5.5G Short Report

Thoth Advisory Perspective on 5.5G Technology

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Executive Summary

5G adoption has experienced the fastest growth of any previous cellular generation with 260 commercial 5G networks deployed as of June 2023 and over 750 5G smartphone models available to users. In terms of the number of global 5G connections, 5G broke through the 1 billion mark in December 2022 and at end of June 2023 surpassed 1.2 billion. Of the 1.2 billion 5G connections, roughly 10% or 115 million were gigabit 5G connections. In Asia Pacific according to the GSMA, 41% of mobile connections will be 5G by 2030 or roughly 1.4 billion 5G connections. Developed Asia Pacific will reach 93% 5G adoption by 2030 and Greater China will reach 88% by 2030.

As customers start to experience the higher performance of 5G relative to 4G, especially when watching videos, uploading high-resolution photos, and surfing, the monthly data usage will continue to grow at a brisk pace of 20-30+% per annum, depending on the market. In more and more markets, mobile-commerce and fintech has fast become the preferred way for consumers to order food and groceries, order car rides, order software and media content, even appliances and so on. Many governments, especially during the pandemic, were proactive in developing and expanding digital citizen services for healthcare, taxes and vehicle registration and so on. At the same time the semiconductor industry continues to make breakthroughs in microfabrication enabling chip designers to integrate more image processors, GPUs, neural network processors, and RAM storage into the smartphone chipsets. Semiconductor fabrication advances will enable 5.5G manufacturers to pack a lot of compute power into mobile devices. Network equipment suppliers are incorporating cloud-native designs into the 5G RAN and 5G Core which will enable 5.5G to be more automated and intelligent and capitalize on AI/ML technologies.

Use cases that started to emerge with 5G will be expanded and given more performance with 5.5G across a wide range of industries due to the >2X peak and user experienced data rates, lower latencies and higher reliability that is being designed into 5.5G.

In this White Paper, we review briefly the path to 5.5G and take a closer look at how 5.5G will impact and drive the acceleration of four broad categories of use cases: connected people, connected families, connected things (industrial), and connected vehicles.

Introduction – The Road to 5.5G and Beyond

From 3GPP Release 15-17 to 5.5G Rel-18+

5G began with the first release Rel-15 Non-Standalone (NSA) in 2018 which laid the groundwork for future enhancements in subsequent releases in the packet core (e.g. network slicing), enterprise ultra-reliable low-latency communications (URLLC), time-sensitive network (TSN), Fixed Wireless Access (FWA), enhancements for vertical industries, 5G-to-satellite access (Non Terrestrial Networks), and Vehicle-to-everything (V2X). Rel-16, which is being integrated in commercial network infrastructure and devices starting in 2023, provides a number of enhancements focusing on support for URLLC, time sensitive networking for industrial IoT (IIoT) use cases, enhanced machine type

communications(eMTC)/narrowband IoT (NB-IoT), precision positioning, and vehicle-to-everything (V2X).

Rel-17 continues the evolutionary improvements including Reduced Capability (RedCap) IoT, integrated access backhaul (IAB), V2X positioning, and satellite-based non-terrestrial networks (NTN). Rel-17 also introduces a number of enhancements targeting specific vertical industries including factory automation, utilities/smart grid and public protection and disaster relief (PPDR), and railways.

The 3GPP release in aggregate provide a timeline and framework for the network equipment suppliers to develop competitive differentiated solutions around the 5G Core, radio access/fronthaul, mobile optical backhaul, active relays to further extend the 5G signal into hard-to-reach places including indoors.

The three pillars of all 3GPP 5G standards specifications are:

1. eMBB (enhanced Mobile Broadband)
2. URLLC (Ultra Reliable Low Latency Communications)
3. eMTC (enhanced Machine Type Communications)

and deal with specific aspects of the 5G network – from system architecture to Radio Access interface. Basically, all new evolutionary enhancements and revolutionary features fit into one of the above three pillars. Some of the features in Rel-18 were supposed to be in Rel-17 but the work was not completed in time so these items became part of Rel-18.

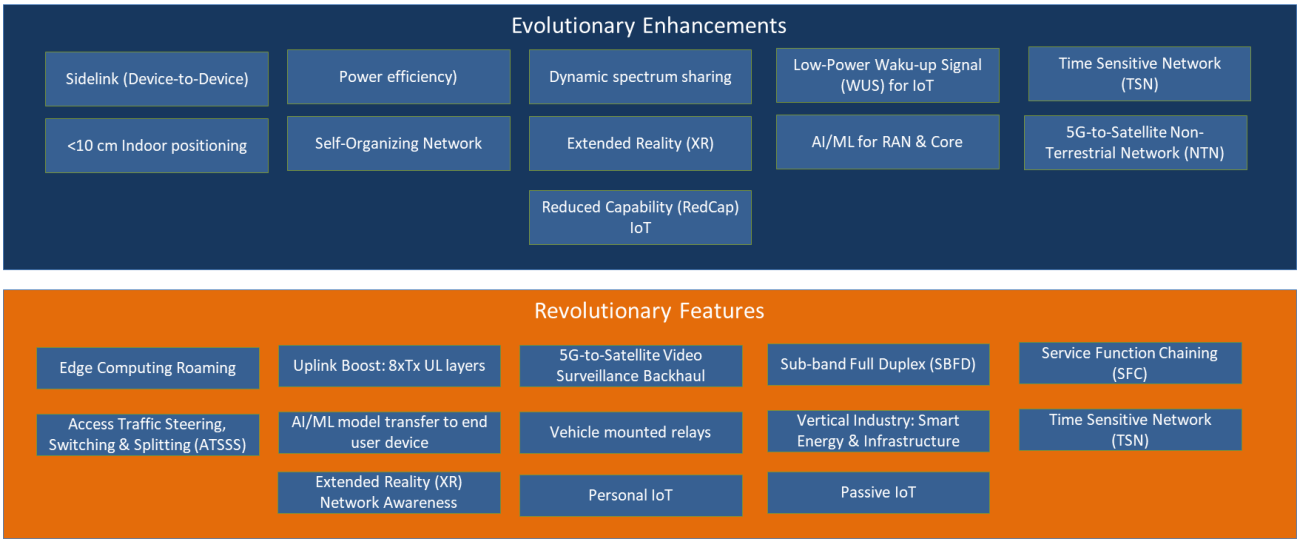
Rel-18 starts the next set releases, leading up to 6G in 2030, which the 3GPP has branded the 3GPP as "5G-Advanced" and which we refer to here as 5.5G.

5.5G will introduce a major step up in system and end user bandwidth: up to 10 Gbps downlink and 1 Gbps uplink. The modulation is being increased from 256 QAM to 1024 QAM and extremely large antenna arrays (ELAA) will be deployed in 5.5G. As shown in Figure 1 enhancements can be considered as evolutionary while others might be better described as revolutionary in that a totally new service is being introduced. According to the GSMA's Network Transformation survey half of 5G operators expect to support 5.5G within two years of launch. Some of the kay enhancements that will impact 5.5G use cases is summarized below:

Time synchronization. Rel-18 is expected to include the detection and reporting of time source failure or degradation and time synchronization with two different techniques: 5G clock synchronization and gPTP synchronization. Synchronization is needed in order to implement deterministic networks (DetNet)

AR/VR/XR awareness. This is a set of enhancements that will make the network and RAN aware that the uploaded and download streams are AR/VR/XR since this type of data streaming but be maintained at very low latencies <5 ms to prevent user dizziness. AR/VR/XR awareness means that the 5G basestation, gNB, is able to measure and manage a number of KPIs such as traffic characteristics, QoS metrics, and application layer attributes. Moreover, the increase in the number of transmit Uplink layers to 8 means is critical to ensuring adequate bandwidth for AR/VR/XR.

Figure 1 5.5G will include both evolutionary enhancements and revolutionary features



Source: Thoth Advisory, 2023

Precision positioning is first introduced in Rel-17 with accuracies on the order of several tens of cm. In Rel-18 the accuracy resolution will be taken down to sub-10 cm levels which first and foremost will be extremely helpful in complex environments such as a factory floor.

Edge computing was first addressed in Rel-15 and later in Rel-17 with traffic steering, network exposure to edge application server, and discovery of edge application server. In Rel-18 however, access (e.g. roaming) to edge hosting environments (EHE) where the Core and the Edge Compute might be owned by different entities which would typically be the case of multiuser gaming.

Sidelink, which was originally introduced in 4G LTE Rel-12/13, allows devices to communicate directly without a basestation and has application in multiple use cases including transportation safety, public safety communications, range extension, intelligent connected edge, wearable connectivity, and data offload. In Rel-18, sidelink is expected to utilize carrier aggregation to increase capacity.

Energy efficiency is a critical KPI in designing and assessing mobile technologies. Rel-18 will address energy efficiency in the RAN across different domains – time, frequency, spatial, and power.

Standards bodies such as the ITU, 3GPP, ETSI and the World Radio Council have worked to harmonize and encourage regulators around the globe to make 5G spectrum available. The recent 5G auctions in India at the end of 2022 is a testament to the importance of operators having low-band, mid-band and high-band spectrum. In India's case low-band 700 MHz means that an operator like Reliance Jio can provide wider coverage in rural areas extending 5G's reach into the hundreds of millions of rural inhabitants. mmWave can be used to provide FWA service in dense cities such as Delhi where the rapid pace of FTTHX buildout can hardly keep up with the demand for broadband.

5.5G's Impact on Digital Transformation and Connectivity Services

The new features and enhancements in Rel-18 are going to further enable and accelerate digital transformation and the digital economy by introducing AI/ML deeper into the network, delivering higher bandwidths, enabling time-sensitive services, achieving lower latencies and broader coverage:

- **Digital Economy and Digital Transformation.** Policy makers and regulators are looking to fuel growth and innovation by supporting mobile deployment in industries through 5G private networking, education, healthcare, tourism, citizen services, and management/monitoring of government assets such as roads, bridges, railroads, tunnels, water reservoirs, lakes, and coastlines.
- **FinTech**. The impact mobile fintech on a number of emerging markets such as the African continent, India, Philippines, Vietnam and Indonesia cannot be understated: mobile fintech has become part of mainstream daily life.
- **Internet of Things (IoT) and Personal IoT.** Another important trend is the proliferation of IoT across industries which has thus far been implemented with 3G and 4G LTE. Moving forward, the introduction of 5G RedCap will increase bandwidth for IoT devices with improved power efficiency enabling connected IP cameras. For very remote use cases, Rel-17 5G NTN brings 5G IoT-to-satellite possible.
- **Fixed Wireless Access (FWA).** The unexpected rise of 5G Fixed Wireless Access (FWA) in a number of markets including the U.S., Saudi Arabia, Hong Kong, and Australia has encouraged vendors to continue to improve capacity and coverage through various innovations around the MIMO antennas. As of January 2023, according to the GSMA, there were 90 broadband service providers (mobile and/or fixed) that had launched commercial 5G FWA service. Most of the 5G FWA deployment use the C-Band 3.5-3.8 GHz but in some markets such as the U.S. mmWave has been utilized for FWA. T-Mobile, for example, added 500k FWA users between October 2021 and March 2022.
- **Generative AI (GenAI).** With the release OpenAI's groundbreaking Chat-GPT in November 2022, both enterprises, academic organizations and telecom service providers are looking to capitalize on the capabilities of GenAI and Large Language Models (LLMs). Mobile network operators (MNOs) and vendors have been developing various AI/ML technologies for different purposes in the RAN and Core network as well as in the OSS/BSS and customer service. For telecom service providers, GenAI and LLMs offer potential for improving customer service and reduce churn through multi-lingual voice and text interaction, intelligent search, tailored service discovery, and content (image, text, code) generation. LLMs can be used to discover new revenue streams comprising tailored personalized offerings. On the network side, LLMs can identify IP traffic and congestion patterns which can then in turn be used to enhance network performance, Quality of Service (QoS), cybersecurity, capacity planning and managing resource allocation in the core and edge.
- A**ugment Reality (AR), Virtual Reality, Extended Reality (XR) and Metaverse**. These technologies are gradually being introduced into the consumer space but have been actively utilized in both industry and academic research. Although there are many engineering challenges around the mobile AR/VR glasses (such as heat generation in the frame and battery life) remaining, progress continues to be made and by 2025, when 5.5G reaches commercialization, AR/VR/XR will start to go mainstream especially if smartphone makers introduce mass-consumer friendly devices.

5.5G Cellular Technologies for IoT

5G RedCap or "RedCap" from Rel-17 is the first pure 5G IoT standard following in the footsteps of NB-IoT and CAT-M1 and is expected to be commercialized from 2023. 5G RedCap is set to make a broad impact on connected things by providing low-power (as compared to 4G LTE) but high-bandwidth 95-80+ Mbps downlink on a 20 MHz channel in the sub-6 GHz bands and 100 MHz in the mmWave bands). OEMs will be able to choose from 1 or 2 Rx antennas. RedCap is expected to be adopted in automotive, transportation, logistics, healthcare, and smart city. The high bandwidth of RedCap means that it is also well suited for connecting HD and 4K cameras in the field. For high security scenarios that require a primary fiber port, RedCap can be a backup/switchover for enhanced redundancy. 5G enhanced Machine Type Communications eMTC) in Rel-17 is designed to support device densities of up to 1 million devices per square kilometer and bandwidth on the order of 1/2 Mbps in the downlink. NB-IOT in Rel-17 will provide 254 kbps DL essentially doubling the bandwidth of the original NB-IoT standard.

5G IoT NTN brings IoT to remote areas where fiber and cellular coverage does not exist. 5G RedCap will start to replace 4G LTE IoT endpoints over the next several years. Perhaps the most important use case that RedCap will enable is IP Cameras for vehicles as well as stationary CCTV surveillance. This additional bandwidth will require a 5G SA core that can handle much larger aggregate data traffic. Rel-18 will provide uplinks up to 1 Gbps making it possible to have dense IP camera and other sensors in the field which can be aggregated into 1 Gbps uplinks.

5.5G Personal IoT Networks

5.5G introduces the concept of "*Personal IoT*" which includes broadly speaking the cellular 5G and other indirect communications or other macro networks such local gateways. Typically a Personal IoT network will communicate with the 5G network via at least one Personal Element Gateway Capability (PEGC). An important characteristic is that Personal IoT devices or "*elements*" can also communicate directly with each other separate from the cellular network; an example is the sidelink. Thus, smartphone and tablets connecting to 5.5G network will be able to act as a PEGC gateway to send and receive aggregated data from Personal IoT elements (such as sensors). The 3GPP is working to specific a range of cybersecurity functionality for authorization of personal IoT elements via the 5G Core components including the Session Management Function (SMF), Policy Control Function (PCF) and Application Functions (AF).

5.5G Passive IoT (P IoT)

5G Advanced will support a breakthrough technology called *extended IoT*, which is also known as "Passive IoT". Passive IoT will enable large numbers of sensors to transmit data without the need for batteries by collecting energy from the surrounding environment. Passive IoT is thus an environmentally friendly technology that eliminates the use of batteries for low-data throughout. China Mobile has been testing such a network of passive IoT in Chengdu, Sichuan province, China. The estimated power and dollar cost for Passive IoT will be on the order of 1-100 μW and $0.01-0.05 per device. 5G.5 will use OFDM beams, inter-site resource coordination, and joint scheduling optimization to connect to the passive IoT device as a backhaul. Compared to RFID which has a

coverage area of about 10m, P IoT can provide coverage of 100-200 m. Examples of sensor data that could be collected include temperature, humidity, daylight/cloud covering, and vibrations.

5.5G in Enterprise/Industry

Prior to 5G, enterprises generally saw limited benefits with cellular connectivity except to issue corporate SIM cards to employees. Cellular IoT started with use cases such as 3G vending machines and smart meters. As mobility and bandwidth became an increasingly important requirement, 4G LTE started to be deployed from 2017-2018 actively in connected motorcycles, connected cars, smart farming, smart mining, fleet management, and so on. The 3GPP understood the utility of 4G LTE in IoT deployments and developed enhancements in Rel-17 mentioned above in order to enable video transmission at lower power consumption as well as higher device densities per square kilometer. Thus, for vertical industries 5G IoT will enable a much broader acquisition of data that can be analyzed with video analytics and other types of algorithms including AI/ML.

Verticals are also deploying 5G private (meaning non-public) wireless networking (PWN) and edge computing and the number of deployments is increasing across a broad set of industries from construction to manufacturing to transportation to utilities. The leading markets employing 5G private networking include, China, Japan, Australia, Germany a number of emerging markets including Thailand. Regulators in many of these early adopter markets have developed allocated dedicated spectrum for enterprises to license and have created licensing regimes for private networking in specific areas such as Australia' Area Wide Licenses and Hong Kong's Localized Wireless Broadband System (Private) Licenses. Hong Kong for example allocated 400 MHz from a total of 4,100 MHz in the 26 GHz (24.25-27.5 GHz) band and 28 GHz (27.5-28.35 GHz) band for non-exclusive and geographically shared basis target university campuses, sports complexes, and industrial parks.

The mobile industry is now looking to the next several years to a critical milestone known as Release 18 5G-Advanced (or "5.5G" for short) which will pave the path to the next cellular generation, 6G expected from 2030 onwards. 5.5G is expected to be commercially ready in late 2024/early 2025 and will provide a number of significant upgrades and features that will make it more than an evolutionary release.

Upgrading the infrastructure to prepare for 5.5G

In order to support the many features and bandwidth of 5.5G, Service Providers will need to transform their network architecture, upgrade their RAN access and fronthaul, converge their broadband and mobile access and backhaul transport, and build implement a Standalone (SA) Core. The 5.5G core will need to support large number of 5G IoT connections with a wide range of bandwidths from <100 kbps to 100 Mbps+, URLLC, and network slicing. The 5.5 core will also need to enable bandwidths of up to 10 Gbps while also supporting time-sensitive networking (TSN). Use cases that need TSN can are typically found in transportation, manufacturing, mining, construction and utilities. The 5.5G core will deploy advanced technologies to achieve 5G NR SA services at >2X bandwidths as compared to Rel-15 to Rel-17. To that end, 5.5G core implementations from vendors can be expected to utilize virtualization in the form of container network function (CNFs), enhanced automation, high-bandwidth VPNs, converged telco architecture, support for 5G mobile private networking, 4K/8K video, intelligent calling, and mesh MEC (Multi-Access Edge). AI/ML including

GenAI will play significant roles incorporating network intelligence, optimization and energy efficiency.

The optical access, aggregation and transport/backhaul networks is a critical system component that if not properly dimensioned will become congestion bottlenecks. With average DL speeds of 10 Gbps, 5.5G basestations will need optical ports supporting a minimum of 25 Gbps and/or 50 Gbps. If one considers the thousands of 5G cells that are being deployed by MNOs it becomes clear that the optical transport itself needs to undergo modernization.

Leading global and regional integrated service providers (fixed + Mobile services) have begun active modernization programs to converge their fixed broadband and mobile aggregation/backhaul networks onto the same physical transport network. FixedBB providers are already under pressure to continue to support >20% per annum data usage growth by residential customers and in many markets have begun to upgrade their 1 Gbps/2.5 Gbps networks to the next generation of 10G PON, namely XG-PON (2.5 Gbps in the UL) and XGS-PON (10 Gigabit Symmetrical Passive Optical Network) with 10 Gbps in the UL. The long term target of the industry will be to reach 100G. The optical equipment sector is actively promoting 50G as a future ITU standard while with some vendors also proposing 25G as an interim step.

New Revenue Opportunities for Telcos

As organizations and homes/consumers expand their IoT footprints, new revenue opportunities will emerge for telecom service providers to offer managed and bundled services such as smart home solutions for consumers, 5G private networks services for industrial companies, and various management and monitoring services for government/smart cities. One of the newer areas of opportunity is integrated communication networks (ICN) in smart buildings and non-premise connectivity for IoT sensors and cameras in bridges, tunnels, highways, traffic lights and streetlights. Some operators are also offering horizontal IoT platforms for collecting endpoint telemetric data. As an additional add-on service SPs are also beginning to offer edge compute and storage services as well as cloud storage services for organizations. IoT is thus essentially a collection of industry (including consumer) ecosystems that fits in well with the physical ecosystems that exists made up of suppliers of components and modules, ICT systems and software solutions.

Connected People

Immersive User Experience AR/VR/XR and AI

5.5G will greatly improve the user experience for mobile users by providing lower latencies and higher DL and UL bandwidth for cloud and multi-player gaming. 5.5G will also greatly improve the user experience for AR outdoors because very fast uploads (~ 1 Gbps stream from the AR glasses or smartphone camera is needed in order for the cloud server application (navigation, restaurant location, Google lens) to respond in under 1-2 seconds. AR glasses are expected to start to see adoption in the 2025 timeframe right around the time that 5.5G networks are commercialized.

In order to understand the computation and connectivity requirements for Virtual reality (VR) one must understand that VR uses three degrees of freedom (3DOF) panoramic videos or 6+DOF (Degree of Freedom) real-time computer graphic (CG) renders. Panoramic videos are used for on-demand

and live streaming with 360° real-world videos, where the positions and visual angles in virtual scenes are fixed. CG renders are typically used for gaming, training, or collaboration, where the positions in virtual scenes are flexible, and different visual angles can be created. All of the CG based virtual scenes are rendered using specialized GPUs in real time. They are highly immersive and are advanced forms of VR.

Panoramic video streaming uses wireless WAN (e.g. 5.5G) connections. However, whether CG VR can use wireless WAN connections has not yet been proven in the industry with 5G Rel-15-16 . CG VR systems and future WAN IP network capabilities would need to match with one another in order to produce a feasible solution. Network Equipment vendor's vision is to enable wireless WAN connections for CG VR and migrate GPU resources to the cloud in order to reduce user investment and enhance service iteration capabilities. CG VR will need to utilize 5.5.G eMBB. Currently, 4K panoramic video only requires 20 to 40 Mbps data rate and 50 ms latency. As 5G networks contribute to considerable improvement in data rate (~100 Mbps) and latency (less than 10 ms), users will enjoy more comfortable viewing experiences. 5.5G will ensure that the user experience is even better and more stable.

CG (Computer Graphic) Cloud VR will deliver 2K services initially. For better visual experience, the image resolution has to be 4K or 8K. In addition, the feature of strong interaction turns the CG Cloud VR services to be more latency-sensitive. Operators can selectively launch 360° VR or CG VR services based on their own service and network capabilities. Since 360° VR video is a derivative of video services, operators equipped with traditional video platforms can swiftly run such VR services at low cost. In order to deploy CG VR services, which have high requirements on GPU rendering and streaming, operators have to add GPU resource pools (i.e. GPU Cloud) to further supplement their existing cloud platforms and data centers.

Figure 2 Network data rate and latency requirements for 360° Cloud VR video

360° Video Resolution	Frame rate (fps)	Coding	Transmission	Data Rate (Mbps)	RAN Latency*(ms)
4K (3840x2160)	60	H.265	Sphere	20-40	≤ 50
8K (7680x4320)	90	H.265	Sphere	90-130	≤ 20
			Field of View (FOV)	30-50	
12K 3D (11520x6480)	120	H.266	Sphere	500-700	≤ 20

Source: GSMA, 2021

Inside the home it is anticipated that VR would be attached via Wi-Fi 6 and 7 and with 5G.G once the user steps outside the home premises the connection would switch to 5.5G.

There are other services that can be mixed and matched to provide a richer user experience. For example, recently, conversational AI voice and metaverse-like 3D avatars have garnered a lot of interest in the consumer and enterprise space. The additional bandwidth and stable, low-latency of 5.5G will encourage application developers to integrate new services into existing applications. One of those new services that is gaining global interest is Generative AI and we can expect that GenAI

will be integrated into many types of products similar to the way a smartphone might be used to set controls for an induction cooker.

The concept of the hotspot will also evolve. In much of the developing markets, it was commonplace to find 4G USB hotspots that output Wi-Fi signal. 5.5G takes this concept to a new level especially in markets where the fiber access speed is below 100 Mbps. 5.5G hotspots could be used to enable AR/VR glasses/headset via Wi-Fi in the outdoor environment. Up until a few years ago most desktop computers were the size of a briefcase but with the mini-form factors powerful desktops have been packed into a volume the size of a 300 page book. 5.5G hotspots could be built with a CPU/GU to provide personal edge compute.

Personal IoT

Since 2012 when the 3GPP first started to release 4G LTE and NB-IoT it had not envisioned what would happen in the ensuing decade with the proliferation of consumer IoT devices that can be categorised into two specific areas:

a. **Connected Home.** in the home (e.g. door sensors, switch controls, cameras, thermostats, garage door openers, ovens, voice assistant devices TVs, washing machine, fridge etc) (aka the Smart automated home). These will be discussed under "Connected Famlies" below.

b. **Connected People.** (e.g. cameras, headset, earphones and earphones with voice intelligence/interface, watch, car, AR glasses, VR headsets, other modes of transport etc) collectively called personal IoT devices.

One of the technologies that is being enhanced in 5.5G is Sidelink. Sidelink enables device -to-device communications without going through the cellular network. Improvements in resource allocation, power saving enhancements and new sidelink frequency bands and Layer 2/3 relay capabilities means that people will be able to setup their own IoT network in their residential premise in the outside lawn and garage and backyards and even in farms and ranches. Sidelink is not a new technology but with 5.5G it will become much more compelling and open up new Personal IoT use cases.

5.5G will support smartphones and tablets and other programmable devices to act as a gateway in a personal IoT network which can also include Passive IoT devices such as a GPS location beacon for on-person.

Connected Families

Connected families includes home automation and indoor and outdoor connectivity for the residential property which might be an urban dwelling or a rural dwelling, the latter of which typically will occupy a much larger land area. Connectivity devices in the home environment will utilize some combination of different access technologies: Satellite broadband – connecting to Geosynchronous (GEO)or Low Earth Orbit (LEO) satellites via flat panel array antenna mounted on the roof or other platform, Fixed-Broadband Fiber-to-the-Home (FTTH) (which is typically a PON port. The latest generation of fiber PON is XG-PON and XGS-PON, the latter of which is symmetrical 10 Gbps and the former is 2.5 Gbps in the uplink), Cellular 4G and/or 5G, Zigbee (used in smart meters), Wi-Fi 5/6/7,

Bluetooth, Passive IoT, 5G-to-Satellite NTN, and Device-to-Device (D2D) (such as Wi-Fi Direct, Bluetooth and 4G/5G sidelink).

Potential new revenue opportunities will continue to grow for telcos as the industry moves to 5.5G but at the same time satellite broadband will gain adoption, especially in certain demographic areas/zones where the population density does not justify FTTH expense.

Customer satisfaction with current 5G services is very important as this could impact the interest from consumers in new services such as "5.5G. Telcos will have the opportunity with 5.5G to increase incremental APRUs while strengthening customer loyalty and reducing churn. An interesting example that is often cited in the industry is how HKT (Hong Kong) was able to curtail fixed line voice churn by moving the home phone service to a Wi-Fi-based tablet solution that enabled the operator to offer content (free and for a fee) to homes thereby essentially extinguishing the classic home phone. HKT has continued to expand its Eye 3 service to include various offering for telemedicine and home IoT services including surveillance.

Telcos will look to develop ecosystem partners around Wi-Fi 6 and 7, 10G PON, and 5.5G for the access technology and cloud for delivery of content and software as a service (SaaS). An example of SaaS in the consumer space is voice translation, conversational ai, and Generative AI search avatars.

Figure 3 provides a list some examples of family connectivity services . Home devices will vary in terms of the need for continuous power, latency requirements, bandwidth requirements, and multi-mode action (for example telling the smart lighting system to "turn off" a light bulb. Many of these examples will over time benefit from 5.5G either from the increased DL/UL eMBB bandwidth or lower latencies.

Figure 3 Connected family

Narrow/Wide-band	Narrow/Wide-band	Broadband	Broadband
Pet locator	EV charging station	Baby monitor	Media sharing
Child location tracker	Smart toothbrush	Home Security	Gaming tethered to Smart TV or PC
Wearables	VR location beacons in each room	Immersive calling	5G cloud Gaming on smartphone
Smart Lighting		Holographic calling	Home gateway
Smart Faucet		5G VR games	AR/VR eBooks/Study
Thermostat with sensors in each room		Cloud gaming	Real-time translation
Leak detection		eSports	Conversational AI
Smart locks		Live feed broadcasting	3D TV
Smart plugs		Connected passenger car	Connected scooter
Smart sprinkler		Generative AI Avatars	Home IoT Dashboard (narrowband or broadband)

Smart appliances		Energy & Trash Management	Property perimeter sensors & IP Cameras

Source: Thoth Advisory, 2023

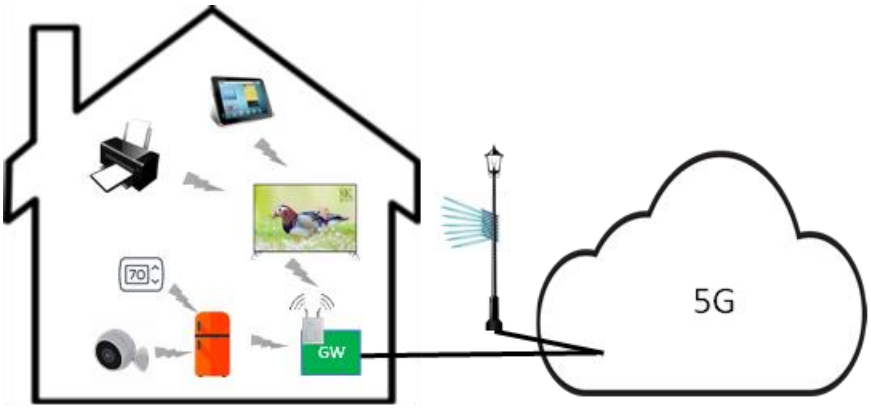
- ***Pet location and monitoring*** - LGU+ for example is expanding their home pet care service by offering various hardware devices and services to monitor and managing pet behavior remotely when at the office. A *lost dog service* could for example tap into public surveillance cameras in the neighborhood near the home of the dog to try to locate the pet.
- ***Baby monitor***. High-resolution camera with video analytics can alert the parents to sleeping positions and crying patterns. Traditional baby monitoring systems do not provide analysis of the baby's sleep or movements in the crib.
- ***Media Sharing***. Nowadays people have many electronic devices, such as smartphone, TV, earbuds, speaker, smart watch, and AR glasses (these are all Personal IoT elements). Ideally the user should be able to choose the device he/she wants to watch the video/listen to the audio among all the devices the user has, with simple operation, without interrupting the media being watched. The media transmitted by a Personal IoT Element could voice, video, Game audio/video and other type of data traffic. The media could be generated locally in the Personal IoT network or from application/gateway server. One can imagine a dashboard on the smartphone that allows the feed from say a sport channel into the ear buds although the ear buds are connected to the smartphone via bluetooth. Currently, the smartphone would have to have the sports app installed in order to get the audio/video feed but if a media gateway is setup in the home then media sharing and routing could be done.
- ***Immersive VR and Holographic calling***. Holographic calling refers to real-time capturing, encoding, transporting and rendering of 3D representations of each party shown as stereoscopic images (similar to 3D movies). Verizon and KT demonstrated live hologram international call over 5G in 2017 between Seoul and Los Angeles. Since then, KT has developed 5G-immersive media services that include a 360-degree live VR which allows users to watch VR content across 260 degrees. In 2018, Vodafone placed the UK's first holographic call using 5G. England and Manchester City captain "met" a young fan virtually as a hologram. Holographic calling could someday become the premium way to do business conference calls and virtual events replacing the 2D windows that are used today. Since that time a number of telcos have tested and demonstrated holographic calling including Deutsch Telekom, Orange and Telefonica.
- ***Gaming***– In South Korea, Samsung, SKT and LGU+ have been actively developing VR games for 5G. It is possible to place IoT beacons in the rooms and hallways to help provide precise positions into the AR/VR games where the end user is allowed to move around the room or house.
- ***Sporting experiences*** – this can include AR/VR glasses as well as POV links to actual live sports and music stadiums. SKT, for example, developed an AR game called "Jump AR" which allows users via AR to "teleport" to an eSPorts Stadium, Lol Park, through their smartphone screen. By moving their smartphones around, users can get a 360-degree view of Lol Park interior, leave AT messages of support, watch greeting videos of players and read messages left by other eSports fans.
- ***Broadband home entertainment systems.*** Home entertainment systems will start to support AR and VR headsets. 3D TV viewing is a related service that telcos could consider but will require building up a library of 3D videos.

- ***Broadcast live feeds*** - In Korea KT offers mobile news gathering (MNG) equipment with a single 5G sim card transmit UHK 4K videos. TVU Networks Corporation and LiveU Ltd in Korea are using the KT solution. In the future, individuals will be able to create high-resolution live news
- ***Study using Ar/VR tools/ebook****. I*n the next 3-5 years AR will become a commonplace tool for education and training.
- ***Real-time translation*** – this would be a cloud service similar to the new conversational AI contact center solutions that are coming to the market.
- **Home gateways**. These could evolve to become "on-home premise" for AR/VR and gaming applications especially for graphics intensive applications. There have been security issues with some wirelessly connected (Wi-Fi) gateways but 5G-connected gateways could be more secure.
- ***Home IoT.*** This includes temperature, humidity, vibration sensors, home structural sensors, surveillance and intrusion detection cameras, sound detection and so on. One of the first early IoT connected devices in the home was actually the home broadband modem because telecom service providers were able to see the status of the CPE and could initiate tests and resets. Home Wi-Fi routers thus became the central part of the home consumer IoT network.

Essentially, the connected home and the connected family have become an entire ecosystem complete with on-premise compute (media gateway) and cloud content services. The list of suppliers of manufacturers of smart cameras, sensors, smart lighting control, air conditioning and heating control, home security, smart appliances and entertainment and media systems (smart TVs, games and online gaming machines) continues to grow.

Some devices might not require the high-bandwidth of 5.5G but could benefit from the IoT features of 5.5G. Telcos could offer service to manage the number of IoT devices in homes which in a few years will reach 100+.

Figure 4 Connected families



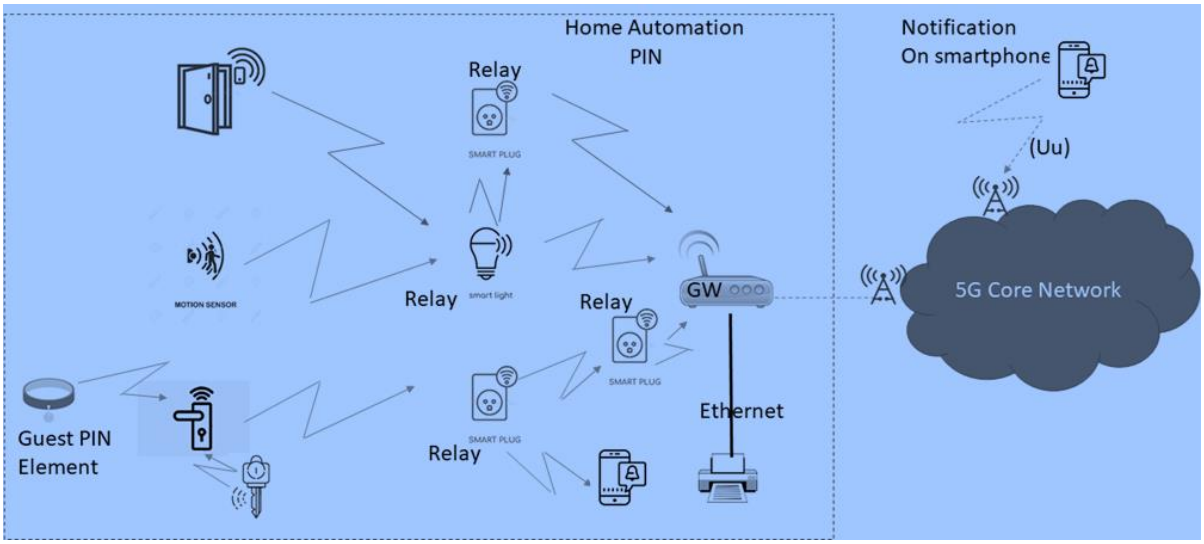
Source: 3GPP TR 22.859 V18.2.0 (2021-12)

The low latency and higher bandwidth of 5.5G will open up many new uses case and/or augment existing 5G use cases by improving performance. As an example, consider a mobile device that is being used for simultaneous translation. With a 10 Gbps link to a conversational AI platform in the cloud, the mobile device can appear to be doing all the work. Users are already starting to get acquainted with this type of service in conferencing systems that provide transliteration, albeit still

rather primitive. From the Service Provider perspective, there will be a plethora of new services that could be offered by teaming with media, content, consumer product companies. For companies that offer media content in the cloud a 10 Gbps connection suggests that one could sell "blocks" of content that can be downloaded in the matter of seconds.

AR/VR as a consumer service has achieved early success in some markets such as South Korea and China. None of the leading smartphone brands has yet to release an AR or VR mass market winner but there are already consumer headsets on the market from various companies such as Meta and Microsoft. AR/VR for consumers could start to gain traction, finally, around the time Rel-18 5.5G is commercialized.

Figure 5 Personal IoT Network (PIN) in Home Automation



Source: 3GPP TR 22.859 V18.2.0 (2021-12)

Connected Things

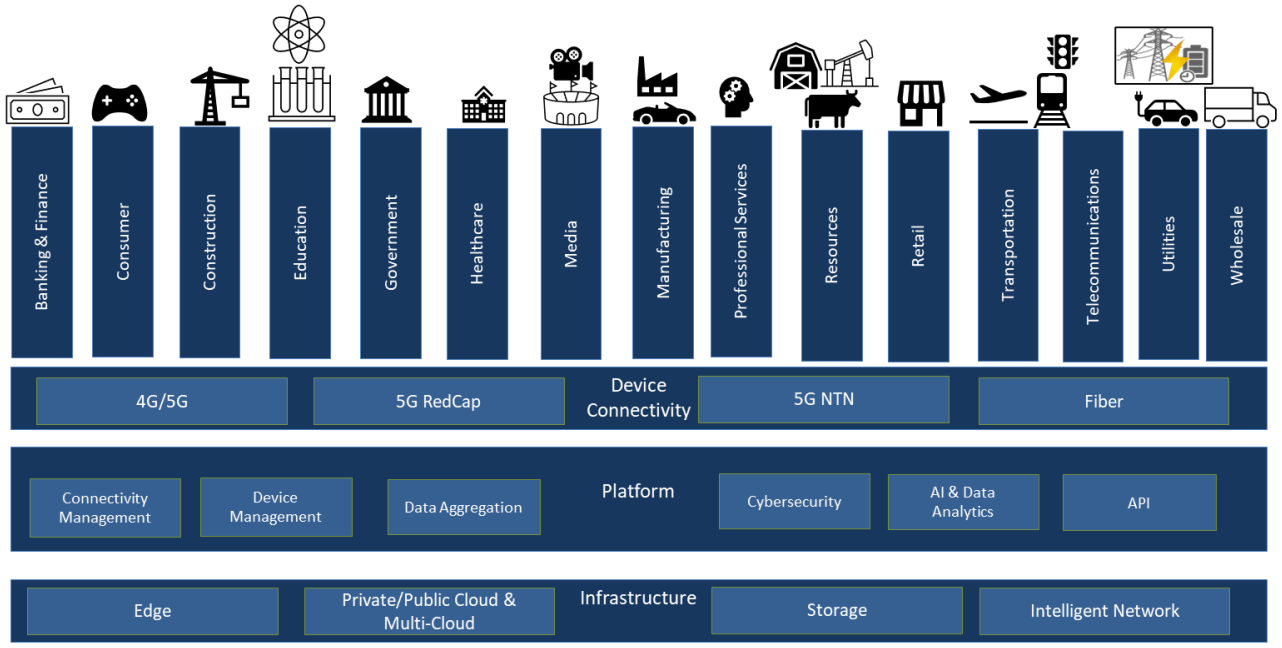
Telco revenue opportunity/ opportunities - Telcos can provide national/regional monitoring/alarm services as well as cloud server and storage and big data analytics. **5.5G** will deliver 20 Gbps peak DL speeds and 1 Gbps UL speeds and this will facilitate a wide range of high-performance and also low-latency use cases such as smart stadiums, smart transportation, AR/VR/XR and 3D displays. 5.5G will also deliver high-bandwidth backhaul links for a wide range of **Internet of Things (IoT)** deployments, many of which are narrowband today but will be migrated to 10-80+ Mbps in order to provide video functionality. IoT is a critical trend that has been evolving over the past 5-7 years. IoT is being deployed in enterprise and industries, government and consumer sectors. In Asia Pacific alone there will be over 10 billion IoT fixed and wireless connections by 2026. In China at the end of 2022 there were over 1.4 billion cellular IoT connections.

Internet of Industrial Things (IoIT) encompasses a wide range of connected robotics and machines in manufacturing operations including Automated Guide Vehicles (AGVs), Automated Mobile Robots (AMR), video analytics for reading older machine dials and monitoring/directing factory floor traffic

and so on. If we consider Operational Technology (OT) is all the technology needed to operate a business then the role of IoT is to connect a business/organization's assets via IoT endpoint devices that transmit data back to a data-centric platform either in the edge or the cloud, private and public. In some instances, the link from the endpoint will be bidirectional such as the case in Phase Measurement Units (PMUs) used in modern electricity distribution networks. IT/OT convergence is proceeding at a steady but industrial companies are cautious about moving their operational data to the public cloud the increasing pervasiveness of connected devices and things is driving enterprises to extract maximum value from data around design, testing, manufacture, delivery and customer experience. 4G LTE has played an important role in showing enterprises and organization the benefits of IoT and value of the data generated by IoT endpoints. As non-premise fiber broadband connectivity expands with the launching of Low Earth Orbit satellites, fiber optic pluggables, and 4G/5G cellular IoT it is becoming possible for any organization to collect valuable data about assets in the field, in the warehouse, at motion and at rest.

New sensor technologies, wireless connectivity options (NB IoT, LEO/GEO satellite — NB IoT NTN, 4G/5G, microwave), the rise of AI/ML, and the maturation of cloud platforms (hybrid, private, public), distributed storage architecture, and massive sold-state storage capacity, are all driving the possibility of much better visibility and predictability of operational performance.

Figure 6 Connected Things enhances operations across many industries



Source: Thoth Advisory, 2023

Enhanced/precision positioning is a critical feature that is being incorporated into Rel-16 to Rel-18+. This will important for V2X (see discussion below) as well any type of use case that needs the highly precise positioning such as in smart factories with lots of Automated Mobile Robots (AMRs) and Automated Guided vehicles (AGVs). The accuracy level in Rel-16 will be around 3 meter indoor and 10 m outdoor. Rel-16 features Round Trip Time for time sensitive networking and Angle of Arrival

(AoA) and Angle of Departure (AoD) and Time Difference of Arrival (TDOA). Rel-17 is aiming to bring the precision to under 20-25 cm for indoor with 100 ms latency.

Government, **public infrastructure and smart cities** is a broad area where many use cases have been deployed. For example, across Asia Pacific federal and state governments are discovering the benefits of connected assets such as smart traffic lights with 4K cameras, security CCTV surveillance in public areas and schools, smart streetlights equipped with sensors and IP cameras, waterway level sensors, flood monitoring sensors, vibration sensors for railways, fire detection sensors in remote areas, and so on.

Transportation is another sector that is ripe for IoT deployments – from train stations to railway control and monitoring, public bus security and surveillance, vehicle traffic monitoring, cargo shipping, truck platooning and so on. Commercial airplanes for example are equipped with satellite transponders to transmit location and other telemetric data and at the same time are equipped with 4G/5G modems to that are used to upload large amounts of telemetric data when the aircraft docks at airport gates.

Utilities and resources industries have long been an important space for IoT applications. Mining has been utilizing IoT for autonomous trucks, vibration sensors, real-time drilling monitoring and sensing. In very remote areas mining companies typically utilize a combination of satellite for backhaul and 4G wireless private network to connect the various devices and sensors. The agriculture sector has also been a big proponent of IoT in field soil and nutrients monitoring, farm animal counting and weighing, crop analysis, and water monitoring. The emergence of LEO satellite connectivity is further expanding the agriculture IoT adoption by providing a lower cost backhaul to the internet cloud.

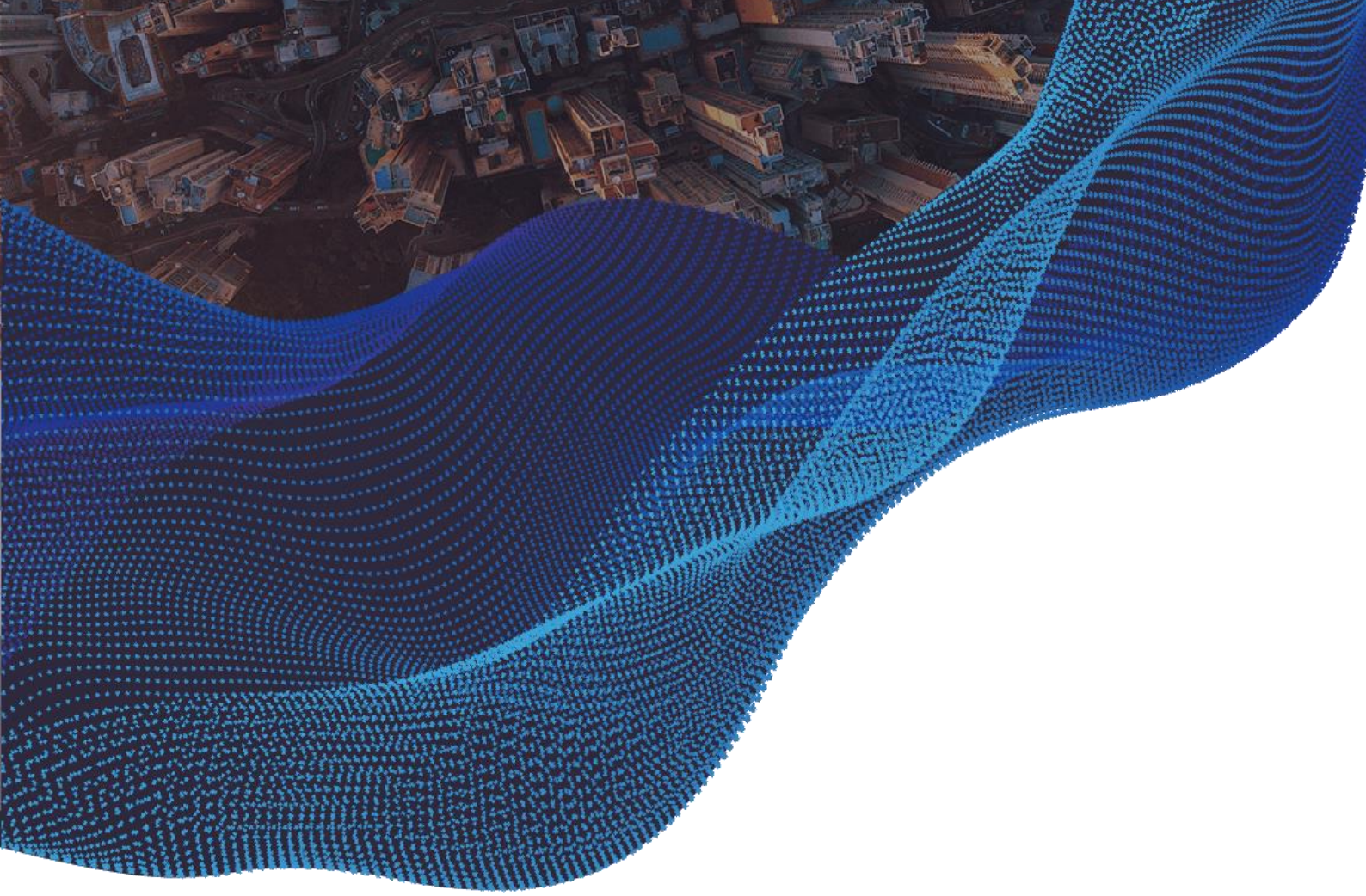
Network Slicing and AR/VR/XR Use Cases in Industry

The combination of network slicing and AR/VR/XR is a powerful combination that will enable a wide range of enterprise and industry use cases. Many of the early network slicing deployments are being implemented indoors or in smart campus scenarios and gradually macro outdoor slicing will become available as MNOs build out their 5G coverage. Moreover, MEC (Multi-Access Edge Computing) infrastructure will be needed in order support computationally intensive applications such as AR/VR, the role of slicing will be central to assuring the levels of SLAs needed to support both AR and VR. Telcos will have the opportunity to provide edge compute resources in the field or co-locate at specific manufacturing and logistics centers as well as stadium, shipbuilding yards, and smart ports.

A partial list of use cases would include:

- **Banking:** mobile banking. In markets where national smart IDs are issued it has recently become a trend for financial institutions and government services to authenticate the user's smart ID card by asking the user to hold the ID card in front of a camera and rotate the card up and down exposing certain holographic images stored in the card. Thus. It will be possible in the future for banking institutions to utilize advanced video analytics to authenticate large on-line transactions.
- **Consumer:** Cloud Gaming
- **Education and Training**: Smart Campus, Remote Training for Military, Medical professionals, technicians

- **Energy**: Smart mining, gas and oil. AR/VR/XR will be used in digital twins for these industries.
- **Government**: Smart City surveillance with IP Camera CCTV, airport and stadium broadband delivery – this includes IP Cameras and other types of sensor devices such as Infrared for temperature control of passengers and crowds
- **Healthcare:** Emergency medical services (smart ambulances), telemedicine, remote patient monitoring, Tele-rehabilitation, robotics for assisted living
- **Manufacturing**: Machine vision, control of Autonomous Mobile Robots/Automated Guided Vehicles (AMRs/AGVs) and forklifts, IoT sensor networks, dangerous welding positions, IP camera+AI-based floor shop management
- **Construction and Government**: Drone control and video streaming via VR headset
- **Retail and Transportation:** Small Cell indoor AR/VR for train stations/subways/tunnels, shopping malls, and other public spaces, macro coverage for railway lines, V2X Infrastructure management (this is the data streams between cars and between cars and the infrastructure)
- **Utilities:** Electricity, water and gas distribution and control



Contact Us

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