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Chapter 3: Accelerating connectivity through 5G: Deployment strategies, use cases, and future outlook

3.1. Introduction

Modern civilization is characterized by increased use of mobile devices. This trend is only accelerating with the ever-increasing variety of devices, higher computational capacity, and capabilities of mobile devices that make them the popular choice of users. Like the devices, the service requests sent by these devices are increasing also in variety and complexity, including high-definition content streaming, online gaming, and support for autonomous vehicles, as well as the common use cases such as web surfing and online social networking. The requests are also more latency sensitive. At the same time, with the reduced size and power of each user device, the number of mobile users in a given area is ever increasing. This user-density growth, coupled with the explosive increase in traffic generated by mobile devices and IoT-enabled devices, is expected to challenge the performance of existing wireless access networks, causing degraded quality of service and limiting connectivity among users (Abbas et al., 2018; Nguyen et al., 2021; Spicher et al., 2021).

Smart devices and particularly mobile devices have become an integral part of daily life, impacting all aspects including work, communication, education, travel, smart city implementation, etc., and the ongoing pandemic has accelerated the pace of digital transformation globally. The expectations on next-generation mobile systems are their ability to provide universal connectivity, support a humongous number of devices and connections, and deliver secure, high-speed, low-latency, seamless communications for all mobile and fixed applications. These demands require developing wireless systems capable of providing 10 to 100 times better performance than the current mobile systems, which is the key goal of 5G. The design and implementation of a network capable of supporting 5G demands is a major challenge and have been a hot research topic for several years, including topics such as 5G architecture, enabling technologies, air interface design, localization support, and security and privacy (Yang et al., 2019; Yao et al., 2018).

3.1.1. Background and Significance

The advent of wireless technology has transformed contemporary society, bridging divides and shrinking distances across the globe. The evolution from 3G to 5G has been accompanied by an explosive increase in both the demand for and supply of services and resources, as well as an extraordinarily rapid advancement in semiconductor speed and architecture, communication technology, and wireless economics. The fifth generation of mobile connectivity promises to bring about profound societal changes, including ubiquitous communication that expands access to global resources for businesses of all sizes, mass deployment of novel applications based on real-time data that increase productivity in sectors vital to economic development and growth, a vast ecosystem of devices that improves the quality of life, and critical infrastructure that enhances security.

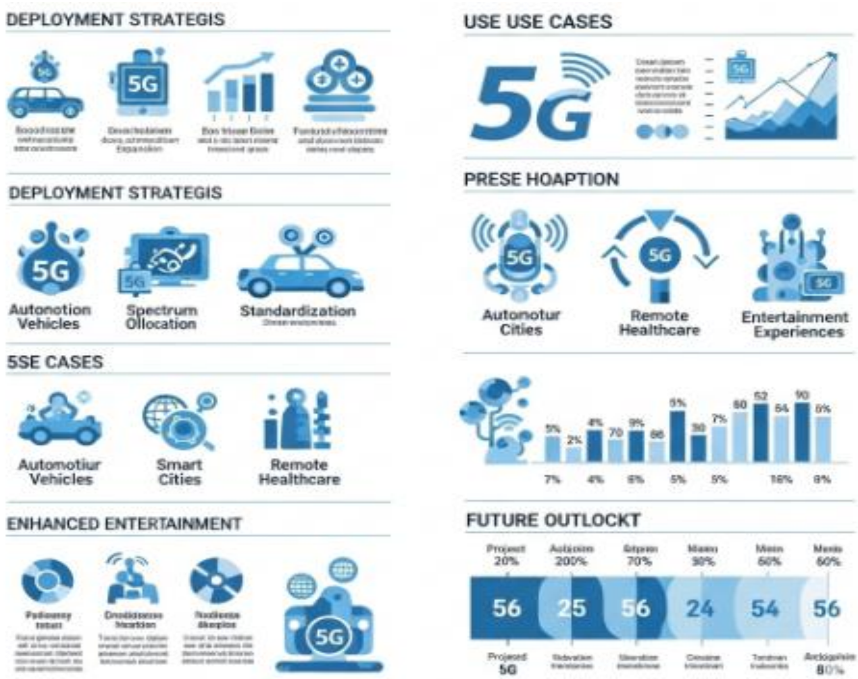

Fig 3.1 : Accelerating Connectivity Through 5G: Deployment Strategies, Use Cases, and Future Outlook.

Unlike its predecessors, which enhanced connectivity primarily for large consumers, business users, and carriers, 5G enables a plethora of formidable use cases that positively impact consumers, business enterprises, and other facets of the economy. It utilizes a paradigm shift in radio network architecture—one that enhances connectivity by integrating a multitude of wireless systems to unlock the next level of Massive Connectivity—for the deployment of extremely low-cost devices that extend global connectivity to billions more people and millions of businesses. It also supports an unprecedented number of highly diverse Machine Type Communications use cases, including highly reliable and ultra low-latency services in connected vehicles, health care, and public safety; broadband connectivity in key sectors such as education and healthcare; and massive MTC communications in smart cities, factories, and buildings. The dimensions of diversity are brought in by services that involve diverse classes of use cases—those having diverse applications, from remote control to augmented reality; diverse performance requirements—requiring a wide range of peak and average data rates, latency, and reliability; and diverse payers—such as consumers; enterprises requiring enhanced mobile broadband, ultra reliable low latency, or massive machine type communication services; and public safety agencies.

3.2. Understanding 5G Technology

Fifth-generation wireless systems (5G) are the next-generation cellular systems that will succeed fourth-generation wireless systems (4G). 5G has key features that include high peak data rates, high and low user densities, wide channel bandwidths, extreme low latency, high reliability, the ability to connect many devices or sensors, and low energy consumption to meet the requirements of various emerging use cases. These key features have made quite a big impact on industries spanning across automation in healthcare, government defense, financial services, manufacturing, transportation and logistics, and energy and utilities, as well as enabling other phenomena such as the industrial revolution.

5G innovation is substantially based on the key technologies of the new radio (NR) technologies. The key technologies for NR include wider channel bandwidths in the millimeter band, new spectrum resources such as millimeter wave bands, a large number of antennas enabled by massive multiple input/multiple output technologies, new waveforms to support low latency, new functions for low power consumption and low cost, and new network technologies such as software-defined networks and network function virtualization. 5G brings new and innovative solutions, such as cloud-centralized radio access networks, the new radio concept of ultra-low power devices for low-power wide-area networks, and machine-type communications.

3D networks are designed to meet the requirements of diverse ways to connect people, machines, and sensors for various use cases and applications, such as virtual reality for gaming, remote medical operations for healthcare, autonomous driving for connected vehicles, connected energy systems for energy management, smart factories for industrial IoT, and smart buildings for smart spaces. The key performance indicators to be achieved are very high speed for enhanced mobile broadband, low latency for ultra-reliable low latency communications, and a large number of connected devices for massive machine type communications.

3.2.1. What is 5G?

As the successor of 4G technology, 5G is the upcoming wireless networking standard designed to connect virtually everyone and everything together, including machines, devices, and objects. Built on an evolving platform with increased speed, reduced latency, and the ability to connect more devices at once, 5G is expected to impact all sectors of the economy, but especially the telecommunications sector. With faster speeds, more reliable service, and massive data capacity, 5G is likely to power applications and innovations that have not yet been invented.

In the coming years, almost every moment of our lives will be shaped by a digital connection. Future innovations will be dependent on communications that are instantaneous, secure, and autonomous. 5G wireless technology will drive the future of connectivity, unleashing the next generation of advanced technologies, including: autonomous vehicles; augmented and virtual reality; high-definition video streaming; drone technology; and the Internet of Things. From the inception of low-power IoT networks to the launch of megaconstellations of satellites in low Earth orbit, wireless connectivity has rapidly expanded. Each generation of wireless technology has provided a new level of improvement over its predecessor. 5G is the latest leap in the wireless journey. It combines the best of prior generations and expands upon them. 5G will primarily enhance the wireless experience for consumers. Enterprise business models and use cases are also emerging around latency, reliability, density, and overall performance benefits that 5G offers.

3.2.2. Key Features of 5G

5G technology is introduced as the latest cellular technology with superior features including greater speed, increased capacity, lower latency, and the ability to connect more devices. 5G is here to not only accelerate our previously established capabilities but also to create new opportunities through narrowband Internet of Things technology for industries. 5G is the latest generation of wireless technology and is expected to introduce a completely new architecture and other features that are significantly different from its predecessors. These substantial changes could involve challenges for wireless carriers because compared to previous radio technologies, 5G radio requires different design goals, protocols, waveforms, and use cases. Not only will the new features enhance existing services but also they will enable new services that were not available before.

5G networks will have significantly improved capabilities, including reduced latency, higher data speeds, expanded capacity, improved coverage, lower costs, improved reliability, and the ability to connect more devices. 5G will succeed in meeting these changes by differentiating itself through a new, high-performance Radio Access Technology that is intended not only to provide the reinforcing effect of complementing existing mobile networks but also to be revolutionary enough to bring their substantial changes; differentiate through the emulation of other wireless applications that do not belong to the mobile broadband by non-standard electromagnetic landscapes.

3.2.3. Differences Between 4G and 5G

First generation wireless networks ushered in the cell phone era. Second generation measures digitized speech, as well as the ability to send limited data such as SMS. Third generation focused on increasing the ability to send data, allowing browsing and limited multimedia. Fourth generation measures the mobilizing of the Internet, including high-speed data transmission using packet switching and wireless hotspots. Fifth generation goes a step further and is even bigger than wireless. It is one step on the Internet of Things continuum, enabling applications in Edge and Fog computing and huge expansion of IoT-enabled devices.

Fifth generation is a radical departure from previous generations. Although 1G–4G all focus on mobile devices, 5G takes the primary user experience as static sensors and not mobile end-user devices. 5G has the ability to support one million connections per square kilometer, to service at least one hundred thousand simultaneous connections on a single mass event, and to connect an enormous number of low-power devices such as health monitors and industrial sensors. Unlike previous generations, which require faster and faster data rates, 5G's incredible ability to support numerous devices operates at data rates comparable to 4G. In an IoT-driven world, the amount of traffic is of less concern than the number of simultaneous connections. With this, 5G has increased the use of Low Power Wide Area technology, enabling long-range reliable connections at a fraction of the power consumption of previous technologies, allowing nodes to operate on tiny batteries for years. Data capacity will also progress through densification of mobile broadband and increased use of high-frequency millimeter wave technology. This technology provides large data rates and capacity using small cells, particularly in urban areas, while lower-frequency layers will operate using larger cells connected through a dense fiber backbone.

3.3. Deployment Strategies for 5G

5G's defining characteristics including extremely high speed, low latency, enhanced reliability, massive device density, and support for mobility are expected to open new market opportunities related to new use cases and applications such as connected autonomous vehicles, virtualized aggregated testing, tactile Internet, tele-medicine, and industrial Internet that rely on extreme performance requirements. This presents a unique opportunity for a large number of stakeholders in the global telecom ecosystem including mobile users, industry customers, telecom service providers, enterprises, municipalities, and global technology vendors to collaboratively design, build, and roll-out 5G infrastructure. The most critical consideration in this regard is how to ensure speed-to-market while also maintaining low cost, responsible implementation, and high quality.

At a high level, the factors that can influence and guide key players in the telecom infrastructure ecosystem in deciding upon their 5G rollout strategies include the economics of deploying 5G, topical industry concerns and questions that telecom businesses are grappling with, and success factors that telecom businesses must put in their place to ensure successful investment and deployment decisions. Most of the discussions and deliberations among telecom leaders revolves around whether there is enough short-term demand to warrant the investment of scarce resources. Despite all the market research studies and education of the C-suite on the longer-term economic benefits associated with 5G, the telecom leadership at top operations are still concerned about whether they will ever recoup their investments. 5G implementation comes with a heavy price tag coupled with uncertainty regarding ROI due to the challenge of effectively instrumenting the network to find the right balance of premium pricing, quality of service, customer segments, and locale.

3.3.1. Infrastructure Requirements

The current landscape of mobile connectivity isn't just a need for faster data speeds. It's a need for ubiquitous, resilient, low-latency, high-capacity connectivity. We expect to gravitate towards a world where every human and machine offers its services to the cloud while consuming services from it. A decent 5G deployment will need to consider the innovation and services that infrastructure meets. While traditional analysis usually rolls up to speed, latency, coverage, and cost per bit, True 5G services and products are always available; ultra-large capacity with ultra-low latency and resilience; low power consumption; environmental sustainability; safeguarded cyber and digital security; balance between urban and rural; balance between enterprise and mass market; balance between private and public consumption; balance between mobile and fixed wireless distribution. Such services and products are complex to provide. Data rates vary, power consumption is not constant, capacity and latency are not independent.

In parsing the 5G vision from policy analysis and true availability statements from mobile networks, among the major routes nodes of the transport core segments are expected to be 5-7x current node routings. Passive and active fiber count need to grow by 40-50%. Wireless transport may grow by 100-120%. Within the RAN, antenna counts need to go up 5-10x. Photonic bandwidth within the base stations, between REM and poles, and on the legs between poles, demand growth rates of photonic capacity vary from 20 to 50x. All in all, those numbers indicate that 5G commercials will not be available tomorrow. While from current major vendors' announcements place, it appears that commercial equipment items will be available in the timeframe, such scales of deployments will take a decade or two to achieve.

3.3.2. Regulatory Challenges

To achieve the desired levels of agreement, time-to-market, and geographic coverage with low operating expense, the wireless industry must address a number of critical challenges, including high device costs and untestable hardware, high operating expenses, evolving investments, and revenue opportunities. However, one of the largest obstacles facing the deployment of 5G systems is regulatory. These regulations are needed to spur on market investment in network infrastructure and are largely focused on the administration of radio spectrum policy, including spectrum allocations, sharing, licensing, and auctioning. If done in a timely manner, these actions will help to ease concerns of uncertainty in network investment early on in the makeup of the ecosystem before it matures.

According to recent regulatory feedback, some of the posed questions to be answered in order to entice investment include, "To what extent will the potential for interference constrain the deployment of new services in the spectrum developed for 5G systems? What steps should the Commission take to avoid or lessen the potential for harm?" It is the interpretation of our work that such questions relating to deployment will benefit from including a link through which to achieve access to the communication networks. Unfortunately, the agencies that are primarily responsible for regulating the use of the communications networks have failed to invent policies that will stimulate the development of a national and commercially viable broadband communication network.

Further, both parts of the information systems architecture Communications Service Provider technologies and the Managed Services Provider technologies need to be sufficiently unapologetic and interoperable on all fronts; otherwise, it will divert from the efficiency gains available from shared infrastructures.

3.3.3. Investment and Funding Models

The major portion of investment in 5G deployment needs to be provided by the private telecom sector due to the limited appetite and capacity of governments of both emerging and advanced economies for large-scale infrastructure investments. Further, the user-pays and technology-neutral principles need to be the dominant theme in 5G financing. Some of the infrastructure elements for 5G may be provided by private-public partnership model, shadow toll arrangements, tax credits, area licensing for IoT service providers in urban centers for smart city applications. An alternative model for IoT segment is 5G network investment and support from traditional IoT service providers with access to application level revenues such as Insurance, Manufacturing, Municipal or Utility Service Providers by rolling out a low-power, longrange, reliable debugged, dark fiber based private network over licensed, shared unlicensed spectrum. Such private networks with mutually negotiated service level agreements with carriers could augment enterprise core investments such as autonomous driving, industrial automation, Robotics Process Automation, location services.

Experiments indicate that consumers are willing to pay a premium for mobile service differentiation such as enhanced experience related to augmented or virtual or simulated reality in the business case to generate additional activation & service revenues to overcome funding gaps. The limited funding opportunities with large capex investments needs to be supplemented with alternative strategies utilizing chiplets that leverage ID & silicon components, modular LCD for custom RF designs delivering cost effective, power & footprint efficiencies driving Flex-Antenna miniaturization. Niche market opportunities for satellite-terrestrial growth market segments around delivery of pertinent geo-fenced value-added services to multi-band small cellphone capabilities also needs to be factored into telecom operator revenue streams.

3.3.4. Phased Rollout Approaches

The phased rollout of 5G connectivity delivers the infrastructure via a series of narrow phases that expand in geographic coverage. The narrow phases could be focused on use cases identified as near term by industry and government as critical to economic growth or public safety. First responders, major industrial players, and early investors could use these areas first while regulators and industry learn from the initial deployments how and when to enable adjacent geographic regions in order to foster a robust ecosystem of device and application markets. Government agencies could initially approve uses for devoted vehicles to vehicle communications equipment. The approach further invites areas such as cities with public safety and transportation stimulus projects to partner with industry to develop specific deployments. Coordinating with such special focuses, operators could layer in additional abundant covering for mass market locations, notably concentrated downtowns for cities or urban zones for rural localities. These locations would most benefit from additional high-density connectivity. The corresponding anticipated revenue generation must be available in these heavily populated locations in order to justify capital investments. Developers could then enable suitable high capacity infrastructure implementations. Operators are likely to judiciously flip on, innovate for, and ramp up 5G capabilities on their shallow deployments on timescales established by industry interest. As demand requires capable infrastructure, often offloading significant wireless capacities from narrowband communication means to higher capacity ultrawideband arrays, a competitive balance in deployed capacity and service cost will evolve.

3.4. Use Cases of 5G Technology

5G accelerates connectivity across industries, and it is bringing a new set of capabilities. Thanks to its increase in capacity, ultra-low latency, and overall performance, 5G is anticipated to introduce diversification of use cases or vertical solutions enabling new revenue streams for mobile network operators. We believe that enhanced mobile broadband, massive machine type communications, and ultra-reliable low latency communications are the three main enhancement use case pillars of 5G compared to 4G.

Exceeding the performance of 4G and delivering a new set of capabilities, enhanced mobile broadband has already been adopted for various near-term use cases including fixed wireless access, high-resolution video streaming, and mobile augmented reality/virtual reality implementations. These use cases leverage the better peak data rates and user-perceived performance enabled by the new technologies introduced in 5G New Radio, such as higher order modulation, 4G, and mmWave support on 5G NR. Looking beyond, enhanced mobile broadband will enable higher speed mobility use cases such as media content on-the-go with the vehicle moving at high speeds, and enhanced location awareness for a better experience at closed venues.

Massive machine type communications, which targets billions of IoT devices with sporadic sensing-type traffic, is expected to enable smart homes, buildings, and cities. Beyond these popular applications, massive machine type communications is expected to play an important role in enhancing environmental protection, safety, and security solutions in everyday life. Significant advances in sensor technology, driven by expanding demand, are enabling more disruptive IoT solutions at considerably lower costs and power consumption. For example, low cost sensors combined with the superior coverage and energy efficiency, in particular, of the new narrowband Internet of Things standard are anticipated to facilitate a sensor deployment explosion.

3.4.1. Enhanced Mobile Broadband

Enhanced Mobile Broadband (eMBB) technology covers typical mobile and portable user scenarios that market researchers see in service in the period from 2020 to 2030. As 5G is rolled out, it will create a new level of connectivity for the world's evolving smart devices. The eMBB mobile user experience will rise to levels only hinted at by previous mobile connectivity speeds. In addition to faster average data rates, connections will be much more reliable and much denser to accommodate more consumers. 5G eMBB will on average have a high level of connection reliability. Network service providers will be able to manage minimum levels of reliability for extreme environments and mission-critical applications.

Ultra-High Definition 4K streaming video requires up to 25 Mbps of throughput. 8K streaming video, as well as virtual reality (VR) and augmented reality (AR), require higher levels of throughput. 5G is capable of supporting several data-heavy applications simultaneously at speeds of up to 10 Gbps. eMBB provides the maximum achievable connection data rates offered under the new specification when wide channels are engineered with good radio conditions in the low, midrange, or millimeter wave bands. At the low transmission powers in the mmWave bands, base stations must be densified to provide sufficient coverage and control channel availability.

5G eMBB can architecturally layer physical channels to hit the performance sweet spots. Mismatch Channel Bandwidths (MCBWs) are used in ultra dense urban (UDU) areas to simultaneously support high-bandwidth data sinks via a number of 5G-enabled small cells, while mobile users browsing the web can leverage a macro cell operating at a lower channel bandwidth to manage a larger number of slower throughput connections in a power-efficient way. Each 5G base station manages its own backhaul and fronthaul links to support heavy streaming applications in a dense micro or picocell architecture.

3.4.2. Massive Machine Type Communications

Introduction paragraphs should introduce, clearly identify, and define 1 or more topics that are contained or implied in the power of the words of your title and 2 or more words must appear in the title. There should be 2 to 4 such introduction paragraphs.

Machine type communications (MTC) represent a specific use case of the Internet of Things (IoT), which targets the vision of seamless connectivity of a myriad of wireless devices that collaborate in a shared environment for the enhancement of human convenience and efficiency. MTC has been in existence prior to 5G, and has been focused on the radio access link.

5G will serve to add more MTC devices to the IoT. Moreover, enhanced mobile broadband and ultra-reliable low latency communications, two other use cases of 5G, contain an element of MTC intended for higher performance requirements. In that context, MTC becomes an integral part of the 5G system. The goal of MTC in 5G is to enable the underlying management framework, including charging, provisioning, policy, quality of service, user/device profiling and the data model level to be available across all devices in a seamless manner.

The scale and diversity of potential 5G use cases, ranging from augmented reality applications serving an individual user to highly automated and interconnected transportation systems supporting billions of devices, have implications for MTC. The scale and the underlying sensor traffic that is transacted will impact network design. In a future with diverse MTC use cases, the trends of integrating communications into devices such as sensors and gateways will need to be balanced with the necessity of making communications and IoT components (and, in particular, MTC) performant and economically feasible in a heterogeneous and sustainable manner.

3.4.3. Ultra-Reliable Low Latency Communications

Ultra-Reliable Low Latency Communications, also known as URLLC or uRLLC, is one of the three main use cases of 5G, in addition to enhanced Mobile Broadband and massive Machine Type Communications, that was specified by the 3rd Generation Partnership Project. While the eMBB use case targets applications that deliver massive and fast broadband service for video with high throughput demand, and mMTC supports a large number of simple devices with low mobility and data rate demand, in a very efficient way using sub-meter latency, uRLLC targets mission-critical and highly reliable applications with sub-millisecond radio latency.

Introduction of the ultra-reliable low latency use case as a key feature of the 5G Network was driven by the demand to support new verticals like Industry 4.0, Smart Factory, V2X, Smart Grid and the smart application area. These new vertical segments require network capabilities to serve either mission-critical applications requiring real-time responsiveness of the underlying services, or services that require significantly enhanced reliability from the network when exposed to failure conditions. Therefore, a large number of applications can benefit from uRLLC Resilient Communication Services, including industrial control, robotics, factory automation, automated guided vehicles, automated traffic, precision remote control, vehicle management, remote healthcare and connected assistance services, smart grid and critical infrastructure, wireless safety services, drone control, critical information distribution, mission-critical public safety, remote monitoring, public safety, health ICT monitoring, and animal health.

3.4.4. Smart Cities and IoT Applications

As Smart Cities are implemented globally, it is critical to encourage their development and advance public knowledge of smart technology. There is a new sense of urgency for urban innovation as almost 70% of the world's population will live in urban areas by 2050. Smart Cities use various IoT technologies connected through 5G wireless networks to collect and analyze various city data related to traffic, weather, air quality, energy consumption, and other urban factors to improve urban life. A combination of Smart Cities and 5G technologies can be a game-changer for city planners as they will be able to use real-time data to address urban issues, changes, and needs. The smart technology components that constitute a Smart City can enable smart public services (such as smart lighting, smart metering, smart waste management) and smart mobility networks (such as advanced traffic management, smart parking, and public transport monitoring). The added value of these public services lies in several IoT capabilities and 5G technology-related advantages: ubiquitous connectivity, rapid deployment, robustness, advanced analysis, and scalability.

The implementation of Smart Cities and IoT applications on a large scale will have a socio-economic impact. Before the deployment of the 5G technologies, Smart Cities would run invalid simulations because of noise or data noted in the area that could alter their conclusions and did not allow them to offer advanced services. 5G technology allows cities to become smarter through five core areas: citizen engagement, background data collection, smart governance, predictive asset management, and advanced mobile services. It helps ease developers' lives and citizens living through better interactions and more intelligent assistance.

3.4.5. Healthcare Innovations

As 5G technology is expected to enable fast and reliable internet connectivity with very low latency, it is opening doors to some amazing innovations in the field of healthcare, thus reshaping the way medical services are delivered. 5G will support novel use cases such as remote surgeries, remote patient monitoring, real-time health data analytics, and augmented reality-based medical training, creating huge business opportunities for telecom operators and healthcare service providers. The deployment of 5G technology in the healthcare industry is projected to generate significant revenue. The reduction in latency and faster throughput enabled by 5G infrastructure will allow the aggregation of large volumes of health-related data generated by personal health devices, including wearable and implantable devices, and apps, thus enabling real-time health data analytics and better and faster decision-making by doctors and healthcare providers.

5G technology will drastically change the scope of telehealth by enabling remote surgeries and remote diagnosis of offline patients. Remote consultations using video conferencing applications will become much easier with faster 5G internet. Additionally, patients will be able to undergo XR-assisted remote diagnosis and treatment through connections made possible by 5G networks. XR (or extended reality) refers to the combination of augmented reality, virtual reality, and mixed reality. In addition, the high speeds and low latency enabled by 5G technology will increase access to telehealth services, add new and advanced remote healthcare services, and enhance the collaboration capability of medical professionals. Healthcare services will also be able to draw meaningful insights and quickly act upon them.

3.4.6. Autonomous Vehicles

The autonomous car market focuses on three main use cases: car manufacturer internal and external infrastructure for R&D of autonomous vehicles; commercial testing and pilot projects for connectivity and technology trials; and roll out of autonomous ridesharing and goods delivery fleets. We group each type of application for autonomous vehicles further below. We also describe here investments related to the use cases. Technology can help with low latency transport of V2X data, high bandwidth transport of sensor data, and high density IVN deployments due to the wireless nature of access technology.

Technology can help with low latency, high reliability V2X connectivity, as required by safety systems and ADAS of autonomous cars. The first years of ultra-reliable low latency communications deployment will likely be focused on these applications. We note that California does not require prior map buildup, and requires L4 vehicles to stay in CDAS mode provided data is received from infrastructure updates, sensor difference detection between car and infrastructure, and V2X telemetry. A mature connected vehicle ecosystem may allow testing closer to Level 5 too. We can have car manufacturers in CA like Ford test Level 4 in driverless mode, alongside Santa Clara's expansion of its existing wireless data network. With fast growing levels of connected cars by 2025, we expect Level 4 and Level 5 pilot Level 5 autonomous vehicle deployments to occur from 2025.

We see complexity and costs of cars, for rider friendly performance and safety features increasing due to the need for L5 compliance. We expect higher mass and costs of sensor heavy vehicles to migrate use of L5 urban mobility to platforms with economies of scale. Shuttle buses with passenger pickup and drop-off places can also help increase demand for L5 use by lowering costs. We also expect autonomous goods delivery in non-revenue areas, with Level 4 use of remote monitored vehicles a precursor for Level 5 deployment. Retailers with same day deliveries becoming a growing sector in the retail market could increase demand for L4 and L5 enabled vehicle use.

3.5. Challenges in 5G Deployment

Despite the advantages offered by 5G, the deployment of 5G networks is not free of challenges, which may negatively impact its timeline. The challenges may be classified into four categories: technical challenges, security concerns, public perception and acceptance, and geopolitical considerations for advancing or restricting 5G deployment.

Fig 3.2: Challenges in 5G Deployment.

The true potential of 5G cannot be felt unless devices with 5G capabilities are in the market. Presently, there are only a handful of devices capable of utilizing the full potential of 5G networks. The availability of devices is one of the main reasons for the delay in 5G rollout. More such devices need to be produced. The extensive deployment of small cells, along with the fiberization of backhaul, are important requirements for 5G. The high-capacity backhaul network involves high-cost and laborious requirements. Many operators are still in the process of migrating to fiber backhaul, particularly in developing countries. Apart from this, 5G relies on mmWave, which is temperamental. The absorbing characteristics of oxygen, particularly in the 60GHz band utilized for 5G, create a radiation barrier, absorbing a significant part of the 5G signals. Furthermore, 5G utilizes beam tracking. Any misalignment of the beam from the device and its corresponding base station can cause degradation in the quality of signals. The algorithm for better beamforming and optimization needs to be perfected.

5G technology is vulnerable to security threats targeting the centrality of the technology. Also impacted are File Integrity and Malware Threats. These encrypted files can be attacked and malware threats executed to compromise the integrity of a connected device. The technology is also vulnerable to targeted Denial of Service Attacks. Targeting the core of the service will lead to exposure economically as well as politically to the organization. Also damaging will be the man-in-the-middle attacks from criminals hijacking 5G-enabled devices.

Public perception or acceptance of 5G technology also involves peculiarities such as a few sets of vulnerabilities that 5G possesses compared to LTE.

3.5.1. Technical Challenges

With the ever-increasing demand from users for higher speed data and higher quality services, mobile network operators are striving toward a mobile network that can deliver on these promises and serve as the backbone for digital transformation. In pursuit of this goal, one of the major questions in the network equipment vendor brokering process is—where do we deploy 5G into the carrier network? From the initial 5G networks deployed, the major focus has been in the high-cost market, deploying dense indoor and outdoor Radio Access Network using mmWave frequencies. This approach has shown remarkable improvement in bandwidth availability, but the costs associated with this RAN are extremely high and inherently unscalable. The reason for this is that deploying/operating a mmWave network requires massive investment in RAN resources including more fiber, backhauls, and radios at the base stations as well as many more antennas in a RAN with higher density. Despite these challenges, mobile carriers are still willing to invest with the hopes of it translating into an opportunity for differentiation and higher mobile ARPU.The problem is vital for a different set of reasons. For one, mapping the locations of 5G hotspots directly influences the revenue acquisition and optimization opportunities for the carrier. More importantly, we believe that decisions made today regarding where to deploy 5G will impact the long-term capabilities of these systems. From a service perspective, 5G services can provide both data and latency. The data provided by these massive MIMO RAN deployments offer very low data rates relative to the cost of the base station. However, the improvements in channel utilization; i.e., the high array gains with dense RAN systems; allows service providers to offer low latency as a differentiating factor for specific LTE services such as eGame and AR/VR, allowing some charging opportunity.

3.5.2. Security Concerns

The 5th generation wireless system (5G) supports a variety of new applications, enabling key technologies for smart factories, smart transportation, smart cities, and smart living. However, the 5G system faces different risks in terms of cybersecurity, placing a heavy burden on the back-end architecture design. In this section, we summarize the major 5G security risks and open issues. Radio access authentication over untrusted RAN/Legacy devices. Cyberattacks include signaling attack, DDoS attack, RAN overflow attack, tunneling attack, hijacking attack threat, and subversion attack. Security protocols, including key management, mutual authentication, user privacy attack, spoofing attack, and message replay attack. Data integrity.

Fifth generation wireless systems have different levels of security: the same as previous financial transactions below a limit or even similar to the security of an ATM. The rapid development of the Internet of Things and connected vehicles has raised significant concerns over security levels in 5G, considering the diversity of device categories under various levels of vulnerabilities. Moreover, we have very little experience in terms of host-to-host transaction design and key management in this context. We summarize existing mechanisms, hoping that our design notes can sustain a longer discussion beyond 5G and provide a basic complement for security architectures developed in general in the last years. A wireless system is usually constituted by a risk-averse and biased toward higher security level infrastructure provider and user devices that are variable in technology, within lower resource levels.

3.5.3. Public Perception and Acceptance

Despite the many technological advances made in areas like Internet Communications Technology, Artificial Intelligence, and Privacy, with regards to 5G technology specifically, it is perceived to be an IT-intensive technology. Such intense IT technologies or advances are often received with skepticism and distrust primarily from the most vulnerable sections due to lower proficiency with such advancements. With regards to 5G, this distrust is mainly because of the idea that newly developed remote sensing networks may be more inclined towards security and privacy violations than the previous wired sensor networks, thus offering less transparency, and therefore less awareness and knowledge of the possible vulnerabilities associated with it. Moreover, such concerns often go unchecked and cement in the minds of users with the presence of many conspiracy theories that often relate advanced technologies, specifically wireless technologies, to causes of diseases and health concerns. With respect to 5G, the Connect / WiFi Models may not be as well equipped as opposed to other models in addressing the user concerns and issues with less security. Researchers have elaborated on studies where public acceptance issues concerning IT-intense and advanced technology like 5G, very much rely on the IT competences of users.

The mobile and other wireless health and safety-related services may also suffer from the negative perception effects, such that mobile service users may refrain from adopting a technology as important as 5G in its vast uses in the backbone of many other advanced technologies. Such a lack of trust has been found to cripple other personalized almost-to-demand services immensely, as trust issues have been known to lower the pioneering digital behavior of users. Comparatively, the younger generations have been famously known to openly publicize the details of their life, leaving just a bit of private information, due to the absence of trust or privacy concerns with regard to social media platforms which serve as medium of sharing.

3.5.4. Global Competition

Although technology ingredients for 5G, such as network virtualization/trust with SDN/NFV, MIMO, millimeter wave RF, and telecom cloud infrastructure are available in the market, first-movers in the 5G space will reap the most benefits by controlling the infrastructure that other sectors are built upon. Leadership in the policy and economics of communication infrastructure will circulate larger amounts of wealth back to telecom operators and hardware manufacturers in those sectors. Enterprises moving into these 5G core areas will displace traditional telecom with cloud-enabled portfolio players. Business as usual for traditional telecom will lead to diminished revenue streams as big technology templates diminish opportunities within the enterprise cloud sector. China, Korea and the United States lead both in the level of 5G development and the focus sectors. China is the first mover in mass deployments via aggressive expansion policies and its market is structured to enable immediate MBB revenues. The Chinese state is and will continue to invest heavily, as evidenced by massive increases in 5G-related spending. MBB will drive up mobile service revenues, while revenue footprints grow in IoT services. China and Korea are set to be the first movers in key infrastructure sectors such as telco cloud and MBB as an enabler for cloud. America’s focus is on aligning traditional telecom and big technology so that collaboration to enable business verticals becomes the focus. But still, beyond the blockbuster first-mover opportunities, other such as Indonesia, India, Brazil, Germany, Malaysia, South Africa also will enter the market shuffle. It is the first movers who will define the structure of 5G, both the challenges and benefits ahead. Global competition is set to explode.

3.6. Future Outlook of 5G

The 5G era has clearly started, and with that, we will have to face many challenges. New technological developments are being adopted continuously, and also new business models are being explored by both operators and enterprises for specific verticals. Also, new actors are starting to play important roles in the ecosystem, as hyperscalers, cloud providers, service and OEM vendors, technology startups, sectoral partners, and many others, both as companions of the telcos networks and exploring new models. Market research is an important instrument to collect information and learn about market expectations. Analyses estimate that in 2030, 70% of global enterprises will have 5G private networks in operation and, as consequence, will require supporting services from CSPs.

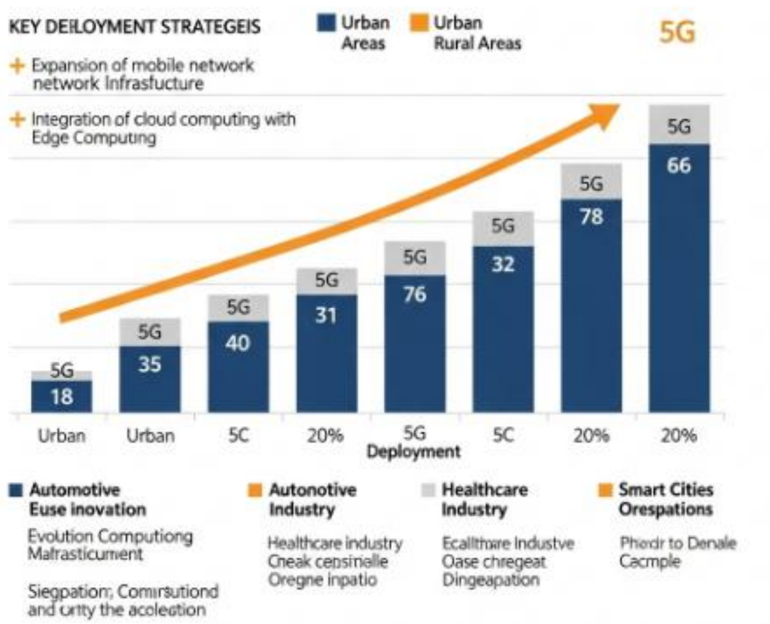

Fig : Accelerating Connectivity Through 5G: Deployment Strategies, Use Cases, and Future Outlook.

New technologies are constantly being developed and implemented in the industry, like advanced technologies and materials, automation and robotics, machine learning and artificial intelligence, sensors, Internet of Things, blockchain, digital twins, big data analytics, quantum computing and communications, augmented and virtual reality, and more. They are being combined with intelligent connectivity, and the industry sees the advancement of both intelligent 5G and 5G for intelligent services. This trend is led by the convergence of several technology and services sectors, being implemented for the benefit of both society and economy. In this regard, 5G is advancing from pure industry 4.0 initiatives and deploys. Different examples related to the services domains are already seen, such as health, security in public places, education and training, manufacturing, smart buildings and offices, transportation seats, agriculture, media and entertainment; and we have already highlighted in the previous sections several points on both societal and economical impact. But, about the overall positive impact that advanced connectivity brings to society and economy, it is needful to mention that supporting networks, like optical, edge and cloud, new electromagnetic spectrums, security measures, global standards being achieved and evolution to be made on the entire ecosystem still must be considered.

3.6.1. Technological Advancements

As 5G technology continues to mature, advancements in its capabilities are also on the horizon. Currently, the three main enhancements of 5G are URLLC, eURLLC, and ultra-HR. These capabilities have undergone extensive research and many of them are tightly coupled with the next releases of the standard. These advancements will be critical in realizing the real-world vision of 5G technology. To this end, some upcoming releases develop and finalize new features, such as reducing latency through the use of basic functions. These include RAN developments, such as utilizing a shorter Transmission Time Interval or enhancing New Radio synchronization. Other works touch on functions that reduce jitter and key architectural components of the 5G system. These advancements represent different actor perspectives of latency reduction. In the RAN, the reduced TTI can help in critical use cases, such as vehicular and factory automation and co-design, while on the core side, the function implementations and architectures can help towards super low delay applications, such as remote robot controls.

Moreover, developing technologies like Non-Terrestrial Networks, Network Slicing, Reconfigurable Intelligent Surfaces, Multi-Access Edge Computing, Network Automation, etc. will play a key role in enhancing 5G. By dynamically modifying the propagation conditions with cheap passive devices, a RIS will reduce the radiated power, enhance the communication reliability, and allow for a joint optimization of delay and throughput. In addition, NTN represents a natural extension of wireless networks that will complement Ground Network solutions for providing universal service coverage while also relieving network congestion in hotspot areas. Edge Computing enables both cloud and mobile edge facilities to solve the critical latency problems of ultra-reliable services by shortening the distance of user equipment.

3.6.2. Potential Market Growth

As enterprises continue their digital transformation missions, the 5G opportunity continues to become more prevalent. 5G is a natural enabler for enterprises looking to adopt technologies, such as AR/VR, Edge Computing, IoT, Smart Factories, and Smart Logistics, among others. While 5G-enabled devices have been slow to come to market, they will proliferate over the next couple of years, including private 5G networks, allowing various use cases to flourish. These enablers will pull a significant demand for global 5G-driven private networks, which are expected to be responsible for more than 50% of the overall enterprise-wide private networks spending by 2025 and 80% by 2030. Driven by massive growth in mobile data traffic due to the increased penetration of 5G devices and increased revenue opportunities through low-latency, high-bandwidth 5G-enabled services, mobile network operator spending on 5G networks in the commercial phase will accelerate exponentially over the next couple of years. Spending during the commercial rollout phase will be directed mostly toward the deployment of the last mile access, focused on the RAN technology, including fiber to the tower RAN Backhaul as well as RAN equipment, to enable high-bandwidth 5G services, such as Enhanced Mobile Broadband, initially targeting urban/suburban environments.

The forecast estimates that worldwide service provider spending on 5G equipment and services during the commercial deployment phase is expected to surpass $1600 billion by 2030, with the majority of that spending coming from mobile network operators, particularly in the first half of the decade. Spending in the first couple of years of the commercial rollout phase is anticipated to be uneven, given the diversity of deployment phases undertaken by the different mobile network operators around the world, ranging from the penny-pinching early adopters to the spend-thrift leaders that will accelerate worldwide rollout, enabling all the enabling technologies tied into 5G spending acceleration.

3.6.3. Impact on Society and Economy

Given the positive contribution of 5G technology to the economy, experts agree to consider such investment as necessary and prioritize it among other infrastructures, aiming to define a firm deployment timetable. Some countries stride forward faster than others, investing heavily in state-of-the-art manufacturing technologies and related 5G adoption, in order to minimize business disruptions, causing a growing concern for inequality arising also from a growing number of monopolies. It is most expected not only for countries to assist in a familiar scenario but for companies too: histories have resigned the business disruption strategy, causing the spread of the GIG economy. These changes in global economy favor societies to adopt consciously or unconsciously some new trends, such as multi-homing and consumer activism, business to minimize the trace and accelerate purchase-facilitation ensuring at the same time the respect of earning rules due to competition, and regulators to be alerted in considering anti-competitive restrictions. At the same time, mHealth and telehealth systems are spreading up in order to offer services that can be coupled with proximity ones, thanks to the possibility of patients using their own devices connected to 5G networks.

Finance, service and industry 4.0 are on the verge of a new revolution, given all the opportunities offered by technological coupling with Artificial Intelligence, IoT, Blockchain, Cloud/Edge/Fog Computing, which has been defined as a quantum leap. 5G technology is supporting companies to update and enlarge their proposition of hybrid products/service, thus improving their economics, affecting also stock market players, company valuations, and data analysts that have to shift the view from only Balance Sheet, focusing on IC such as brand equity, customer loyalty, and employee efficiency. Strong growth prospects are expected for Emerging Markets, as a positive consequence of investments in technology infrastructures that will reduce the risk distance from developed countries, in consideration of the position they occupy in the production chain due to outsourcing and nearshoring trends.

3.6.4. Emerging Technologies and 5G

The mapping between Fifth Generation and Artificial Intelligence is meant to provide a technology layer that can improve Artificial Intelligence tasks latency and security features needed to manage privacy. The minimizing latency feature could help small businesses that are focused on Artificial Intelligence micro features. Another possible linkage is the acceleration of the Blockchain technology distribution. The advantage of a 5G mobile network can accelerate the speed of delays on Blockchain data exchange. The implication is the growth of new business based on these two technologies' interaction. Virtual and Augmented Reality grows at a fast pace and the implementation of these technologies in the entertainment sector and training field is greatly dependent on new technology features. Immersive experience implication in the user's day-by-day life will be an accelerating factor in the Marketing segment and other segments that rely on training and immersive approaches to physical and information simulations. To implement Augmented Virtual Reality technologies properly will be the goal of many Marketing agencies. However, problems like security, life quality improvement based on privacy and the management of social disconnectedness are trending research and are linked into a successful future roadmap. Integrated Robotics needs to interact properly with environmental perception sensors. Robotics and self-driving evolution are also linked, opening new possible use cases in all sectors of industry and service research. The vision of everything connected in the IoT ecosystem should become a reality. 5G is the technology that can probably afford this large amount of data traffic, hence supporting a wide set of devices connected to the same network. Such a wide connectivity is the wide connectivity that could be necessary to support Earth monitoring and large seas environmental monitoring based on cluster observation satellites and devices.

3.7. Case Studies

As 5G continues to roll out across the globe, increasingly diverse use cases are emerging, attracting new actors to the industry. 5G is being adopted for use in sectors ranging from energy to transport, from retail to factors, and from trade to health care. These sectors aim to innovate and reinvent using the advanced features that come with 5G. Claims have been made that 5G can revolutionize these sectors, and that companies within those sectors that do not embrace change will lose market share. This chapter investigates different cases of how 5G can be adopted to meet different connectivity needs, for urban, suburban and special use cases, and in asset dense and asset light configurations. Deployers have different choices that they need to make that lead them to select different approaches in terms of access technologies, operators, sites used in deployment, business models, devices, and related technologies. All of these choices lead to a different architecture of the solution that is being deployed. The chapter also discusses how these deployers are facing dilemmas that need to be resolved. These are strategy dilemmas addressed by key stakeholders: balance vs. focus, make vs. buy, and growth vs. profit. Building access and edge data centers are capital-intensive investments. The safety of the investment is enshrined in upfront spectrum fees and service agreements. Enabling the selected use cases at the desired quality and service level becomes critical. The investment relies on the number of transactions created by the addressed use case and the margins necessary across the ecosystem partners to make it interesting for the deployer. Moving key capabilities to the edge for the relevant use cases for a specific area — industrial zone, university, shopping mall, etc. — drives many critical decisions. Each deployer needs to make sure that deploying in an asset light way is sufficient to fulfill the local demand but also to make sure that the density of sites and edges is not too low to provide adequate capacity and coverage, leading to a loss of quality of service.

3.7.1. 5G in Urban Areas

The deployment of 5G cellular systems in urban areas has already begun in many cities, with communications service providers beginning to offer pre-standard experiences and services. New technology trials are being evaluated in smaller cities and colleges. The challenge faced by everyone inside the service chain—the operators, the infrastructure providers, and the device makers—is to get inside a pre-standard environment that leads to early 5G revenues, while managing cost and expectation. Consumer and enterprise performance and enhancement use cases are driven by new services introduced by the CSPs and new technology ecosystems. The first important consumer service externalizes an earlier mobile promise and enables an immersive video experience through either virtual reality or augmented reality. Upload speeds of at least 1Gbps will be required, while performance metrics need to be met with real-world 5G use conditions. These conditions will require large amounts of bandwidth, spectrum, and easily densified mmWave infrastructure in order to support the bandwidth needed by thousands of users in close proximity. To monetize these experiences, insufficient data or inexperience cannot be used; the CSPs will likely need to partner with the enterprise experience enablers, such as game publishers or VR network software firms. These enablers may provide the appropriate data to make the user experience functional and valuable for CSPs. Existing cable operators that also have Wi-Fi hotspots may provide competitive challenges if they can partner with cable content providers and/or OTTs over Wi-Fi or launch own-brand OTT services within those same experiences. The revenue model then becomes one of reducing churn by making the experience preferable to wireless devices, while reducing the connectivity cost. If the additional Wi-Fi traffic can be supported by their existing fixed network data centers, then the overall operating cost for either infrastructure provider is actually lower.

3.7.2. 5G in Rural Connectivity

About 3.6 Billion people live in Rural Areas across the World, mostly in developing countries, and the majority of them still lack access to decent Connectivity. Most of the People living in these Remote Areas desperately need the Internet to improve their Quality of Life, make Health Services available, get access to Education Opportunities, and give a Leap to the Economic Growth of their Remote Communities. However, the Urban Centric Internet Technology Evolution was not designed for Rural Areas, where the Population Density per Square Kilometer is extremely low. This Fiscal Inefficiency has been enhanced over the Years, mainly since the dominant Urban Operations can now be covered by Fierce Competition amongst several Service Providers, mainly utilizing advanced Technologies. In general, the Supply side Providers are not necessarily interested in the Demand side and Service Quality in Rural Areas of their Service

Regions, mainly because of Humanitarian Constraints. On the other hand, the lack of decent Rural Communications has also prevented Competition, and pushing the Prices down.

To meet both, the Demand side Consumers' Needs and the Supply Side Operators' Fiscal Availability Constraints, Package Agreements are a promising Model for reopening an Internet Supply Market. The Challenge that remains is how to overcome the Stubbornness of the Incumbents controlling both sides and being afraid of Cannibalizing their existing monopolies. The Hi-Tech Industrial Giants that employ monopolies in Cloud or Content Services are suggested to be the key Providers, mainly because of their huge Cash Reserves. This proposes Innovative Technology Solutions based on Long Range, Low Bit Rate Technologies to be employed in order to allow ISP Companies to provide Decent Internet Access, influenced by the Global 5G Evolution, making Connectivity Services Affordable for all Customers. 5G Role in urban and developed areas is undeniably assisting, and in many cases, huge Corporations can afford financing Node deployment considerably. 5G Role in remote and developing areas is, however, less significant due to the cost associated with deploying the full stack. Hosting backend Services in Operator Edge Locations enabling Service Locality may permit creating a significant Pull for the development of a Remote Area's Economic Drivers.

3.7.3. International Case Studies

China has always been the first mover in 5G development and infrastructure. In terms of coverage, China's carrier has deployed over 500,000 small cells so far, which helps mobile to reach high capacity. In terms of capacity, deployment provides 300 MHz full-band continuous spectrum such as 2.6 GHz, 3.5 GHz, 4.4 GHz, and 700 MHz. In terms of enablement capability, together with other telecom operators jointly developed the 5G system architecture – network slicing. Mobile now provides multiple vertical applications and customisation by network uptime, latency, speed and reliability. Those vertical applications include factory automation, connected transportation, and connected healthcare. Mobile's customers include various companies. At the same time, other 5G enablement activities, such as self-driving, are also carried out to realise commercial deployment in 2025.

The world leader in commercialisation activities is the United States. In terms of coverage, currently, the US carrier provides coverage for more than 30% of the country by FWA, especially focusing on urban and suburban areas. In terms of coverage reaching rich content consumption experience, the US carrier has deployed 160 MHz of spectrum, covering more than 180 million people with high capacity. In terms of vertical application enablement, the US carrier collaborates with other operators and service vendors to drive the development of some applications such as telehealth and remote education. In short, the United States would continue the commercialisation to prepare for the next draught.

3.8. Conclusion

While designs targeted for the standalone 5G UC may currently be used for a few unique private wireless network deployments leveraging licensed spectrum, there has been little commercial implementation to date. However, deployment of low power 5G NR systems in shared spectrum or unlicensed systems are underway and are proving out use cases and deployment strategies as part of implementations. The R&D investments being made in private networks to leverage new use cases and new technology implementations is sure to lead to a burst of commercial implementation results as proof-of-concepts and early trials become prototype deployments proving performance and fueling market growth.

5G has truly many unique capabilities that when applied to carefully selected vertical markets lead to significant effects both within the organizations adopting the technology as well as to the users of the funded implementations. By reducing labor intensity, increasing productivity, reducing cycle times to market, reducing resource needs, and lowering engagement costs, using 5G technologies can lead to significant return-on-investment results to the organizations developing unique applications and to the ultimate adopters seeing the benefits of the new advanced capabilities. The use of funded market verticals can directly lead to new markets as well as in creating and supporting business cases to stimulate the growth of a large-scale commercial economy for 5G. These will lead to more products being developed by manufacturers generating further benefits to the ultimate users supported by extensive 5G infrastructures.

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