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An Overview of The Main Factors for Implementing 5G Networks Globally for Socioeconomics Benefits

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Abstract: *With every generation of communications technology, the focus of the network changes. Both the 2G and 3G technologies focused on human-to-human communication through voice and text messages. 4G announced a fundamental shift to the massive consumption of data through video streaming, while the 5G technology has transferred its focus on connecting the Massive Internet of Things (MIoT) and industrial automation systems.*
The amount and the type of spectrum impacts the network's capabilities. 5G networks require access to multiple ranges of frequency bands from low, mid to high. All these frequency ranges are essential for 5G deployments as they allow operators to optimize their networks based on environmental and network coverage and capacity targets.
However, 5G deployment challenges over the last few years have made it quite evident that mid-band spectrum offers the unique combination of capacity and coverage necessary to satisfy smart phone users' expectations for availability of 5G and beyond everywhere. With exponential growth of mobile data consumption and proliferation of new bandwidth hungry smart phone applications, it is vital that regulatory bodies ensure availability of timely licensed mid-band spectrum beyond what's already been allocated.
5G Mobile network are very important telecommunication infrastructure for worldwide wireless networks and has become integral to the productivity of many organizations and crucial to the provision of public services and industrial automation systems.
High speed data transmission, area traffic capacity, connection density and low latency are key requirements in present-day applications. 5G networks also provide enormous capacity and wider bandwidth to support billions of devices and users which are reliable for long-distance, critical communications, and mobile broadband services. This paper gives an overview of 5G technology challenges and deployment options, 5G network capacity, future trends of 5G applications and Socioeconomics benefits for subscribers and businesses towards the next generation.
Keywords: *5G, mid-band spectrum, cell sites, MIOT and industrial automation systems.*

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I. INTRODUCTION

One of the main pillars in the vision for 5G is to provide ubiquitous high-speed wireless mobile connectivity to support several use-cases: "IMT-2020 is expected to provide a user experience matching, as far as possible, that of fixed networks". The need for IMT spectrum is driven by the requirements for 5G as set out in the ITU-R requirements for IMT-2020[1]. In assessing the need for additional IMT spectrum we are focusing on three of these new 5G requirements as shown in figure.1:

- The user experienced data rate jumps from 10 Mbit/s to 100 Mbit/s - a factor of 10 increase; and
- Area traffic capacity moves from 0.1 Mbit/s/m^2 to 10 Mbit/s/m^2 – a 100-fold increase;
- Connection density increases from 10^5 to 1 million devices per Km^2- a 10-fold increase.

As a result of the huge increase in the use of mobile phones and the Internet and the emergence of modern applications and multiple uses in all areas of life, this has led to a huge increase in consumption of data volume for each subscription on communications networks, and mobile networks are no longer able to accommodate this terrible increase in data traffic, so it was necessary for the 5G technology to emerge with the allocation of frequencies with wide communication channels to accommodate this. Consumption of data varies from one country to another according to income rates and place of residence in urban or rural areas.

Average monthly mobile broadband traffic per subscription in high-income countries is 16.2GigaBytes (GB) is roughly eight times that in low-income countries (2GB). The world average monthly traffic is 13.9GB. Monthly traffic per subscription for fixed broadband traffic is similar across low-income and middle-income economies (between 200 and 250GB), about half that in high-income countries (435GB). The world average monthly traffic is 311GB [2].

The total mobile broadband traffic around the world reaches 1.3zettabyte (ZB) in 2024(end-user Internet traffic), up from 1ZB in 2023. Fixed broadband traffic reaches 6ZB in 2024, up from 5.1ZB in 2023. But, mobile broadband traffic since 2021 has grown on average by 19.6% annually, faster than 15.2% for fixed broadband traffic [2]. Ericsson has a more optimistic forecast for the global average monthly Mobile data traffic per active smartphone in 2024 (19 GB per month) while it is expected to reach 40 GB per month in 2030[3].

Policymakers will, therefore, need to consider making more mid-band available and prepare national spectrum roadmaps that carefully consider future 5G demand. There is a concern in the mobile industry that regulators may not be fully aware of the scale of the 5G traffic density challenge specially in urban areas. Specifically, there is a concern that regulators may not be planning to clear and award enough licensed mid-band spectrum for 5G between now and 2030.

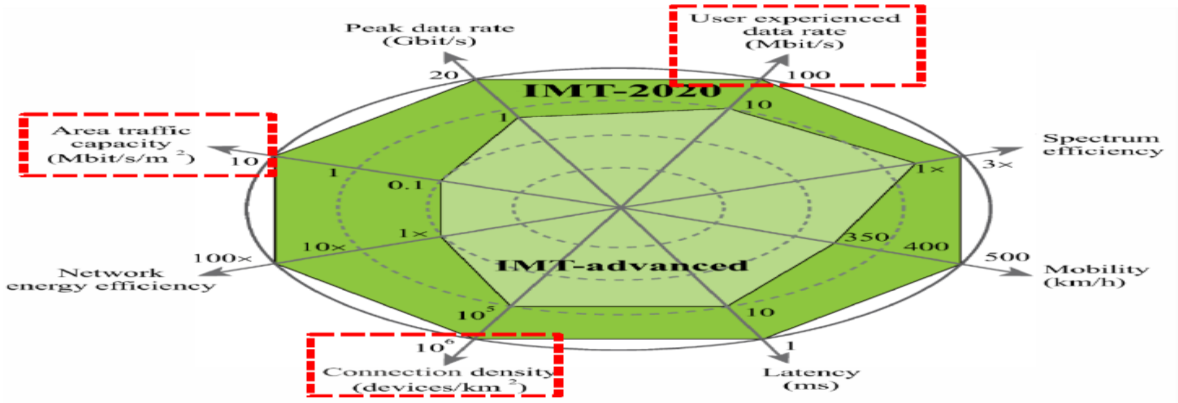


Fig.1: main 5G requirements [1]

Radio frequencies are the key factor to deliver these requirements. Therefore, there is also a step change in the need for IMT spectrum. Clearly, improved spectral efficiency associated with higher orders of MIMO, and densification of base station sites or a combination of all will enable mobile operators to extract more capacity out of existing spectrum resources.

This paper will provide an overview the main challenges to implement 5G networks around the world for Socioeconomics benefits and possible future applications.

The rest of the paper is organized as follows. Section.2 presents Economic value created by 5G Technology. Section.3 describes global data capacity of mobile networks. Section.4 describes the main 5G Enablers and Features. Section.5 presents the main elements and approaches of achieving deployment of 5G network capacity. Section.6 presents top applications and uses of 5G networks. Finally, section.7 concludes the paper.

II. Economic Value Created by 5G Technology

The digital economy is defined as economic activity relaying on, or enabled by digital technologies and their applications. This includes activities that increase human well-being or lead to social or environmental benefits. The digital economy is projected to grow three times faster than the global economy to reach approximately US$24 trillion in 2025, representing 21% of global GDP [4].

Mobile operators account for more than 60% of the economic value created by the mobile ecosystem. The rest contribute the remaining 40%, including infrastructure providers; retailers and distributors of mobile products and services; mobile device manufacturers; and mobile content, application and service providers.

The direct economic contribution to GDP of the mobile ecosystem is estimated by measuring their value added to the economy, including employee compensation, business operating surplus and taxes. Most of the value-added increase will be due to productivity gains. In the developed world, the adoption of IoT solutions will drive increased productivity. In developing countries, productivity growth will be mostly driven by the adoption of mobile internet services. As adoption grows, 5G revenues will reaching $1.15 trillion by 2025. Looking further ahead, 5G alone is forecast to contribute $2.2 trillion to the global economy by 2034 as shown in figure.2[5].
Total 5G connections will reach around 1.35 billion by the end of the forecast period in 2025. At this point, 5G connections will account for close to 15% of the total mobile connections. This does not include Internet of Things (IoT) connections. Separately, GSMA forecasts 1.9 billion licensed cellular low power wide area connections by 2025, setting the base for Massive IoT.

5G technology is expected to yield more than $960 billion in additional GDP value-add to the global economy in 2030. The frequency bands of 5G technology can be categorized into 3 main bands as follows [6]: -

• Mid-band 5G will account for an uplift of more than $610 billion to global GDP in 2030 (approximately 65% of the total 5G benefit).

• High-band 5G adds another $220 billion of GDP (23% of the total 5G benefit).

• Low-band 5G is expected to account for $130 billion of GDP (14% of the total 5G benefit).

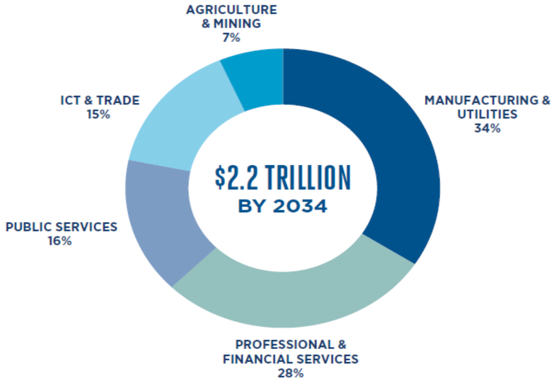


Fig.2: Contribution of 5G to the Global Economy

5G benefits will be directly determined by the rate of 5G penetration by 2030. 5G subscription uptake continues to be strong and Global 5G subscriptions are forecast to reach 6.3 billion and make up 67% of all mobile subscriptions in 2030. 5G's share of mobile data traffic reached to an estimated 34% by the end of 2024, this share is expected to grow to 80% in 2030[3].

A second factor that will directly impact 5G benefits is how use cases can be applied to different economic sectors. This depends on a number of factors, including overall ecosystem readiness and the degree of available technologies and related skills among workers. For example, Massive Internet of Things (MIoT) related applications are expected to play an important role in the digital transformation of the manufacturing sector, increasing productivity and reducing costs. The sector has historically been relatively quick to adopt new technologies. Therefore, it is expected that the sector will be highly affected by 5G MIoT-related applications.

For the period 2020–2030, eMBB and FWA will be the largest use cases over the period to 2030 and driving most of the 5G benefit these encompass a variety of applications for example (HD videoconferencing, HD streaming, e-health, Education, etc.), while others are being developed. The manufacturing sector, together with the public administration and services sectors, is expected to drive most of the benefits associated with mid-band 5G spectrum. However, 5G will also drive innovation across other sectors, including retail, agriculture and transportation.

Depending on the specific requirements of the associated 5G use case application, different bands are used. For example, a smart city MIoT solution will require wide coverage, so mid- and low bands will be preferred for deployment. Meanwhile, a factory floor is expected to require lots of capacity but will be less concerned with coverage, due to limited/confined space, highlighting the relevance of mid- and high bands for the related applications.

III. The Growth of Demand for Mobile Data

Each new mobile generation has encouraged and supported the development of new applications and services. 5G Mobile network has become integral to the productivity of many organizations and crucial to the provision of public services.

Mobile data traffic growth between years can be highly unstable and vary significantly between regions, markets and service providers, depending on local market dynamics. Some factors that could further change the forecast for 2030 for mobile data traffic include: global macroeconomic changes (inflation and interest rates), the pace of subscriber migration to later generations, smartphone shipment development, the uptake rate for new consumer applications, new advanced devices and AI-enabled tools, changes to the split between FWA and mobile data traffic when FWA connections grow, and continued improvements in the performance of deployed networks.

In 2024 fully 5.5 billion people are online which represents 68% of the world population, compared with 65% in 2023. The year-on-year growth rate is itself increasing, from 2.7% in 2023 to 3.4% in 2024, but 2.6 billion people of the global population are still offline [2]. Internet use remains tightly linked to the level of development.

In high-income countries approximately 93% of the population uses the Internet, but this contrasts with the situation in low-income countries, where only 27% of the population is online.

The growth in traffic has been driven by the evolution of mobile technologies; the wide adoption and use of sophisticated smartphones and the development of new applications making use of the greater capabilities of mobile networks. For example, image sharing was followed by video streaming and sharing and then by the addition of augmented reality interfaces and filters.

The world is moving slowly and carefully towards universal access: 96% of the global population is now covered by a mobile broadband network that enables Internet access. However, this achievement masks significant gaps. In rural areas of low-income countries, nearly 30% of the population does not have the possibility of connecting to the Internet. It must intensify the efforts to remove the barriers that keep people offline and close the usage gap: despite steady growth in Internet use one-third of humanity still does not use the Internet.

For those who are online, the quality of experience and the ability to leverage online resources vary significantly. For instance, while Internet prices continue to decline, affordability remains a major barrier. People in the least developed countries still dedicate a disproportionately large share of their budget to access the Internet. Moreover, the affordability gap between the most and least digitally connected countries has widened. In 2023, mobile Internet costs in Africa were 12 times higher than in Europe—a gap that increased to 14 times in 2024[2].

Equally concerning is the gap in the quality of access: 84% of the population in high-income countries already has access to 5G. In contrast, 5G covers only 4% of the population of low-income countries, where nearly 20% have no access at all, and another 28% rely exclusively on 3G, limiting what they can achieve online.

Mobile networks today reflect MNOs' deployment decisions informed by a range of factors including available spectrum capacity in a given area, geography, practical feasibility, and the expected returns on any investment. While demand for mobile data has grown across the world over the last 5years, data traffic density has remained highly correlated with where people live, work and travel. For example, in 2021 an average dense urban site carried five times as much data traffic as an average rural site [2].

MNOs have primarily addressed growing demand for more and higher quality data intensive services by increasing the capacity of their networks. This has been primarily achieved by upgrading equipment to the latest technology to deliver greater data traffic per unit of spectrum and by the deployment of additional spectrum as it has been made available as well as the densification of mobile sites.

As we have noted, spectrum is a finite resource and there is a need to consider demand from other users and ensure it is used efficiently. Additional new mobile spectrum beyond the existing pipeline of spectrum could help facilitate the provision of additional capacity, but would not on its own be expected to be sufficient to meet future mobile data traffic growth in all areas. Making additional spectrum available for high-power outdoor mobile use would likely require clearing bands of existing users. The process for clearing frequency bands of current users usually takes long time and it would be subject to consultation and may require an impact assessment of the costs, benefits and risks involved. The area traffic demand per user will increase over time driven by the following factors:

- Increased adoption of 5G smartphones and associated data usage;
- Increase in sustained video streaming downlink and uplink;
- Higher bit rates demand by better device capabilities;
- Application driven high bandwidth and low latency requirements; and
- Increasing density of non-human connected devices.

Looking at the increase in data usage from humans, already today mobile network usage is dominated by smartphones and is increasing rapidly. This is driven by the fact that users are choosing 5G plans which offer unlimited data usage and do not reduce speed above a certain limit. The key driver in the growth of mobile usage is video, including streaming content, video calling, video gaming, and streaming from cameras. These all demands need a constant speed over longer time periods that can run into the hours rather than minutes. Long streaming times leads to a situation where more people use their devices concurrently in the same cell. Not only is the duration of video sessions increasing, but also the bit rate. For example, the capabilities of smartphones are advancing offering ever higher video quality and 4K video is now available on mobile orientated streaming platforms such as YouTube, TikTok.

Traffic generated by connected vehicles, cameras, and video-based sensors could be a multiple of traffic generated by human users as illustrated by the following examples [7]:

- Conventional and LIDAR cameras stream data continuously, i.e., they demand bandwidth over hours, and even 24/7.
- Connected cars today generate hardly any traffic. However, over a 10-year time frame a connected car may generate about as much data as 3,000 people.

Over time, more and more high-band sites will be deployed in dense areas and, hence, the proportion of 5G traffic served by high-band sites will increase. However, high-bands will not provide continuous coverage in a city, but will be deployed to serve indoor and outdoor locations with a very high traffic density.

IV. 5G Enablers and Features

5G provides a superior experience to end users, 5G networks will provide between 10-times and 100-times faster data rates, at latencies of up to 10 times smaller when compared to current 4G networks. This improved performance will come from a more advanced core network and by using more efficient radio technologies (i.e. spectral efficiency), using more spectrum bandwidth (i.e. spectral capacity) and more network densification (i.e. spectral reuse).

There are a set of features and enablers of 5G technology. We will review the main important of them in brief detail in this section.

4.1. Enhanced Mobile Broadband (eMBB)

Enhanced Mobile Broadband (eMBB) is at the forefront of 5G technology, let's explore and highlight the key features of eMBB:

- High-speed connectivity and Quality streaming: eMBB delivers speeds of up to 10 Gbps, ensuring seamless streaming with content in 4K or 8K resolutions, eliminating buffering issues, quick downloads, and responsive online gaming.
- Ultra-low latency: With just 1ms latency, eMBB facilitates real-time applications like remote surgery and augmented reality.
- Exceptional capacity: eMBB handles numerous connections, ideal for crowded events and urban areas, ensuring consistent high-speed access.
- Remote work efficiency: eMBB supports remote work with reliable and fast internet, enhancing video conferencing and collaboration tools and allowing to work together seamlessly, regardless of their physical locations.
- Internet of Things (IoT) enablement: eMBB is crucial for MIoT growth, connecting various smart devices, from wearables to autonomous machines.

Enhanced Mobile Broadband (eMBB) powered by 5G technology improves connectivity with lightning-fast speeds, minimal latency, and extensive device support. This will help to revolutionize the digital experiences and drive innovation across industries.

4.2. Massive Internet of Things (MIoT)

As much as IoT plays an important role in the current lives, it is evident that the use of IoT will play a critical part in the infrastructure of technology in the coming years. According to a recent prediction in 2025 the total number of connected devices in the world will approximately be 75.44 billion as shown in figure. 3 [8].

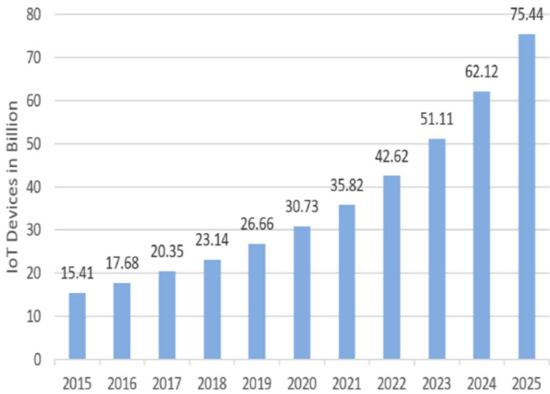


Fig.3: IoT prediction from 2015 to 2025[8]

Let's explore and focus on the advantages of integrating with 5G technology:

- Massive connectivity: 5G's low-power, wide-area coverage efficiently links IoT devices, powering smart cities, connected homes, and industrial automation.
- Low latency: 5G's reduced latency ensures real-time IoT applications such as autonomous vehicles and remote monitoring operate seamlessly.
- Data Analytics: With its capacity to handle vast volumes of IoT data, 5G facilitates advanced analytics and actionable insights across various sectors.
- Enhanced security: Robust security measures within 5G protect IoT devices from cyber threats, ensuring the integrity of critical systems.
- Energy efficiency: 5G's design supports IoT devices with extended battery life, benefiting applications like environmental monitoring and precision agriculture.

In summary, the partnership between 5G and IoT promises an era of uninterrupted connectivity. This partnership fosters innovation across industries and transforms the way for engaging with surrounding environments.

4.3. Augmented Reality (AR) and Virtual Reality (VR)

The convergence of 5G technology with AR and VR promises in a new era of immersive experiences. Let's explore and highlight the key aspects of integrating 5G with AR and VR:

- Ultra-high-speed data: 5G's ability to transmit data at ultra-high speeds ensures that AR and VR applications can deliver seamless, high-definition content in real-time. This is crucial for providing users with immersive and lag-free experiences.
- Remote collaboration: With 5G, real-time remote collaboration becomes possible within augmented and virtual environments, allowing professionals to work together seamlessly, regardless of their physical locations.
- Entertainment: 5G-powered AR and VR offer enhanced gaming, interactive storytelling, and virtual tourism, enabling users to explore new dimensions of entertainment.

The synergy between 5G and AR/VR represents a transformative era of enormous experiences, revolutionizing gaming, entertainment, and remote collaboration. This partnership is also reshaping how interacting with digital content.

4.4. Edge Computing

A computing framework that allows computations to be done closer to data sources, is fast becoming the standard for enterprises. Ultra-reliable edge computing and 5G enable the enterprise to achieve faster transmission speeds, increased control and greater security over massive volumes of data. Together, these twin technologies will help reduce latency while increasing speed, reliability and bandwidth, resulting in faster, more comprehensive data analysis and insights for businesses everywhere.

Devices and applications can exploit edge cloud computing resources without needing to access a centralized data center potentially thousands of miles away. Edge Computing, empowered by 5G technology, brings many benefits to data processing and analysis. Let's explore and highlight the key aspects of them:

- Bandwidth efficiency and decision making: Processing data locally reduces the stress on network bandwidth, optimizing data transmission and improve efficiency. Edge Computing enables instant data analysis, facilitating real-time decision-making in applications like autonomous vehicles and industrial automation.
- Low latency: Edge computing, architected as MEC for mobile networks, is the critical component to achieve low latency in mobile networks. Its conceptual development aims for sub-1 millisecond latency.
- IoT integration and Enhanced security: Edge Computing seamlessly integrates with the IoT, accommodating the massive data generated by IoT devices. Edge devices can implement localized security measures, boosting data protection and privacy.

The synergy of 5G and Edge Computing empowers real-time processing, bandwidth efficiency, heightened security, and efficient IoT integration. This sets the stage for transformative applications across diverse industries, ranging from healthcare to smart cities. Intelligent edge computing operates at the convergence of 5G's ultra-low latency, IoT, and AI technologies.

4.5. Network slicing

Enabled by NFV and SDN, Network Slicing enables the creation of two or more virtual networks with different performance parameters over a single physical network infrastructure, so each of the virtual/logical networks can serve a specific purpose. Conceptually, it can be depicted as slicing a physical network into many networks to serve specific use cases as shown in figure. 4. With network slicing, operators can address a variety of different client requirements, especially enterprises, with one physical network.

Network slicing, however, also comes with complexities in the context of interoperability and roaming. A customer using one network when switching to another network will expect a comparable experience.

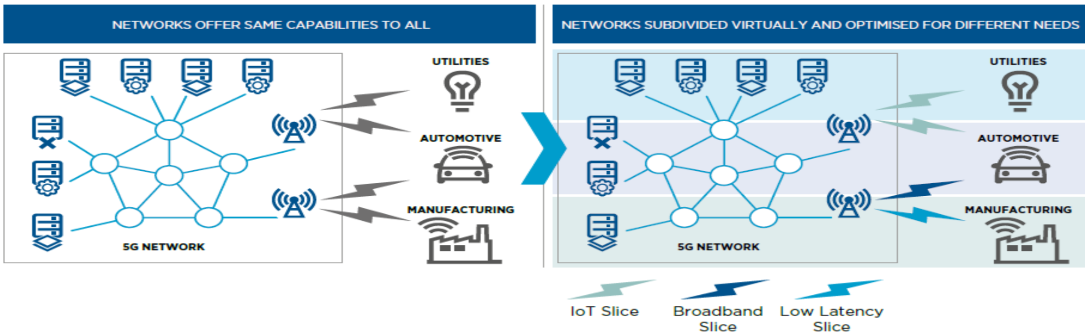


Fig.4: Concept of Network Slicing

4.6. NFV/SDN

Network virtualization is not a 5G-specific cost issue as it has already begun on 4G networks. However, it is a essential to deploying and operating a 5G network because 5G networks are virtualized and cloud native by design.

NFV enables network functions to be isolated as software that can run over Commercial Off-The-Shelf (COTS) hardware as shown in figure.5. NFV enables cost reduction, faster time-to-market and a broader ecosystem with more specialist market players. SDN is where network control planes and user planes are separated, and the control plane is centralised. Centralizing the control plane enables the network to make globally optimized routing decisions, makes the network flow programmable to fit specific requirements and also broadens the ecosystem with layer decoupling.

Therefore, SDN can enable a programmable transport network, which is able to create multiple and isolated transport slices. The transport resources can be dynamically allocated to different clients, interconnecting virtualized and physical network functions distributed geographically, which are likely to be located across different network domains. SDN is also able to provide network programmability through standardized APIs and networks resources abstraction, in order to obtain the required operational flexibility and dynamicity required for 5G, at the speed of signaling network control protocols propagating to the networks. Additionally, the centralized control plane capabilities of SDN provide E2E visibility of network resources for establishing and maintaining an optimized connectivity.

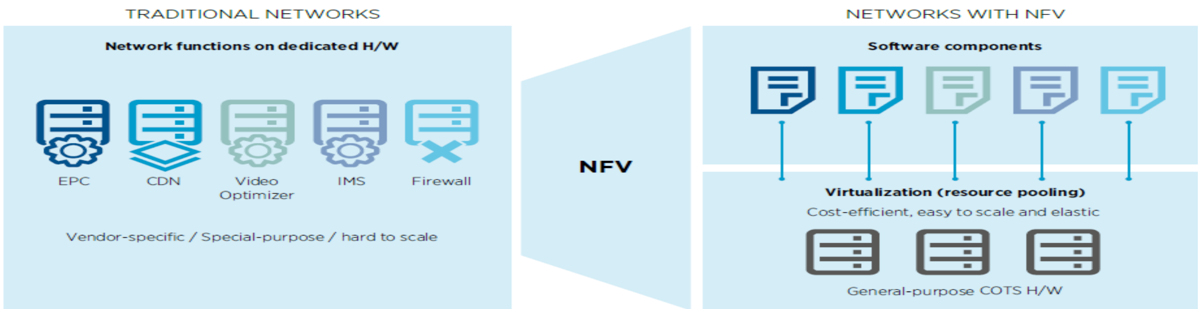


Fig.5: Traditional Networks to Visualized Networks.

Experience from operators who have virtualized their 4G EPC networks is that virtualization can generate cost savings of 40% of Total Cost of Ownership. This comes from the use of COTS, reduced time to market, and reduced need to over-provision network capacity and redundancy. Nevertheless, the complexities associated with decoupling the layers and increasing the vendor combinations must not be overlooked in virtualizing the network and the operator will need to balance the long-term cost savings and short-term investment required.

4.7. Cloud RAN

Cloud RAN is a radio access technology where some components of the radio access network are virtualized and centralised so that one physical location handles hundreds of cells, reducing the cost and complexity of operating a cell site.

The Cloud RAN architecture is possible because virtualization allows for the baseband processing to be done in virtual equipment running on generic hardware. The result is that fewer and lower cost COTS servers are used when compared to a distributed RAN (DRAN) architecture, today's predominant approach. The Cloud RAN also simplifies network management and enables resource pooling. The Cloud RAN architecture is highly suitable for the small cell era, where lower cost, flexibility and scalability are key operational factors.

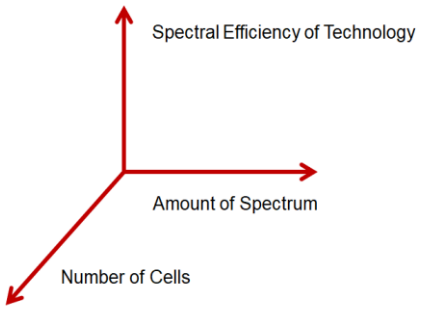
Cloud RAN enables significant savings that would not have been possible with traditional configuration. It should be noted that the CAPEX and OPEX savings depends strongly on the availability of fiber and space for the baseband farms.

V. Methods of increasing Capacity of Mobile Network

Mobile data traffic has grown by an average of 40% year on year in recent years and it is expected to continue to grow [9]. Mobile networks will need to continue to expand their capacity to meet future demand for good quality mobile services for people and businesses. The mobile industry has called for further spectrum beyond that already in the pipeline to be made available to support this. However, new spectrum is not the only way for network operators to increase capacity. There are four main considerations for network capacity, it can also be delivered through spectral efficiency, spectral capacity, spectral reuse and backhaul. In some circumstances MNOs may also look to offload traffic onto other access networks (e.g., Wi-Fi) that use licence exempt spectrum to provide additional capacity and this has given the importance of indoor mobile traffic.

Typical strategies for achieving the 5G capacity targets include base station densification approach, increase of spectral efficiency and the availability of additional spectral resources as shown in figure.6a, and these factors may range from 1000-10,000-fold [10] as illustrated in figure.6b.

Spectral efficiency dictates how much data can be carried per unit of bandwidth of a communications channel at a time given the ratio of signal to unwanted noise. Spectral capacity is determined by the number of spectrum channels in use. Spectral reuse makes it possible to use the available spectrum channels many more times. Densification is the most important determinant of access network capacity. The transport network determines the rate of transferring traffic from the cell site to the core network. It can be backhauled or fronthaul depending on which nodes of the radio access network are connected through the transport.



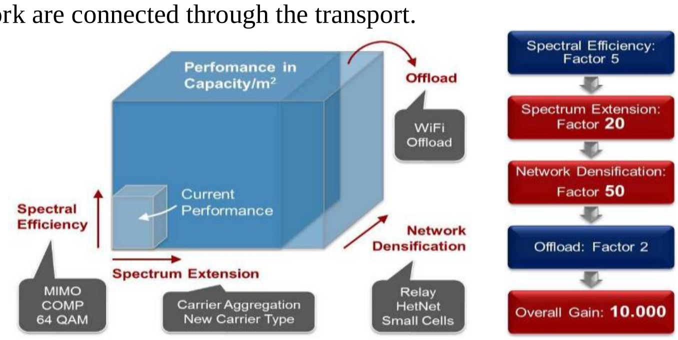


Fig. 6a: Increasing capacity needs efficiency, densification, and more Spectrum.

Fig.6b: Degrees of freedom for areal capacity increase [10].

5.1. Increasing Network Capacity with Spectrum

5G needs a variety of spectrum bands to support a range of applications and services. Low bands provide coverage and indoor reach; mid-bands provide a balance of coverage and capacity; and mmWave or high bands can provide capacity in densely populated urban areas and in factory settings, for example. Therefore, we need to assess the demand for additional IMT spectrum depending on the frequency range. The large number of frequency bands can be categorized into groups: low-bands, lower midbands, upper mid-bands, and high bands.

- Low-bands (e.g., 600, 700, 800, 900 MHz) are effective at addressing very wide area coverage and deep indoor coverage given their good propagation characteristics. However, there is a few spectrums available and hence the channel bandwidth does not provide more capacity.
- Lower mid-bands (e.g., 1800, 1900, 2100, 2300, 2600MHz) are already used for IMT for 2G, 3G, 4G and 5G. The lower mid-bands have been the capacity layer for 4G data traffic and in most countries the spectrum is used in FDD mode. But there are some countries with 5G deployments in the 2600MHz band with a TDD mode.
- Upper mid-bands (e.g., 3.3-4.2, 4.5-5, 5.925-7.125GHz) are newer to 5G and offer much wider bandwidths and this is a key 5G capacity resource. Upper mid-band spectrum used in most countries is in the range of 3.3 to 4.2GHz. Upper mid-bands offer a good combination of propagation and capacity for cities. 3GPP standards currently support a 100MHz wide channel and for a maximum bandwidth of 400MHz in carrier aggregation mode.
- High-bands (e.g., 26, 28, 40, 50, 66 GHz, also referred to as mmWave) are effective at addressing areas with very high traffic density and extreme peak data rates.

In higher frequency bands (i.e., 24 GHz–40 GHz), the signal propagation loss is too high; that will significantly reduce the individual cell site coverage and the radius of it around 100 m compared to several kilometers in low bands and Lower mid-bands.

Each new generation of mobile technology is more efficient than the last and can use spectrum to provide greater connectivity. Spectrum refarming, dynamic spectrum sharing and other mechanisms support the use of existing bands for new technologies. However, the capacity demands on 5G networks will be a step-change from previous mobile generations. This is driven by the larger number of connected devices as well as growth in data traffic per user. Additional spectrum needs are driven by the growth in demand for connectivity, outweighing the efficiency gains of the next generation of technology. Generally, lower mid-band spectrum is already in use (or planned for use) for 4G, while upper mid-band spectrum is used for 5G. However, there are cases of refarming or sharing between the two technologies in lower mid-bands.

As spectral efficiency gains reach a peak with 5G, increasing the bandwidth of the communications channel increases traffic capacity. This is the core of the industry's focus on securing wider spectrum bands for 5G. In this context, higher spectrum bands (e.g., 3.5GHz bands and mmWave bands) are great 5G options as they offer from 80MHz to 1,000MHz contiguous bandwidth for 5G use per operator depending on spectrum band considered. Furthermore, higher order MIMO and massive MIMO provides even more data throughput than conventional radio systems, and would be more efficient when used in large contiguous bandwidth.

Even where regulators do not allocate full contiguous bandwidth, mid-to-high spectrum bands offer much more bandwidth than the 20MHz bandwidth typically allocated in 4G. For example, for C-Band, awards to date have shown that the available bandwidth varied significantly, from the 80-100MHz. Of course, disjointed spectrum bands can also be aggregated using carrier aggregation technology to give single data pipe of up to 100MHz block which offers a more uniform capacity or user experience though.

5.2. Technology Upgrading for More Capacity

New technologies can enable better spectral efficiency [9], so more data can be carried over a given quantity of spectrum. Two key opportunities for mobile networks are upgrades in technology and antenna systems.

System upgrades such as changing the use of a band from 4G to 5G, and then the roll-out of SA 5G will boost spectral efficiency, with even greater gains from moving from a band being used for 2G/3G technology to 4G/5G. MNOs intend to free up current 2G/3G spectrum for providing services via 4G/5G networks during a few years.

While currently 2G, 3G and 4G are deployed in low-bands and lower mid-bands, in time these will all be refarmed to 5G-NR. Therefore, we used the higher spectral efficiency for 5G with an appropriate MIMO configuration. The ITU target for dense urban eMBB is 7.8bit/s/Hz which could be achieved by using 64-element MIMO at the base stations [10]. However, across a city in upper mid-bands a mix of MIMO configurations will be used and hence a blended average spectral efficiency is used.

Deploying antenna technologies such as Active Antenna Systems (AAS) and higher order massive MIMO [9] can enable substantial capacity gains. These technologies increase the number of transmitting and receiving antenna elements in radio equipment and exploit spatial multiplexing and beamforming [9] to carry multiple data streams simultaneously and increase spectral efficiency.

Massive MIMO solutions are targeted towards improvement of spectral efficiency and offer enhanced coverage and capacity. This is achieved through using multi-antenna technologies such as beamforming, null forming and spatial multiplexing, that takes advantage of specific channel and antenna array properties.

The purpose of beamforming is to amplify transmitted/received signals in a specific direction. Massive MIMO enables beamforming in both vertical and horizontal directions. Having a much higher number of antennas elements enables sharper beams, which helps concentrate energy in one direction more than the other and provide higher SNR to end user.

The scope for capacity gains through upgrading antennas varies by frequency band. Today, massive MIMO and beamforming techniques are mostly exploited in mid-band spectrum (between approximately 2 GHz and 10 GHz). At lower frequencies (below about 2 GHz), the physical size of antenna elements limits the number of elements that can practically be accommodated in a single base station antenna. Spatial multiplexing can still be exploited, but with more limited MIMO techniques [9]. Antennas at mmWave frequencies can accommodate a very large number of antenna elements compared to low or mid-band. Beamforming at mmWave using high order massive MIMO antennas should allow even greater spectral efficiencies.

5.3. Expand Capacity Through Densification

Capacity can be expanded by adding additional sites to a network, using macro sites or small cells. To date mobile networks have largely relied on macro site deployments, but network planning considerations and access to new locations for macro sites can be challenging, particularly in dense urban and urban areas.

Small cells operate at lower powers than macro sites and cover a smaller area. They are typically installed below rooftop level or in indoor locations. They can either make use of the same spectrum bands deployed on the macro layer in that area, or different bands. The mmWave spectrum may be particularly suited to deployment on small cells, providing high capacity and speeds in localized areas, but other bands such as 2.6GHz and 3.4-3.8GHz could also be used.

5G will require network densification to meet both coverage and capacity objectives. However, one of the biggest cost uncertainties is the level of network densification needed. This will be driven by the need for more capacity, the use of higher band spectrum, continued growth in 4G networks, and new 5G cells to deliver new capabilities. The cost of adding new sites varies from country to country and from operator to operator. However, with the increase in the number of mobile stations to accommodate the increased volume of data traffic transfer, this will inevitably lead to increased energy consumption, in addition to increasing operation costs. Additional network densification will generate a carbon footprint 1.8-2.9 times higher without sufficient spectrum. The high level of densification may not even be feasible for other reasons (such as too much interference, site availability, restrictive electromagnetic field rules) [12].

The network's power consumption had broken down and Base Stations (BSs) alone represented around 57% of the entire network consumption and showed that most of the BS consumption is caused by the power amplifier [13]. This led the International Telecommunications Union (ITU) to consider energy efficiency as one of the key capabilities of 5G. These results have forced major operators to begin finding ways to improve energy efficiency in their operation.

Macro Cells and Small Cells

Macro cells are the primary means for operators to reach their customers and will still be important in the 5G era despite the growth of small cells. They provide large coverage ranges (1 ~ 20km), delivered via high power cell sites combined with tall towers/masts.

Macro cells coordinate the small cells and connectivity to the core network, and are critical for effective small cell deployment and operation. In addition, macro cells are appropriate for use cases that require significant coverage, but not necessarily high-capacity requirements (e.g., high data rate or low latency).

Small cell deployments will grow significantly over the coming years to meet the huge data traffic capacity required by 5G technology. Small cells are low-powered radio access nodes or base stations operating in licensed/ unlicensed spectrum that have a coverage range from a few meters up to a few hundred meters. It is essential for mobile usage inside buildings, where over 80% of mobile usage occurs in developed markets. Therefore, dense urban areas will see significant increase of small cells in the 5G era, while sparsely populated areas can be covered by densifying macro cells.

Indoor Connectivity

Indoor coverage is a specific challenge because the ability of mobile signals to penetrate through buildings depends on factors including the thickness of walls, and the types of materials used in construction. Overall indoor coverage sits between 90% and 95% across the MNOs but are very weak for rural areas. However, these levels apply an average building loss of 10dB across buildings which may ambiguous and more complex picture [14]. The challenge is going to increase as buildings become more energy efficient. Additionally, the higher frequencies that are increasingly being used to provide bandwidth for 5G increase the difficulty of propagation.

MNOs have to a large extent relied on an 'outdoor in' solution to this problem, using their lower-frequency spectrum to provide indoor coverage from outdoor cells. However, there is not enough of this spectrum to address capacity demand in future, even if more were made available. Therefore, it is likely that indoor solutions will play an important role in addressing connectivity challenges inside buildings and could also free up outdoor macro layer spectrum for outdoor use. Wi-Fi is already a popular indoor solution, with many consumers able to use Wi-Fi. Some people select to use self-installed repeaters to make and receive calls and texts/SMS over a Wi-Fi network.

There are several alternative solutions where Wi-Fi is unavailable or unsuitable. As noted above, neutral host solutions can provide the means for multiple operators to provide indoor coverage to larger buildings through third-party infrastructure. Alternatively, MNOs may be willing to supply additional technology like femtocells and picocells which create mobile hotspots from a fixed broadband connection. Some people select to use self-installed repeaters which boost the signals between a network operator's base station and a mobile phone, and so improve access to mobile services without requiring a broadband connection, but this is costly and may cause interference problem.

Transport (Backhaul/Fronthaul)

Network densification raises the need for high capacity and reliable transport solutions, in addition to the cost of extra sites. While transport for 'fronthaul' (connections from the antenna to their controllers) will grow in importance in the 5G era, by far the biggest transport requirement will be for backhaul.

Operators will face a challenge of backhauling the rapidly growing 5G mobile data traffic from varied environments, such as urban; suburban; rural; offices; residential homes; public buildings; tunnels etc., regardless of whether it is from macro or small cells. In fact, there is a potential risk of a 'network bottleneck' if higher 5G access network capacity is not matched with a proportional increase in backhaul capacity.

VI. 5G Applications and Use Cases across Different Sectors

5G network capabilities offer the potential for revolutionary applications extending far beyond smartphones and other mobile devices. A new range of 5G use cases and applications that converge connectivity, intelligent edge, and Internet of Things (IoT) technologies will benefit everyone.

5G technology represents the changing face of connectivity. Designed for maximum speed and capacity, 5G has the potential to vastly expand how data is moved and will enable a wide range of new applications and use cases that go far beyond the smartphone.

The 5G technology will not only provide much higher data rates but newer applications for example smart factories with more automation, medical procedures at healthcare centers remotely, Smart cities give consumers new levels of control over their homes or cars, Smart transportations and beyond. The manufacturing, public administration and services sectors will benefit the most from the 5G technology. New applications such as real-time cloud gaming, VR/AR devices will also offer new potential revenue streams. Applications including smart factories, smart cities and smart grids will drive a boost in productivity and the creation of new revenue streams.

5G applications represent tremendous opportunities for consumers, homes, businesses and communities. IHS Markit estimates that potential global sales activity across multiple industry sectors enabled by 5G could reach $13.2 trillion in 2035 and this represents about 5.0% of all global real output in 2035[15]. Manufacturing will achieve almost $4.7trillion which represents 36% of the $13.2 trillion in sales enablement. The 5G-enabled sales percentage by industry will vary from a high of 10.7% in the information and communications sector to a low of 2.2% in the hospitality sector. 5G could enable 6.3% of public service (government) applications and 5.3% of agricultural output in 2035, driven by smart city and smart agriculture deployments, respectively.

By expanding the scope of wireless technologies and making devices more autonomous, 5G will help to reduce carbon footprint and conserve natural resources. Last, economic growth will boost direct and indirect employment in all economies. Below are several examples for future trends of 5G applications.

6.1. 5G Applications for The Manufacturing Sector

The manufacturing sector is continually looking to improve the productivity of its processes, reduce costs and remain competitive on the global stage. 5G has unique properties and attributes that can facilitate and improve manufacturing processes. The global manufacturing industry requires high-quality, time-sensitive, automated, intelligent and flexible industrial control, so that materials, products and processes can be monitored, optimized and controlled in real time. Currently, most factories use wired connections, which satisfy the technical performance requirements, but they are complex and inflexible for reconfiguration purposes. 5G will provide more flexible and convenient wireless connections, which will meet industry requirements and will increase contribution of manufacturing to global GDP and it is expected to be high.

The supply-chain disruption created by the Covid-19 pandemic means future factories will need to develop their ability to be reconfigured for different production lines depending on sudden shifts in demand. A promising technology that could be transformed by 5G is extended reality (XR), referring to technologies including virtual reality (VR) and augmented reality (AR) where digital objects appear and can be manipulated in the real world. XR is expected to play an important role in sectors such as construction and manufacturing, where participants need to see detailed models of complex machinery.

Smart manufacturing, empowered by 5G technology, is reshaping the industries and manufacturing. With the low latency of 5G technology, 5G facilitates seamless communication among robotic systems, enhancing automation in manufacturing, supports real-time quality control measures and ensuring consistent product quality. The integration of 5G in smart manufacturing fosters real-time monitoring, predictive maintenance, factory automation, and quality control for reducing costly breakdowns time and improving productivity in the manufacturing industry.

Machine vision for plant management is a further 5G-enabled application expected to revolutionize the manufacturing sector. High-resolution cameras offer a low-cost, reliable way to monitor broad areas of a manufacturing site's operations. From security through to monitoring complete production cycles, cameras offer a flexible and good general-purpose sensor with many applications that complement and enhance the data derived from 'traditional' IoT sensors.

Intelligent automation is one of the future trends in 5G network development that can be integrated greatly in manufacturing industries. Due to the high level of precision and wireless assurance for critical production, the internal goods will be checked and inspected efficiently by Artificial Intelligence (AI) instead of a human to monitor the quality in real-time [16].

6.2. 5G Applications for Smart Cities

In smart cities, sets of connected sensors and devices are strategically placed around the city to generate large amounts of data. This is aimed at improving transparency and efficiency within the city's infrastructure, resulting in a more cost-effective public administration.

The idea of a hyper-connected urban environment that uses 5G network speeds to motivate innovation in areas like law enforcement, waste disposal and disaster mitigation is fast becoming a reality. Some cities already use 5G-enabled sensors to track traffic patterns in real time and adjust signals, helping guide the flow of traffic, minimize congestion, and improve air quality.

In another example, 5G power grids monitor supply and demand across heavily populated areas and deploy AI and ML applications to "learn" what times energy is in high or low demand. This process has been shown to significantly impact energy conservation and waste, potentially reducing carbon emissions and helping cities reach sustainability goals. Smart cities, driven by 5G technology, are shaping the future of urban living. 5G's high-speed data transfer allows for real-time data analysis, enabling better decision-making for urban planning and resource allocation.

IoT is a cornerstone of smart cities, with 5G connecting various devices for improved urban services, like light, traffic and waste management and public safety. 5G's extensive coverage ensures that even remote areas within smart cities have access to high-speed internet and services.

5G's promise of low latency and high network capacity helps to eliminate the biggest limitations to IoT expansion. Giving devices nearly real-time ability to sense and respond, 5G and IoT are a natural pairing that will impact nearly every industry and consumer.

Street light which can be equipped with sensors for detecting cars or human movement and which can then dynamically be turned on when there is some activity in the zone and turned off otherwise. It can help to save energy (and money) for the city, whilst ensuring security by avoiding to create dark zones around people.

Smart metering is a further aspect of smart cities, allowing precise, up-to-date monitoring of public and private electricity consumption, increasing overall grid efficiency and resulting in cost savings and increased environmental sustainability.

The fusion of 5G and smart cities fosters efficient infrastructure, advanced Data Analytics, extensive IoT integration and unparalleled connectivity. This results in urban environments that are more sustainable, interconnected, and responsive to the needs of their inhabitants.

6.3. 5G Applications for Smart Transportation System

The Intelligent transportation system (ITS) will provide efficient transportation control and management using advanced technology of sensors, information and network. The ITS can have many interesting features such as non-stop electronic highway toll, mobile emergency command and scheduling, transportation law enforcement, vehicle rules violation monitoring, reducing environmental pollution, anti-theft system, avoiding traffic jams, reporting traffic incidents, smart beaconing, minimizing arrival delays etc.

The integration of 5G technology has profound implications for the development and operation of autonomous vehicles. 5G's ultra-low latency allows autonomous vehicles to communicate with each other and infrastructure in real-time. This real-time data exchange is critical for ensuring the safety and efficiency of self-driving cars. 5G technology is expected to provide safety development of autonomous vehicles. Google and Tesla have already developed autonomous cars that have been demonstrated in several countries which encourage the public to accept this technology.

5G enables vehicles to access high-definition maps, sensor data, and AI-driven algorithms, enhancing their perception of the surrounding environment. 5G connectivity is essential for fleet management and remote monitoring of autonomous vehicles. It allows for real-time tracking, maintenance updates, and route optimization, reducing downtime and operational costs. Vehicle-to-Everything (V2X) communication is facilitated by 5G, enabling vehicles to interact with traffic lights, road signs, and pedestrians. This interaction enhances safety and traffic management.

5G's contribution to autonomous vehicles extends beyond faster speeds. It also provides the critical infrastructure for safe and efficient self-driving experiences, transforming the future of transportation. The benefits of transportation using 5G technology supports [17]:

- Safer driving as sensors can track vehicles ahead and communicate with the driver and among vehicles simultaneously;
- Updating the driver of road condition and any hazards in real-time;

• Real-time navigation of current positioning and route destination, quick response for nearby workshop or maintenance through driver's instrument panel screen;

6.4. 5G Applications for Retail and Logistics

5G brings significant improvements to customer experience and operational efficiency. Stores of tomorrow may no longer look like today's pathways of stocked shelves. The retail industry is undergoing a revolution in customer experiences thanks to the integration of 5G technology. Here's how it can revolutionize customer experiences:

- 5G enhances AR shopping experiences by letting customers visualize products in their real environment before making a purchase and the real-time data from 5G-connected sensors improves inventory management, reducing stockouts and overstock situations.
- 5G capabilities enables cashierless checkout systems, enhancing convenience for customers and streamlining operations for retailers and retailers can deliver highly personalized marketing messages and offers in real time for improving customer engagement.

The fusion of 5G and retail transforms customer experiences through AR shopping, efficient inventory management, cashierless checkout, and personalized marketing.

This not only benefits retailers by increasing efficiency but also offers customers more interactive and convenient shopping experiences. In shipping and logistics, keeping track of inventory is expensive, slow, and difficult. 5G offers the potential for greater communication among vehicles, as well as between vehicles and infrastructure itself. Fleet monitoring and navigation will become significantly easier at scale with 5G. Driver navigation could potentially be powered with an augmented reality system that identifies and flags potential hazards without distracting a driver's attention away from the road.

6.5. 5G Applications for Public Safety

5G technology is paving the way for improved public safety measures, presenting several essential elements. 5G's low latency enables faster communication between emergency responders, resulting in quicker response times during critical situations. 5G facilitates the deployment of IoT devices for monitoring and reporting incidents, improving situational awareness for first responders. The combination of sensors and their autonomous coordination and simulation will help to predict the occurrence of earthquakes and tsunamis by detecting vibrations or other natural disasters and to take appropriate actions in advance.

5G enhances video surveillance capabilities, providing high-quality, real-time footage for monitoring public spaces and ensuring safety. With high-speed data transfer, 5G supports real-time data analysis, allowing authorities to make informed decisions swiftly.

5G networks are designed to be more resilient during disasters, ensuring that essential communications remain robust and right. One of the leading causes of employee injury is inspection of equipment or project sites in remote and potentially dangerous areas. Drones, which are connected via 5G networks, can safely monitor equipment and project sites and even take readings from hard-to-reach gauges. Integrating 5G in public safety enhances emergency response and disaster response [5].

5G helps improve safety, efficiency, and project management in construction. 5G-powered drones and cameras can monitor construction sites, providing real-time updates on progress, safety compliance, and potential hazards, so that Project Managers can make quick adjustments without needing to be on-site. Autonomous construction machinery can operate on-site with minimal human intervention, performing excavation and grading with precision and without manual operation. Construction workers can use 5G-connected wearables that track heart rate, temperature, and movement. In the event of an emergency, the device can alert supervisors, improving response times and safety outcomes.

6.6. 5G Applications for Healthcare

5G healthcare use cases that enable doctors and patients to stay more connected remotely than ever. Patients will carry medical sensors to continuously monitor parameters such as body temperature, blood pressure, heartbeat, blood glucose level, blood oxygen level [5]. Other sensors will be used to gather data used to monitor patient activities in their living environments. Information will be locally aggregated and transmitted to remote medical centers, which will be able to perform advanced remote monitoring and will be capable of rapid response actions when needed. This will reduce the traffic volume of incoming patients in the hospitals, just by staying at home and create smart healthcare services digitally.

Hospitals, doctors, and the healthcare industry as a whole already benefit from the speed and reliability of 5G networks every day. One example is the area of remote surgery that uses robotics and a high-definition live stream that is connected to the internet via a 5G network. Another is the field of mobile health, where 5G gives medical workers in the field quick access to patient data and medical history. This enables them to make smarter decisions, faster, and potentially save lives.

Wearable devices could alert healthcare providers when a patient is experiencing symptoms-like heart attacks that automatically alerts a team of emergency cardiologists to be ready for an incoming patient, with a complete record of data collected by the device.
5G extends telemedicine access to rural and underserved areas, improving healthcare equity and reducing the need for long commutes. In addition, the availability of big data from a large number of patients offers an unprecedented opportunity to explore correlations, build models and tools for predictive diagnosis, early treatment and make drug discovery more efficient and effective. Similar considerations hold for the elderly and the disabled, as constant non-obtrusive monitoring allows for better and highly responsive/predictive care, while preserving individual's independency and offloading hospitals.
Lastly, as we saw during the pandemic, contact tracing and the mapping of outbreaks are critical to keeping populations safe. 5G's ability to deliver of volumes of data quickly and securely allows experts to make more sophisticated decisions that have implications for everyone. The combination of 5G and telemedicine promises to enhance healthcare accessibility and effectiveness. It enables real-time consultations, remote monitoring, and improved patient outcomes on a global scale.

6.7. 5G Applications for Enhanced Education

Remote education, empowered by 5G technology, is transforming the way we learn. 5G's high-speed connectivity ensures smooth, high-definition video streaming for online classes, enhancing the learning experience. 5G supports efficient content delivery and distribution, making educational resources more accessible to a global audience.
Low latency in 5G enables real-time interaction between students and educators, making virtual classrooms more useful. 5G extends remote education to more remote areas, bridging the digital divide and providing equal learning opportunities.
The integration of 5G in remote education enhances video streaming quality, content delivery, interactivity and accessibility. This revolutionizes the educational landscape, offering flexible and inclusive learning experiences that surpass geographical boundaries.

6.8. 5G Applications for Agricultural Technology (AgTech)

5G is transforming agriculture by making it more efficient, sustainable, and data-driven. Farms of the future will use more data and fewer chemicals. Taking data from sensors located directly in fields, farmers can identify with pinpoint precision which areas need water, have a disease, or require pest management.

AgTech is undergoing a significant transformation with the integration of 5G technology, and it offers several benefits through critical components. One of the primary benefits of 5G is it enables precision farming. It provides real-time data on soil conditions, weather, and crop health. This data helps farmers to make informed decisions, optimize resource usage, and increase yields.

Connected agricultural machinery powered by 5G improves efficiency and reduces operational costs. Farmers can remotely monitor and control equipment, leading to better productivity.

5G enables real-time monitoring of soil conditions, weather, and crop health. Farmers can use this data to apply the exact amount of water, fertilizer, or pesticides needed, reducing waste and increasing yield. 5G supports remote crop monitoring through sensors and drones, allowing for early pest detection and efficient irrigation management. Autonomous drones on a 5G network are able to communicate in real time across large fields, monitor crop health and detect issues, such as pest infestations or nutrient deficiencies. 5G enhances the monitoring of agricultural products from farm to end users, ensuring food safety and reducing waste and optimized supply chain.
Wearable 5G devices for livestock can track health, location, and activity levels; this can allow Farmers to monitor health and wellbeing of each animal in real-time.
In essence, the synergy of 5G and AgTech promotes precision farming, smart machinery, crop monitoring, and supply chain optimization. This not only boosts agricultural productivity but also contributes to sustainable and efficient food production.

6.9. 5G Applications for Financial Inclusion Technologies

The finance industry requires a secure, reliable and widely adopted platform to enable advanced financial services. 5G will provide such a platform and accelerate the digital transformation for banks, boosting ubiquitous banking operations and delivering better customer service [18]. 5G offers an array of capabilities that can be matched with the finance industry's needs, including:
• robust connectivity using vast numbers of devices to accelerate the ability of devices to share data and provide personalized payments and micro-payments over ubiquitous connected devices. These numbers of devices and connectivity could lead the development of a new era of finance services and financial inclusion;

• enhanced security, that will significantly improve security and trust of banking operations for both banks and customers, thereby helping to ensure authenticity of transactions and preventing fraud.
• ultra-reliable and low latency communication that enables fast response and control on high-frequency mobile trading, and ensures time-critical buying and selling transactions take place at the edge of the mobile network by using multi-access edge computing technology;
• gigabit data rates that enable collection of a vast amount of high-frequency stock market data for fast analysis;

6.10. 5G Applications for Smart Energy

The smart grid is a recent kind of intelligent power system that can improve energy efficiency, reduce environmental impact, improve the safety and reliability of the electricity supply, and reduce the electricity transmission of the grid. The integration of IoT technology in smart grids can help to implement fault detection and monitoring, as well as consumption monitoring, through the installation of energy sensors [13]. Other groups of related solutions envision the heat and energy management in homes and buildings to accomplish an energy savings purpose. Using IoT technology to collect data on energy consumption can also help to improve the energy efficiency and competitiveness of manufacturing companies at the energy production level.

The application of Facilities Energy Management is combination of Information systems, operational technology and advanced metering, that is capable of tracking, reporting and alerting operational staff in real time. These management systems are highly capable of allowing dynamic visibility over buildings and other facility performance. They can also provide dashboard view for energy consumption levels and allows data feeds from a wide range of building equipment and other subsystems.

Another useful example is the Home Energy Management (HEM) which set the temperature and light in a room as a function of the number of people in the room, the time of day, the external conditions, the cost of the utility. It optimizes production and consumption of residential energy. The HEM system includes applications that analyze energy usage levels, and energy management sensors that are connected to home area network that responds to the variable power supply when optimizing energy. A combination of these solutions can contribute towards reducing overall energy consumption and carbon emissions from homes. The IoT can also be used to control the appliances in home remotely and useful in detecting and avoiding thefts.

6.11. 5G Applications for Environmental Monitoring

Using of wireless identifiable devices and IoT technologies in environmental conservation and other green applications are one of the top most promising market segments in the future. There will be an increased usage of these devices in environmentally friendly programs in worldwide, like remote sensing, soil monitoring, water monitoring and air quality monitoring. IoT can be used to advance environmental programs, including the collection of recyclable materials for the reuse, the disposal of electronic waste (RFID used to identify electronic subcomponents of personal computers, mobile devices and other consumer electronics products to increase the re-usage of these sub parts and to reduce e-waste). A very important IoT application is monitoring Air Pollution: Control of $CO2$ emissions of factories, pollution emitted by cars and toxic gases generated in farms, Forest Fire Detection: Monitoring of combustion gases and preemptive fire conditions to define alert zones, Weather monitoring: weather conditions monitoring such as humidity, temperature, pressure, wind speed and rain, Earthquake Early Detection, Water Quality: track the release of waste and harmful chemicals into the rivers and sea for reducing water pollution, can also maintain the quality of water being supplied for drinking, River Floods: Monitoring of water level variations in rivers, dams and reservoirs during rainy days, Protecting wildlife and tracking wild animals and communicate their coordinates[19].

6.12. 5G Applications for Smart Tourism

Provide visitors more immersive tour experiences of fascinating locations and hot tourist spots with Augmented Reality (AR) in detail. High quality videos and photos can be transferred to the cloud and there will be smart crowd flow management. This new experience will offer new opportunities for Video on Demand (VOD) and entertainment.

Smart tourism promises to give tourists the ability to have an immediate understanding of the city, such as availability, crowdedness or quietness of different places to receive dynamic recommendations on tours that adapt to their disposition, other than already available factual information on places. 5G technology is enhancing experiences, making them more engaging and efficient. Tourists can use AR applications on 5G to increase interactivity, for example, pointing a smartphone at a historical site could display videos, recreations or fun facts. For those unable to travel, 5G enables high-quality remote virtual tourism by allowing users to "visit" landmarks and destinations. Hotels are integrating 5G-powered devices like smart mirrors, voice-activated room controls, and virtual concierge services to allow guests to customize their room environment and receive recommendations and support.

VIII. Summary

The amount and the type of spectrum impacts the network's capabilities. 5G networks require access to multiple ranges of frequency bands from low, mid to high. These frequency ranges are essential for 5G deployments as they allow operators to optimize their networks based on environmental and network coverage and capacity targets.

However, 5G deployment challenges over the last few years have made it quite evident that mid-band spectrum offers the unique combination of capacity and coverage necessary to satisfy smart phone users' expectations for availability of 5G and beyond everywhere. With exponential growth of mobile data consumption and proliferation of new bandwidth hungry smart phone applications, it is vital that regulatory bodies ensure availability of timely licensed mid-band spectrum beyond what's already been allocated.

Mobile data traffic is expected to continue to grow over the coming years. However, the specific implications for mobile networks could vary quite substantially according to the eventual growth rate and where the growth arises. It is anticipated that mobile networks will need to evolve to meet future demand for mobile data and deliver a good quality of experience. A number of strategies are available including technology upgrades, making full use of existing spectrum holdings, and densification, including by deploying new mmWave spectrum using small cells. The densification will be needed in the medium to long term to meet anticipated growth in demand, including the use of mmWave spectrum in capacity constrained locations.

MNOs have primarily addressed growing demand for more and higher quality data intensive services by increasing the capacity of their networks. This has been primarily achieved by upgrading equipment to the latest technology to deliver greater data traffic per unit of spectrum and by the deployment of additional spectrum as it has been made available as well as the densification of mobile sites.

The evolution of wireless technology especially 5G, has improved experience and transformed lives in so many ways. The 5G wireless network is becoming more and more important because of the demand for much higher data rates and bandwidth to support a greater number of connected devices and machines. Today a tremendous amount of data is used, and there are major changes in industries towards automation and intelligent systems. Advanced technologies such as massive MIMO, high-level intelligent network architecture, for instance, the integration of Service-Based Architecture is expected to grow and allow more services to be discovered in the future.

Embracing the full potential of 5G will undoubtedly lead to a more connected, efficient, and technologically advanced world. 5G wireless network will bring great benefits to consumers and businesses in the future. New applications such as real-time cloud gaming, VR/AR devices will also offer new potential revenue streams. 5G deployments will also bring benefits beyond an uplift in GDP. Mobile broadband plays a significant role in poverty reduction, improving education and increasing well-being.

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