR Training for Security Forces:** Implementing VR and AR for police and army training to handle complex scenarios effectively.

Expected benefits of 5G to user operations

The introduction of 5G will impact network deployment, given the density of cell sites required for high band 5G and operations. The adoption of a new 3GPP-defined service-based architecture with network functions built to exploit the advantages of cloud technology platform will enable end-to-end resource flexibility, robustness, security and stability of operations.

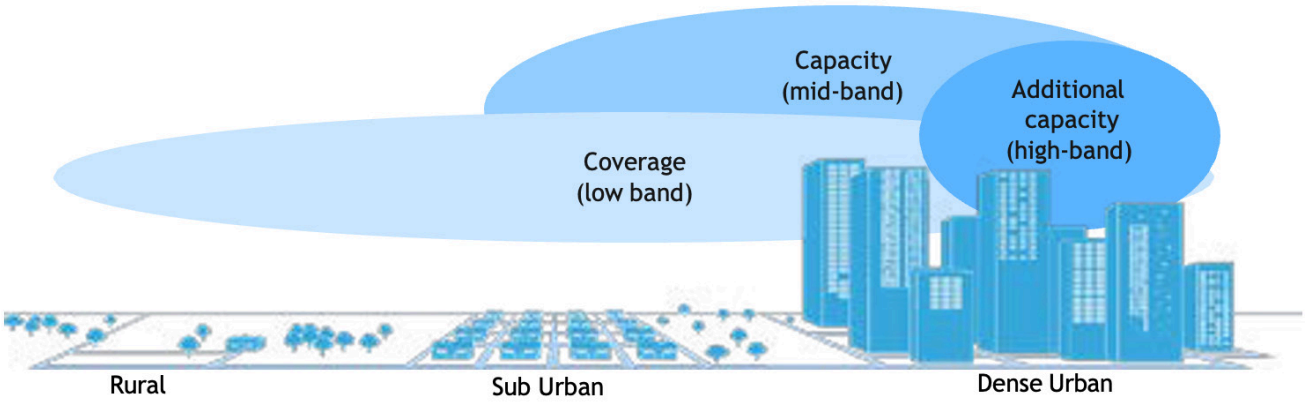


Figure 5 Relative coverage characteristics of different 5G bands

5G infrastructures will provide improvements in network management that drive much higher levels of resilience and robustness, raising the service levels for operating mission-critical applications, and will do this using complementary technologies such as automation, analytics and AI. The service-based architecture will allow operators to customise network performance for users to match specific needs at a specific moment in time, allowing both mission-critical and non-mission-critical applications to share the same infrastructure simultaneously.

5G technologies will provide first responders fast and robust communications. It will give the dispatchers an accurate view of a situation and therefore enable them to better allocate resources. The information between agencies can be more easily shared, complemented by cloud-based applications. The sharing of information between police, fire and rescue services and ambulance service is of vital importance and noting weaknesses in previous approaches. This all means that the cooperation between first responders can be more effective, improve the safety of users and save lives.

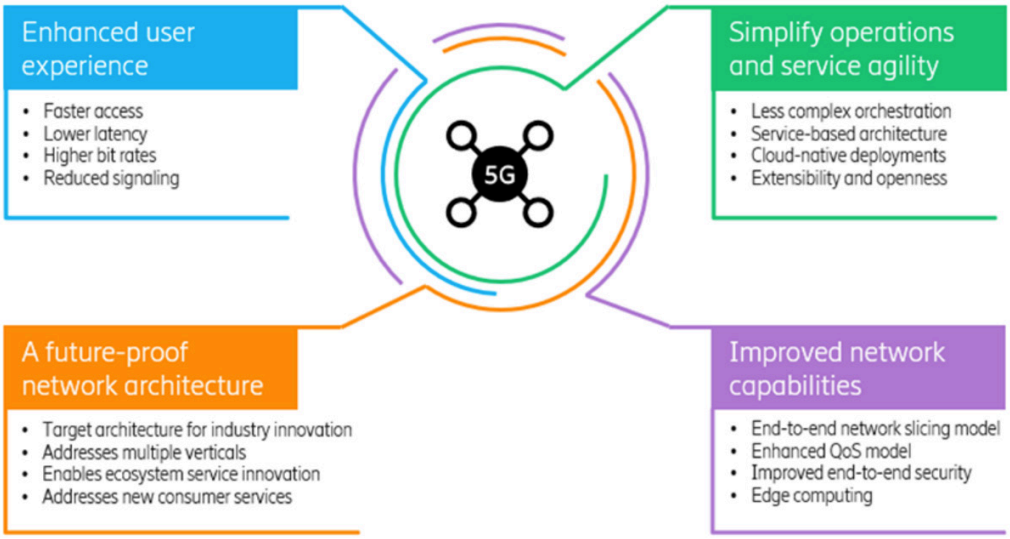


Figure 6 General Benefits of 5G

What is the likely market timing and availability of 5G Services?

5G is an evolution of 3GPP-driven standards and, as such, it is possible to gradually transition from 4G LTE to 5G as the ecosystem evolves.

In addition, for critical communications, key enablers need to be in place before 5G can be deployed for field operations, those being:

- Suitable and available spectrum to ensure coverage
- Integration of MC services with the network, delivering the required end-to-end performance versus over-the-top (OTT) implementations
- Fit-for-purpose ecosystem of devices and applications

5G spectrum is categorised into three segments: low band [<1 GHz], mid band [1-6 GHz] and high band (or 'mmWave') [>24 GHz]. The high band represents new spectrum not previously used, while the low-band and mid-band can be either refurbished 2G, 3G or 4G LTE spectrum or new spectrum allocations. To build nationwide 5G services low, mid and high band spectrum will be required. Low band provides ideal geographic coverage in rural areas, mid band is chosen for urban and suburban coverage providing a balance between capacity and coverage, and finally the high band is ideally suited to significantly boost capacity in dense urban areas, including in-building coverage.

Around the world, 5G spectrum has initially been made available to operators to roll out eMBB services, and, more recently, some countries have allocated spectrum for industry-specific use. In general, these early deployments have utilised high and mid bands; notable exceptions to this include early adopters such as Switzerland where both LTE and 5G-NR co-exist in low bands. Commercial services provided by operators have been available since 2020, across many countries. However, it will take several years before operators have enough 5G spectrum available and deployed to provide extensive nationwide coverage. The build-out of 5G continues, with around 320 networks launched worldwide. Global 5G population coverage is expected to reach 55 percent at the end of 2024. Outside mainland China it is projected to increase from 45 percent in 2024 to about 85 percent in 2030.In the meantime, existing 4G LTE spectrum will play an important role for reliable geographic coverage, whilst new 5G NR spectrum will mainly act as a capacity booster.

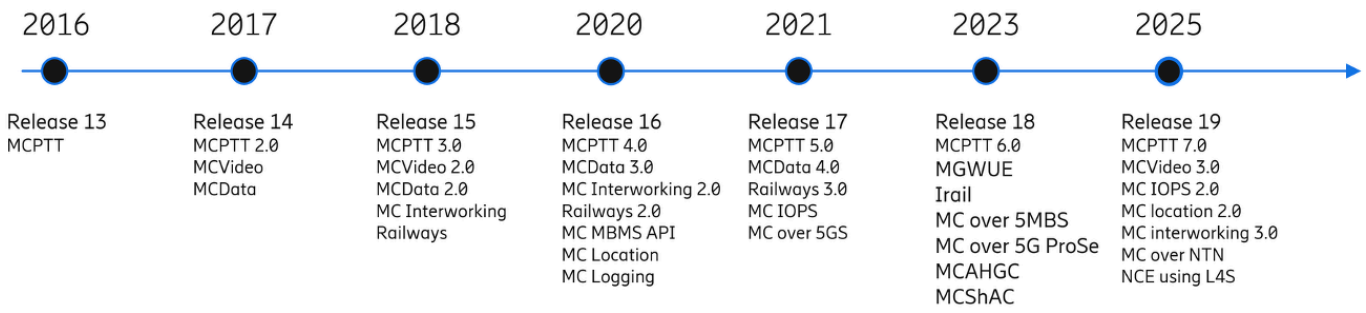


Figure 7 3GPP Roadmap for Release 13 through 19 with respect to MC functionality

Summary of 3GPP MC Roadmap Developments related to 5G

- 3GPP Release 15 is the early 5G standard phase focusing on enhanced mobile broadband. This phase usually relies on a 4G foundation including EPC (using non-standalone architecture NSA), with the use of additional spectrum, meaning that subscribers in a 5G coverage area will get higher uplink and downlink throughput. This is the Release typically deployed in networking equipment today for the first 5G commercial launches happening all over the world using the first generation of mass-market commercial 5G terminals.
- 3GPP Release 16: Work for migration and interconnect between MCPTT systems was started and continued in Release 17.
- 3GPP Release 17: This Release introduces the key network enablers and initial features for critical communications services.
- 3GPP Release 18: This release specifies how key 5G network enablers are used in conjunction with Mission Critical Services, as well as enhancements to the key enablers.

Similar to 4G LTE adoption, the standards development in 3GPP, device availability and deployment processes of 5G are going to be incremental. Figure 7 shows highlights from the current 3GPP Roadmap. It should be noted, however, that once standard Releases are defined, it then takes typically an additional one to two years before these features are commercially available (including network equipment, devices and applications).

How the different mission-critical services must be integrated with the network, and which network enablers to involve, has been extensively specified in 3GPP for 4G LTE networks, and a similar exercise is required for 5G networks in order to ensure the performance levels required for critical communication users.

Several of the network enablers were specified in Releases 15 and 16, such as the QoS-framework and architecture. With release 17 and 18, with the exception of IOPS, all the remaining network enablers and equivalent set of mission critical services are now in place for 5G however enhancements taking advantage of 5G capabilities are still being standardised.

The 5G ecosystem is rapidly evolving, there are already some early 5G devices available and applications relying on 5G performance, such as sub-5 millisecond latency. Because of that, it is likely that devices for critical communications will not be available for some years at least for a mass market. And while there are applications designed for 5G-networks that would benefit critical communications users, they are not yet mature enough for operational use.

Implementation timeframe for 5G SA services

An operator planning to deliver 5G services to PPDR users will need 5G technology as described in this paper. The timeframes mentioned herein relate to when the technology will be available to an operator.

It is expected that a nationwide 5G SA network, supporting a comprehensive set of critical communication services for PPDR networks, will be possible from 2027. That said, a subset of critical communication functionality that utilises 5G services – e.g. use cases taking advantage of low latency and high throughput - has been demonstrated in proof-of-concept trials from 2023, relying on 3GPP Release 17 functionality that includes MCX and network slicing amongst other capabilities.

Of course, the expected timings here are also dependent on the ecosystem development as well as operational needs, however if history is anything to go by then neither of these are likely to be the critical path here. Critical communication users have just begun to adapt their operations to using these new technologies, and it is likely that we are several years away from implementing a comprehensive set of use cases that only 5G can address.

Migration path to 5G

Starting with a critical communications 4G LTE network, the migration path to 5G will be a smooth transition that keeps pace with the ecosystem maturing and appropriate spectrum coming on stream. This process is already underway at the present time in several NSA deployments, which enables both 4G LTE and 5G services. For clarity, in this case, control signalling is conveyed over 4G LTE whilst the user plane data is transmitted over 4G LTE or 5G for different services. This enables critical communication services to use 4G LTE user plane whilst also allowing use of 5G user plane for data offloading in order to free up resources and for specific critical applications.

5G coverage is now more widely available but still lags behind that of 4G LTE. Critical communication services using MC Data and MC Video will be in use over 4G and 5G, however in general MCPTT services will largely remain operating over 4G LTE given availability of wide area coverage, broadcast services (where necessary) and the ecosystem of compatible devices. Circa 2027, when critical communication services and network enablers have been standardised over 5G NR, and equipment commercially available and deployed, it will be possible to implement standalone 5G networks suitable for PPDR networks.

Further, more detailed, considerations for the migration path include:

- **5G core network evolution from 4G:** LTE EPC addresses the need for enhanced mobile broadband. New 5G radio access is added by introducing 5G radio via dual connectivity mode with LTE as an anchor. Early adopters can then offer 5G services mainly to address capacity demand in hotspots. This first phase protects the investment of public safety operators who invested in a mission-critical LTE network, while allowing them to offer first responders some 5G benefits. A cloud-native core is fundamental for 5G services, that is a core software that can run in a dynamic and scalable cloud environment. These services include the ability to independently scale

control and user-plane resources to meet varying application requirements and service demands — as well as gaining the flexibility to place core resources at the edge of the network for improved network latency and performance.

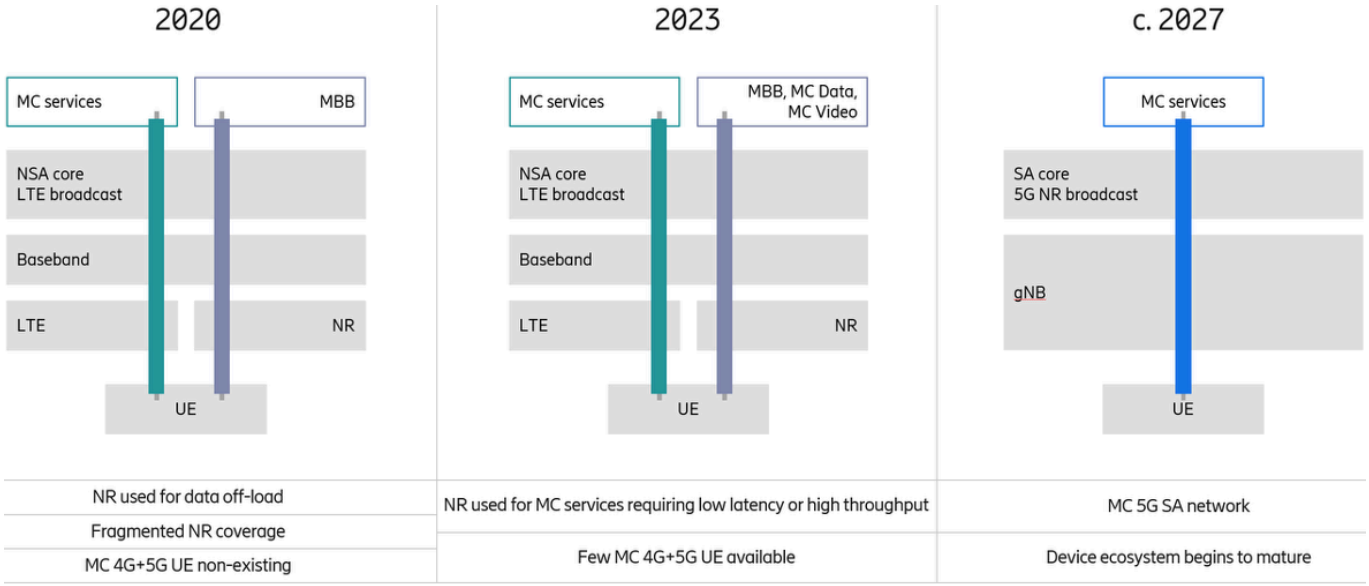


Figure 8 High-level migration path for critical communications from 4G LTE to 5G

Evolving transport networks for 5G: Transport networks have played a foundational role in LTE. With the development of the 5G radio network and the 5G core, the transport networks that carry data traffic between them must evolve to meet the increased demands. A specific consideration for public safety is the diverse location of radios required to support new use cases, which need agile transport network services to reach them. These agile transport networks – typically using a mix of wired, microwave and optical technologies – will utilise software-defined networking (SDN)[7] capabilities able to provide the service assurance and optimisation necessary to meet end-to-end SLAs across 5G networks.

Strengthening network-based security: 5G networks will facilitate mass adoption of the Internet of life-saving things such as connected defibrillators, connected Early Warning Systems and other sensors and systems used in mission-critical operations. This evolution will likely cause these networks to become greater targets for cyber- attacks. In the 5G era, more than ever, security must be designed and built into the network from day one. The security framework should adapt to address changes in attack vectors and detect these as early as possible for faster responses, using the whole 5G network to do so. The entire security cycle will have to be covered, from prevention to detection, assessment and response.

[7] https://sdn.ieee.org/

Conclusions and recommendations

The main conclusions from this white paper are as follows:

- 4G LTE has proven to be a capable mission-critical broadband technology: secure, reliable, available and able to offer high performance mobile communications over a wide coverage area. New use cases are now supported, focused on the use of mission-critical video and data, as well as voice, delivering clear user benefits. It is widely available today with a clear path to evolve to the 5G era, delivering the full capabilities of 5G technology.
- Whilst 4G LTE offered a step change in terms of capabilities for critical communication operators and users versus previous technologies, 5G is providing evolutionary enhancements in terms of greater performance, security, breadth of use cases and quality of service. As mission-critical 4G LTE networks are deployed, and user adoption of these services grows significantly, this is encouraging further innovation and enhancements to 5G and future generations of 3GPP Releases.
- From a technology perspective, 5G will provide a plethora of new capabilities, most notably enhanced mobile broadband services with ultra-reliable low latency communications and support massive machine-type device deployments. Whilst these capabilities will be available across all bands, the benefit of some will be more pronounced at higher frequencies due to correspondingly larger channel bandwidths.
- 5G technology is essentially delivering improvements to users in two distinct ways: (i) Enhancing use cases initially enabled by 4G LTE e.g. in terms of scaling up these services to more users within a given locality, and (ii) Address new and emerging use cases made possible with advancements in technology such as ultra-low latency mobile connectivity. Both will provide important user benefits, ranging from enhanced situational awareness - through the use of advanced video recognition capability, artificial intelligence analysis of data collection and new immersive user applications - to greater use of remote and specialist expert analysis of incident ground environments and first responders.
- 5G networks will provide first responders with fast, robust and high-performance communications. They will enable the dispatchers to have an accurate view of a situation and allow them to better allocate resources. The information between agencies can be shared more easily via cloud-based application platforms. The net result is that the cooperation between first responders can be more effective and efficient, improving the safety of users and saving the lives of others.
- In 5G networks, the use of a service-based architecture with networking functions built for cloud-native server platforms is allowing operators and users to customise network performance to match specific needs at a specific moment in time, allowing both mission-critical and non-mission-critical applications to share the same infrastructure simultaneously – be that public, private or a hybrid mix.
- 5G covers an array of new capabilities and ways of deploying network services. In general, it is implemented as a complementary add-on to existing LTE networks, termed Non-Standalone (NSA). Over time, these NSA deployments will gradually transition to full 5G Standalone (SA) networks. Therefore, networks are likely to support dual mode 4G-5G equipment, enabling a smooth migration path from 4G LTE to 5G SA, before going to a full 5G SA network and providing access to the full range of 5G capabilities.
- The global 5G ecosystem is driving further standardisation and development of mission- critical services but industry is also investing and delivering solutions providing new ways of monitoring network performance and assuring service levels using complementary software technologies such as automation, analytics, and artificial intelligence.
- To build nationwide 5G services low, mid and high band spectrum will be required. Low band (<1 GHz) provides ideal geographic coverage in rural areas, mid band (1-6 GHz) is suitable for urban and suburban coverage providing a balance between capacity and coverage, and finally the high band (>6 GHz) is ideally suited to significantly boost capacity in dense urban areas, including in-building coverage.
- Since 2020, commercial 5G operator services have been made available in many countries, however these are mainly deployed in the mid and high bands; notable exceptions include Switzerland which has rolled out relatively quickly 5G-NR in low bands through software updates only.
- 5G technology offers highest throughput and lowest latency in the higher bands, where operators and/or agencies typically have 100+ MHz of channel bandwidth in urban and suburban areas in comparison to low bands used for wide area coverage. Note, combining low and higher bands can substantially increase the coverage of capacity gains from higher bands – the latter typically deployed within suburban areas.

- To meet PPDR user needs with regards to the availability of nationwide mission-critical broadband services, a range of coverage solutions will be necessary using 4G LTE, 5G or optimally a combination of both. These solutions will typically involve “fixed” wide area macro networks – in many cases relying on the networks of public operators - as well as rapidly deployable networks, complemented by User Equipment (UE) with Device-to-Device (D2D) communication capability using the 5G Sidelink feature.
- Applications such as video surveillance and mass rollout of sensors across government and critical infrastructure will have an increasingly greater importance for critical communications and are likely to have a profound effect on the provision of future PPDR services. Nevertheless, voice will continue to play an important role in mission-critical communications, hence the driving force behind the porting efforts in 3GPP of (MCX from 4G LTE to 5G New Radio (NR). This together with other factors mentioned throughout this paper forecasts that PPDR 5G SA systems, with a comprehensive suite of mission-critical functionality, are likely to be in the market by 2027.
- Whilst this paper describes the capabilities and general timing of 5G technology to operators and agencies planning for mission-critical services, the exact implementation and availability of those services will always depend on country-specific conditions.

Recommendations for further action:

Whilst a significant amount of progress has been made by the critical communications community over the past decade - establishing mission-critical broadband spectrum, standards, technology and a competitive marketplace - there is still more to achieve. Listed here are recommendations that should be considered for further action:

- Support, communicate and endorse the continued rollout of mission-critical 4G LTE networks, providing new and vital operational capabilities as well as fueling ongoing innovation in use cases, applications and communications technologies.
- Continue to target and make use of all available dedicated spectrum, working together as a community to create self-sustaining and competitive ecosystems.
- Expand collaboration efforts with commercial mobile network operators (MNOs) to deliver and enhance mission-critical mobile broadband services for critical communication users, leveraging 3GPP defined capabilities and utilising shared and/or dedicated spectrum.
- Continue to prioritise, resource and support further 3GPP-driven standards definition and testing for the features identified in this paper, and of particular benefit to the critical communications community.
- Identify any new 5G functionality that could be of benefit to those PPDR operators looking to deploy networking solutions involving multiple MNO infrastructures, such as improvements in handover performance, security and interworking in general.
- Continue to build and develop end-to-end ecosystems, including widespread chipset support and device form factors required for PPDR applications, from the traditional to radically new.
- Develop a road map of mission-critical broadband-enabled use cases, working across eco-system partners, to ensure that end-to-end 5G capabilities can be delivered at the earliest opportunity.

Looking forward, international collaboration on service deployment experiences and sharing of best practice is highly recommended, and TCCA is the ideal organisation in which to discuss this.

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Acronyms and Abbreviations

2G	Second Generation 3GPP Technology Standard
3G	Third Generation 3GPP Technology Standard
3GPP	Third Generation Partnership Project
4G	Fourth Generation 3GPP Technology Standard
4K	Ultra-High-Definition Video
5G	Fifth Generation 3GPP Technology Standard
5GC	5G Core (Network)
5MBS	5G Multimedia Broadcast Services
AI	Artificial Intelligence
API	Application Programming Interface
AR	Augmented Reality
ATO	Automated Train Operation
CA	Carrier Aggregation
cMTC	Critical Machine-Type Communications
D2D	Device-to-Device Communications
EAS	Extensible Authentication Protocol
eMBB	Enhanced Mobile Broadband
EPC	Evolved Packet Core
FRMCS	Future Rail Mobile Communications System
GSMA	Global System for Mobile Communications Association
GSM-R	GSM for Rail
HAP	High Altitude Platform
IAB	Integrated Access and Backhaul
IMT	International Mobile Telecommunications
IMT-2020	International Mobile Telecommunications standard for 5G Networks
IMT-Advanced	International Mobile Telecommunications standard for 4G LTE Networks
IoT	Internet of Things
IP	Internet Protocol
ISAC	Integrated Sensing and Communication
ITU-R	International Telecommunications Union – Radio Communications
LTE	Long-Term Evolution
MBMS	Multimedia Broadcast and Multicast Services
MC	Mission-Critical

MCData	Mission-Critical Data Services
MCIOPS	Mission-Critical Isolated Operations for Public Safety
MCN	Mission Critical Network
MCOver5GS	Mission-Critical over 5G System
MCPTT	Mission-Critical Push-to-Talk
MCVideo	Mission-Critical Video Services
MCX	Mission-Critical Services
MIMO	Multiple-In Multiple-Out
mMTC	Massive Machine-Type Communications
MU2N	Multi-hop UE to Network relaying
MU2U	Multi-hop UE-to-UE relay
NB-IoT	Narrowband Internet-of-Things Services
NPN	Non-Public Network
NR	New Radio
NSA	Non-Standalone
NTN	Non-Terrestrial Network
OTT	Over-The-Top
PON	Passive Optical Network
ProSe	Proximity Services
QoS	Quality of Service
RACH	Random Access Channel
RAT	Radio Access Technology
SA	Standalone
SDN	Software Defined Network
SLA	Service Level Agreement
TCCA	The Critical Communications Association
TETRA	Terrestrial Trunked Radio
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UHD	Ultra-High Definition (4K) Video
uRLLC	Ultra-Low Latency Communications
VoNR	Voice-over-New Radio
VR	Virtual Reality
XR	Extended Reality

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