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Research Paper

Upgrading to 5G Networks: Existing Challenges and Potential Solutions

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Abstract: The introduction of t The fifth generation (5G) networks indeed brings significant advancements in connectivity and has the potential to revolutionize various industries. The technologies that make 5G powerful include features such as faster speeds, reduced latency, increased capacity, and the ability to connect a wide range of devices and objects.
However, implementing 5G networks involves upgrading existing infrastructure and deploying new infrastructure, which can be both costly and time-consuming. This process requires significant investments from telecommunication companies to install new equipment and upgrade existing infrastructure to support 5G technology. Additionally, the deployment of 5G networks requires a substantial amount of radio spectrum, and regulatory frameworks need to be in place to allocate and manage the spectrum effectively. This paper provides an overview of 5G technologies, highlighting their key features and potential benefits. It also delves into the existing challenges that arise with the implementation of 5G networks and discusses some possible solutions to address these challenges.

Keywords: 5G, Non-Standalone, Standalone, Radio Access Technology, Mobile Broadband, Infrastructure Requirements.

1. Introduction

5G is the successor to the previous mobile telecommunication standards global system for mobile communications (GSM/2G), universal mobile telecommunications system (UMTS/3G), and long-term evolution (LTE/4G). Development and standardization are being carried out by the 3rd generation partnership project (3GPP) standards organization and have not yet been finalized. The new communication standard goes far beyond digital telephony and fast mobile internet.

It is seen as a response to the increasing data traffic worldwide in the course of digitalization, which expected to set new standards in terms of data speed, network capacity, response time, reliability, data security and enable real-time data communication [1, 2].

5G significantly reduces network latency, which is the time it takes for data to travel between devices and the network. With latency as low as a few milliseconds, 5G as described in Table 1 enables near-instantaneous communication, making it ideal for applications like autonomous vehicles, remote surgeries, and immersive augmented and virtual reality experiences [3, 4].

Table 1. Comparison of 3G/4G and 5G latency times

Network Type	Milliseconds (ms)
3G Network	60 ms (Typical)
4G Network	50 ms (Typical)
5G Network	1 ms (theoretical)

For capacity and connectivity 5G networks can support a significantly higher number of connected devices per square kilometre compared to previous generations. This capacity increase allows for a massive expansion of the Internet of Things (IoT), where billions of devices, sensors, and machines can seamlessly communicate and share data.

Also 5G introduces network slicing, a technology that enables the creation of multiple virtual networks within a single physical network infrastructure. Each network slice can be tailored to specific use cases, such as autonomous vehicles, smart cities, or industrial automation, with customized performance characteristics to meet the unique requirements of each application [5].

5G enhances mobile experiences by enabling high-quality video streaming, immersive augmented and virtual reality (AR/VR) applications, and seamless cloud gaming. It also allows for real-time collaboration and communication with minimal lag, transforming the way people work, communicate, and interact with digital content.

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In addition, 5G technology opens up opportunities for transformative applications and services in various sectors, including healthcare, transportation, manufacturing, agriculture, entertainment, and smart cities. It enables advancements such as telemedicine, connected and autonomous vehicles, industrial automation, precision agriculture, and immersive entertainment experiences.

As 5G continues to be deployed globally, it holds the promise of revolutionizing industries, fostering innovation, and enabling new use cases that were previously not feasible. Its high-speed, low-latency and massive connectivity capabilities are expected to bring significant societal and economic benefits, paving the way for a more connected and technologically advanced future [7].

This paper highlights the challenges associated with upgrading to 5G networks and explores potential solutions to overcome these obstacles. It discusses the key challenges faced in the transition to 5G and offers various strategies and solutions to address them effectively.

2. Non-Standalone Architecture and Standalone Architecture 5G

5G brings faster, more reliable, and vastly more capable telecommunications than ever before, but it also presents logistical, financial, and operational challenges for network operators who have to invest a massive amount of time and treasure upgrading infrastructure and organizations to bring 5G to life.

To help manage the migration of networks from LTE to the 5G new radio standard (NRS), the 3GPP codified two deployment modes for 5G networks, which are non-standalone architecture (NSA) and standalone architecture (SA) [8].

NSA 5G leverages existing networking infrastructure, while SA 5G modernizes core network infrastructure to suit the myriad needs of enterprise.

NSA as illustrated in Fig 1 initial rollouts of 5G networks provide customers with higher data transfer speeds by pairing a 5G radio access network (RAN) with the LTE evolved packet core (EPC), because the 5G RAN remains reliant on the 4G core network to manage control, signalling information and the 4G RAN continues to operate.

By leveraging the existing infrastructure of a 4G network, carriers are able to provide faster and more reliable enhanced mobile broadband (eMBB) without completely reworking their core network technology and pushing customers to new devices. NSA 5G provides a transitional platform for carriers and customers alike.

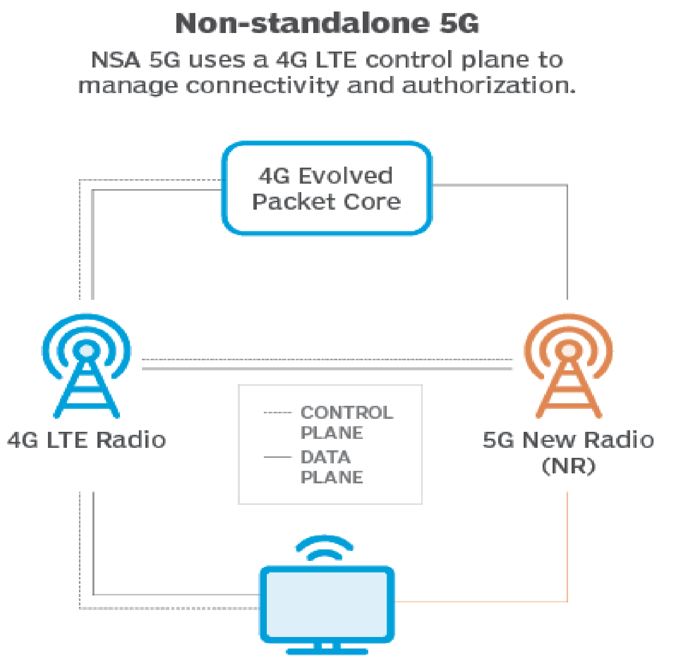

Fig 1. Non-Standalone (NSA) 5G

SA as illustrated in Fig 2 5G does not depend on an LTE EPC to operate. To some extent, it pairs 5G radios with a cloud-native 5G core network. The 5G core itself is designed as a service based architecture (SBA), which virtualizes network functions altogether, providing the full range of 5G features enterprise needs for factory automation, autonomous vehicle operation, and more [9].

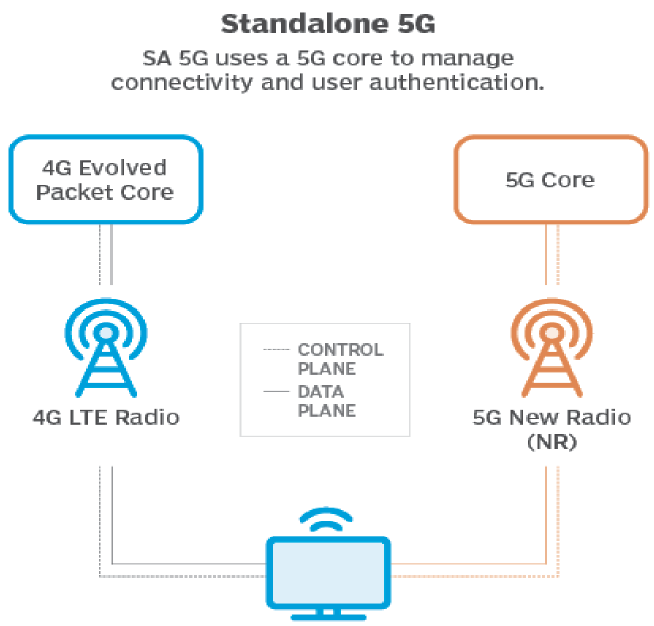

Fig 2. Standalone (SA) 5G

With SA 5G networks, network carriers will be implementing not only a 5G RAN, but also a cloud-native (or new radio) 5G core. This is where 5G is going to see its full capabilities of ultra-low latency, high bandwidth, greater throughput and high speeds.

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The roll out is going to take time, however, network operators will not only need to deploy the infrastructure, but learn how to manage the network. 5G SA is often split into three segments:

A. Massive machine-type communications (mMTC)

This segment refers to the ability to connect devices in the billions to support widespread applications such as smart cities, precision farming, connected campuses, asset tracking, fleet management, smart energy, utilities, and much more.

B. eMBB

Broadband internet has commonly been available, but it has been limited by the fact it is stationary. As illustrated in Fig 3 high-definition streaming and connecting to rapid speeds in a mobile environment will be possible through eMBB. This will enhance business applications of video streaming and monitoring in countless use cases, as well as the ability to integrate augmented reality and virtual reality [10].

C. Critical IoT

With lightning speeds, high throughput and low latency, automation is going to be a large growth area within the critical IoT sector. Use cases include automated guided vehicles (AGVs) that can be used in logistics and warehousing, remote surgery and automation within industrial [12].

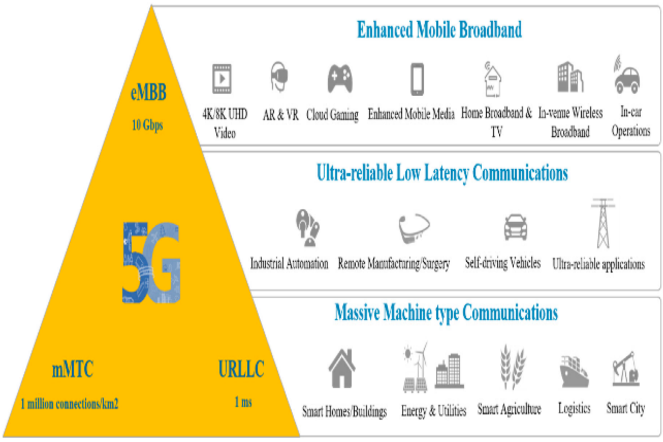

Fig 3. 5G Key Usage

SA 5G is one of the models of deployment of 5G, network services, which are provided through an end-to-end core 5G network. While in a NSA 5G a 5G radio signal is delivered over an existing 4G infrastructure. Comparatively, SA 5G is said to deliver faster and more reliable telecommunications over the NSA 5G.

5G Upgrading Challenges

While upgrading to 5G technology provides numerous benefits, there are several challenges and issues that telecommunication companies may encounter during the process.

D. Infrastructure Requirements

Deploying 5G networks often requires significant infrastructure upgrades. Telecommunication companies need to invest in new base stations (BS), small cells, and fibre-optic networks to support the increased capacity and coverage demands of 5G. These infrastructure upgrades can be time-consuming, costly, and may require cooperation with local authorities for permits and rights-of-way [6].

E. Spectrum Availability

Acquiring the necessary spectrum for 5G deployment can be a challenge. As illustrated in Fig 4 the available spectrum bands may vary across different regions, and obtaining the required licenses can involve complex regulatory processes.

5G networks require access to a wide range of spectrum frequencies to deliver the promised high data rates and low latency [11]. However, the availability of suitable spectrum varies across regions, and securing the necessary spectrum licenses can be challenging.

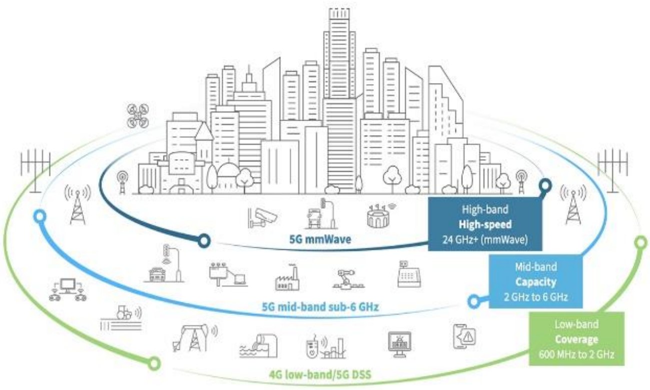

Fig 4. Frequency Bands at the Core of 5G Networks

Telecommunication companies may face competition for limited spectrum resources, and the allocation and availability of spectrum can impact the speed and scale of 5G network deployments.

F. Coexistence with Legacy Systems

During the transition to 5G, telecommunication companies need to ensure the coexistence of legacy systems, such as 2G, 3G, and 4G networks, to provide uninterrupted service to existing customers. This requires careful management of network handovers, backward compatibility, and seamless integration between different generations of technology [12].

G. Interference and Compatibility

The introduction of new frequency bands for 5G can lead to interference issues with existing networks, such as 4G LTE. Telecommunication companies need to carefully plan and manage the coexistence of different technologies to ensure smooth transition and compatibility. This may require network optimization, spectrum sharing agreements, and the implementation of advanced interference mitigation techniques [3, 12].

H. Backhaul Connectivity

5G networks generate significantly higher data traffic, requiring robust backhaul connectivity to transport the data from BS to the core network. Upgrading the backhaul

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infrastructure, such as deploying fiber-optic cables or microwave links, can be challenging and time-consuming. The availability of suitable backhaul options in certain areas, especially remote or rural locations, may pose additional difficulties [15].

I. Power Consumption

5G networks consume more power compared to previous generations due to the increased number of BSs and data-intensive operations as illustrated in Fig 5. This can lead to higher operational costs and necessitate upgrades to power supply systems.

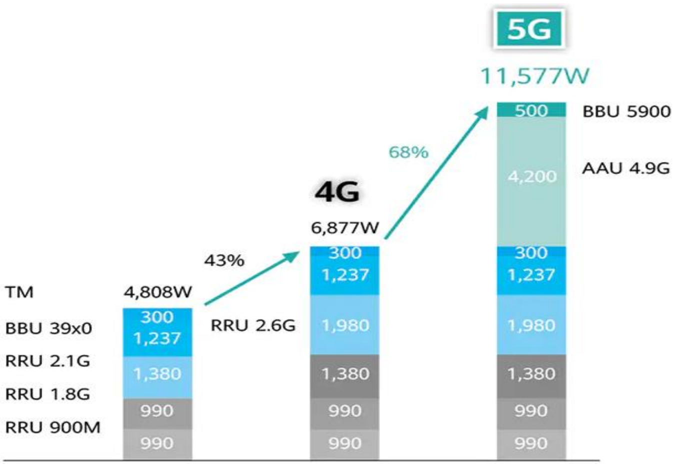

Fig 5: Typical Power Consumption of a Single 5G BS

Telecommunication companies need to consider energy-efficient solutions and optimize power consumption to mitigate these challenges [7, 8].

J. Regulatory and Environmental Factors

Compliance with regulatory requirements and environmental considerations can pose challenges during 5G deployment. Telecommunication companies must adhere to local regulations on spectrum usage, tower placement, and electromagnetic radiation limits [3, 5].
They must also consider environmental impact assessments, aesthetic concerns, and community engagement when installing new infrastructure.

K. Security and Privacy

The increased connectivity and data exchange in 5G networks introduce new security and privacy challenges. Telecommunication companies need to implement robust security measures to protect the network from cyber threats and ensure the privacy of user data. This includes implementing encryption, authentication mechanisms, and monitoring systems to detect and respond to potential security breaches [11].

Telecommunication companies need to address these challenges through meticulous planning, collaboration with stakeholders, and continuous monitoring of network performance. Overcoming these issues enables companies to realize the full potential of 5G technology and provide enhanced communication services to their customers.

3. Infrastructure Requirements

The earliest uses of 5G technology will not be exclusively 5G, but will appear in applications where connectivity is shared with existing 4G LTE in NSA mode. As illustrated in Fig 6 when operating in this mode, a device will first connect to the 4G LTE network, and if 5G is available, the device will be able to use it for additional bandwidth.

For example, a device connecting in 5G NSA mode could get 200 Mbps of downlink speed over 4G LTE and another 600 Mbps over 5G at the same time, for an aggregate speed of 800 Mbps [1, 3, 14].

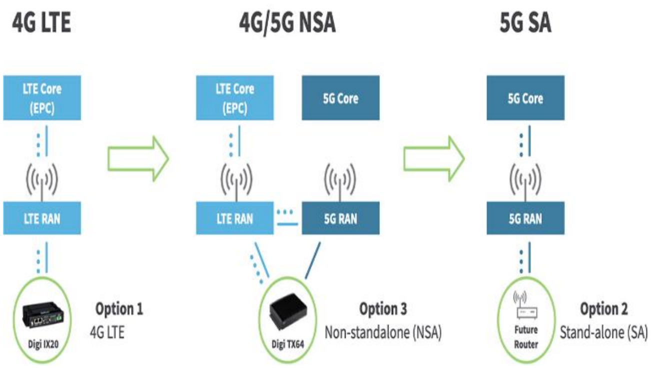

Fig 6. 5G Infrastructure Migration Over Time

As more and more 5G network infrastructure goes online over the next several years, it will evolve to enable 5G-only SA mode. This will bring the low latency and ability to connect with massive numbers of IoT devices that are among the primary advantages of 5G, which needs to overcome lots of an infrastructure issues.

A. Millimeter Wave (mmWave) Technology

5G networks utilize higher frequency bands, including mmWave spectrum as illustrated in Fig 7, to achieve faster data speeds and greater capacity [13].

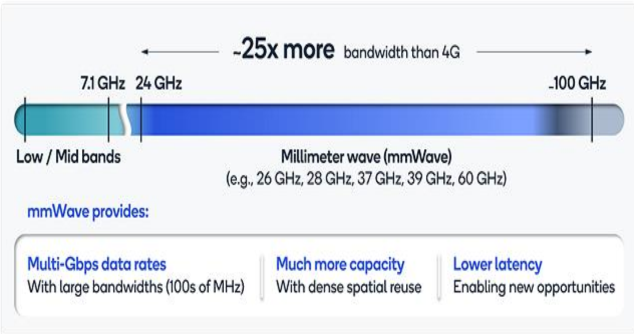

Fig 7. 5G mmWave Technology

However, mmWave signals have shorter range and are more susceptible to blockages by buildings and other obstacles. To overcome these challenges, telecommunication companies need to deploy a dense network of small cells equipped with mmWave antennas to provide coverage in urban areas and high-traffic locations. These small cells are typically installed on lampposts, rooftops, or other infrastructures to ensure line-of-sight connectivity [16].

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B. Massive Multi-Input-Multi-Output (MIMO)

Massive MIMO technology is a key component of 5G networks as illustrated in Fig 8. It employs a large number of antennas at the BS to enable efficient transmission and reception of multiple data streams to multiple users simultaneously.

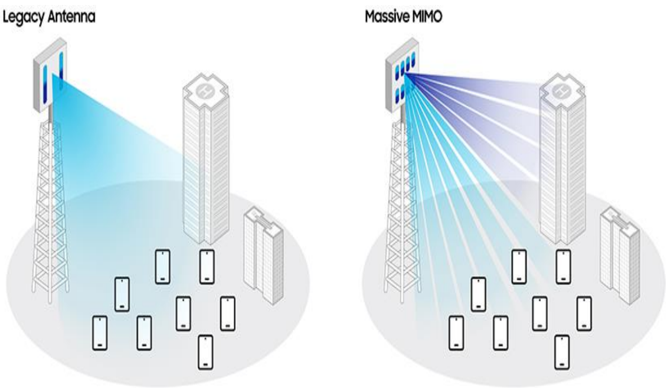

Fig 8. 5G Massive MIMO

It significantly enhances network capacity, coverage, and spectral efficiency. Telecommunication companies need to upgrade their BSs with massive MIMO antenna systems to fully leverage the benefits of 5G technology [16].

C. Network Densification

5G networks require a higher density of network infrastructure compared to previous generations. To provide seamless coverage and capacity, telecommunication companies need to densify their network infrastructure by deploying more BSs, small cells, and distributed antenna systems (DAS) [18].

Network densification is the process of increasing the number of cell sites by adding DAS, small cells and fibre optics in a geographic coverage area to increase capacity and coverage, it is particularly important in urban areas and venues with high user density, such as stadiums, shopping malls, and transportation hubs.

D. Backhaul Upgrades

Backhaul refers to the connection between the BSs or small cells and the core network as described in Fig 9.

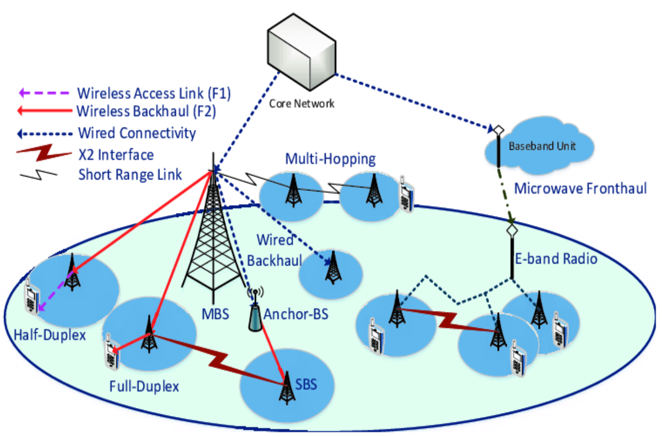

Fig 9. Backhaul Development of 5G Small Cell Networks

5G networks generate massive amounts of data traffic, necessitating high-capacity and low-latency backhaul links. Telecommunication companies need to upgrade backhaul infrastructure to support the increased data throughput of 5G. This may involve deploying fiber-optic cables, microwave links, or a combination of both, depending on the specific requirements and availability in each location [15, 17].

E. Cloud-Native Architecture

5G networks leverage cloud-native architecture, which involves virtualizing network functions and running them on cloud infrastructure. This allows for greater flexibility, scalability, and agility in deploying and managing network services.

Telecommunication companies need to adopt cloud-native principles and technologies, such as containerization and orchestration platforms to efficiently deploy and manage 5G network functions.

F. Network Synchronization

5G networks require highly accurate synchronization to ensure reliable communication between BSs and devices. Telecommunication companies need to implement precise timing synchronization mechanisms, such as GPS-based timing or IEEE 1588 precision time protocol (PTP), to synchronize the network elements and maintain the required synchronization accuracy [10, 16].

G. Power and Space Considerations

The increased deployment of BSs, small cells, and other network equipment for 5G requires adequate power supply and physical space. Telecommunication companies need to ensure sufficient power availability to support the operation of the infrastructure, including backup power options to maintain network uptime during power outages [7].
Additionally, they must consider the availability of suitable sites for installing equipment, whether it's on existing towers, rooftops, or new infrastructure.

H. Network Management and Orchestration

5G networks introduce greater complexity in terms of managing and orchestrating network resources. Telecommunication companies need to implement advanced network management and orchestration systems to monitor and control the network elements, automate network operations, and optimize resource allocation.
These systems help ensure efficient utilization of network resources and enable dynamic scaling and provisioning based on the changing network demands [4].

I. Radio Frequency Spectrum

Telecommunication companies require access to suitable radio frequency (RF) spectrum to deploy 5G networks. They need to acquire the necessary spectrum licenses from regulatory authorities to operate in specific frequency bands. Depending on the available spectrum, telecommunication companies may deploy 5G in sub-6 GHz bands (mid-band) or mmWave bands (high-band) as described in Fig 10 [18].

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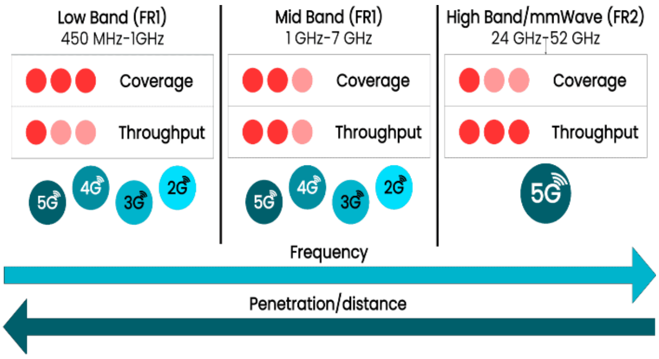

Fig 10. 5G Radio Spectrum Frequency

Acquiring and managing spectrum resources is a critical aspect of 5G deployment for telecommunication companies.

J. BSs and Antennas
Telecommunication companies need to upgrade their BSs and antennas to support 5G. This involves installing new BS equipment that can operate in the desired frequency bands and support advanced features such as Massive MIMO. BSs should also be capable of supporting MIMO technology for efficient data transmission [2].
Telecommunication companies may need to retrofit existing BSs or install new ones to accommodate 5G requirements.

K. Small Cells and DAS
Small cells and DAS represent a concentrated way of enhancing network coverage and capacity. Indeed, both systems consist of individual antennas, placed at low elevations relative to the wireless user as described in Fig 11. Furthermore, small cells and DAS allow for densification of wireless networks. This enables the widespread adoption of 5G wireless networks.

To achieve the desired coverage and capacity in densely populated areas, telecommunication companies need to deploy small cells and DAS.

Small cells are low-power radio access nodes that are typically deployed in urban areas, stadiums, shopping malls, and other high-traffic locations [2, 12].

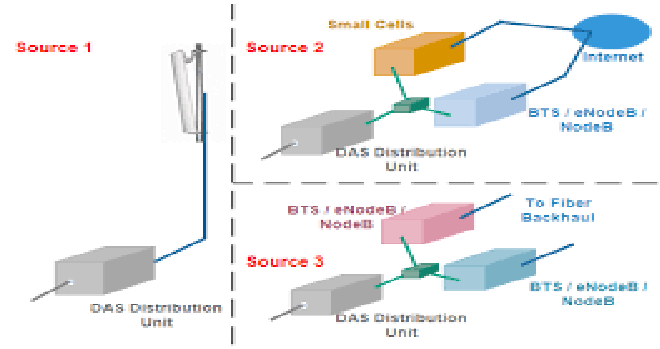

Fig 11. Distributed Antenna Systems (DAS)

DAS involves distributing antennas throughout a building or venue to enhance indoor coverage. Telecommunication companies must strategically deploy small cells and DAS to ensure reliable and consistent 5G connectivity.

L. Fiber-Optic Infrastructure
5G networks require a robust and high-capacity backhaul infrastructure to connect BSs and small cells to the core network. Fiber-optic cables as described in Fig 11 provide the necessary bandwidth and low latency required for transmitting large amounts of data quickly [1, 3].

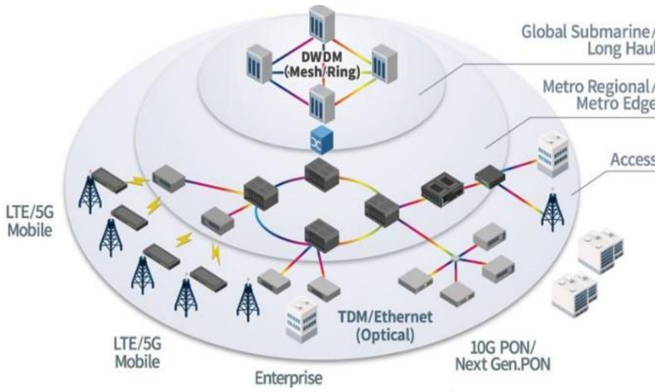

Fig 11: Fiber-Optic Communication Infrastructure

Telecommunication companies need to expand their fiber-optic networks or establish partnerships with fiber providers to support the increased data traffic of 5G [3, 18].

M. Core Network Upgrades
Telecommunication companies need to upgrade their core network to support the specific requirements of 5G. This involves deploying cloud-native architectures, virtualizing network functions, and implementing software-defined networking (SDN) principles [2].

Upgrading the core network allows telecommunication companies to efficiently manage and orchestrate the 5G network, scale resources as needed, and enable advanced services and applications.

N. Security Infrastructure
Telecommunication companies must prioritize security measures when deploying 5G networks. 5G brings new security challenges due to its increased connectivity and complexity.

Telecommunication companies need to implement robust security measures such as encryption, strong authentication mechanisms, intrusion detection systems, and security analytics [6, 8].

They should also conduct regular security audits and implement appropriate security protocols to protect the network and user data.

4. Promising strategy for overcoming 5G Challenges

5G is the development and deployment of advanced network infrastructure and technologies. The following are some key strategies that can help address the challenges:

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O. Dense Network Deployment

Increasing the density of base stations and small cells is essential for delivering high-capacity and low-latency connectivity. By deploying more cell sites in closer proximity, the coverage and capacity of the network can be significantly enhanced.

P. mmWave Spectrum

Utilizing the higher-frequency mmWave spectrum bands can provide significantly higher data rates and increased network capacity. These frequencies have large bandwidths available, allowing for faster data transmission. However, due to their shorter range, mmWave requires a denser network infrastructure.

Q. Massive MIMO

Massive MIMO technology employs a large number of antennas at both the BS and user devices, enabling the transmission of multiple data streams simultaneously. This enhances spectral efficiency, increases network capacity, and improves overall performance.

R. Network Slicing

Network slicing allows the creation of multiple virtual networks on a single physical infrastructure. It enables the allocation of dedicated resources and customized network configurations for specific applications or user groups. This flexibility ensures optimal performance for diverse use cases, including ultra-reliable low-latency communication (URLLC) and mMTC.

S. Edge Computing

By bringing computational resources closer to the network edge, edge computing reduces latency and enables real-time processing of data. This is particularly beneficial for applications that require immediate response times, such as autonomous vehicles, remote surgery, and AR/VR.

T. Security and Privacy Measures

With the increased complexity and connectivity of 5G networks, robust security measures are crucial. Implementing end-to-end encryption, secure authentication protocols, and advanced threat detection systems can help protect against potential cyber threats.

U. Collaboration and Standards

Collaboration among industry stakeholders, including network operators, equipment manufacturers, and regulatory bodies, is vital for addressing 5G challenges. Establishing global standards and best practices ensures interoperability, fosters innovation, and facilitates a smooth transition to 5G.

V. Spectrum Availability

Governments and regulatory bodies need to allocate sufficient spectrum resources for 5G deployment. Ensuring appropriate spectrum availability and harmonization allows network operators to deploy networks with optimal coverage and capacity.

W. Fiber Optic Infrastructure

A robust and extensive fiber optic network is essential for supporting the high-speed and low-latency requirements of 5G. Expanding fiber optic connectivity to reach base stations and small cells provides a solid foundation for reliable and high-capacity 5G networks.

X. Continued Research and Development

Ongoing research and development efforts are crucial to addressing emerging challenges and unlocking the full potential of 5G. Investing in areas such as advanced antenna technologies, network automation, energy efficiency, and network optimization can further enhance the performance and capabilities of 5G networks.

By implementing these strategies, network operators and industry stakeholders can overcome the challenges associated with 5G and create a robust and reliable infrastructure that supports the diverse needs of future applications and services.

5. Conclusions

Despite the challenges, the benefits of upgrading to 5G networks are significant. Faster speeds and reduced latency enable quicker data transfer and response times, which can enhance user experiences and support real-time applications such as autonomous vehicles, remote surgeries, and virtual reality.

Upgrading to 5G networks brings numerous challenges, but several potential solutions can address these obstacles. By focusing on collaborative deployment, efficient spectrum management, advanced signal propagation techniques, and energy-saving strategies, these challenges can be mitigated, enabling a seamless transition to the next-generation networks.

Ongoing research and development efforts aim to address issues related to infrastructure upgrades, spectrum allocation, and regulatory frameworks. Telecommunication companies, governments, and industry stakeholders collaborate to find solutions and ensure a smooth transition to 5G networks.

It is important to keep in mind that there is a common evolution with new technological developments. Initial efforts to develop new technology are often complex and proprietary at the outset, but over time, innovation and advancements provide a clear, unified pathway forward. This is the path that 5G is bound to follow.

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