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5G VERTICAL USE CASES

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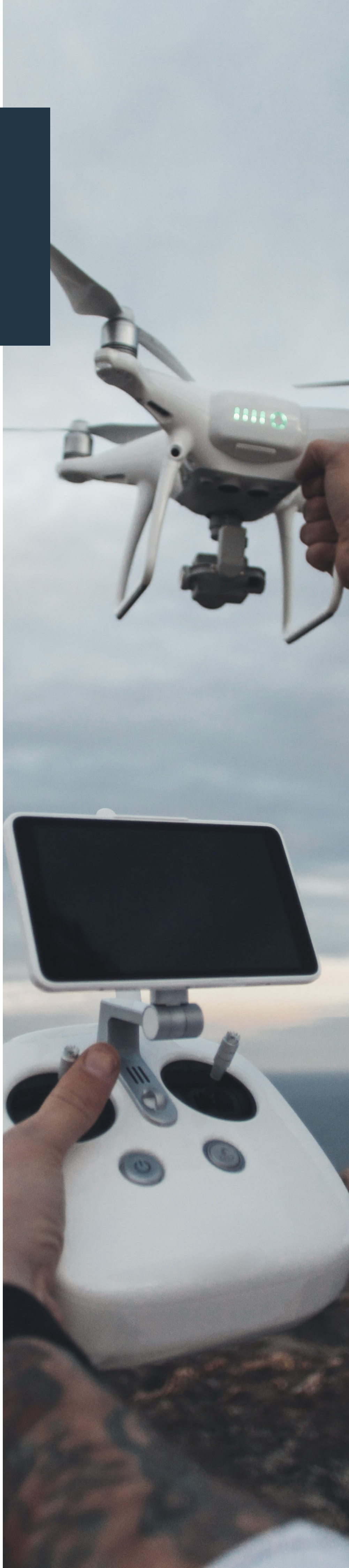

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Executive Summary

Ideas presented in this paper have originated from early discussions of the group authors with enterprises who are considering and evaluating private cellular and, specifically, private 5G technologies. These early discussions have led to a good deal of learning about what enterprises consider as their primary pain points and how they like to see them addressed with improved wireless connectivity.

In parallel, many 5G technology developers have also been considering benefits that can be brought forth for enterprises through sets of new innovative technology that 5G standards encompass. Ultimately, these parallel discussions should ultimately intersect to allow 5G to be adopted and effectively put into good use by both enterprises and consumers. We hope that this paper will help shed light on some of the hidden nuances of enterprise requirements to better fine tune what 5G can offer to match the expectations of what enterprises are looking to deploy.

This paper is intended to be complementary to many other 5G use case papers, including "5G Technologies in Private Networks" published in 2020, which focused on technical details of enterprise use cases that are possible with 5G technology. While that paper focused on technology features, this paper intends to focus on enterprise requirements.

The enterprise verticals covered in this paper are a representative selection of various verticals that can benefit from 5G. This paper does not intend to be exhaustive for either coverage of all potential verticals or issues that can be encountered in each vertical. Instead, the paper broadens the scope of discussions for 5G vendors and 5G users alike to facilitate further discussions on requirements and, eventually, complete solutions to drive faster deployment.

Questions we intend to answer in this paper include:

- *What are enterprises looking for in "better wireless" and how can 5G help?*
- *How can 5G providers fulfill needs of enterprises in their quest for better wireless?*
- *What gaps are preventing 5G adoption in enterprise verticals?*
- *What corollary topics need to be discussed, analyzed, clarified, to promote 5G adoption in enterprises interested in 5G?*

The following topics are out of scope for this paper:

- *Analysis of technical or market requirements of various industrial verticals. We will only articulate requirements that are relevant to 5G.*
- *Analysis of 5G market and adoption rates*
- *Comparison of 5G and other wireless modalities such as Wi-Fi*

1. Introduction

5G technology is a must-anticipated game changer in mobile networking, promising exponentially faster download speeds and data sharing in real time. The last generation of wireless cellular, 4G LTE, enabled connectivity of billions of smart phones with data service capabilities that have ushered in a new era of mobile applications changed the way billions of people live around the globe. Now, 5G is promising to use the same LTE packetization technology with significant improvements in the radio and packet core to connect things beyond phones and enable smarter cars, roads, cities, factories, hospitals, schools, etc.

If the 5G promise proves to be as successful in changing our world as 4G has been, we can expect tremendous innovations and changes in the coming years. Current 5G thinking is very focused on details of technology such as ultra-low latency wireless connectivity or slicing of provider networks. While these details are interesting there are even larger effects looming on the horizon.

One of the foundational changes in 5G is disaggregation and virtualization of legacy packet core. Disaggregation and virtualization are transformational enhancements that have been applied to compute, network, and storage industries in the past 15 years. The concepts are now being applied to the cellular packet core, as defined at the “Third Generation Partnership Project” (3GPP), as well as the Radio Access Network (RAN) being defined in other forums, as well. Successful implementation of these transformations has resulted in increased flexibility in design leading to new forms of deployment and consumption, which could not have been possible earlier. A great example is the emergence of cloud computing, which itself was made possible through virtualization of compute.

Another foundational enhancement in parallel with 5G lies in the application layers, made possible due to the availability of greater processing power more widely available through cloud hosting. This increased computational capability enables the application of intelligence to compute at nearly real-time for many user interactions, such as analytics, artificial intelligence, and augmented reality. In many practical use cases, end users are already enjoying such capabilities, whereas these uses had been previously limited to well-defined, highly complex venues, primarily in lab or controlled environments.

From a transformational change standpoint, the broad adoption of these uses will be tremendous. Over the next several years, these transformational waves of high-powered computation are expected to change the way cellular networks are designed and cellular services are consumed. New Business to Business (B2B) relationships are expected to create novel opportunities and new types of service providers will likely emerge. New consumer form factors that enable new unimagined types of interactions will come to the market, such as wearables that take User Interface (UI) from primarily text/voice/video to new levels - much like what happened with 4G LTE and smart phones. For what is considered merely a set of enhanced technologies today, 5G will eventually be transformational at a much broader business, society, and human experience level.

While it is expected 5G technologies will provide unprecedented capabilities to enterprises looking to successfully evolve through their digital transformation, it is not clear if and when these capabilities will be successfully translated into components that can solve an enterprise's specific problems and benefit its bottom line. As such, some are starting to think that 5G for the enterprise may be ahead of its time - a solution looking for a problem.

In this paper, we will try to shed light on what is immediately deployable and what gaps need to be filled to speed up deployment of more complex use cases. While details of 5G technology, architecture, and various addressed use cases are comprehensively discussed in many publicly available publications, we refer to the following papers for setting the basis of our current writing:

- Global 5G: Implications of a Transformational Technology*: A comprehensive look at the markets that 5G intends to address written by Rysavy Research and published by 5G Americas in 2019*
- 5G Technologies in Private Networks*: A detailed look at the 5G technology as it applies to primary enterprise use cases.*

To understand enterprise requirements that are relevant to 5G, we propose examining several industry verticals where companies are considering digitization and looking at 5G to modernize their wireless connectivity. These include manufacturing, transportation, mining, oil & gas, utilities, healthcare, education, hospitality and venues, banking, public sector, and gaming. From there, we raise the following questions:

- *What are highest priority improvements in business outcomes that they wish to achieve, how fast are they moving on digitization tracks?*
- *What modes of wireless are they using today and what problems do they have with wireless connectivity?*
- *How familiar are they with 5G and its benefits, are they using any 4G LTE technologies already?*
- *How would they describe their ideal wireless connectivity and how do these map to their digitization plans over an extended period (i.e., what do they need in the short term and what do they plan for the longer term)?*
- *What are main pain points preventing them from digitizing faster (e.g., regulatory roadblocks, lack of application or user equipment, lack of trained personnel, cost)?*

For this paper, information collected from these verticals will be sourced primarily from individual discussions and interviews that the authors have conducted with people involved in specific verticals, as opposed to general market analysis. We hope that through actual and current interviews, we can provide a more realistic view of the status of the verticals and their wireless needs, their readiness for adoption of 5G, as well as 5G offer readiness to address specific needs of these verticals. The paper will ultimately consolidate information collected from various verticals and derive a set of conclusions and recommendations that will hopefully be useful for the 5G user, developer, and operator communities.

2. Promise of 5G

Let's take a quick look at some of the innovations that 5G offers which makes it very different from 4G LTE. 5G's many benefits are well described by organizations, such as the Global Mobile Suppliers Association (GSM),[1] as well as many other publications, but we summarize the highlights here:

- **Higher speed and enhanced connectivity** - *5G introduces new radio technologies, such as Massive MIMO (Multiple Input Multiple Output) and millimeter wave spectrum (mmWave). These improvements enable higher device density – up to one million devices per square kilometer versus a few thousand devices with 4G LTE, as well as exponentially more data throughput Over The Air (OTA), delivering up to 10 gigabits per second data throughput, which is roughly 100 times faster than 4G LTE.*
- **Dedicated resource management-** *5G introduces the concept of 'network slicing,' which allows mobile network operators (MNOs) to split their monolithic network into independent slices that can be tailored for given use cases. Different network slices can offer different capacity, speed, latency, security, among other things - and offered to separate customers. Each network slice can potentially function as a 'mini' cellular network dedicated to a 'private' use. This powerful slicing concept can enable MNOs to expand their business to serve enterprises with a set of well-defined services with guaranteed response time and resiliency.*
- **Highly reliable communication** – *Ultra Reliable and Low Latency Communications (URLLC) is perhaps the most novel feature of 5G, enabling OTA latencies of less than 10 milliseconds, which enables cellular deployments to support mission critical industrial use cases like robotics, autonomous vehicles, augmented and virtual reality (AR/VR), and others. URLLC requirements demand more resources to ensure high reliability. Technologies like network slicing makes it possible for MNOs to reserve network resources and dedicate a full slice for supporting ultra-low latency use cases.*
- **Improved security** - *5G introduces a new network function SEPP (Security Edge Protection Proxy), which provides application layer security and protection against eavesdropping. With SEPP concealed identifiers are used to protect the exchange of actual user identity between various network function. This complements end to end authentication, integrity and confidentiality using HTTP/2 over transport layer security (TLS) and Open Authorization (OAuth) based authorization between various Network Functions (NFs) in 5G.*
- **Distributed Packet Core** – *Disaggregation and virtualization of the packet core enables spreading of core functions onto the edges of the network to both scale deployments, as well as lower latency of interactions with end users and optimize on traffic exchange across the network. A distributed packet core paired with Multi Access Edge Compute (MEC) and Service Based Architecture (SBA) can enable new forms of service delivery which might not have been possible with legacy centralized packet core models in 4G.*
- **Flexible Service Creation and Deployment** - [Service-Based Architecture] *(SBA) breaks the legacy point to point connection between NFs and*

provides a framework where 5G NFs connect with each other in producer-consumer model. A consumer NF chooses the producer dynamically based on criteria like location or load before starting any transaction. Each NF registers itself with a repository which can be queried by a consumer NF before choosing the right producer and starting a transaction. SBA simplifies the inter-process communication between NFs in a highly distributed core but also allows dynamic discovery and selection of NFs to optimize on reachability and use of overall network resources. Each NF can assume the role of service consumer or service producer and exposes its services and functionality through Southbound Interface (SBI) - a well-defined Representational State Transfer (REST) interface using HTTP/2. These architectural enhancements will be enabling carriers and service providers to more easily offer services that can be suitable and consumable by various enterprises. The emerging managed service capabilities will be much improved over what was possible in the past.

Of course, the above listed innovation concepts are not unique to 5G. Many of these ideas have been developing in various technology forums for several years. However, clear consolidation and standardization of these ideas is now aiming to enable mass deployment in a way that can facilitate major system overhaul activities across the globe.

A major difference between 4G LTE and 5G deployment waves is that 4G LTE focused on commercial cellular and individual subscribers, but 5G is set to go beyond the individual subscriber service. New service creation and delivery models involving carriers, cloud providers, application providers, enterprises, municipalities, and more are on the horizon. Full realization of these new service delivery models requires expansion of existing providers' footprints and capabilities, some through system overhaul, and some through acquisition and partnerships. These activities and discussions have started but need more time to mature.

Central to many of these new service ideas is the role of the enterprise, which can be defined as an independent group of users with specific requirements that go beyond commercial cellular use cases. Due to the complexity of their requirements, enterprises have tended to exist as independent islands in the sea of provider networks, using their own dedicated IT department and deploying enterprise grade networking gear to fulfill their needs.

5G technologies open a window of opportunity for these independent enterprise networks to be served by the carriers and emerging providers. But to capture this opportunity, both Commercial Service Providers (CSPs) and enterprise consumers need to learn more about each other's needs and potential capabilities to develop and deliver consumption models that can benefit both.

Furthermore, each enterprise vertical is compelled by a set of technology standards of their own, which will have to be aligned with 5G capabilities to fulfill regulatory and safety compliance requirements, and/or new enterprise specific standards will need to emerge to ensure safe deployment of new 5G technologies. These topics are all currently under discussion and will need more time to mature.

In the following section, we will look at what benefits enterprises are seeing in the 5G set of technologies.

3. Wireless Needs of Enterprises and Industrial Verticals

Ultimately, improving business outcomes drives all enterprise technology refresh cycles. 'Digitization' is a term used to define process modernization, automation, and increased use of the Internet to lower the cost of a business' operation and increase revenue. As enterprises consider their digitization plans, they are keen to understand alternative and complementary wireless options. This is where discussions on private cellular networks start with enterprise verticals. Private cellular networks operating on 4G LTE have been in existence for many years, but mostly in limited venues where Wi-Fi is not a suitable option or where public cellular is not offered at the right price and required SLA in the right vertical – such as in mining. However, the introduction of 5G has been creating a renewed interest in private cellular in recent years, due to its ability to improve wireless connectivity everywhere, both indoor and outdoor,

Discussions with enterprises about 5G usually start with conversations involving the powerful capabilities that 5G can offer, but tend to stall due to several factors. These factors can include the complexity of carrier-grade 5G, lack of ready-to-use 5G gear (either radio or user end point), as well as a lack of a clear understanding of the cost differences between 5G and other enterprise wireless options, such as Wi-Fi 6 that claims similar functionality to 5G.

Currently, first generation 5G offers tend to be very carrier-oriented. The 5G equipment vendors are currently focused on helping their carrier customers to deploy 5G commercial cellular networks. With managed service offers by carriers still in their infancy, most carriers do not yet have a sufficient 5G radio footprint to enable services very broadly. Enterprises that are eager to evaluate 5G are using smaller cellular grade solutions packaged for the enterprise, which remain complex and hard to integrate into existing enterprise networks. The ideal enterprise grade 5G solution has not yet emerged.

With that in mind, let's take a closer look at what enterprises are looking for in a 5G private cellular solution.

3.1 Radio Frequency Spectrum

The first topic in virtually all wireless discussions in an enterprise involves the choice of Radio Frequency (RF) spectrum, specifically in terms of its characteristics for providing coverage and throughput at acceptable cost. Sources of spectrum include:

- **Unlicensed spectrum**, *which powers Wi-Fi networks, is free and highly suitable for indoors and many outdoors venues, remains the primary choice for wireless among almost all enterprises. Enhancements introduced through [IEEE 802.11ax (Wi-Fi 6),] as well as expansion of the RF range through introduction of [6E] aims to solve many existing problems with Wi-Fi, including congestion and interference. Wi-Fi range of coverage is limited due to its lower power requirements, and as such, it is considered not useful in vast areas where many access points will be needed to cover the same area that a macro cell can cover.*
- **Shared spectrum** *is a new category of spectrum that is issued by the regulators in which there is an existing incumbent who takes priority for usage of spectrum. These bands can provide more expansive coverage*

for outdoor use cases at a lower cost than licensed spectrum. However, there is additional complexity of potential interference with incumbent users which needs to be managed by a spectrum management system. Examples of shared spectrum include Citizens Broadband Radio Service (CBRS) in the US.

- **Licensed spectrum**, *owned and managed by cellular providers, presents a rich and versatile set of spectral bands that can offer high throughput and expansive coverage for a fee.*
- **Any combination** *of the above can be used to support complex use cases for an enterprise.*

Availability of suitable RF spectrum enables or limits any wireless deployment, and more spectrum is needed as wireless use cases grow in scale and complexity. While there is much more that can be said about RF spectrum, most is out of the scope of this paper. Further details involving radio frequency spectrum can be found online, including:

- *5G Americas white paper, "5G Spectrum Vision"*[2]
- *Wikipedia articles on radio spectrum,*[3] *cellular frequencies,*[4] *LTE frequency bands,*[5] *and 5G NR frequency bands.*[6]

Additionally, there are a few points about spectrum that do come up in discussion with enterprises, which include:

- **Higher frequency bands***, e.g., mmWave, that offer higher throughput at shorter distances and are sensitive to environmental factors, such as metal fuselage or caging. mmWave use cases can be similar to Wi-Fi 6 in terms of coverage and performance, but mmWave uses licensed spectrum versus unlicensed spectrum used in Wi-Fi 6.*
- **Lower frequency bands** *offer larger area coverage and lower throughput, but they are also capable of penetrating through RF challenged environments.*
- **Mid band frequencies** *are very versatile as they can provide a good amount of throughput, a decent latency, and resilience to environmental factors.*
- **Most immediate outdoors use cases** *that can benefit from 5G involve mid band and lower band spectrum.*

In all spectrum-related discussions, cost of ownership and operation is top of mind. Enterprise IT teams will often consider the most readily available solutions at lower costs before moving onto more complex and costly solutions. For all cases, switching from one wireless mode to another requires significant cost analysis to demonstrate improved bottom lines.

3.2 Spectral Determinism

The source of spectrum alone is not sufficient in considerations for private use. For most advanced use cases, such as industrial automation, the ability of spectrum to be used 'deterministically' becomes an essential characteristic. That is, is the available spectrum sufficient to deliver upon its intended purpose of use when it is needed? Whether spectrum is licensed, unlicensed, or shared, does not necessarily assure the required determinism either, but rather the nature of the resource and spectrum management systems deployed in the spectrum that guarantees this.

Licensed spectrum has been historically expensive to acquire, and as such, much attention has been paid to managing the spectrum and resources efficiently to maximize its utilization. Scheduling mechanisms that are inherent to cellular communication systems that use licensed spectrum make these systems more deterministic with predictable access delays. Furthermore, with each successive generation of licensed spectrum technology (2G, 3G, 4G and 5G) the access delay has been reduced to the point where, with 5G systems the system is deterministic enough to enable highly sensitive use cases that need resilient and ultra-low latency communication.

On the other hand, because unlicensed spectrum can be accessed freely by anyone with a legitimate device, communication channel access mechanisms have been developed over time that ensure fair access. Since no single body had absolute control over access to the communication channel, distributed exponential back-off mechanisms were employed that permitted fair access to the communication channel. The implication is that for 802.11 systems prior to 802.11ax, once the load in the system increases, access to the communication channel becomes increasingly contentious and hence access to the channel becomes less deterministic. However, with the advent of 802.11ax (Wi-Fi 6) this situation has changed, in the sense that more scheduled channel access management has been employed. The implication of this is that, even in unlicensed bands, access becomes more deterministic, and, if applied in clean unlicensed spectrum (at 6GHz, say) then we may reach the required levels of determinism needed for industrial use cases.

Other factors that can affect determinism when it comes to wireless connectivity is the end-to-end quality of connection. While scheduling mechanisms can enhance Over-the-Air connection quality, i.e., connection between the radio and user end points, other problems in the end-to-end application path can result in packet drops, delay, and jitter. As such, comprehensive system design and attention to end-to-end packet flow is needed to ensure quality.

Enterprises with mission critical use cases are considering parallel networks, a Wi-Fi network for their existing IT applications, and a private cellular network for their mission critical applications that need dedicated clean spectrum. Given the trajectory of increased wireless demand, it is expected that in few more years, both unlicensed and licensed bands will be in demand to satisfy various use cases. Alignment of these heterogeneous wireless network to enable a holistic experience for the consumers will continue to be a challenge.

3.3 Area of Coverage

Geographic area coverage is a critical decision criterion for enterprises considering private cellular. Enterprise physical footprints are varied with characteristics, including:

- **Campus**, *a collection of buildings that are close enough to allow physical cable or fixed wireless connections. While indoor use cases for these campuses can be covered with Wi-Fi, outdoors remains a challenge for Wi-Fi due to its lower power profile. Larger, more powerful radios can cover broad outdoor spaces more efficiently. The private cellular coverage enabled by these radios can be part of a privately owned solution operated by the enterprise IT, or as a managed service offered by carriers.*
- **Distributed remote sites** *can be additional campuses, which need connection to the same enterprise network. Each remote site can have indoor and outdoor needs like the main campus.*
- **Branch offices** *are smaller offices with limited connectivity needs but which also need to be connected to the main enterprise IT network.*
- **All combinations of the above** *are possible with locations spreading over municipal, national, and international boundaries.*

Private cellular needs of these centralized or distributed locations must be considered in light of availability of fiber for direct wireline connection to the main campus, and/or through provider based Wide Area Network (WAN) connections. Ultimately, all the locations need to be brought under the same security and access policy.

Broader geographic coverage is needed for many emerging solutions in public sector, utilities, healthcare, and education, where the location of the connection can involve people, cars, homes, streets, electric poles, roads, etc. In these cases, a carrier's presence and coverage capabilities may exceed any privately owned and operated option.

Use cases that fall into diverse national and international boundaries must also be considered in light of local regulatory issues, as well as availability of spectrum. Lack of uniform spectrum availability across multiple boundaries can cause a problem for multi-national enterprises that need to standardize on their enterprise architecture, tool usage, and compliance.

3.4 Security

As cyber-attack surfaces expand due to increased digitization, security demands of enterprises continue to increase. Emerging wireless technologies need to align themselves with security requirements of the venue in which they are to be deployed. For example, insertion of any new wireless system, such as LTE and 5G, in industrial environments must comply with the Purdue Model and industrial security standards such as ISA-99 (now also known as IEC-62443). This standard identifies levels of operation and key zones for industrial networks to enable defense-in-depth security strategy with Industrial DMZ (IDMZ) between IT and OT networks. IDMZ is where the policies and organizational control can be divided/segmented to allow data and services be shared between IT and OT in a controlled manner. All communication between the lower levels of the operational network and the higher levels of the carpeted enterprise or corporate environment must be tightly controlled and kept separate with no direct access or communication.

Any private cellular solution, be it privately owned and operated, or offered as a managed service must be able to fit within the unique security policy framework of the enterprise.

3.5 Availability and Reliability

Most industrial venues tend to be a 365/24 operation, meaning that production is continuous throughout the year. Outages have adverse financial consequences (loss of sales, loss of security, delivery penalties, etc.). Therefore, any wireless system being placed into an industrial environment must have high availability designed into the architecture and be able to be monitored for reliability. 5G technology and systems are designed to enable carrier grade high availability and pervasive monitoring for reliability. Nevertheless, the proof is always in the pudding and these benefits must be demonstrated in end-to-end systems that use 5G to realize new industrial use cases. As with security, many industrial venues have their own specific set of requirements for availability and reliability which need to be complied to.

3.6 Data Sovereignty

Enterprise data protection is a high priority requirement and a major discussion in all private cellular considerations. Many enterprise IT managers prefer wired connections and even enterprise owned and operated connections to ensure data protection and prevent costly data breach. In public cellular wireless networks data forwarding is handled by the base station and the packet core. The northbound interface from the base station is an IP-based tunnel back to the packet core gateway function, located centrally in the provider cloud, which acts as a mobility anchor for the data.

For private cellular networks, this may not be desirable as enterprise traffic may not be permitted to leave the enterprise network boundary or because of the internal operational segmentation the data forwarding plane may be restricted to a given operation domain. In more recent 3GPP LTE standards including 5G, the packet core gateway function has been functionally split into control and user plane elements. The User Plane Function (UPF) takes care of forwarding the user's packet traffic and in a public network it is normally placed centrally high in the network. In private cellular use cases it may be necessary to keep the UPF within the enterprise security boundary to ensure enterprise data remains within the enterprise domain. In other use cases this may not be possible or necessary.

This type of distribution and placement of network functions is possible with the highly virtualized 5G packet core architecture. Placement of the UPF is just one example of how 5G core can facilitate emerging requirements. Other network functions can also be placed flexibly in different locations, at the enterprise site, in regional data centers managed by carriers or other providers, or in central data centers. These functions can also be aligned and integrated with existing enterprise specific functions to provide tighter security and easier operation.

3.7 Ease-of-Use

For full and effective adoption of cellular systems by enterprise IT, much of the complexity that 4G LTE and 5G systems have inherited through the evolution of 3GPP, and which is necessary for carrier grade systems, must be either reduced or hidden from the IT and OT managers that will supervise the enterprise network. In addition, it is highly desirable that these private cellular systems to merge with, or at least align with, existing enterprise policy, security, and management systems. Enabling ease of use and full alignment of these heterogeneous networks is a work in progress.

Introducing a new, unfamiliar, 3GPP-based wireless system can be challenging, not only from a knowledge base perspective but also from a cost perspective. There are multiple ways to implement a 5G solution, including building and operating your own private network, contracting an MSP (Managed Service Provider) to install and operate a private network for you, or contracting with a CSP (Commercial Service Provider) for general 5G service or a private network slice. There are advantages and disadvantages of each option, from a cost, complexity, and performance angle. For example, a healthcare facility operating its own 5G network has advantages in that it can be customized to meet its needs, the data can be secured without leaving the premises, and there are no data caps. On the other hand, the network is limited to the area that has been built out, whereas contracting with a CSP can provide service through a nationally deployed network. Ideal solutions may involve a combination of offers. Fortunately, there is a growing list of vendors that are optimizing complete solutions for the enterprise user, which vary in cost and capability to meet the exact needs of the enterprise.

3.8 Liability, Responsibility and Ownership

The responsibility and ownership of Private LTE/5G systems can become complicated in cases where not all components of the system are owned by one entity. For instance, when spectrum and packet core may be offered by a carrier while the user end point and application may be owned by the enterprise. How does one define liability in these mixed ownership cases? This becomes a major issue, particularly for highly mission critical use cases where outage or malfunction can be extremely costly. These inherent issues are not well understood by the market yet and may prove to be the major roadblock for adoption. In other words, 5G may be technically ready to fulfill many use cases but business level legal agreements may not be in place to allow deployment.

4. Enterprise Verticals Considering Private 5G

In the following sections, we will investigate the requirements of a series of sample verticals, where companies are looking at deploying private cellular and private 5G networks, focusing on the challenges that were outlined above. Specifically, we will be looking at the verticals listed below, while merely a subset of the full set of verticals mentioned earlier, demonstrate characteristic sets of requirements and venues considered very representative of all industry verticals.

- **Manufacturing** *is perhaps the most challenging and demanding venue for wireless enhancements which 5G promises to fulfill. Many of the requirements that are being looked at in the manufacturing context can be applied to other venues.*
- **Mining** *has been using 4G LTE technology for several years. There are many lessons to be learned from past experiences of these deployments.*
- **Utilities** *is a huge emerging sector where 4G LTE and 5G technologies can provide benefits at a tremendous scale. The venues represented in this vertical are like many public sector verticals such as smart cities, smart infrastructure, and transportation.*
- **Healthcare and Education** *verticals have emerged as immediate beneficiaries of better wireless and specifically 5G due to COVID-19 pandemic.*
- **Gaming** *is a unique vertical which demands better wireless and has been looked at as a catalyst for adoption of unique aspects of technology such as Multi-Access Edge Compute and AR/VR.*

Details about requirements and enterprise networking architectures for these verticals can be found at various vendor sites, such as those provided by Cisco.[7]

4.1 Manufacturing

Manufacturing is perhaps the most noted vertical to be benefiting from 5G, mostly due to Industry 4.0 transition that is set to drive next wave of modernization in manufacturing. Born in Germany and launched in 2011, Industry 4.0 (I4.0) refers to the introduction of a fourth Industrial Revolution through the fusion of the cyber and physical worlds to drive value and competitiveness in a global marketplace. Foundations of I4.0 are broad and consist of several design principles and technology pillars which are more broadly described in detail in the following paper.[8]

While 5G can be instrumental for many I4.0 enhancements, 5G alone is not sufficient to realize I4.0. There are many other aspects of manufacturing processes that need to evolve in parallel to enable 5G features to be usable and effective, which is a point that sometimes gets undermined in our enthusiasm to deploy 5G. The following Digital Transformation Assessment[9] summarizes current challenges faced by manufacturing sector and is a good summary of where 5G fits in the larger set of manufacturing top of mind and demands.

4.2 Manufacturing Wireless Use Cases:

Manufacturing is a broad practice that can involve many activities, anywhere from supply chain interactions, warehousing of goods, production processes and assembly lines, shipment of goods, and many more other steps. Primary concerns in all manufacturing venues include:

- **Need for greater operational efficiency and resilience** - *Preventing interruptions in production lines, improving quality of production, and decreasing cost of production are everyday concerns in all manufacturing contexts. Interruptions are very costly and can have many root causes from failures of an outdated tool, to lack of sufficient network bandwidth causing poor connectivity of critical tools, or even outdated processes requiring a complete modernized redesign of the factory.*
- **Delivering on existing commitments** – *Maintaining production commitments while identifying meaningful cost savings in procurement, manufacturing methodology, logistics and service are a top priority for all manufacturing sectors. In all cases operational managers tend take the most immediately available and cost-effective solution to their production problems. Introduction of new tools or redesign of factory floor and network has to take into account existing tools and enable continuity of operation as much as possible. New factory designs in a greenfield context are being considered but even timing and cost of new factory launches will dictate choice of solution.*
- **Cyber vulnerabilities** *remain a huge concern. Control of access and protection of data in compliance with enterprise policy as well as industry and regional regulations are extremely important and can dictate choices of technology.*

Auto manufacturing is one of the most complex practices and one vertical where companies have been considering 5G for process enhancements. Almost all auto manufacturing plants world-wide have either already started a PoC (proof of concept) and trial for 5G or are considering it. Here is a list of typical requirements being considered:

- **Robotics and automation** - *Production robots are usually not mobile due to large power requirements, however, there are many aspects of a large robotic arm operation that can benefit from low latency wireless sensor capabilities. In most cases similar features can be implemented with wired, industrial ethernet. Nevertheless, new cases are continuously being identified as factory design evolves. Automated Guided Vehicles are a moving robot which can benefit from rich wireless connectivity with low latency. Modern AGVs are sophisticated machines that can do very many activities if provided enough intelligence, which increasingly requires rich, low latency, secure, and resilient wireless connectivity that can be provided with 5G. Introduction of AGVs into existing factory floors needs to be considered with care as there are many safety compliance requirements. While AGVs are not a priority for auto manufacturers, once proven effective and safe, they can become a very powerful addition to factory floors.*
- **Tracking and monitoring** *of various aspects of production through video and sensor surveillance with application of analytics to study production patterns and optimize processes. Many of these activities can be done with existing Wi-Fi based cameras and IoT sensors, but 5G can provide enhancements, particularly in outdoors venues.*
- **Life Cycle Management** *of auto inside and outside of factory, this may include download of massive amounts of data Over The Air (OTA) in the form of firmware or software to enable troubleshooting, testing, and upgrading car components in various stages of production, shipment, and eventual use. These massive data and control exchanges need to be enabled inside the factory during production as well as outside the factory in remote shipyards or dealer shops, as well as when the car is*

put in use at the mechanic shops or even owner's home. Data download requirements can be very large for factory floors where large numbers of units may need to be handled in parallel for production.

- **Small wireless tools** *such as scanners or radio frequency identification (RFID) readers are pervasive and usually supported with Wi-Fi, but here 5G can also provide enhancements, particularly in outdoors venues.*
- **Smart factories of the future***: whether these flexible assembly stations can be almost totally cord-less except for power, is a vision that is being designed and evaluated. These smart factories will use massive amounts of wireless connectivity which translates into not just 5G usage, but many other wireless modalities, as well. These designs are in ideation stages and their full realization will take a few years. Nevertheless, new factories are considering enabling all forms of wireless to be ready for new tooling and processes that may emerge.*
- **Wireless connectivity** *on factory campus to prevent pulling cables.*
- **Augmented and virtual reality** *applied to various venues to enhance operator experience.*

4.3 5G Considerations for Use on Factory Floors

Following on the vision of Industry 4.0, many 5G innovators have been looking at factory floor requirements and potential application of 5G technology. There are many reports and articles[10] summarizing possibilities available online.

Early feedback from trials indicates that private 4G LTE or 5G does deliver the promised user experience for automation use cases in factory floors, but most use cases have been prototypes and tried in isolation. Introducing these use cases to factory floors depends on availability of spectrum, maturity of end point devices, compliance to industrial safety standards, as well as operational fit into existing factory wireless architectures.

Spectrum availability for LTE or 5G uses cases remains a challenging topic for factory settings. Shared or locally licensed spectrum, such as CBRS in the US or other Industrial Scientific Medical (ISM) bands in Europe and other parts of globe, have pointed the way to the possibility of using LTE and 5G in private mode. While alternatives to dedicated private spectrum involves leasing licensed spectrum bands from public providers, the total available throughput from shared spectrum sources must be sufficient to enable basic use cases such as surveillance and tracking.

To fully partake of the rich 5G benefits of automation use cases, for example, one will have to count on a broader range of spectrum which is only available as licensed spectrum from public providers. Public providers are indeed uniquely positioned for enabling spectrum heavy use cases with their licensed bands as well as possibility of aggregation and channel bonding of various bands. However, the main challenge for supporting automation rich use cases through public providers is incorporating a managed service offer with existing private enterprise network on the factory floors. These types of hybrid deployments are being considered but clear solutions have not yet emerged.

RF challenges in factory floors due to prevalence of metal caging is also an issue for all wireless communications, 5G included. In the case of Wi-Fi, these challenges can be overcome by placement of more Wi-Fi access points to enable RF saturation in hard-to-reach areas. Covering the same factory floor area with a few macro cells might not address the RF challenges. Enabling 5G mmWave technology with small cells requires a similar density as Wi-Fi access points. Such replacement may or may not be justified depending on the use case, application, and overall integrated solution. Comparisons of mmWave vs. Wi-Fi 6 based solutions may be required to allow effective decision points.

For outside factory use cases, 5G is clearly a leader. Intelligent ongoing cellular communication with a sophisticated device, such as an automotive, is a major use case which can only be provided with better cellular technology like 5G. These modes of communication can include, basic tracing and tracking, software and firmware download, troubleshooting, telemetry, ownership/insurance/compliance status verification, location services, etc. This list is expanding as more innovation gets applied to auto production as well as auto use. Automobiles are just one example of a sophisticated tool that needs to be monitored and interacted with through richer cellular communication in vast public venues.

5. Mining

The mining vertical is one of the early adopters of private 4G LTE. Communication in remote mining venues, need for automation and worker safety in isolated and dangerous terrain, as well as lack of reliable carrier based cellular coverage has promoted mine operators to build and operate their own 4G LTE networks. Going forward, modernization and digitization of the mining vertical is putting additional demands on these early 4G LTE networks and promoting them to expand and evolve to accommodate additional functionality. For any mine operator primary goals of deploying a communication solution can be summarized in the following:

- *Prevent failures/breakdowns/unplanned downtime*
- *Enhance worker safety*
- *Improve efficiency*
- *Reduce energy consumption*
- *Meet environmental requirements*

For a more complete analysis of the mining vertical use cases, there are several additional resources available online at Cisco[11], Baker Hughes[12], World Economic Forum[13], and Enterprise IoT Insights[14].

5.1 Mining Venues and Use Cases

Mining sites are usually located in isolated geographic areas where spectrum coverage by cellular providers is limited or non-existent. Sites can include massive areas of undulating terrain that may be constantly changing due to excavation and rock removal activities. Venues can be over ground or underground. Underground mine shafts can be extensive and deep with unusual environmental characteristics that may cause wireless spectrum to behave differently. Communication services using Wi-Fi mesh or 4G LTE platforms have been in use in mining sites for many years. These are usually simple standalone platforms that enable basic services for connectivity, worker safety, automation of haulage or drilling equipment, and monitoring of site and activities for security purposes.

Demand for more and better wireless has increased by orders of magnitude with the evolution of the mining industry. Specific use cases can include:

- **Innovative worker wearables and tools**, *beyond existing Push to Talk (PTT), to enable more intelligent monitoring and hands-free richer interactions of workers remotely. Wearables may be sensors located on hard hats, body cams, and remote expert goggles. These devices need to be ruggedized and functional in hard-to-reach places such as mine shafts.*
- **Extensive use of environmental sensors** *to ensure early detection of dangerous chemicals for both safety reasons as well as conformance to emerging environmental protection requirements. These sensors can encompass a very large network needing low throughput and low power connections. Data collected from these sensors will need to be accumulated and analyzed to derive trends for intelligent decision making.*
- **Fleet Management Solutions (FMS)** *for task scheduling and routing of haulage vehicles. These systems are human controlled but need*

connectivity, in the order of kilobytes, to a central site to communicate route and order details to the drivers of haulage vehicles.

- **Automated Haulage Solutions (AHS), Automated Drilling solutions (ADS)** *such as dozers, excavators, and loaders. Increased automation is the ongoing trend for all heavy vehicles. Currently, most haulage or drilling vehicles can only arrive to level 3-4 of autonomy, meaning while they can control a lot of their activities independently, they still need a human controller who can control this equipment remotely while sitting at their workstation in a central NoC. The amount of bandwidth required for control of this equipment is not very large, around one megabyte. However, for each piece of equipment, there is also a massive amount of data that is being collected, through video or other sensors, some of which needs to be used in real time to fine tune the activity of the equipment. These additional data paths can increase bandwidth demand for each equipment to 15-20 Mbyte uplink traffic. For example, automated drilling bits can be monitored closely to see what type of rock formation is being exposed, which can then be used to increase or decrease the power of the bit.*
- **Massive live video and Light Detection and Ranging (LIDAR) surveillance** *via either static or using drones, combined with other venue surveillance for security and safety purposes is top of mind in mining, as well.*
- **General connectivity in changing terrains** *(e.g., mine shafts, mine pits). Most mines are in constant churn and topological change. Wireless set ups need to be able to change and adapt to these topographical changes.*

5.2 5G Considerations for Use in Mining

In addition to the benefits, there are also certain considerations regarding the use of 5G networks in mines, which can include:

- **Spectrum sources for mines have been either private or leased carrier spectrum**. *Availability of CBRS and ISM bands as shared spectrum sources are intriguing developments for mines, however, effective deployment of these spectral bands are yet to be seen. Additionally, major concerns for use of shared spectrum or carrier's licensed spectrum in mining venues is lack of complete reliability and availability. Any outage at the mine can result in massive revenue loss or decreased worker safety. As such mine operators prefer to have full control of their spectrum and radio sources to prevent outage.*
- *Other spectral considerations can relate to how spectrum behaves in different mine locations, such as a mine shaft where higher frequency spectrum does not propagate very well due to weaker reflection capability. For all use cases, a complete RF analysis of mine site and venues is necessary to assess effective spectrum performance and outcomes. Ongoing RF analysis and expertise may need to be applied due to the changing terrain of a mine site.*
- **Mining venues will tend to cost optimize for all needs,** *as with other legacy venues such as oil and gas. Any 5G equipment and solution will have to prove its value for enabling overall cost saving. Existing Wi-Fi mesh and 4G LTE solutions are just being deployed and put to trial. It is not clear how much cost saving 5G will bring.*
- **The choice of a privately operated network versus a managed service** *through a carrier operated network is a question, as with other verticals. So far, large complex mining operators have chosen expert IT and network operations firms who are very familiar with nuances of the mining vertical to set up and operate private networks for the mines while smaller and simpler mining sites have used carrier services.*
- **Lack of approved hardened 5G hardware for mining venues.** *5G adapters or industrial routers with 5G adapters will need to be ruggedized and integrated into AHS and ADS, and these systems will then need to be tested for performance and reliability in specific mine venues.*

6. Utilities

Utilities are representative of public sector verticals, which reflect a huge group of organizations interested in deploying their own private LTE and eventually private 5G networks. They are in urgent need of secure, flexible, reliable, broadband wireless connectivity to fully realize the potential of their grid modernization and digital transformation initiatives. Many of these initiatives involve deploying new applications that enable the utility to collect and use data from a wide variety of grid assets, including smart meters, gas sensors, voltage regulators, distributed energy resources (DERs), and drones. Other initiatives involve the rollout of new or enhanced workforce management, safety, or other applications that connect to vehicles and field workers.

In both cases, utilities are depending on these initiatives to help them to realize important organizational objectives, including lower operating costs, improved grid safety and reliability, better customer engagement, and more renewable energy generation. For these initiatives to succeed, connectivity with strong cyber security is essential. As the grid becomes automated, the cyber-attack surface increases because there are more devices, applications, and support staff with full access to these new systems.

Some forward-thinking utilities are realizing the cyber security benefits of a private LTE network. LTE, the global standard, is very secure on its own. A private LTE network allows utilities to install additional cyber protection systems such as identity and access controls, heuristic based monitoring systems and others. With private networks, organizations can completely isolate this communications control network from the Internet, often called “air gap” deployments, if they choose to do so. When you own the network, you make those decisions. When you subscribe to someone else’s network, they make those decisions.

More information regarding how utilities are embracing private LTE networks can be found at Anterix[15].

6.1 Utilities Venues and Use Cases

Utilities facilities consist of expansive territories, stretching across hundreds and thousands of square miles. Many areas are not served by major carriers, while many millions of devices may need to be connected, monitored, maintained, and managed. All potential 5G network activities may impact power generation and delivery to consumers, with a sharp focus on outage prevention and/or fast outage recovery. These can be summarized as:

- **Smart Grid**[16] – *is the digital technology that allows for two-way communication between the utility and its customers, and the sensing along the transmission lines is what makes the grid smart. Like the Internet, the Smart Grid will consist of controls, computers, automation, and new technologies and equipment working together, but in this case, these technologies will work with the electrical grid to respond digitally to our quickly changing electric demand. Smart Grid related use cases can be summarized as below:*

  » **Distribution Automation (Volt/Var Optimization and Circuit Reconfiguration)** *refers to digitized management of the electricity* *distribution network components. Activities include monitoring and measuring of specific metrics on grid devices and taking necessary actions to ensure quality and compliance to regulations.*

- » **AMI and substation backhaul** *refers to collection of usage metrics from customer meters, aggregation of these data points and processing at substations as well as further up in the network. These backhaul networks complement a low throughput metering network.*
- » **Emerging modes of energy production** *through renewables such as solar and wind, either regulated or non-regulated, are causing increased scale, introduction of enterprise and residential class generators and need for new electricity flow and control devices which have to be incorporated into the modern grid and managed. Effective management of these new modes of production requires a level of monitoring and applied intelligence that needs to rely on increasingly more and better wireless.*
- » **Independent Power Producer interconnection and Microgrids** *are emerging entities that need to be enabled and incorporated into existing grid infrastructure. Ramifications of these new developments is increased need for flexibility and change in a traditionally static grid infrastructure.*

- **Remote Worker** – *reliable connectivity for office and field workers enabling rich media collaboration at close to real time speeds. All emerging collaboration applications can apply to the utility's personnel, such as enhanced Push to Talk, mobile video conferencing, remote expert, hands free connectivity, etc.*
- **Robotics** – *Drones have started to be used for observation and maintenance, and these use cases are expanding as robotics technologies mature.*
- **Cyber-security** – *is a critical requirement and consists of strong access control for personnel and devices, and active monitoring of all networking activities to prevent and protect against malware. Increased automation of grid networks, as well as dependence of large user communities and critical infrastructure on electricity has huge implications on cyber-security requirements of smart grids.*
- **Situational awareness –** *includes detecting and correcting outages in the most optimal way possible. Early detection of location and cause of outage requires intelligent connectivity of devices as well as extensive telemetry and analytics. Increase in scale and complexity of the smart grid imposes additional requirements on these traditionally manual event detection and correction.*

Detailed set of use cases and requirements can be found at Cisco[17].

6.2 5G Considerations for Utilities

As smart grid designs evolve, it is still not clear how much wireless demand, and of what form and function, would be required in a fully modernized grid. What we do know is that the scale of devices supporting modernization is expected to be at least six times greater than today's quantities of devices being deployed. To give a sense of scale, there are currently 150 million smart meters deployed in households across US, that number is expected to increase by at least six-fold as the electric grid modernizes - and this does not include the actual meters. If meters also use LTE, then the scale of new devices increases by another order of magnitude. Furthermore, performance of future devices is expected to be 10x faster and they need to be more reliable than today's devices.

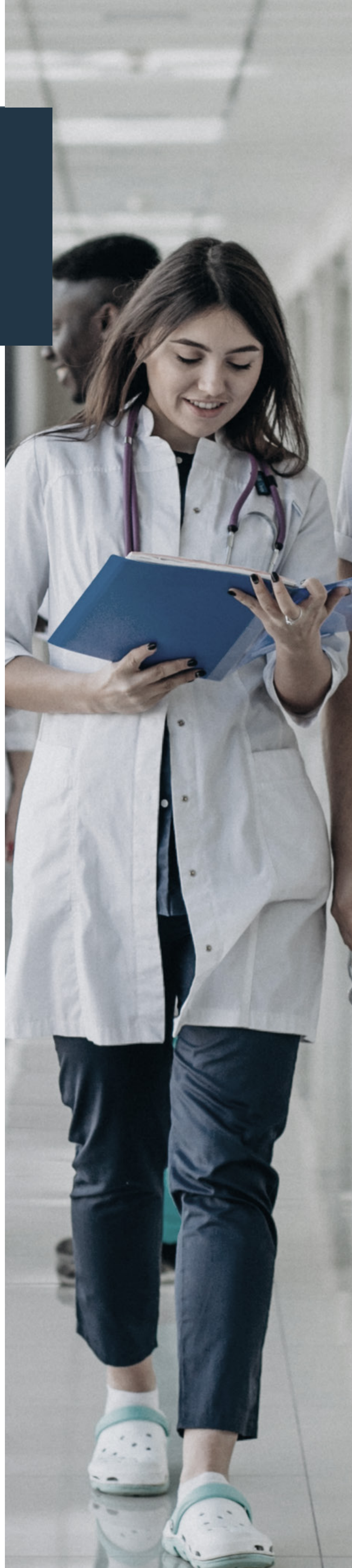
This massive increase in scale will have to be provided in new and future proofed deployment profiles that can last decades without need to change. As such, there is no surprise that 5G technologies are being considered for next generation utilities designs. 5G proposed enhancements that can benefit utilities include Massive Machine Type Communications (mMTC) to address the projected high density of IOT-based devices, Ultra Reliable Low Latency Communications (URLLC) to address the performance and reliability requirements for connectivity of mission critical components and Enhanced Mobile Broadband (eMBB) to improve communications to mobile users (fleet and mobile workers).

Some unanswered questions remain regarding 5G deployment by utilities, which are more focused on deployment logistics, cost, and ownership. These specifically include:

- **Private cellular versus managed service** – *Utilities are considering both privately owned cellular networks that can be owned and operated by themselves, as well as managed services offers from carriers. Both deployment scenarios are considered viable and beneficial. The privately owned scenario enables a utility company to have total control over their assets which is preferred by all utilities, but it also incurs higher operational cost for maintenance of radios and packet core. The managed service offer enables utility companies to take advantage of the expansive footprint of carriers, and to offload complexity of radio and packet core management to the carriers.*
- **Availability of suitable spectrum** - *Many utility companies have acquired spectrum and/or are considering using shared spectrum (CBRS in the US and ISM bands in other parts of the globe) for their immediate uses. Managed service offers by carriers will enable utilities to take advantage of the larger spectrum holdings of carriers as well. What remains to be seen is cost structure of these offers, can carrier owned spectrum be cost effective or not. Or should the FCC (or similar authorities in other countries) dedicate spectrum bands for use by utilities?*
- **Resilience and high availability** – *All deployment scenarios being considered must be able to ensure a high level of resilience and availability. Utility companies can design and build these reliability requirements into their private networks through redundant design and comprehensive monitoring and assurance. When using a managed service, they will need similar assurances from the service provider. To satisfy the utilities requirements carriers may need to dedicate spectrum, radios, packet core instances, and edge computing to utility customers. These dedicated resources can be enabled through the 5G slicing feature set.*
- *Nevertheless, it is not clear how the cost structure of a dedicated slice for utilities will compare with privately owned networks. Also operationally speaking, any slice that gets offered to utilities may be part of a shared resource which may be subject to congestion. Carriers will need to prove their ability to prioritize grid traffic from their commercial cellular traffic in all shared slice platforms. These are challenges that are yet to be solved in practical and business acceptable terms although 5G technology does provide a technical blueprint.*
- **Edge compute** – *massive scale needed by utilities is going to force processing to the network edge to optimize network traffic flows. 5G's virtualized form factors of packet processing, as well as support for Multi-Access Edge Compute, can enable highly distributed designs at the edge. More renewables will force the need for control of the grid in real time, increasing low latency requirements which also drives the need for more capable edge computing to support required latencies.*
- **Cyber security** *remains a top of mind for all smart grid systems. Beyond technical requirements to ensure cyber security it is also expected that government regulations will play a role as Grid safety becomes a more pronounced requirement for national security.*

Additional information regarding the impact of 5G networks on utilities can be found at Smart-Energy.com[18] and Edison[19] [20].

7. Healthcare



The healthcare vertical can benefit greatly from 5G. It is a broad category that can include anything from enhanced telemedicine and remote home monitoring systems to improved responsiveness with connected ambulances using high-throughput computational processing and application of analytics. 5G can improve operations within a healthcare facility with AR/VR assisted education and training, asset tracking and interconnectivity for real-time patient data, as well as even innovative emerging use cases such as remote surgery in unique venues which today are limited to military health support on frontline soldiers.

However, 5G adoption in healthcare faces similar hurdles of budgets and business cases, as well as healthcare-specific hurdles such as concerns over liability, and conformance to Health Insurance Portability and Accountability Act (HIPAA) regulations.

The global COVID-19 pandemic has been a catalyst for rapidly adopting innovation in healthcare. Technology was called upon to enable connectivity with patients, while protecting them and frontline workers and other personnel. The pandemic created a great urgency to set up field clinics to address patient surge and later for vaccinations. Visits and patient exposure were reduced with tele-medicine and remote patient monitoring at home and hospitals, highlighting benefits of improved wireless connectivity that is easy to use and set up. It is expected that the innovation trends that started with the pandemic will continue to drive adoption of new technologies such as 5G and private cellular.

7.1 Use Cases and Deployment Venues

Wireless use cases for the healthcare vertical generally fall into two large categories based on location: use cases inside of healthcare facilities and those outside of them.

Use-cases inside healthcare facilities

Within healthcare facilities, key use-cases for 5G include:

- *location of equipment (asset tracking)*
- *connectivity of devices for data entry (e.g., tablets, laptops)*
- *automated collection of biometric health data for patients (IoT)*
- *remote surgery (long term objectives, which create precedents in AR/VR 'assisted surgery')*

These in-house use-cases will likely start by keeping all data "within the four walls," with mobile edge compute (MEC) to help with HIPAA compliance.

Use-cases outside of healthcare facilities

Outside of healthcare facilities, the following use-cases enable better and less costly extended care:

- *telemedicine/tele-visits*
- *remote patient monitoring*

Chronic patients can be released from a hospital while maintaining necessary monitoring, freeing up valuable hospital space without compromising care. HIPAA concerns here have largely been solved as solutions already exist using a patient's own home Wi-Fi. The use of public macro network 5G could expand reliability and coverage for patients, while maintaining confidentiality through the cellular network's inherent privacy features versus relying on patients configuring equipment to work on their home networks.

This can be especially valuable for older patients who are less mobile—5G could give them access to diagnostics that they normally would not have. Mobile diagnostics (which is a subset of telemedicine) requires more bandwidth than is available today and this helps healthcare organizations reduce their risks and improve patient care by diagnosing early in the process. These bandwidth-heavy diagnostics also apply in ambulance and clinics on wheels or temporary clinics.

7.2 Benefits of Deploying 5G in Healthcare

5G can help address the growing need for connectivity within hospitals. While Wi-Fi is already deployed in most healthcare facilities, challenges arise from growing demand from administration and operations (e.g., connecting and tracking an increasing number of mobile assets/sensors per bed) as well as from a patients and visitors with multiple devices such as phones, tablets, laptops, and wearables. A complementary 5G network can free up capacity on the existing Wi-Fi system and enable new high capacity, low latency applications.

In addition, new requirements for temporary healthcare facilities have emerged because of the COVID-19 pandemic, including temporary outdoor care facilities, quarantine centers, alternate temporary indoor testing locations, and mobile vaccination sites. A 5G wireless system is better suited to support these highly mobile requirements.

Outside of permanent and temporary healthcare facilities, tele-visits have proven their worth through 2020 and 2021 during the COVID-19 pandemic. According to McKinsey, only 11% of US consumers used telehealth in 2019, but this rose to 46% by mid-2020. Congress loosened rules to allow telehealth under Medicare to enable vulnerable patients to get care. A survey by Juniper Research has projected that telemedicine will save the global healthcare industry $21B in costs by 2025 (from $11B in 2021, a YoY grown of > 80%).

This increasing adoption will likely remain even as the pandemic subsides as there are clear efficiencies for both doctors and patients. Improved technologies will enable a wider range of telemedicine to be covered, such as with higher resolution cameras and real-time connected biometric sensors. In the case of tele-visits, unanticipated needs not provisioned by the healthcare system may depend on an individual patient's own devices and bandwidth. Here, the rapid public adoption of new mobile broadband devices makes this use-case available to more consumers.

Telemedicine and tele-visits have large benefits: over 20% of all ER visits could be avoided via virtual urgent care, 24% of office visits and outpatient care could be virtual, and 35% of home health attendant services could be virtualized. The net effect could be 20% of all office, outpatient, and home health spend could be shifted to telemedicine. This shift improves outcomes by increasing access to care and efficiency.

7.3 Challenges for Deploying 5G in Healthcare

There are two major unknowns to work through when deciding on which path to take for 5G connectivity:

- **How predictable is the 5G connectivity?** *While the general perception of 5G is that all 5G is "much faster," there is a lack of awareness of how to predict, design, and achieve the needed coverage and capacity for current and future use-cases.*
- **What will it cost?** *It is difficult to determine and compare the costs of the various options to address the tangible and intangible benefits and ROI (return on investment).*

For use-cases outside of healthcare facilities, working with CSPs is the obvious choice. Temporary healthcare facilities can make use of 5G gateway routers to connect the entire facility. The toughest challenge is in migrating to 5G use-case inside healthcare facilities, where a new 5G network coverage needs to be built, and the device ecosystem needs to be established.

Due to concerns over liabilities, the more extreme use-cases taking advantage of the many attributes of 5G, such as dedicated network slices with guaranteed throughput, ultra-high speeds and low latency, will take time to emerge. These promise to enable revolutionary services such as remote surgeries.

However, it will be simpler to initially focus on the simpler use-cases that provide proven value:

- **Remote Patient Monitoring.** *5G-connected devices can be used for patients that need to be tracked and monitored 24x7 both inside and outside of healthcare facilities. By partnering with the CSP and an IoT healthcare service provider, a hospital can get a dedicated network slice and edge storage, as well as processing and AI capabilities to analyze patients' vital signs in real time.*
- **Telehealth.** *It proved its value during the COVID-19 pandemic. Live video consultations and other services bring quality care directly to those who need it, regardless of location. As a result, healthcare organizations have begun equipping their doctors and care providers with cellular broadband solutions to ensure secure, compliant, and reliable telehealth services can be dispensed from anywhere.*

In the mid to longer term, increasing adoption of 5G-enabled IoT devices and applications can expand services to the above-listed use cases. Doctors and patients no longer need be in the same place to gain access to real-time data from connected diagnostic and medical devices such as stethoscopes, otoscopes, vital sign monitors, ultrasound devices, blood glucose monitors and ECG machines. In addition, 5G could further improve remote healthcare. For example, in the future a doctor can use specially designed haptic gloves and VR equipment to perform procedures remotely through robotic machinery.

The use of emergency vehicles is evolving too. Most ambulances in the US are already equipped with cellular in-vehicle networks to support computer-aided dispatch, mobile data terminals (MDTs), automated external defibrillators (AEDs), live video streaming and connected medical devices. These technologies enable the communication of critical patient information between the field and the hospital and help save lives. Many of these ambulatory capabilities are being deployed over 4G today. However, the low latency, high bandwidth, and enhanced security of 5G are essential for mainstream adoption.

8. Education

The education vertical is a broad topic and can range in scope from a small metropolitan grade school to a large, rural university campus. Education vertical use cases include:

- *Remote learning*
- *Enhanced mobile broadband for large campuses*
- *Immersive lessons through AR and VR*
- *Smart classrooms and campuses*
- *High-capacity video downloading and streaming*

As in healthcare, COVID-19 pandemic has impacted education in numerous ways, catalyzing remote learning in more ways than we could have imagined. Remote learning is severely hindered when broadband access is not available or is not sufficiently capable of providing rich connectivity to emulate classroom situations for younger students who need active supervision to carry on their learning. 5G can close this gap either through a CSP service plan or through a private 5G network. Multiple examples[21] of private 5G networks for remote learning have popped up throughout the US in the past year and the trend continues.

Key pain points for this vertical include:

- *Operational budget*
- *Better wireless indoor (capacity) and outdoor (coverage)*
- *Full broadband access for remote learning*
- *Security, need to own and control the communication network*
- *Commercial Service Provider coverage*
- *Need to future proof to keep up with the latest complex technologies*

One of the main barriers to 5G adoption in the education vertical is available capital and operational budget. There may be the perception that a large, top-ranked, private university has plenty of budget through grants, tuition, or endowments to implement the latest technologies, but direct feedback through multiple interviews advise that is simply not the case. Most of that money is earmarked for specific projects or for specific departments.

There are advanced 5G networks on university and college campuses, but most of them are isolated to specific buildings for research purposes. For instance, one IT director at a major university in California explains, “Trying to pull money out of the general fund to put in a campus-wide 5G network means taking money from some department that is trying to construct a lab that may help cure the next cancer or solve the next energy problem or develop the next student who figures that next problem out, whatever that happens to be.”

Fortunately, there has been some momentum around government assistance for public and private schools at all levels to close the digital divide. For example, the American Rescue Plan Act of 2021 provides $7.2 billion for the E-rate program that makes it easier to connect homes and libraries to the Internet[22].

Other than remote learning, some of the more popular potential use cases for the education vertical includes high-speed outdoor connectivity on large campuses, immersive lessons through AR and VR, smart classrooms and campuses, and fast video downloading and streaming. It is interesting to imagine students going to school, putting on VR glasses, and taking a tour inside Saint Peter's Cathedral, flying through the solar system, or witnessing a march on Washington as if they were there. The high throughput and low latency capabilities of 5G can make this a reality.

College campuses all have existing Wi-Fi solutions that likely provide excellent indoor coverage today, but many college administrators or IT personnel explain it is a constant game of catch up. There is a seemingly insatiable appetite for broadband service. New devices are constantly coming to the market, and it is an inevitability that some will find a corner where the coverage is poor or inadequate.

Additionally, there may be large areas of outdoor space where coverage might be insufficient. University architects and land planning groups are averse to visible access points or antennas, so it can be challenging to build the infrastructure necessary to complete an outdoor Wi-Fi system. A new 5G wireless system would better support the outdoor requirements and can be used to complement the indoor Wi-Fi system. An outdoor 5G system could also facilitate the evolution to a smart campus environment providing the medium to support wireless security cameras, digital information kiosks, and many other devices and sensors. Once established, the 5G system can easily migrate indoors to offload the Wi-Fi system, which could be dedicated to specific use cases.

Lack of commercial wireless coverage indoors is a common complaint for various verticals including college campuses. A private 5G solution could not only complement the Wi-Fi system by supporting secure and staff dedicated applications, but it could also serve as a carrier grade, neutral host system bringing CSP services indoors. As mentioned previously, there are multiple ways to implement a neutral host 5G solution.

On the public network side, an active distributed antenna system (DAS) solution could be installed and shared among all CSPs, but the price tag can be high for both the university and the CSPs and performance can be difficult to optimize. As an alternative, a Distributed Radio Access Network (DRAN) could be deployed, but this would be dedicated to each CSP, so it could be highly intrusive from the vantage of the university.

On the private network side, a neutral host network could be setup to support roaming agreements with the CSPs, where their customers roam onto the University's private 5G network. While the end user would see the university's network identifier on their phone or device, they would still be able to access their CSPs voice and data services. One disadvantage could be that the end user may not have all their subscription services available to them from their home network.

Alternatively, a private/neutral host network can also be configured as a shared Radio Access Network (RAN) solution. The Multi-Operator Radio Access Network (MORAN) option, allows sharing of the RAN equipment, enables each CSP to use their own frequencies and connects the system back to their own core. However, there are limited equipment options that support this type of deployment. In a Multi-Operator Core Network (MOCN) configuration, both the RAN equipment and the frequency spectrum are shared. The MOCN based network connects to the CSP core through a MOCN gateway in a fashion transparent to the end user. End users will see their home network identifiers on their devices and access all services they have subscribed to from their CSP. While there are no major technical roadblocks to implementing either a MORAN or a MOCN solution, it may be difficult to come to commercial terms with the CSPs. That is where partnering with a large MSP may be beneficial, as commercial terms may have already been agreed upon and connection processes formalized.

9. Gaming

Gaming is a unique vertical that drives innovative usage models, which may not have been previously imaginable and are changing the way wireless services are offered and consumed. Much in the same way that texting services replaced basic SMS and paging services in the early days of 4G LTE, gaming has grown in leaps and bounds in ways unimaginable 20 years ago. Similar sets of innovations may be driven through new usage methods and emerging technologies surrounding gaming.

Democratization of the gaming experience and availability of games for any smartphone user is already making the appealing gaming vertical even more potentially lucrative to the 5G-enabled telco industry. The combination of improvements to network infrastructure, as well as the evolution of the gaming industry ecosystem towards better catering to mobile users, will have the most significant impact for the future of mobile gaming. 5G network improvements will unlock better speeds, throughput, and most importantly, low latency for better mobile gaming. However, what matters more than these network characteristics is the consistency of delivery for ideal gaming experiences.

To appeal to the valuable 5G gaming segment, the industry ecosystem will likely evolve as follows:

- *Expanded cloud gaming offering - continuation of gaming on any screen*
- *Advancements in mobile wearables i.e., VR and augmented and mixed reality (AR/MR)*
- *High fidelity immersive environments (better graphics, shapes, textures, sound etc.)*
- *Game creation specifically for 5G mobile device access*
- *Greater industry collaboration, partnerships, and sponsorship*
- *5G gaming focused value bundling, gaming-as-a-service (GaaS) and innovative new business models*

Together, these improvements will create a more dramatic shift to cloud gaming, smoother gameplay, more immersive (VR and AR/MR) and social experiences, as well as refined go-to-market approaches to incentivize 5G gaming.

9.1 5G Technology Considerations for the Gaming Vertical

- **5G New Radio (NR) architecture** – *Gaming performance and experience will improve as telecommunications providers shift from 5G NSA (non-standalone) to 5G SA (standalone) networks. Additionally, there will be enhanced coverage densification provided by mid-band spectrum, and both enhanced speed and coverage from high-band and mmWave spectrum. More specifically, 5G SA's enhanced mobile broadband (eMBB) and Ultra-Reliable and Low Latency Communications (URLLC), will dramatically improve and guarantee speed (reliability of more than 99.999%), throughput and very low latency allowing for next level 5G gaming experience. When it comes to mobile gaming, these advancements could feel like going from the original PlayStation game console to PlayStation 5, leap frogging generations of innovation and creating 5G-enabled high fidelity experiences.*

- **Speed -** *It can be expected that speed requirements will grow over time, but it will not just be speed itself that matters. Other factors determining the likely minimum speed thresholds may depend on cloud provider, game genre type, resolution requirement, accessories used – as well as impact consistency requirements to enable smooth gameplay. While uploading has traditionally not been as important, the growing popularity of sharing video clips on YouTube is starting to change this. Today, games and associated services may require 10-20 Mbps, but this could climb to 20-40 Mbps or more in the future.*
- *Additionally, the lower the volatility of speeds, the better the end user experience. For example, 10-15 Mbps is often better than 10-50 Mbps, if data throughput remains stable. Of course, in general, higher and more consistent speeds are ultimately more desirable (e.g., 40-50 Mbps is better than 10-15 Mbps). Today, game streaming is currently capped at 4K (Google Stadia) but tomorrow this could shift to 8K.*
- **Latency -** *Network features such as multi-access edge computing, regional cloud, network slicing and QoS will assist in bringing users closer to telco networks, as well as prioritizing gaming traffic for improved latency to better support immersive multiplayer and cloud gaming. Improved latency of less than 20 ms also enables VR/AR gaming experiences.*
- **Edge computing** - *will be a critical feature for supporting the ultra-low latency and throughput required by 5G gaming as well as VR/AR, especially since most cloud gaming providers have centralized architecture. Paired together, 5G and edge computing will help reduce workload and battery drain on mobile devices and enable a better overall user experience through reduced frame loss and motion-to-photon latency. Recently, an unexpected finding at an AT&T edge computing test zone at its research center in California found edge computing's delay predictability versus the amount of delay itself.*

As consumer 5G network technical knowledge and understanding grows, expectations will likely shift from simply understanding latency, to knowing how consistently it is delivered (guaranteed), which will make metrics like 'jitter' more important and more commonly understood.

For 5G gamers, pings above 100ms can impact a player's ability to compete in fast-paced games. While 5G with edge computing should help improve this, high motion-to-photon latency (or simply "lag"), can create a side effect of nausea among some gamers. In a recent experiment with Google Stadia, a tester evaluated the cloud gaming experience on different game genres and determined:

- *1-25 ms no perceived lag, feels native*
- *25-100 ms some perceived lag*
- *100+ ms noticeable lag*

Given the 'on the go' benefit of 5G gaming, coverage will also be a growing consideration for gaming consumers. In particular, 'availably rate' is a helpful metric that some third-party sources use to measure the proportion of time 5G users spend connected to an active 5G signal. Availability rate, as per the OpenSignal US report from January 2021,[23] noted that T-Mobile moved from 22.5% to 30.1%, Verizon moved from 0.4% to 9.5% and AT&T moved from 10.3% to 18.8%.

9.2 Gaming Industry Ecosystem

- **Cloud Gaming providers** - *5G network experience improvements will encourage the shift from console / PC gaming to cloud gaming. This trend may lead to greater collaboration between cloud computing and telco providers to enable a better network gaming experience through different technologies like edge computing, as well as increased marketing* *partnerships. An example of such a partnership is the recent three-year deal Verizon signed for the official 5G network service partnership with Riot Games for League of Legends and Valorant e-sports.*

- **Game Developers and Publishers** - *The industry is anticipating the development of '5G original' high fidelity games, which are adapted to the unique requirements of specific mobile devices, such as leveraging the camera, GPS, sensors, as well as the medium itself. It is expected the overall accelerated shift to mobile will change the perception that mobile gaming compromises quality. A comparable example of this change is like how HD and modern special effects have impacted the Hollywood film industry in terms of production quality. Examples of this popularity include Call of Duty and Mario Kart Tour, which are both major gaming franchises now available on mobile. In addition, the popularity of free-to-play gaming models like the one used in Candy Crush are demonstrating the benefit of the mass adoption of mobile play leading to new, profit-driven business models via advertising and in-game purchases.*
- **Wearables** – *Over the next few years, there will likely be a dramatic progression in wearables, given the substantial improvements in latency. VR will shift to mobile with higher graphic resolution. AR/MR will create immersive gaming experiences through expanded field of view, as well as enable real-time shareable / viewable AR content to facility team experiences. Wearables will essentially create a new 'hardware' category not unlike the first-generation game consoles of the 1980's. One example is the Microsoft HoloLens 2, which demonstrates benefits including an increased ability to see more holograms at once through increased field of view, as well as a more refined ergonomic, instinctual, and untethered experience.*
- **AR/VR technologies** *will be used in gaming applications to immerse players into the heart of a game storyline and provide enticing virtual objects. Due to the more entertaining environment, AR/VR technologies could potentially lead to renewed momentum for outdated games. AR/VR developers can use improved user experience to attract and appeal to gamers in new ways. It is likely that this category will see access to 5G provide an avenue for lower-cost, lighter weight, more comfortable peripherals with better batteries. Better battery life could take the form of improved batteries overall and more efficient devices.*
- *New peripherals will also make it easier to play games on a smartphone, including third-party controllers, VR headsets, and battery packs. Furthermore, through the Internet of Senses, features such as haptics (visceral), spatial (immersive) audio, and smell could eventually make it to the forefront of VR and AR gaming titles. Ultimately, mass adoption of VR/AR will likely be dependent on the quality of the released content, as well as how successful it will be used in other vertical use cases, such as stadium-based entertainment viewing.*
  One example of an innovative VR/AR game title was the November 2019 release of Half-Life: Alyx, which ended up being the highest profile VR game, causing sales to soar for all other VR devices, including Facebook's Oculus.
- **E-Sports** - *This rapidly growing sector of the gaming industry will be heavily affected by 5G gaming. Many telcos are partnering with game developers to demonstrate the benefits of their 5G networks through mobile e-sports tournaments. For players, lower latency can result in more wins. When applied to a competitive setting, network characteristics will have to be on a fair playing field like equitable rules/equipment for any other professional sport.*
- *Audiences can also expect better streaming and more immersive experiences provided by VR/AR (with expanded field of views). It is likely that competitive VR/AR multi-player games could grow in popularity for*

competitive esports, as well. With enhanced fan experiences, increased advertising and sponsorship dollars are likely to follow. Recently, Verizon formed a partnership with Dignitas allowing gamers to train in a state-of-the-art 5G e-sports facility in Los Angeles, CA as part of their 5G Lab.

- **Gaming Genres** - *Existing gaming genres will continue such as: shooting games, sports games, action/adventure games, casual single player & multiplayer games. However, there will likely be developments such as the rise of Massively Multiplayer Online (MMO) games and emergence of new story telling capabilities and new genres like interactive real-world games, given network advancements and improvements in AR. Pokémon Go, a free-to-play, location-based augmented reality game developed by Niantic, has gained growing popularity driven by multi-player and AR features.*
- **Advertising** - *5G gaming should in principle be the catalyst for more targeted and relevant in-game advertising. Dynamic in-game advertising (DiGA) will allow brands to create dynamic in-game events more easily and efficiently. In addition, geo-targeted advertising will be more impactful as more customers take gaming on the go. From fast food geo-targeted ads to a branded experience side-missions, there will be greater potential ad revenue from the shift towards cloud-based 5G gaming.*

9.3 Emerging Business Models in 5G Gaming

The growth of 5G gaming will foster the growth of Gaming as a Service (GaaS). GaaS allows users to access a game or content (via on-demand streaming) from any device through a recurring revenue model. It offers ways to monetize video games either after their initial sale, or through a free-to-play model. There are a variety of GaaS examples ranging from Massively Multiplayer Online Games (MMOs) which use a monthly subscription, game subscription services like Xbox Game Pass which provide access to a large digital library, cloud gaming like PlayStation Now which allow subscribers to play via remote servers on local devices, microtransactions which profit off low-cost purchases and season passes, which provide large content updates over the course of a season or year.

With the ability to target the desirable 5G gaming segment, there will likely be curated 5G gaming specific packages from telco providers to incentivize purchases. These could take the form of the following:

- *Premium packages with abundant data*
- *Discounted / bundled cloud games with 5G contract*
- *Bundled wireless and wireline offering*

Recently, US-based wireless companies have started to aggregate content through discounted digital bundling to differentiate offers, reduce churn, promote 5G usage, and gain consumption data. Verizon offered 12 months of PlayStation Plus and PlayStation Now, starting in late 2020 for 5G customers with select unlimited plans.

There will likely be continued growth in marketing partnerships and sponsorships with cloud gaming providers varying from promotion of edge computing and QoS service features, customer loyalty program benefits, branding with game developers, and co-marketing. Many telcos are seeing the advantages of these partnerships for promoting new 5G offerings to the gaming community.

South Korea Telecom (SKT) partnered to provide ‘SKT 5GX Cloud Game’ powered by Microsoft Xbox Game Pass Ultimate in South Korea. The offering included access to more than 100 games in the Xbox Game Pass catalog for approximately US $14.40 per month, which is viewed as both a revenue generator from an existing base, as well as an acquisition tool for gaining new customers.
In January 2020, a South Korean cellular carrier also launched a cloud gaming service GeForce NOW (January 2020) in partnership with Nvidia and made accessible on the LG Plus smartphone. As a retention play, it was offered free of charge to customers who had subscribed to its 5G service.

Elsewhere, Verizon’s three-year official 5G network service partnership with Riot Games for League of Legends and Valorant e-sports is expected to provide customers with discounts on League of Legends in-game purchases through the Verizon Up program. In addition, AT&T has worked with ESL to launch ESL Mobile Open an all-year e-sports league.

10. Summary of Findings and Recommendations

Having considered several large verticals, mass deployment of private 5G will depend on a balance point between what carriers are willing to offer and capable of generating revenue from, and what for what enterprises are willing to deploy and pay. While the exact balance point is still elusive, we offer several key comments and findings we believe will assist the evolutionary direction of the market.

10.1 Enterprise Expectations of a "Private" Network

The most significant issue that arises out of conversations with enterprises is how the use of 5G technologies in their firms will align with their expectations of a "private" network versus the carrier/provider notion of a private network. Over the years, cellular carriers have optimized their offers based on a massively scalable commercial cellular business model that constitute simple rate plans offered on a subscription basis to hundreds of millions of subscribers, all using the same service type for extended periods of time. In the case of private networks carriers, must create practices and processes to create customized service offers that get deployed at a much smaller scale.

That said, it may be possible to "cookie cut" some offers for specific groups of enterprises, and/or to create new sophisticated rate plans that can meet specific use cases in a vertical. For example, a rate plan for an IoT end point designed for connected cars or frontline personnel might be a specific use case. In general, any service plan that comes close to a commercial cellular subscription will be easier for a carrier to deploy, and that is exactly how carriers have been approaching this problem. Simpler private cellular use cases can be covered with innovative new service plans from carriers, which enable the community to take advantage of the vast radio footprint that carriers own and manage.

However, more complex use cases raise issues surrounding enterprise data privacy and security. Enterprises demand control of their data and operations to meet their security, privacy, and liability requirements. To serve enterprises on their own terms, carriers need to ensure that enterprise data remains within a clearly bounded firewall and protected network perimeter with security and privacy policies applied to all interactions on this data. Enterprise security policies may differ from each other, as there is always the need for unique and custom surveillance, audit, and monitoring of specific enterprise assets and venues. Many large enterprises have multiple sites that are geographically dispersed in different countries, which will need to be brought under the same umbrella policy of the overall enterprise. Given the complexity, private cellular networks that function more like an enterprise wireless Wi-Fi network, and which can be controlled wholly by enterprise IT, are easier to deploy. Carriers who offer 5G services to such enterprises will have to ensure that the offers fit within its security, privacy, and access control policy environment.

10.2 Carrier's Vision of a Private Network

Carriers are the drivers of all 5G deployment when it comes to commercial cellular networks. As such, they are undertaking a major overhaul and enhancement of their public footprint which can last several years as 5G commercial deployments mature.

When it comes to “private networks” carriers find themselves in a new and unfamiliar territory. While they have extensive sets of capabilities: RF spectrum holdings, broad presence and footprint, high-capacity fiber networks, sophisticated and knowledgeable technical staff, it is not clear how they can apply these capabilities to effectively translate to revenue generation from serving private enterprises. These enterprises tend to need custom deployments, a smaller number of end points with higher technical and SLA demands, and competitive pricing to existing commodity enterprise wireless. These business and commercial challenges will continue to beleaguer carriers until new modes of service delivery and consumption are defined and made available. While these new definitions are not very clear, much work is ongoing to define them.

On the technical side, network slicing is perhaps the most significant feature that can facilitate closer alignment of carrier offers with enterprise demand. Network slicing can enable carriers to dedicate bounded portions (slices) of their network to an enterprise with more assurance than general sharing schemes used in all modern IP networks. These features, once fully realized, can raise the reliability and resilience of a shared network resource closer to the older TDM networks where dedicated resource scheduling was a norm. To enable end to end slicing, carriers need to be able to dedicate components of their RAN, packet core, and transport networks in a unified whole to the enterprise service.

These large components each have their separate and unique, segmentation, slicing, and sharing mechanism. For example, RAN slicing can be accomplished with dedication of spectrum bands to an enterprise. Packet core slicing can be accomplished through dedication of virtual network functions (VNFs) with dedicated compute resources to a specific enterprise instance. Transport slicing can be accomplished through dedicated virtual paths that may be traffic engineered through the provider network. For an end-to-end slice to work correctly, all resource allocations must be automatically orchestrated using an end-to-end management and orchestration platform, and end-to-end monitoring and continuous audit has to be enabled to ensure quality, so SLA offers from carriers to enterprises can be enabled.

A detailed set of use cases and requirements for slicing can be found at: 5G for enterprise: Key insights from global survey with service providers - Ericsson. Here is a summary of findings:

1. Capability requirements to fulfill the potential of network slicing

- *End-to-end capabilities*
- *Ease of automation*
- *Customized business models targeting enterprises*
- *Ecosystem support*

2. What can 5G RAN slicing offer and what the key elements to support service differentiation and providing new revenue stream

- *E2E management support*
- *E2E orchestration support*
- *Flexibility and scalability*
- *Guaranteed performance*
- *Secure existing MBB*
- *Maximize spectrum efficiency and utilization*

3. How we can make this happen - network slices can be associated with dedicated QoS characteristics per service (5QI) controlling traffic treatment in the RAN

- *Dynamic Radio Resource Partitioning*
- *Slice-aware QoS Differentiation*
- *Slice-aware observability*
- *Slice orchestration support*
- *RAN transport slicing support*

4. Top priority use case clusters with network slicing – based on Ericsson Enterprise Business Survey, Dec 2020

- *Smart Surveillance – 88%*
- *Monitoring & Tracking – 63%*
- *Real-time automation – 63%*
- *Remote Operation – 56%*
- *Augmented / Virtual Reality – 50%*
- *Connected Vehicle – 41%*
- *Autonomous Robotics – 41%*
- *Enhanced Video Service – 31%*
- *Hazard Maintenance sensing – 22%*
- *Other – 3%*

Slicing features are in various stages of development. The biggest challenge for a complete slicing offer from carriers is in simplification of the and reduction of number of permutations that may be possible in an offer. A highly flexible slicing offer that allows granular resource allocation at close to real time may not be realizable due to complexity. However, simpler offers that can practically ensure critical resource dedication to an enterprise may be achievable earlier. Furthermore, work needs to be done to provide a clear picture of how these features will be monetized and match enterprise expectations.

10.3 Roaming and Private Cellular

Roaming being a major feature in public cellular offers is always considered in private cellular discussions, however, not all industrial use cases need roaming. Basic use cases for surveillance and backhaul are static, while other mobile use cases that enable machine-to-machine connectivity, automation, robotics, or wearables with enhanced I/O are usually used in well-scoped and bounded spaces, such as on factory floors. Use cases that do require roaming usually involve frontline personnel in geographically dynamic venues requiring high quality connectivity using 5G. These latter use cases may be a much better realized through public provider premium commercial cellular, as opposed to private cellular use cases.

When considering private cellular use cases, it is important to fully understand how much roaming is required in each venue, as well as what user end point capabilities are for attaching to multiple networks. There are different methods that can be used, specifically:

Cellular roaming through carriers involves PLMN (Public Land Mobile Network) assignments and roaming agreements that enable users to move from one carrier network to another with carriers still tracking subscriber information such as those needed for charging. For independent and smaller private cellular networks to join these agreements, there needs to be assignment of PLMNs to the smaller private networks, as well as peering agreements between the carriers and private networks. Establishing peering agreements takes a level of complexity that may not be acceptable to either the enterprise or the carriers involved. Overlay networks can be created, with a dedicated PLMN and carrier roaming agreements, to represent large groups of smaller private networks and enable carrier style roaming, examples include shared PLMN IDs defined in CBRS networks.

Open Roaming provides ease of movement from one network to another without further need of authentication and authorization of the device. Networks that enable open roaming can register to a federation which has established agreements, which establishes that users of each member network can be trusted and can, therefore roam to the other network. Open Roaming is a simpler alternative to cellular roaming in areas where multiple trusted networks are co-existing and where subscriber usage information for charging is not required.

A third option for roaming is through the application layer which requires multiple SIMs and possibly radios on user end points to enable parallel connectivity to multiple networks. Dual SIM arrangements are possible for now and can be extended in future. There are always considerations of battery power needed for multiple radios, as well as application layer readiness for intelligent handoff of context from one SIM to another. These details are in discussion in the device vendor community. It is expected that improved device profiles will emerge as multiple network usage becomes more prevalent.

10.4 Co-existence with Other Wireless: Wi-Fi, IoT, Cellular

As enterprises look to reduce cost and simplify their operations, they are keen to align their networks. As such all private cellular providers have tried to simplify their packet core and radio collaterals to look more like Wi-Fi wireless controllers, as demonstrated in early prototypes, and/or hide the complexity of operating a 3GPP style network in cloud hosted offers. The ideal vision is a multi-access network where different access layers, wired or wireless, can be implemented with similar operations, at least at the level of enterprise policy, security, and management. This alignment and co-existence of various wireless networks, as well as alignment with wireline networks, is an active topic of research and development.

10.5 Device (UE) and Application Readiness

As exciting as 5G capabilities can be, there is still a large gap between the current existing state of user end points and applications versus a fully fleshed out and robust user environment. Today, available 5G UEs are limited to cell phones and tablets, as used in commercial cellular cases. Routers, Customer Premise Equipment (CPEs), industrial routers and cellular gateways are emerging for fixed wireless access, point to point, or backhaul use cases. More sophisticated UEs are still in prototype format and are being evaluated in lab settings. For industrial cases, the UEs will not only need to be functional in a 5G network, but many also must pass industrial safety and security compliance testing. Furthermore, many of the emerging use cases involve insertion of a 5G interface onto a larger piece of equipment, such as an Automated Guided Vehicle, with connectivity to applications that can control that equipment. The end-to-end readiness will need more time to mature and become effectively consumable.

10.6 Spectrum Availability

Shared and unlicensed spectrum have been critical drivers for private network enterprise considerations. However, it is not clear how much new additional shared spectrum will be available going forward. Use cases that can benefit from 5G require a good amount of spectrum for high throughput (mmWave). Meanwhile, enterprises are having more choices due to the emergence of Wi-Fi 6 with radio enhancements similar to 5G, as well as improved scheduling algorithms to increase determinism, and the enablement of more unlicensed spectrum (6E) for Wi-Fi use cases.

Many industrial use cases can be realized with Wi-Fi 6 using unlicensed spectrum. For expansive and geographically diverse area coverage, public carriers have a significant edge given their radio presence and rich spectrum holdings. For these outdoors use cases, managed services by public carriers are an optimal choice. What will decide the choice of deployment will be readiness of all components and end-to-end efficiency of solutions. The efficiency and quality of the various types of solutions whether licensed or unlicensed a critical topic that need closer attention.

10.7 Sharing and Aggregation of Radio and Spectrum

One of the topics that comes up in many private cellular discussions with enterprises is the possibility of enterprises to own and operate radios that can serve not only their private cellular network, but also traffic that may originate from their enterprise that needs to be routed to various carriers. This is referred to as ‘neutral host’ capability with some variation.

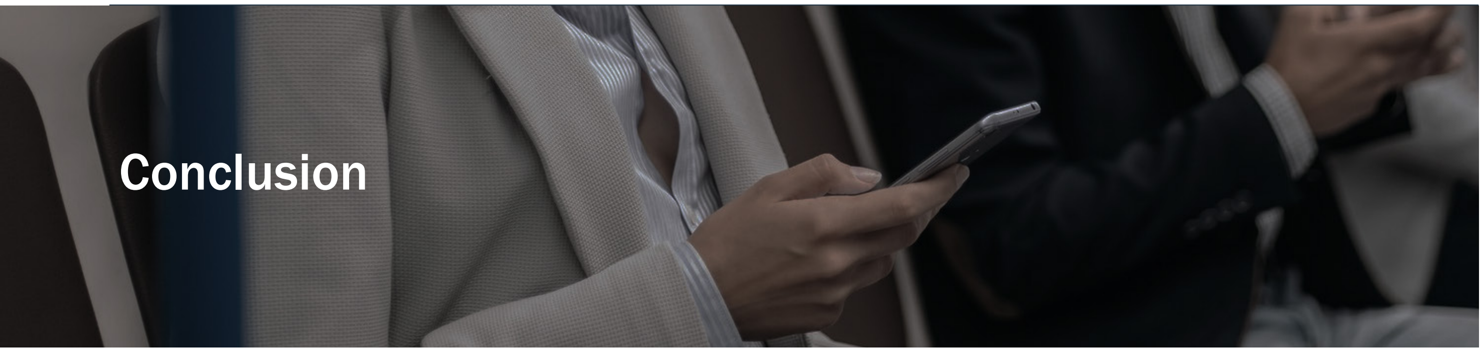
Typically, an enterprise IT department’s motivation of owning their radios stems from need for control, as well as reduction of third-party footprint at their premises. Installations of Distributed Antenna Systems (DAS) in many enterprise venues is a normal practice for all carriers, with its purpose being to improve cellular connectivity for enterprise employees and guests. DAS’ are usually placed in places where outdoor macro cells have a difficulty reaching. These DAS units are owned and operated by carriers or by third-party vendors that represent carriers. In all cases, access to the enterprise premise for monitoring and maintenance of these DAS systems is required. This can become an issue when multiple carriers have separate DAS units placed on various sites of an enterprise premise.

As 5G mmWave small cells are introduced by multiple carriers, there may be a need to place 5G small cell radios in many locations on enterprise premises. The large increase in the number of carrier radios on enterprise premises may be causing some concern for enterprise IT leads and motivating them to consider setting up a neutral host network where they can serve cellular needs of carriers with enterprise owned radios and route the traffic to respective carriers. 5G technology that is relevant to these types of network resource sharing include:

- **MORAN**- *Multiple Operator RAN is a model where operators can share RAN infrastructure. This concept has been around for a while and even though it is simple way of sharing network infrastructure, it has not yet become popular among operators anywhere in the world for any previous wireless cellular generations of technology. MORAN has not been standardized by standard bodies like 3GPP and operators use their own mechanism to share infrastructure. With emergence of OpenRAN, the MORAN could become a good alternative to host Centralized Units (CUs) and Distributed Units (DUs) in a separate virtualized environment and use a common infrastructure for the hosting of all the Radio Units (RUs).*

  Recent indoor neutral host solutions based on small cells enables mobile operators to utilize their dedicated basebands while sharing the radio networks in a MORAN scenario. While neutral host owners can absorb the cost for RF infrastructure and charge mobile operators for utilizing the RF network (like DAS deployments) and use their spectrum, this will provide extra capacity for future 5G networks. Also, it will allow mobile operators to unleash the true potential of 5G network features for indoor deployments, such as location-based services, which DAS solutions are not capable of supporting.
- **MOCN** – *Multiple Operator Core Network is a model where RAN resources, including spectrum, are shared between with multiple packet core network from different operators. This is supported by 3GPP standards for many releases and many Mobile Network Operators (MNOs) are using it for 4G deployments. An example of MOCN includes non-standalone architecture (5G NSA, option 3x (EN-DC)) where a 4G and 5G core can both use 4G RAN resources. With availability of CBRS neutral host owners are positioned to provide indoor coverage and infrastructure for mobile operators based on MOCN. In this scenario, mobile operators connect their core network to the shared baseband and RF network, sharing the spectrum with other operators. Unlike MORAN, in this scenario, mobile operators do not have dedicated spectrum for their subscribers. Still, for markets with limited spectrum availability, this can be a viable solution to provide 5G services with little investment.*

As with other aspects of 5G in private cellular, the business arrangements that are needed for these shared deployments are evolving and being defined. This may be a topic that can be served by third-party vendors that offer neutral host capabilities, and/or functions that can be deployed in a private cellular owned and managed by the enterprise, or yet sharing mechanisms that can be offered by carriers themselves.



Conclusion

Perhaps the most important conclusion that can be drawn from considerations of 5G and 4G LTE in private cellular contexts is that there remains a great deal of innovation to be considered and expected as 5G rolls out and becomes more effectively available. 4G enabled a set of capabilities that were not imaginable earlier, 5G too will be enabling a set of capabilities that may not be imaginable today but are coming.

These early discussions with enterprises are helping pave the way for understanding potential requirements, however, one should not look at these discussions as a final state. All venues and use cases are evolving in several directions, with many possible combinations. As we gaze at the horizon of possibilities, we should all agree to stay open to change and embrace new solutions. Directions that are becoming clear include: virtualization and disaggregation of all network components, including the radio networks, movement of application to clouds of all shapes and forms (private, public, hybrid), emergence of new modes of human interaction ala wearables and applications such as AR/VR, automation at a scale that was not possible before, more machine intelligence at venues that we may not have ever considered, flexible hybrid service offers provided in part by a private network and parts by a public provider, and other unforeseen application combinations.

The possibilities are endless. The only firm, unchanging set of requirements are for a solid foundation of security and data sovereignty, as well as an acceptable cost-to-benefit ratio for all. The 5G wireless ecosystem continues to progress as this next generation of innovation continues to address new use cases, applications, and vertical markets.

Acronyms

3GPP: 3rd Generation Partnership Project

5GNR: 5th Generation New Radio

AI: Artificial Intelligence

AR/VR: Augmented Reality / Virtual Reality

CBRS: Citizens Band Radio Service

CN: Core Network

CSP: Commercial Service Provider

CU: Centralized Unit

DU: Distributed Unit

eMBB: Enhanced Mobile Broadband

FCC: Federal Communications Commission

GAA: General Authorized Access

GaaS: Gaming as a Service

HTTP/2: HyperText Transfer Protocol 2

IoT: Internet of Things

ISA: International Society of Automation

ISA-99: Industrial Automation and Control Systems Security (now also known as IEC-62443)

LAN: Local Area Network

LTE: Long Term Evolution (4G)

MANO: Management and Orchestration

MIMO: Multiple In, Multiple Out

ML: Machine Learning

M-MIMO: massive MIMO

mMTC: massive machine-type-communications

mmWave: Millimeter Wave

MNO: Mobile Network Operator

MOCN: Multi-Operator Core Network

MORAN: Multi-Operator Radio Access Network

MSP: Managed Service Provider

NF: Network Function

NFV: Network Function Virtualization

NOC: Network Operations Center

NPN: Non-Public Network

non-RT RIC: non-Real-Time RIC

NR: 5G New Radio, i.e., 5G radio access technology

NR-U: New Radio Unlicensed

NSA: Non-Stand Alone

OAuth: Open Authorization

OTA: Over the Air

PLMN: Public Land Mobile Network

PLMN ID: Public Land Mobile Network Identification

PNF: Physical Network Function(s)

POC: Proof of Concept

PON: Passive Optical Network

PPF: Packet Processing Function

PTT: Push-to-talk

QoE: Quality of Experience

QoS: Quality of Service

RAN: Radio Access Network

RAT: Radio Access Technology

REST: Representational State Transfer

RRU: Remote Radio Unit

SBI: Service Based Interface

SDN: Software Defined Network

SEPP: Security Edge Protection Proxy

SLA: Service Level Agreement

TCO: Total Cost of Ownership

TLS: Transport Layer Security

UI: User Interface

UL: Uplink

URLLC: Ultra-Reliable Low-Latency Communication

V2X: Communication between vehicles and other devices, Vehicle to Anything

VNF: Virtual Network Function(s)

VoLTE: Voice Over LTE

WLAN: Wireless Local Area Network

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