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5G Core – The Key to Monetizing 5G Standalone Networks

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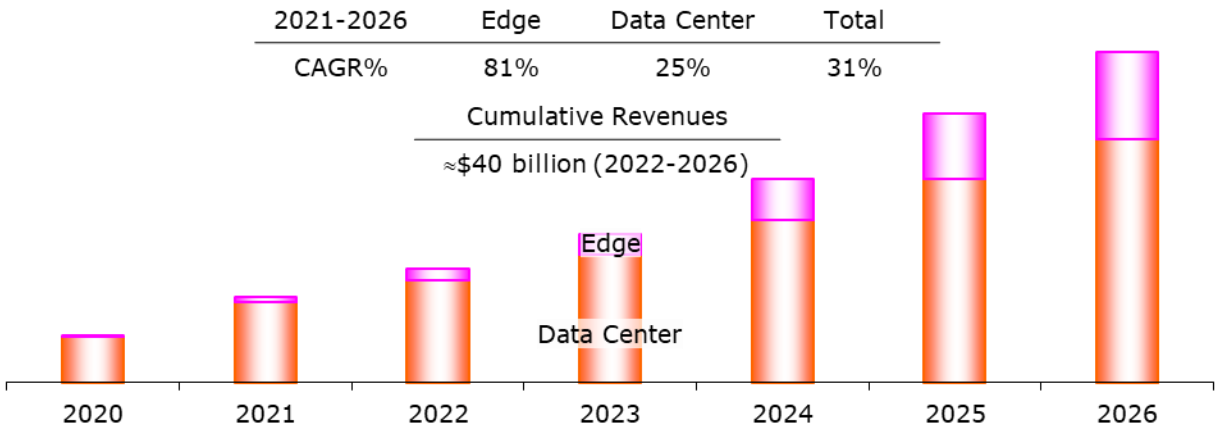
Executive Summary

5G was launched with great fanfare in 2019 as the next-generation technology, boasting new capabilities and features to address a broad base of use cases that 4G LTE could not support. Industry watchers expected that 5G would take Mobile Network Operators (MNOs) to new heights in revenue generation. However, the path to 5G took a detour that spun off a network architecture called 5G Non-Standalone (5G NSA). 5G NSA is anchored to the legacy 4G Evolved Packet Core (EPC), and it is not true 5G. The true iteration of 5G is anchored to a 5G Core and is called 5G Standalone (5G SA).

The 5G Core is the key to unlocking the potential for additional revenue streams for MNOs. For the 5G Core and 5G Server vendor suppliers, we expect 5G manufacturing revenues for the total market to grow at a 31% CAGR, and for the edge segment to grow at an 81% CAGR (2021-2022), totaling nearly $40 billion in manufacturing revenues over the next five years (2022-2026) (Figure 1).

Figure 1: 5G Core and 5G Server manufacturing revenues per location ($ billions)



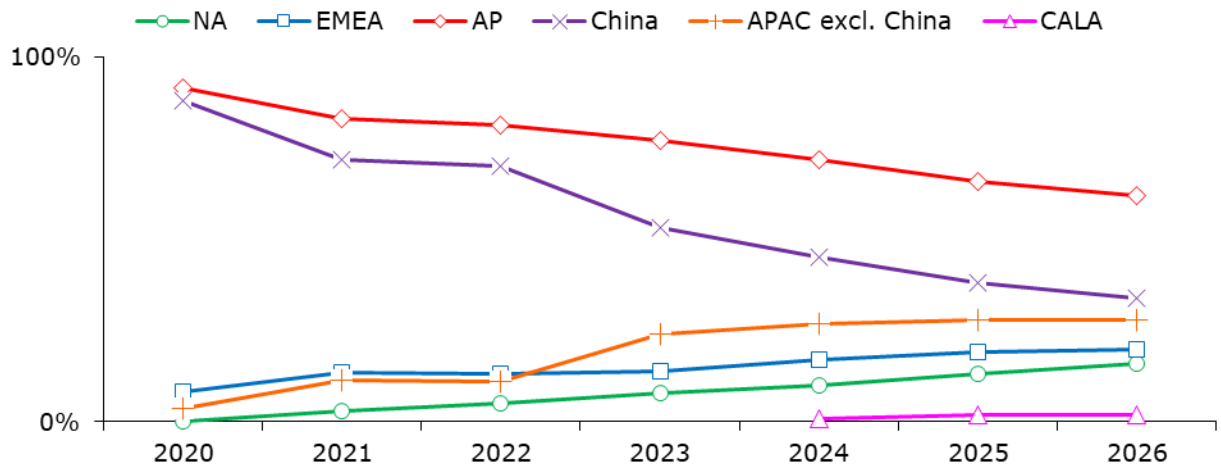
Source: Dell'Oro Group "Mobile Core Network and MEC Market Report," July 2022, and "Telecom Server Market Report," October 2022.

5G SA with large bandwidths and 5G cloud-native technology allows MNOs to address a new generation of high-performance Internet of Things (IoT) devices for low latency-sensitive applications making real-time and near real-time communications a reality. Coupled with edge computing, applications involving Computer Vision are considered the "killer application enabler." MNOs that address this market segment stand to reap new revenue streams from 3.3 billion broadband IoT devices by 2028. In addition, by 2024, new low-cost reduced capability (RedCap) radios will be available to address the rest of the IoT device market, totaling 31.4 billion devices allowing MNOs to harvest additional revenues.

Since 2020, only 36 MNOs have launched 5G SA; most MNOs are maintaining 4G (786 networks) or have launched 5G NSA networks (≈200 networks). As a result, only a small handful MNOs that embraced 5G SA can fulfill the promise of 5G and generate new meaningful revenues. As first movers in their respective geographic regions, they stand to garner the most market share for the new market opportunities that 5G SA can support.

To date, most of the investment in 5G SA has been in China. Starting in 2020, the Chinese MNOs fully embraced 5G SA, including Mobile Private Networks (MPNs) with network slicing and edge computing (Figure 2).

Figure 2: 5G Core and 5G Server regional manufacturing revenue share



Source: Dell'Oro Group

One of China's MNOs, China Unicom, revealed how lucrative the 5G SA MPN market is in its 1H 2022 Interim Report.

- Over $500 million in contract value for industrial applications in 1H 2022
- Over 8,000 cumulative 5G SA MPN application projects
- 2,014 5G SA MPNs completed

In addition, China Unicom reported they implemented Voice over New Radio (VoNR) in 125 cities, which will generate more incremental revenues with new features that can be monetized only in 5G SA networks.

China Mobile revealed 11,000 5G SA MPN commercial projects and revenues up 223% Y/Y for 1H 2022. In addition, China Mobile has over 300 public edge nodes spread across its network. And China Telecom reported signing over 1,300 new 5G SA MPN contracts, and the contract revenues grew over 80% Y/Y for 1H 2022. They claimed over 9,000 cumulative projects signed in their 1H 2022 Interim Report.

Adding it all up, the three Chinese MNOs have completed over 5,000 5G SA MPNs since 2020, with nearly 23,000 MPNs in the backlog. This is incremental revenues that the Chines MNOs are enjoying, enabled by 5G SA technology, by addressing the Mobile Private Network opportunity.

China's MNOs have discovered that the 5G Core is the key to monetizing the 5G SA network:

- Cloud Native Technology – offering microservices that can be offered quickly and efficiently
- Network Slicing – addressing a new lucrative market for mobile private networks
- Edge Computing – addressing a new lucrative market for low-latency applications

4G and 5G NSA cannot address the new use cases that require the capabilities of 5G SA, and MNOs that cling to 4G and 5G NSA could be left behind if they do not embrace 5G SA soon.

In the first section of this whitepaper, we describe the promise of 5G and outline the migration path to 5G SA. We believe that upon reviewing this information, an MNO will realize the importance of moving to 5G SA as quickly as possible to capture more revenues.

In the next section, we consider what makes the 5G Core different from the 4G EPC and what the differences mean to the MNO. The 5G Core allows MNOs to move into the modern cloud era and offer new services quickly and efficiently to generate new revenue streams. We focus on three key features of the 5G Core: (1) Cloud-Native Technology, (2) Network Slicing, and (3) Edge Computing.

In the third section of this paper, we illustrate the size of the market opportunity for Mobile Private Networks—addressed by network slicing—and the size of the market opportunity for low latency use cases—addressed by Edge Computing. This should impress MNOs with the sheer magnitude of the overall market opportunity that 5G SA will make available to them.

We believe it is important for MNOs to understand the underlying technology, as well as what is required to bring 5G SA networks to life. MNOs must partner with many 5G ecosystem players to bring solutions to market and capture new revenues. The elements required will include the Internet of Things (IoT), infrastructure and application servers, and Artificial Intelligence/Machine Learning (AI/ML) Data Analytics.

And finally, we will look at the new 5G SA use cases that involve a new class of 5G high-performance IoT devices from which an MNO can generate new revenue streams. These are high bandwidth-intensive use cases that need real-time processing that only 5G SA networks can meet. The revenue potential is high because of the requirement for high bandwidth and low latency. We will highlight the "killer application" use case enabler—Computer Vision—and its obvious importance.

As noted, MNOs in China fully embraced 5G SA and launched their networks in 2020; thus, we have over two years of data from thousands of mobile private networks in China to learn from, and we can pinpoint the 5G SA applications that are returning the most revenues to the MNOs.

It is vital for MNOs to build out 5G SA networks as quickly as possible to maximize the capture of the market opportunity.

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The Case for 5G Standalone (5G SA)

The Promise of 5G

The promise of 5G can be traced back to an NGMN Alliance (Next Generation Mobile Networks Alliance) whitepaper titled "NGMN 5G Whitepaper," published in 2015. It was co-authored by representatives from 21 MNOs. The 3rd Generation Partnership Project (3GPP) took the mantle of developing the standard and released the first specification at the end of 2017; this standard was commonly known as 5G Release 15 (3GPP TS 23.501, System architecture for the 5G System). Use cases drove the performance requirements outlined in the whitepaper. They were new use cases, and they represented new opportunities for MNOs to generate new revenues (Figure 3).

Figure 3: 5G new use case families for increased MNO revenues

High Level Use Cases
enhanced Mobile Broadband (eMBB)
Ultra Reliable Low Latency Communications (URLLC)
Massive Internet of Things (MIoT)
High-Performance Machine-Type Communications (HMTC)
Vehicle-to-Everything (V2X)

Top-level 5G specifications goals were established to meet the demands of various use cases. While 4G can satisfy some parts of the market, 5G will do it at scale with a magnitude of performance increases enabling new applications (Figure 4).

Figure 4: Top level 5G specifications goals compared to 4G

Use Case	4G	5G
eMBB	1 Gbps	10 Gbps
URLCC	10 ms	1 ms
MIoT	100k connections/km^2	1M connections/km^2

As we will see, the path to 5G took a detour with what is now called 5G NSA. As we know, this is anchored to the legacy 4G EPC, and it is not true 5G with the capabilities defined above, which is now called 5G SA anchored to a 5G Core, "true 5G."

One of NGMN's goals for 5G was to exploit all spectrum options to deliver increased network speeds. The 5G industry has convinced various regulators worldwide to release new spectrum that will make high-speed communications possible (Figure 5).

Figure 5: 5G Spectrum usage increases date speeds and lowers the cost per bit delivered

5G Frequency Ranges	Maximum RF Channel Bandwidth	Maximum CA Channel Bandwidth
FR1 410 MHZ – 7125 MHz	100 MHz	400 MHz
FR2-1 24250 MHz – 52600 MHz	400 MHz	800 MHZ
FR1 + FR2-1 – 410 MHz to 52600 MHz	n/a	1200 MHz
FR2-2 52600 MHz – 71000 MHz	400 MHz	1200 MHz
FR2-2 52600 MHz – 71000 MHz (optional)	2000 MHz	N/A

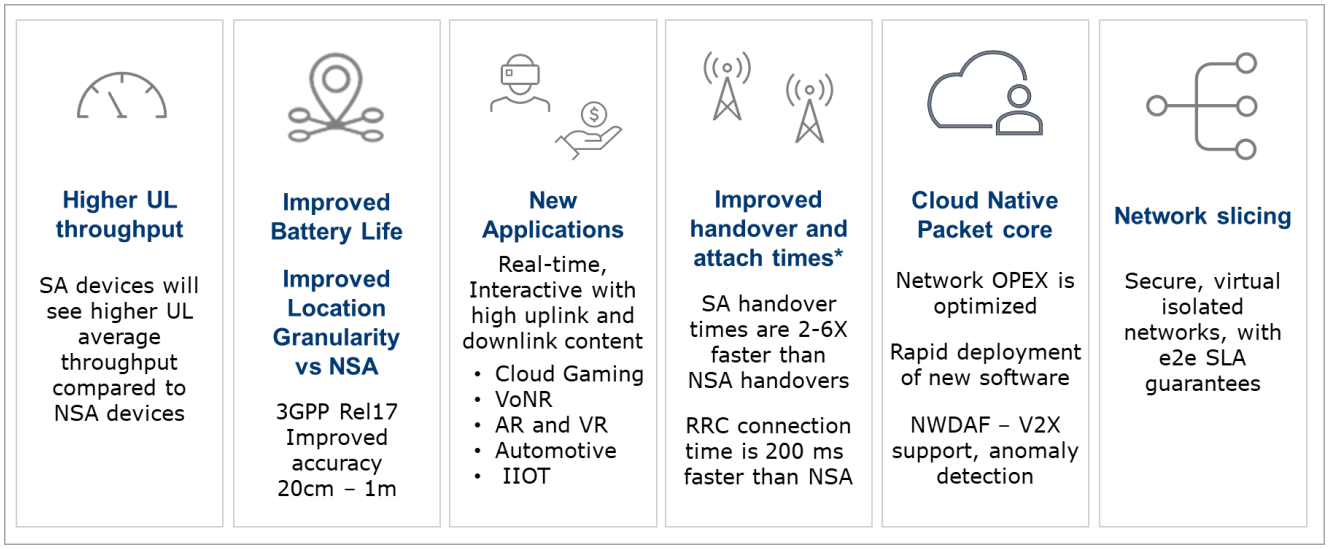
Source: User Equipment (UE) radio transmission and reception 3GPP TS 38.101-2

When comparing the 4G maximum RF channel bandwidth at 20 MHz, and the maximum Carrier Aggregation (CA) channel bandwidth at 100 MHz, it easy to see that 5G will enable use cases that could never be accomplished before in 4G. And 5G can do it at a lower cost per bit delivered.

The State of 5G Standalone

Looking today at the state of the 5G industry, the 5G industry has collectively come together and is making the promise of 5G SA a reality (Figure 6).

Figure 6: 5G Standalone capabilities providing MNOs monetization opportunities



*Source: Mavenir, *Signals Research Group*

5G SA enables a demonstrably superior network that will provide users with higher uplink speeds, improved device battery life, quicker attached times to the network, and quicker handover times. These benefits can support new applications, including rich VoNR and Video over New Radio (ViNR) calling experience beyond an over-the-top (OTT) solution. With mobile edge computing or multi-access edge computing (MEC), 5G SA networks can promise low-latency performance, making real-time or near real-time communications a reality. This opens up a plethora of use cases, such as Cloud Gaming, Augmented Reality (AR), Virtual Reality (VR), Vehicle to Everything (V2X), and the high-performance Internet of Things (IoT). The new use case possibilities are almost endless. The addition of high position accuracy extends the horizon even further for even more IoT use cases. With Network Slicing, performance can be custom-tailored for each use case, providing many avenues for monetization.

Despite the industry delivering on the promise of 5G SA, only a few MNOs have commercially deployed 5G SA eMMB networks. 786 MNOs have launched public 4G SA eMBB services, and around 200 have launched 5G NSA eMMB services (Source: GSA "NTS Statistics November 2022"). Meanwhile, only 36 MNOs have publically launched 5G SA eMBB services (Figure 7).

Figure 7: 36 MNOs have publically launched 5G SA eMBB services

Region	2020	2021	2022
North America	T-Mobile – USA	Rogers – Canada	AT&T Wireless – USA DISH Wireless – USA Verizon – USA
EMEA	Rain – South Africa	Telefónica – Germany Vodafone – Germany stc – Kuwait Zain – Saudi Arabia Vodafone – UK	stc– Bahrain Telekom – Germany
APAC	China Mobile China Mobile – HK China Telecom China Unicom AIS – Thailand TOT – Thailand True – Thailand	TPG Telecom – Australia NTT DOCOMO – Japan Softbank – Japan Smart – Philippines M1 – Singapore SingTel – Singapore StarHub – Singapore KT – South Korea Taiwan Mobile	Optus – Australia China Broadnet KDDI – Japan
CALA			Claro – Brazil TIM – Brazil Vivo – Brazil

Source: Dell'Oro Group, as November 2022

Not all MNOs have had the opportunity to launch 5G SA. In some countries, regulators have been slower to release new spectrum and/or are still beginning to release spectrum. In other countries, the ecosystem for UE devices that support an MNO's RF channel plans have not been available. In some cases, MNOs had no choice but to move forward with 5G NSA for capacity reasons to keep up with increasing traffic demand before 5G SA would have been readily available.

The majority of these roadblocks should be cleared by the end of 2023, and MNOs will have the opportunity to move forward with building 5G SA eMBB networks to increase their revenue streams.

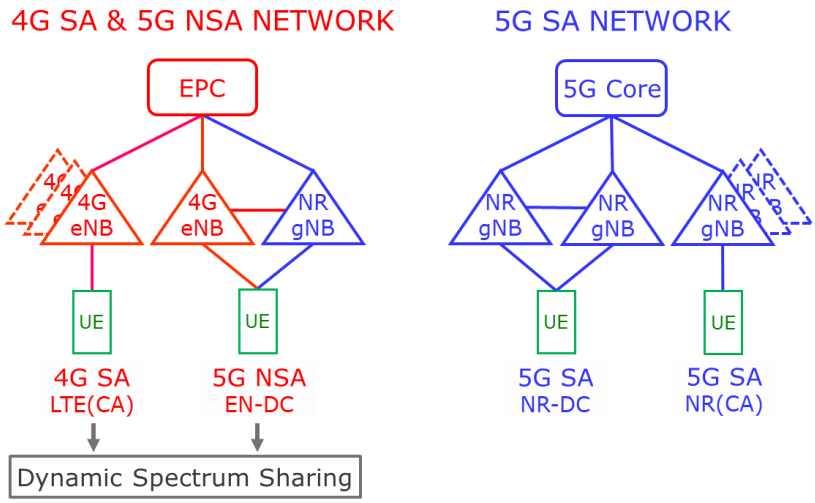
The Route from 4G to 5G Standalone

MNOs have followed one of three routes to 5G; these routes may be characterized by ease of implementation.

- The quickest route to 5G is Dynamic Spectrum Sharing (DSS) over a 4G RAN . DSS provides an incremental speed boost of 10% to 15% over an existing 4G radio within its allocated spectrum and RF channel bandwidth. It is quick because it does not require a network upgrade to the EPC.
- The next most accessible route to 5G is 5G NSA. 5G NSA uses Dual Connectivity (DC) with a 4G radio. It allows user equipment (UE), such as a smartphone, to simultaneously connect to two radios. In the case of a 5G NSA implementation, the 4G radio is the master node, and the 5G radio is the secondary node. This provides the UE with increased downlink speeds (the combined bandwidths of both the 4G and 5G radios), greatly enhancing the user experience. The 4G network must be slightly modified to handle 5G traffic, which is processed by the EPC.
- The final route, 5G Standalone (5G SA), involves a new 5G Core network architecture. The 5G Core can only be used for the 5G SA network, interworking with the EPC, or it can operate as a converged core that handles both 4G and 5G traffic, eliminating the need for the EPC.

On the surface, taking a high-level view of the network topologies, the networks look similar. Both can use DC and Carrier Aggregation (CA) to increase bandwidth (Figure 8).

Figure 8: The route from 4G SA/5G NSA to 5G SA



Source: Dell'Oro Group

However, the difference can be seen when drilling down another layer looking at the capabilities of the 5G Core.

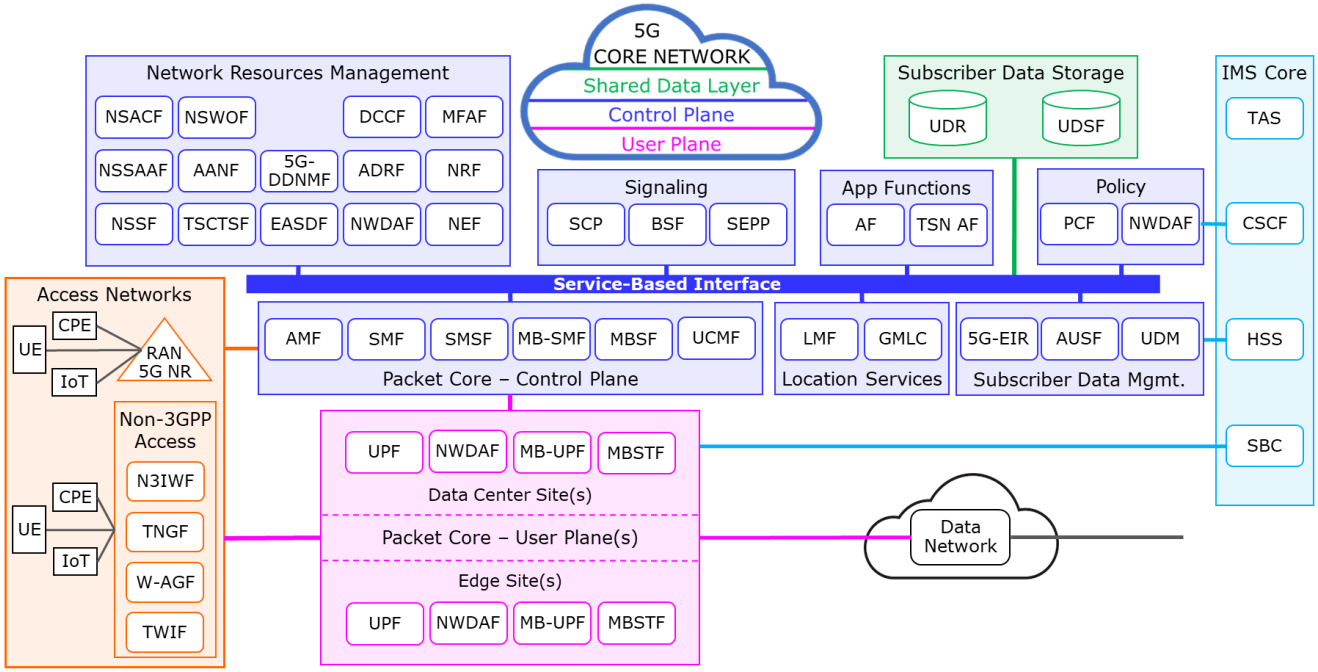
The Case for 5G Core

Cloud-Native Technology

The 5G Core is designed to take MNOs into the modern cloud era. With the 5G Core cloud-native service-based architecture (SBA), MNOs can now operate at webscale comparable to Hyperscale Cloud Providers (HCPs) by offering new services on-demand, generating additional revenue streams, and growing the revenue base.

The 5G Core disaggregates the hardware from the software and separates the Shared Data Layer, the Control Plane, and the User Plane from each other. This makes the 5G Core very resilient and supports its design goals of meeting Telco-grade network reliability of 99.999% uptime. Thanks to the Network Exposure Function (NEF), all network functions tied to the service-based interface are aware of all other network functions and can tap network resources on demand. The software for the network functions consists of container-based cloud-native network functions (CNFs), making the 5G Core deployable over bare metal, virtual machines, private cloud, and public cloud infrastructure (Figure 9).

Figure 9: 5G Core Cloud-Native Service-Based Architecture (SBA)



Source: Dell'Oro Group and 3GPP

Besides providing users with higher data speeds with additional spectrum that 5G can operate in, MNOs can offer custom tailored solutions for specific users or class of users, on the consumer side and the enterprise side of the business. The two primary capabilities that permits offering such services is Network Slicing and distributed User Planes enabling Edge Computing. Now, instead of a one-size fits all as in 4G and 5G NSA

networks, 5G SA data traffic has many paths it can traverse with each path offering unique services that can be monetized. With the additional level of complexity that comes with the 5G Core SBA, an important feature in self-managing the network with Network Analytics to keep it running smoothly.

Network Slicing

MPNs can be set up within an MNO's 5G network—known per the 3GPP specification as Public Network Integrated – Non-Public Network (PNI-NPN)—via Network Slicing. The 5G Core Network Slicing Selection Function (NSSF) can allocate dedicated RAN, Core, and Transport resources to designated users for critical use cases with key performance indicators (KPIs). In some cases—for example, UEs with the Android operating system assigning network slicing to applications through the User Equipment Route Selection Policy (URSP) rules—the UE can select from multiple network slices. Network Slicing creates a logical private network that can only be used by subscribers that have signed up for a custom-tailored Service Level Agreement (SLA). For industrial/enterprise users, this is a low-cost way to build a private network versus industrial/enterprises building and operating their own Standalone MPN. Network slicing is an excellent opportunity for MNOs to monetize their investment in 5G (Figure 10).

Figure 10: Network Slicing provides the capability to monetize many new service offerings

3GPP Pre-Defined Network Slices
Enhanced Mobile Broadband (eMBB)
Ultra Reliable Low Latency Communications (URLLC)
Massive Internet of Things (MIoT)
High-Performance Machine-Type Communications (HMTC)
Vehicle-to-Everything (V2X)

MNOs may want to offer Network Slices for other use cases, such as FWA, Cloud Gaming, Multicast/Broadcast Service, and Public Safety. Each Network Slice can fine-tune parameters, such as data throughput, latency, jitter, packet loss, video resolution, and video framerate, thus optimizing the revenue stream for new services.

Network slices can be created on-demand and for specific times. Singtel, Singapore, the official network partner of Grand Prix Season Singapore 2022, showcased a recent example.

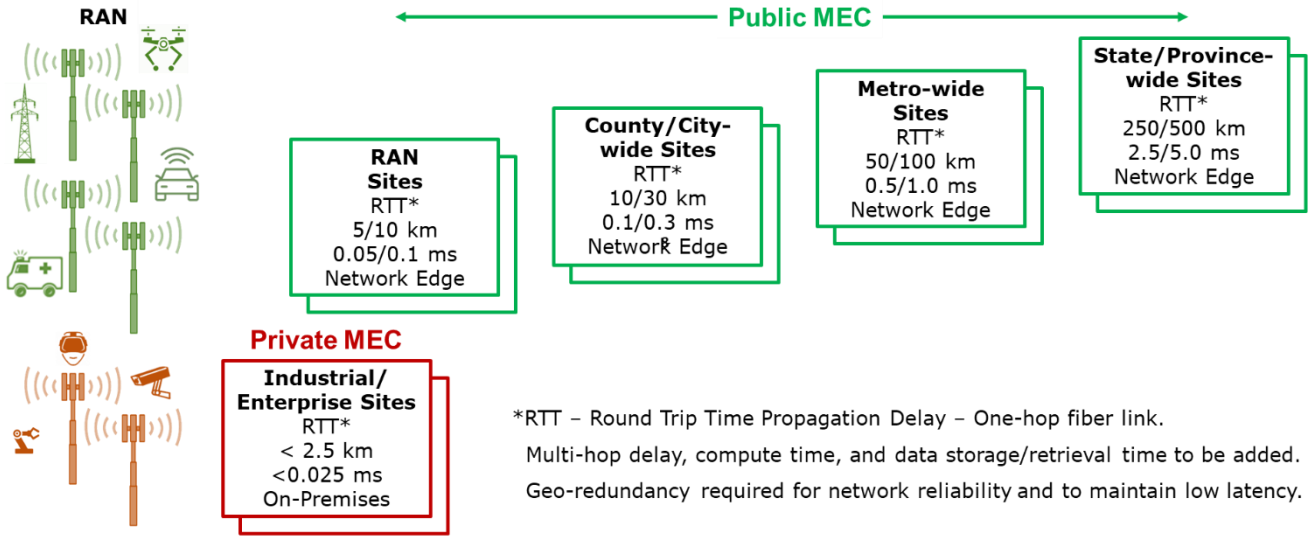
Source: Formula1.com

In a world's first, Singtel will be applying the most advanced form of network slicing technology to support its digital app marketplace, CAST. With Sports Plus on Singtel CAST, race fans will be able to catch the entire high-velocity night race from wherever they are, even around the high traffic areas of the circuit, where over 250,000 spectators are expected, … with Sports Plus on Singtel CAST, at S$9.90 for the week, customers can also enjoy the race on their 5G mobile devices, which will offer an enhanced lag-free, high-speed streaming experience," per Singtel's press release, 27 September 2022.

Edge Computing

With distributed user planes, the user plane function (UPF) can be distributed around a network, enabling MEC. This provides the capability to offer low-latency edge computing. There are two ways to implement MEC. (1) Public MEC—MEC locations at various distances from the network edge—is for industrial/enterprises and consumer users that need broad geographic coverage. (2) With Network Slicing, MNOs can provide mobile private networking for various use case scenarios. Private MEC—located on-premises with RAN—is for industrial/enterprise users that prefer to have the 5G network on-campus to access the ultimate performance in coverage, speed, and low latency. Private MEC also keeps the end-user data on-site, protecting the end user's data sovereignty (Figure 11).

Figure 11: MEC provides the capability to monetize low latency services



Source: Dell'Oro Group

For every MEC site installed, the backhaul costs are significantly reduced versus sending the data back and forth to a faraway data center. Indeed, MEC may become a requirement for MNOs, because—given forecasts of exponential growth in data traffic—it could become impractical to backhaul all that data traffic without MEC.

3GPP Release 17 version of the 5G specifications adds the Edge Application Server Discovery Function (EASDF) to the 5G Core, allowing edge-aware devices to find the closest application server. This makes MEC more efficient and provides better service. This will launch the 5G Edge Aware Networks era in the next year or two.

Source: GSMA, "5G Use Cases for Verticals in China 2020"

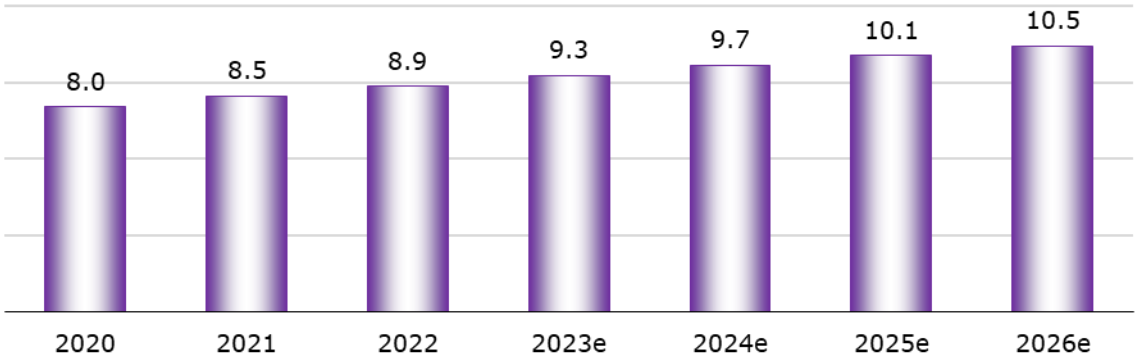
A 5G SA MPN with Network Slicing and MEC was provided by China Mobile to Xinfengming Group, a large-scale business focusing on polyester manufacturing. 8K video resolution cameras on 5G-connected robots are used for quality inspection of micron-level fibers spun up at a speed of 4,000 meters per minute. The 5G SA network met the 100 Mbps uplink speed and low latency requirements, with the processing done using on-premises MEC servers.

The Case for Mobile Private Networks (MPNs)

Shared MPNs

To achieve the lowest latency possible for a Shared MPN with network slicing, the MEC System must be located next to the base station. Public MEC—shared at the network edge—would mean placing MEC Systems next to every macro base station site, representing a potential 10.5 million locations by 2026. This scenario would generate the maximum back-haul cost savings that an MNO could realize, dramatically reducing back-haul user data traffic to and from the data center. The market will eventually mature to this point for applications that require geographic coverage, such as V2X, mission-critical communications for public safety and public health, and some smart city applications. The MNO that addresses this market first will most likely generate the most revenue (Figure 12).

Figure 12: Market potential for MPNs with Network Slicing via Public MEC at 10.5 million macro-Base Station sites (in millions)



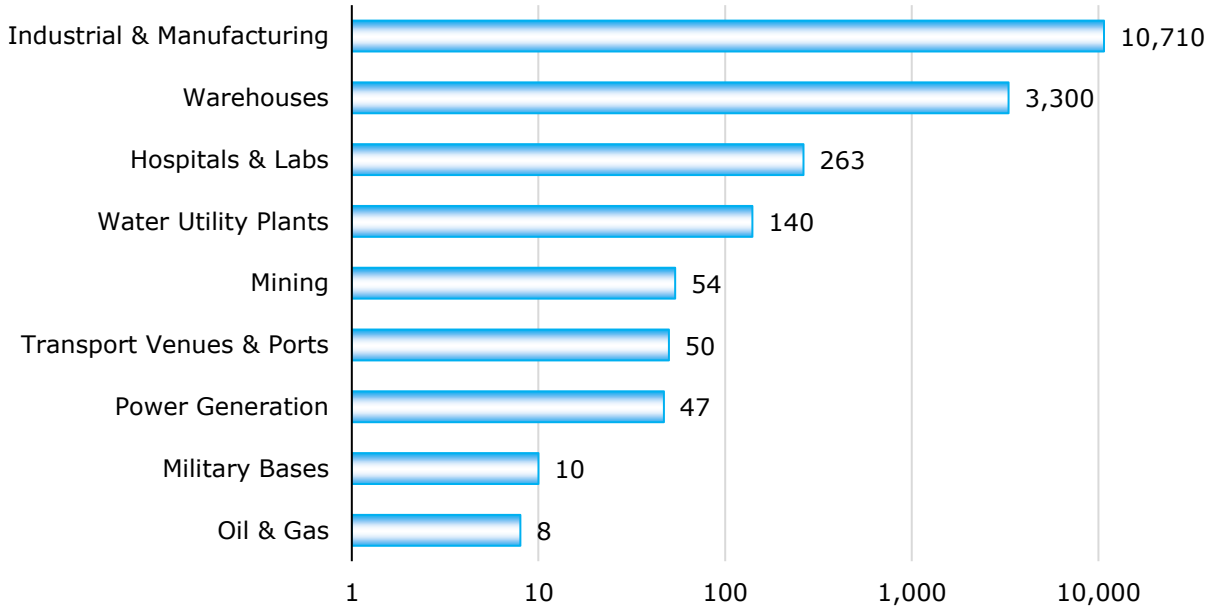
Source: Dell'Oro Group

For consumers, one of the early successes in markets in Asia with 5G SA networks is addressing the needs for the low latency multi-player Cloud Gaming market. Gamers are willing to pay a premium for low latency service to give them a competitive advantage. On the consumer side of the business, we consider Cloud Gaming the "killer application." Another example of generating more revenues with 5G SA is the Singtel use case noted earlier, spinning up a network slice over Public MEC for the low latency requirement for AR to enhance the fan experience at venues for the duration of a sporting event or concert or festival.

Dedicated MPNs

If the Public MEC market opportunity sounds impressive, the Dedicated MPN market for industrial sites is even more so. Over 14 million locations have been identified as having the potential for wireless connectivity. These sites could be addressed with Private MEC—on-premises—for latency-sensitive applications. The 5G ecosystem suppliers are laser-focused on this space because they recognize the tremendous opportunity. MNOs likewise could capitalize on this opportunity and generate more revenues (Figure 13).

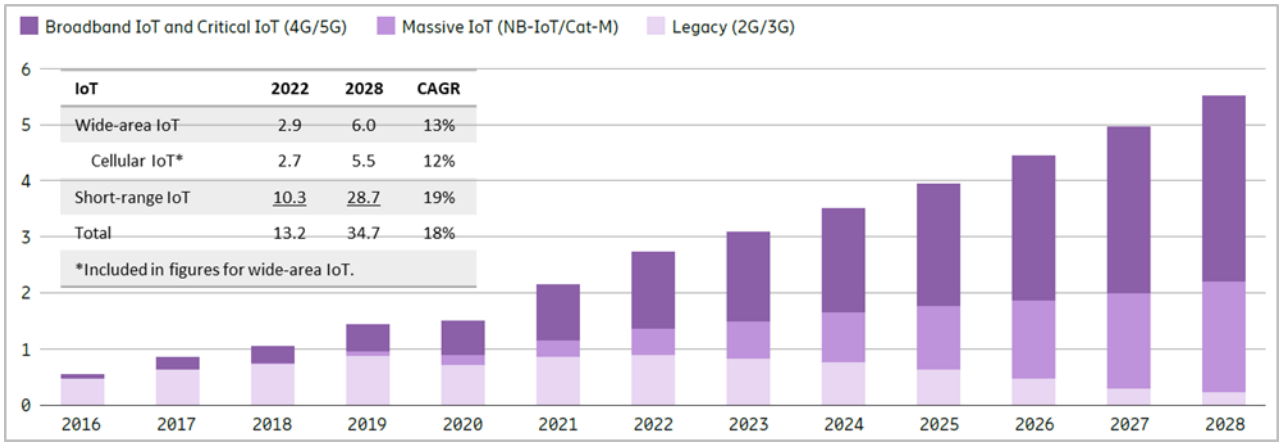
Figure 13: Market potential for Dedicated/Standalone MPN via Private MEC (on-premises) at 14.5+ million industrial sites (in thousands)



Source: Nokia 2019

5G will be required to meet many of the needs of these MPNs, with 60% of 5.5 billion cellular IoT connections expected to be broadband IoT devices by 2028. (Figure 14).

Figure 14: Cellular IoT connections (billion) – 60% of 5.5 billion to be Broadband IoT by 2028



Source: Ericsson Mobility Report, November 2022

Standalone MPNs

Some industrial/enterprises may choose to have a 5G SA MPN, which is not tied to the public network. MNOs can take advantage of this opportunity offering the same solution and services as they do for Dedicated MPNs. The difference is that the 5G Core is on-premises instead of just the MEC.

5G Standalone Supporting Ecosystem

If we think of a 5G SA network standing on a stage, the 5G Core would be center stage. Front and center are the RAN and IoT technologies connected to the audience that represents the associated use cases and the associated data. Behind the scenes would be the Infrastructure and Application Servers that support the 5G Core operation and the IoT data. AI/ML would be the lighting that shows the audience (the users) what they need to see to make sense of the data.

Internet of Things (IoT)

In addition to the 5.5 billion Broadband IoT connections expected in 2028, we also anticipate another 29.2 billion non-cellular IoT devices. These IoT devices would also be a target for 5G MNOs because the 5G Core provides gateways for non-cellular access networks. In the future, many of these IoT devices could become 5G native with reduced capability 5G radios, called RedCap, which are expected to be available sometime in 2024. RedCap would eliminate the need for a gateway for RedCap IoT devices.

The technologies behind the scenes that will allow MNOs to generate more revenues are:

- **IoT Sensors**, such as acceleration, gyroscopic, location tracking, image, infrared, motion, optical, position, and proximity sensors that send data upstream to the application server for analysis.
- **IoT Actuators**, such as electrical, hydraulic, magnetic, mechanical, pneumatic, relay, and thermal actuators, are needed for remote control operation of equipment.
- **IoT Devices**, including a new class of IoT data bandwidth-intensive devices, such as high-resolution streaming cameras, augmented reality (AR) glasses, and autonomous vehicles—automated guided vehicles (AGVs), autonomous mobile robots (AMRs), V2X, and drones—that are required to address the most popular use cases. Latency-sensitivity data from IoT Sensors and IoT Devices must be processed locally at the edge.

Infrastructure and Application Servers

Servers need to be sized to match the performance requirements of 5G workloads and application computing power required for the various use cases being addressed—at the data center and the network edge.

- Decisions need to be made about whether to deploy over bare metal or virtual machine servers in a Telco Cloud or Public Cloud. Either way, the server needs to be optimized for operation in a container-based CNF environment.
- Processing power needs to be assessed for performance needs, with processors that can scale in performance and power consumption based on dynamic traffic patterns for efficient operations. Whether in-memory technology, especially for high-performance real-time processing, must also be determined.

- Accelerator technology for quicker execution times, and security with cryptographic accelerators or Smart NICs for higher speed data throughput, may be required to address specific use cases.

Artificial Intelligence/Machine Learning (AI/ML) Data Analytics[1]

AI/ML are the engines behind the Data Analytics required to automate real-time and near real-time decision-making based on raw data from IoT sensors and devices. In the case of the 5G Core, the data will be generated by events coming from all of the network functions for Network Analytics by NWDAF. The sheer volume of data that may need to be analyzed—on the scale of petabytes—could never be handled manually. MNOs will need to adopt a mix of analytic approaches for consumer and industrial enterprise use cases based on data types, workloads, and business problems that users are trying to solve. Analytics spans five categories:

- **Descriptive Analytics** answers questions about what happened in the past.
- **Diagnostic Analytics** offers insights into why those events happened.
- **Real-time Analytics** (On-demand Analytics or Streaming Analytics) includes:
  - Predictive Analytics analyzes current and historical data to provide insights into what might happen in the future.
  - Prescriptive Analytics suggests actions an organization could take based on those predictions.
  - Cognitive Analytics automates or augments human decisions.

Examples of which use cases employ which kind of analytics include: 5G Network Analytics via MWDAF using Predictive Analytics, and Digital Twin modeling using Prescriptive Analytics.

5G Standalone High-Performance IoT Use Cases

Top Industrial Use Cases

- **Quality Control Inspections** – aided by 4K/8K 5G Cameras with Computer Vision

  Almost any industry that uses manual labor to do quality inspections during production or at the end of the production line is a candidate for automated quality control inspections enabled by high-performance 5G SA networks. Some industries spend 50% of their labor costs on inspectors. The more labor costs required for inspections that could be potentially replaced, the greater the Return on Investment (ROI).

[1] Intel "How Real-Time Analytics Helps You Get Value from Your Data Faster."

Computer Vision inspection, whether applied to a fixed camera or a camera on an AMR, can be utilized for the incoming raw material inspection process at every quality control checkpoint of the production line and in the packing and shipping departments. For outdoor plant facilities, drones can be used for inspection.

5G networking is used to upload images or videos taken with cameras to the 5G MEC. After inspection by the 5G MEC servers, the results are sent to the control node or inspection terminal. The parts are either accepted, rejected, or, depending on the industry, sorted according to their quality grades.

Automated quality control inspections reduce labor costs dramatically and improve overall quality by reducing errors made by manual labor processes.

- **Facilities Surveillance and Security** – aided by 4K/8K 5G Cameras with Computer Vision

  This use case is similar to the Quality Control Inspection use case. Instead of the inspection being applied to parts, entire facilities and security systems can be inspected and monitored with cameras with Computer Vision. Using AMRs or drones, more areas can be surveyed with less staffing, making the facility more secure at a lower cost. Another application of Computer Vision for security is facial recognition and iris recognition for two layers of security at access points used by employees and guests.

- **Maintenance Troubleshooting and Employee Training** – aided by AR Glasses with Computer Vision

  AR Glasses can guide a maintenance technician to troubleshoot equipment problems and provide repair instructions. For employee training, AR Glasses can guide employees step-by-step through training for the safe and proper operation of a piece of equipment.

- **Material/Inventory Handling** – aided by 4K/8K 5G Cameras with Computer Vision

  Manufacturers can reduce labor costs associated with moving materials and inventory around with AGVs and AMRs. AGVs and AMRs come in various sizes and shapes to handle a variety of parts and inventory. In the mining industry and at the shipping ports, autonomous trucks shuttle mining material out of the mine or shipping containers around the shipyard.

- **Remote Equipment Operation of Cranes** – aided by 4K/8K 5G Cameras with Computer Vision.

Industries that employ cranes are Shipping Ports, Steel Mills, and other industries that need to move heavy equipment or material via an overhead crane. Many of these locations can have hundreds of cranes with thousands of operators.

Instead of one operator on-site per crane, a remote control operator can manage two, three, or four cranes at once at an offsite location in an environmentally controlled room, improving working conditions. Productivity, operator safety, and employee retention are increased. Overall efficiency improvements average 20%.

The uplink bandwidth is very demanding, with three or four video feeds per crane, which could result in about a dozen video feeds per operator. The networking requirements are handled by 5G SA RAN with its increased uplink bandwidth capability, and 5G MEC meets the latency requirement, ensuring smooth and safe operation.

In these highlighted use cases, high-resolution camera feeds require high bandwidth for the uplink that 5G SA RAN can handle. These use cases employ high-performance IoT sensors and devices requiring real-time and near real-time responses, not only for performance but worker safety as well. The 5G Core meets with MEC for low latency and 5G Servers with high power computing.

Computer Vision - the "Killer Application" Use Case Enabler

Hollywood gives us sneak peeks of future technology trends in their movies, as it did in 2014 in a film that showed an application of Computer Vision with a retinal scanner for the most secure form of personal identification using retinal recognition. Industry forecasts of data growth are almost exponential, with no end in sight, and most of the growth is driven by video. On the consumer side, streaming video and cloud gaming will be the drivers, and on the business side, applications enabled with Computer Vision will drive growth.

Computer Vision is considered a "killer application" use case enabler because of all the capabilities it will offer when coupled with the right AI/ML data analytics. Here is a sample list of Computer Vision capabilities:

- Image Recognition
- Object Recognition
- Optical Character Recognition (OCR)
- Facial Recognition
- Iris Recognition
- Retinal Recognition
- Gesture Recognition
- Event Recognition

Source: Nick Fury "You Need To Keep Both Eyes Open"

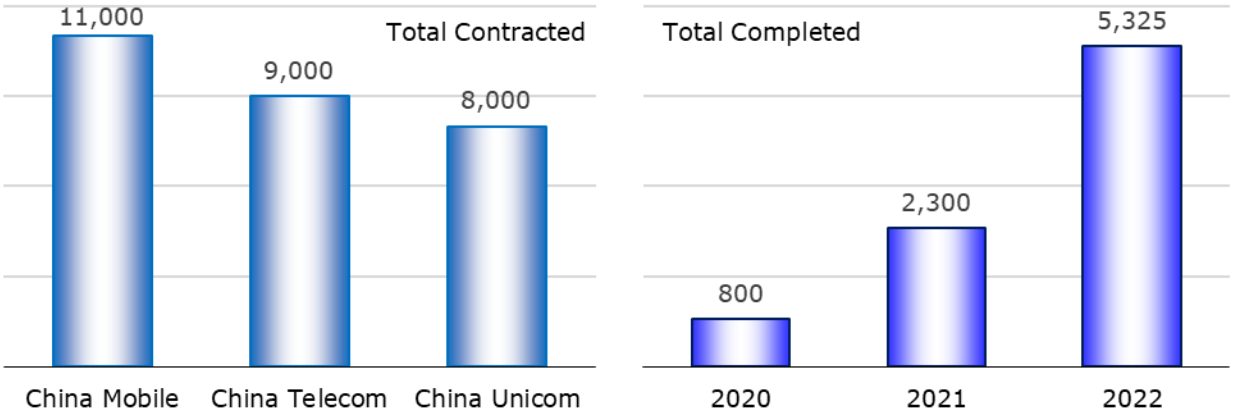
As a high-performance wireless IoT device with high-resolution video—with applications at 4k and 8k resolution now and 12k and 16k resolution on the horizon—a 5G SA network with edge computing is the only wireless technology that can handle the high bandwidth and real-time performance these applications require.

Lessons from China

MNOs in China started early in 2018 in their development of 5G SA MPNs with Network Slicing with or without MEC. As one example, China Mobile began commercial operation of the world's first 5G SA Shared MPN with end-to-end network slicing and Public MEC in September 2019 for China Southern Power Grid Co.

As a result of this head start, Chinese MNOs have quickly ramped up to monetize MPNs, with literally thousands of networks generating new revenue streams (Figure 15).

Figure 15: 5G SA MPN trends in China



Source: China MNOs' 1H22 Interim Reports, and Communications Industry Network, June 2022

The most important takeaway from the Chinese MNOs' experiences is to stay focused on the top use cases that can be leveraged across industries, at scale, with known demonstrable return-on-investments (ROIs) and productivity gains. Also, pay attention to use cases in which users are willing to pay a premium for better performance driven primarily by latency. A note of caution: the technology enables a large and growing number of use cases, but they may not all yield a return, so vigorous research is vital.

The use cases that follow were selected to showcase the ROIs. Most of the examples showcase one use case per company. But most of these companies have multiple use cases in play. GSMA has done an excellent job of cataloging the use cases in detail[2]. The following is a summary of a select few.

SANY Heavy Industry – Material Handling with AGVs

SANY Heavy Industry—China's largest construction machinery manufacturer—partnered with China Telecom to add 5G SA coverage with MEC and Network Slicing. This coverage provides stable uplink bandwidth of 131 Mbps (40Mbps required) and latency of around 19ms (40–50ms required) (measured as approximately 19ms),

[2] GSMA 5G Uses Cases for Verticals in China, 2020 edition, 2021 edition, 2022 edition

which satisfies the requirement of precision within 12cm in obstacle avoidance at 1m/s speed. At one plant, over 200 AGVs with Computer Vision were deployed, yielding a 90% cost savings as compared to the LIDAR-guided AGVs previously utilized.

Xiangtan Iron & Steel – Autonomous and Remote Control Canes

Xiangtan Iron & Steel—the world's most extensive wide and thick plate manufacturing base—partnered with China Mobile to add 5G SA and MEC to control crane operations. Twenty cranes were modified for autonomous operation, increasing production efficiency by 25%. Another 100 cranes were modified for remote control operation, whereby one operator can control three cranes simultaneously, providing a 20% uptick in production efficiency.

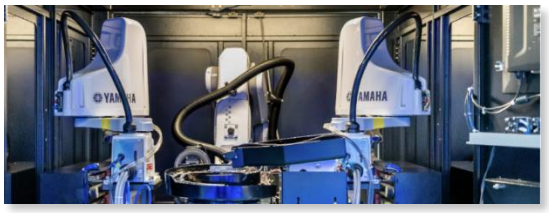
Tianjin Port – Unmanned Container Trucks

Tianjin Port—ranked ninth in port cargo throughput globally—partnered with China Unicom to add 5G SA coverage with MEC for remote control of container trucks. With the adoption of 5G, crewless container trucks have traveled more than 20,000 kilometers, completed 3,000 operation cycles, and transported 4,500 containers, making this the first use case in the world of an integrated port transportation system that has been put into commercial operation.

China Southern Power Grid - Quality Inspections with Drones

China Southern Power Grid Co., Ltd. (CSG)—operating power grids in five southern Chinese provinces—partnered with China Mobile to add 5G SA coverage with MEC and Network Slicing for quality inspections with infrared sensor drones with Computer Vision. Power Transmission Line inspections produced an 80 times efficiency boost, from manual inspection of 15-20 days down to 2 hours. Power Substation inspections boosted efficiency 2.7 times, from manual inspection of 3 days to 1 hour. Power Distribution fault isolation time was shortened from minutes to milliseconds.

Jiangsu Gian Technology – Quality Inspection with Computer Vision



Jiangsu Gian Technology Co., Ltd.—a professional manufacturer and solution provider of metal injection molding (MIM) products—partnered with China Mobile for 5G SA coverage with MEC for quality inspection of metal part surfaces. With high-resolution cameras, machine learning, and 2,000 data samples, the system can detect defects with an accuracy of 99.96% at speed 30 times faster than manual inspection. Previously, inspection workers had to inspect each surface under an electron microscope manually. The inspection workers represented 50% of the workforce. You may use a product partially made by this company if you have a smartwatch, a smartphone, or a laptop. The housing for your device was most likely inspected with the aid of 5G SA and MEC.

Midea Appliance Division – Seven Use Cases under One Roof

Midea Appliance Division has two factories at one site with an annual production capacity of more than 40 million pieces. The factory floor covers 420,000 square meters, with 59 assembly lines staffed by 9,000 employees. Partnering with China Telecom for 5G SA coverage with MEC has effectively reduced the costs of production and maintenance, as well as the cost of production line self-inspections. It has increased operational and maintenance efficiency by 17% and decreased those costs by 10%.

Solutions include:

1. Synchronized 20 staffed forklift trucks and 11 AGVs
2. flexible production line reconfigurations with wireless programmable Logic Controllers (PLCs)
3. campus security and monitoring with reconfigurable hi-res wireless cameras
4. production area inspection robots
5. production line inspection cameras
6. AR-assisted inspection
7. AR-assisted maintenance and troubleshooting.

Xiamen Transportation Bureau – Autonomous Buses

China Unicom completed a proof of concept (POC) with Xiamen Transportation Bureau in November 2019 after two BRT buses were upgraded with 5G equipment to achieve Vehicle-to-Vehicle, Vehicle-to-Infrastructure, and Vehicle-to-Cloud communications. At the same time, five intersections were upgraded with laser radar, high-definition cameras, road side units (RSUs), and 5G MEC servers. It was determined early on that 4G could not meet the uplink speed and latency requirements. Empowered by 5G's low latency and high bandwidth capabilities, the project included four commercial services: non-LOS anti-collision, a real-time cooperative vehicle infrastructure system, intelligent speed strategies, and safe and precise parking. The POC was done over a 60 km route, with 16,000 km of travel. Since completing the POC, 50 buses have been put into commercial service as of August 2020.

Migu Interactive Entertainment – Cloud Gaming

Migu's "Quick Gaming" Platform has quickly grown its Cloud Gaming business on China Mobile's 5G SA Network. For gamers, network latency and jitter are key performance indicators for the gaming experience. The platform can effectively accommodate cloud gaming's requirements for computing power, picture quality, and network latency using 5 G's edge computing and network slicing capabilities. It can support 4K HDR rendering at 60fps with a latency of less than 50ms and a download speed of 50-150 Mbps.

Conclusions

The 5G Core is the key to monetizing the 5G SA network bringing MNOs into the modern cloud era, allowing the MNO to (1) offer new services quickly with CNFs, (2) add Network Slices on demand for mobile private networks, and (3) address latency-sensitive applications with MEC. These new opportunities cannot be addressed by 4G or 5G NSA networks, and the sooner an MNO embraces 5G SA networking, the closer it will be to reaping new revenue streams.

For reference, Figure 16 summarizes the 5G SA ecosystem, IoT ecosystem, and popular use cases.

Figure 16: 5G SA, IoT, ecosystem and popular use cases

5G SA Ecosystem	**Internet of Things (IoT)**	**Popular Mfg. Use Cases**

5G Standalone System
• eMBB
• URLLC
• MIoT
• HMTC
• V2X
 	
5G RAN
• Higher bandwidth – UL/DL
• Lower cost per bit
• Lower Latency
• Faster handovers
• Quicker connect times
 	
5G Core SBA and MEC
• Cloud Native Technology
• Network Slicing
• MEC
 	
5G Servers
• High-performance Compute (CPUs, GPUs, NPUs, VPUs)
• UPF performance optimized for high data throughput, low latency, and low jitter
• Energy efficient
 	
AI/ML Data Analytics
• Descriptive Analytics
• Diagnostic Analytics
• Real-Time Analytics
  • Predictive Analytics
  • Prescriptive Analytics
  • Cognitive Analytics
	IoT Sensors
	• Acceleration
	• Gyroscopic
	• Locations Tracking
	• Image
	• Infrared
	• Motion
	• Optical
	• Position
	• Proximity
	
	IoT Actuators
	• Electrical
	• Hydraulic
	• Magnetic
	• Mechanical
	• Pneumatic
	• Relay
	• Thermal
	
	IoT Devices
	• High-Resolution Cameras
	• AR Glasses
	• Autonomous Vehicles
	  • Automated Guided Vehicles (AGVs)
	  • Autonomous Mobile Robots (AMRs)
	  • Drones
	  • Off-road vehicles
	  • On-highway vehicles
		Quality Inspection, Surveillance, and Security
		• Sensors
		• Cameras
		• AMRs
		• Drones
		
		Predictive Maintenance
		• Sensors
		• Cameras
		
		Troubleshooting Guidance
		• AR Glasses
		
		Operator Training
		• AR Glasses
		• AMRs
		
		Material/Inventory Handling
		• Sensors
		• Cameras
		• AGVs
		• AMRs
		• Off-road Trucks
		
		Remote Equipment Operation
		• Sensors
		• Actuators
		• Cameras
		
		Computer Vision Capabilities
		• Image Recognition
		• Object Recognition
		• OCR
		• Facial Recognition
		• Iris Recognition
		• Retinal Recognition
		• Gesture Recognition
		• Event Recognition

Glossary of Terms

5G DDNMF – 5G Direct Discovery Name Management Function
5G-EIR – 5G-Equipment Identity Register
AAnF – AKMA Anchor Function
ADRF – Analytics Data Repository Function
AF – Application Function
AI – Artificial Intelligence
AMF – Access and Mobility Management Function
AR – Augmented Reality
AUSF – Authentication Server Function
BSF – Binding Support Function
CA – Carrier Aggregation
CNFs – Containerized Network Functions
CPE – Customer Premise Equipment
DC – Dual Connectivity
DCCF – Data Collection Coordination Function
DL – Down Link
EPC – Evolved Packet Core
EASDF – Edge Application Server Discovery Function
eMBB – enhanced Mobile Broadband
FWA – Fixed Wireless Access
GMLC – Gateway Mobile Location Centre
HMTC – High-Performance Machine-Type Communications
LMF – Location Management Function
HCP – Hyperscale Cloud Provider
IoT – Internet of Things
MBSF – Multicast/Broadcast Service Function
MB-SMF – Multicast/Broadcast Session Management Function
MBSTF – Multicast/Broadcast Service Transport Function
MB-UPF – Multicast/Broadcast User Plane Function
MEC – Multi-access Edge Computing
MEO – MEC Orchestrator
MEP – MEC Platform
MEPM – MEC Platform Manager
MFAF – Messaging Framework Adaptor Function
MIoT – Massive Internet of Things
ML – Machine Learning
MNO – Mobile Network Operator
N3IWF – Non-3GPP Interworking Function
NEF – Network Exposure Function
NFVI – Network Function Virtualization Infrastructure
NGMN – Next Generation Mobile Networks
NRF – Network Repository Function
NSA – Non-Standalone

NSACF – Network Slice Admission Control Function
NSSAAF – Network Slice-specific and SNPN Authentication and Authorization Function
NSSF – Network Slice Selection Function
NSWOF – Non-Seamless WLAN Offload Function
NWDAF – Network Data Analytics Function
OTT – Over-the-top
PCF – Policy Control Function
PNI-NPN – Public Network Integrated - Non-Public Network
RF – Radio Frequency
RRC – Radio Resource Control
SA – Standalone
SBA – Service Based Architecture
SBC – Session Border Controller
SCP – Service Communication Proxy
SEPP – Security Edge Protection Proxy
SLA – Service Level Agreement
SMF – Session Management Function
SMSF – Short Message Service Function
SNPN – Standalone Non-Public Network
TNGF – Trusted Non-3GPP Gateway Function
TSCTSF – Time Sensitive Communication and Time Synchronization Function
TSN– Time Sensitive Networking
TSN AF – Time Sensitive Networking Application Function
TWIF – Trusted WLAN Interworking Function
UCMF – UE radio Capability Management Function
UDM – Unified Data Management
UDR – Unified Data Repository
UDSF – Unstructured Data Storage Function
UE – User Plane Function
UPF – User plane Function
UL – Uplink
URLLC – Ultra Reliable Low Latency Communications
USRP – User Equipment Route Selection Policy
V2X – Vehicle to Everything
VoNR – Voice over New Radio
ViNR – Video over New Radio
VR – Virtual Reality
W-AGF – Wireline Access Gateway Function

About Author

Dave Bolan joined Dell'Oro Group in 2017 and is currently responsible for the Mobile Core Network (MCN) and Multi-Access Edge Computing (MEC) market research, as well as Advanced Research Report 5G Workload Moving to the Public Cloud. While at the firm, Mr. Bolan has expanded the MCN research to ensure the program is evolving to address NFV, 5G core architectures, IMS core, and edge computing. Mr. Bolan has written articles and white papers and has been widely cited in leading trade and business publications. Mr. Bolan is a frequent speaker at industry conferences and events.

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