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Demystifying 5G: The Strategic Evolution to Massive MIMO for Enhanced Network Capacity and Economic Gains

Amenah Shabeeb Kamil[1], Norbahiah Misran[1], and T. A. Oleiwi[2]

[1]Department of Electrical, Electronic, and Systems Engineering, Faculty of Engineering and Built Environment, Microwave Technology Research Group, Universiti Kebangsaan Malaysia, UKM, Bangi Selangor, MALAYSIA

[2]Islamic University Centre for Scientific Research, The Islamic University, Najaf, Iraq

Abstract: This paper delves into the world of 5G technology, focusing on the latest strategies and technologies being proposed globally. With over 14 billion devices connected, 5G networks are being implemented by the mobile telecom industry, aiming to increase capacity, connectivity, speed, accuracy, and trust. The paper also discusses the potential benefits of 5G technology, which are expected to deliver practical benefits over years, decades, and even centuries. It estimates that by 1930, 36 billion devices will be connected, transforming mobility into a ubiquitous connected environment of networks, devices, and inbuilt intelligence. The paper synthesizes key insights from technical presentations and literature on the evolution of wireless communications from traditional MIMO to Massive MIMO in the context of 5G, highlighting critical innovations, frequency spectrum characteristics, beamforming techniques, network architecture shifts, deployment challenges, and strategic imperatives for network operators. It also incorporates comprehensive details from recent academic contributions.

Keywords: 5G, Massive MIMO, beamforming, spectral efficiency, network slicing, mMIMO, URLLC, eMBB, network architecture.

1. Introduction to 5G Technology

The year 2020 is the beginning of the 5G era! 5G wireless technology is the most sophisticated wireless technology yet, featuring the deployment of a small cell, a heterogeneous radio access network, which brings challenges to backhaul, fronthaul and overall system performance assessment [1]. On the hand, the cost has become critical because of the huge energy consumption of the 5G wireless system, and as a result how to improve profitability is the key issue facing the wireless operator. Massive MIMO and CoMP are the two key technologies to enhance spectral efficiency and energy efficiency of the wireless system [2]. These two technologies can be implemented and evaluated both theoretically and experimentally, either separately or concurrently: Massive MIMO with single cell; Massive MIMO with CoMP approach to minimize inter-cell interference; Single body integrated massive MIMO base station/relay, as a case study of coexistence and collaborative operation of the lower frequency macro cell and the mmWave small cell; Age-of-information based adaptive Beamforming for

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hybrid analog/digital massive MIMO system. Massive MIMO is a central technology concept in Beyond 5G and 6G in the new future networks [1]. It can lead to significantly increased spectral and energy efficiency, high capacity, low latency and low cost per bit, which cannot easily be achieved by frequency division and distance extension [2]. Deployment of large-scale antenna arrays at ultra-high frequency enables line-of-sight communication with the ability of simplifying the RF chain [3]. Single-numerical-integer-phase power amplifiers facilitate the implementation of high-power co-located massive MIMO arrays with low-cost and low-energy-consumption sub-6 GHz bands. Advanced physical layer and semi-Blind pilot estimation schemes bring a new Future MIMO Paradigm for widespread applications in Beyond 5G and 6G era. Indicator, user distribution and mobile speed will become the decisive factor for capacity performance and further justify the interest of 6G research in a wide range of frequencies from MHz to THz. This paper explores the role of Massive MIMO in 5G networks, highlighting its theoretical foundations and practical implementations, aiming to support massive data traffic and ultra-low latency [4].

2. The Need for Increased Capacity

The demand for increased capacity in communication systems is not solely driven by the desire for 5G, 6G, and enhanced mobile broadband services. Many devices expect 5G-level capabilities, which require higher data rates, lower latency, instant connectivity, remote surgery, tactile internet, massive data transfers, IoT, and M2M communications. With global traffic expected to increase by a factor of 1000 and connected devices by a factor of 10, a wide diversity of IT service performances is expected from a more connected planet. Quality of service (QoS) provides performance objectives for machine type communication (MTC) services, which require connectivity requirements for many devices and low latency requirements. Random access methods with reduced access probability can be realized for checks and data transmission, but more stringent latency requirements than enhanced mobile broadband (eMBB) services.

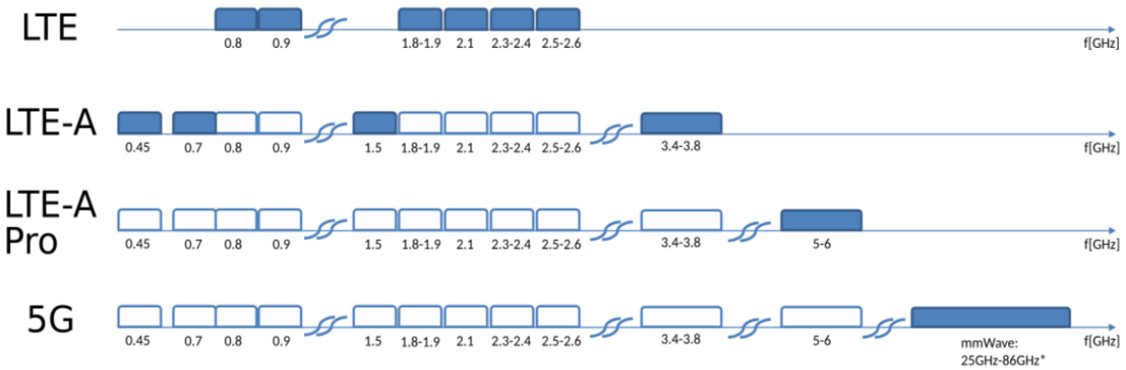

Fig. 1: The figure compares the frequency bands of LTE, LTE-A (Advanced), LTE-A Pro, and 5G, illustrating the evolution and expansion of frequency usage across generations [5].

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LTE technology uses a limited number of frequency bands, primarily supporting sub-3 GHz spectrum. LTE-A includes all LTE bands and additional bands, supporting carrier aggregation. LTE-A Pro introduces more spectrum and better capacity, preparing the ground for 5G. 5G supports all LTE-A Pro bands and introduces mmWave bands for ultra-high-speed data and IoT connectivity.

Table I; The comparison between the frequency bands of different communication systems.

Generation	Frequency Bands [GHz]	Notes
LTE	0.8, 0.9, 1.8–1.9, 2.1, 2.3–2.4, 2.5–2.6	Sub-3 GHz only
LTE-A	LTE bands + 0.45, 0.7, 3.4–3.8	Carrier aggregation
LTE-A Pro	LTE-A bands + 5–6	IoT/Small cells ready
5G	LTE-A Pro bands + mmWave (25–86 GHz+)	Enhanced capacity/speed

5G New Radio (5G NR) is a new standard for mobile cellular communications, developed by 3GPP and deployed globally in 2019 [6]. It offers greater bandwidth, capacity, ultra-low latency, and higher speeds (up to 10 Gbps) [7]. The theoretical peak download and upload speeds are 20 Gbps and 10 Gbps, respectively, using radio waves with higher frequencies [8]. 5G networks use up to three frequency bands for widespread service [9]. The main bands of 5G NR can be classified to:

- *Low-band 5G:* The technology operates at frequencies between 600 and 850 MHz, similar to 4G, with base stations providing similar range and coverage. It offers speeds between 50 and 100 Mbit/s, with a maximum channel bandwidth of 100 MHz.
- *Mid-band 5G:* The most widely used and accessible band uses microwaves between 2.5 and 3.7 GHz, with speeds ranging from 100 to 900 Mbit/s. Base stations cover up to several kilometers, but have limited-service levels due to low-band implementation in some areas. Maximum channel bandwidth is specified at 100 MHz.
- *High-band 5G:* The 5G technology operates in the lower millimeter wave band, between 25 and 39 GHz, requiring a few hundred meters between base stations. It has a maximum speed of 1.8 Gbit/s and a channel bandwidth of 50 MHz to 400 MHz [10]. However, higher frequency signals can pass through solid objects like automobiles, trees, and walls, making it suitable for high-band locations like restaurants and malls. Using carrier frequencies around 60 GHz simplifies m-MIMO technology by reducing antenna distance and size, allowing for hundreds of antenna components for base stations and mobile terminals. This increases the capacity for rapid data transfer speeds, while millimeter waves require numerous tiny cells and have a smaller range [11].

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3. 5G Core Network

The image depicts a simplified architecture of a 5G core network (5GC) based on 3GPP standards, highlighting key network functions and their interfaces. Key components include the Access and Mobility Management Function (AMF) for managing UE access, mobility, and authentication, and the Session Management Function (SMF) for handling session establishment, modification, and termination. Other Control Plane Functions include Network Slice Selection Function, Network Exposure Function, NRF, UDM, AUSF, PCF, AF, and UPF. The 5G base station (NG-RAN) and end-user device (UE) are connected via N2 and N3 interfaces, respectively [12]. Key interfaces include N1 for control signaling, N2 for handovers, N3 for user data transport, N4 for session management, and N6 for UPF and DN.

The architecture, see Fig. 2, follows the Service-Based Architecture (SBA) model, where control plane functions interact via HTTP/2-based service interfaces. The separation of control (AMF/SMF) and user plane (UPF) aligns with 5G's cloud-native design, enabling scalability and flexibility. Possible improvements include clarifying non-standard terms, adding N9 for inter-UPF communication, and including N11 for completeness. This diagram provides a high-level view of 5GC, emphasizing the split between control/user plane and the roles of key network functions.

In line with the requirements of many applications and services that 5G must serve, the 3GPP-standardized 5G core network architecture provides support for larger throughput needs, enhanced dependability, and reduced latency [13]. The 5G core network is built to include fresh ideas that provide the flexibility, simple interaction with outside applications, straightforward supply of services across several industries, and enhanced QoS. These ideas [14] are:

- *Service-based architecture (SBA)*: it is a modular architecture driven by services that may register themselves to deliver specific services, including all 5G interactions and capabilities, such as aggregation from end devices, session management, authentication, and security. Creating logically isolated bespoke networks comprising network parts devoted to a slice is known as network slicing.
- *Multi-access edge computers (MEC)*: The MEC network architecture concept offers cloud computing capabilities and an IT service environment at the edge of the cellular network to help the end user device get closer to the network and lower latency.

Among the basic and crucial responsibilities of the core network are authentication and keeping track of users' whereabouts so that services may be sent to them [15]. Emphasized in the 5G core, the virtualization (NFV) idea helps the network to implement virtualized software functions. Two network function (NF) blocks help to design the 5G core network as seen in Fig. 2.

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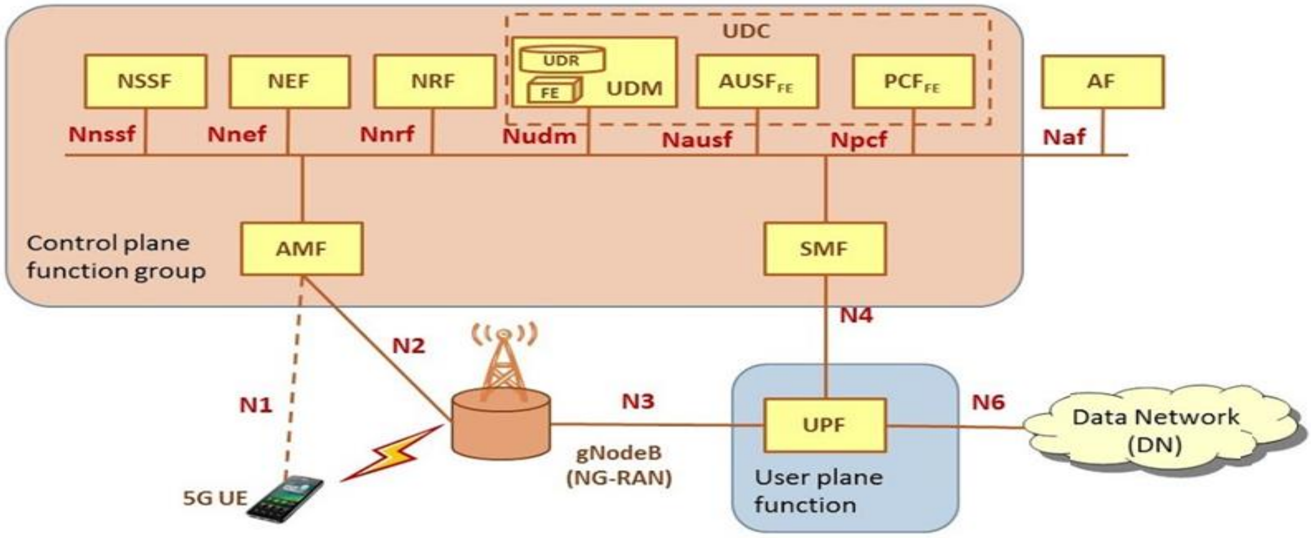

Fig. 2: A simplified architecture of a 5G core network (5GC) based on the 3GPP standards, highlighting key network functions and their interfaces [16].

The standards-setting process outlines the capabilities of various functions in a 3GPP network. These functions include the Authentication Server Function (AUSF), which provides keying materials to the requester NF and serves as a key storage. The Access and Mobility Management Function (AMF) acts as the termination point for RAN CP interfaces, managing connection state, security, and mobility. The Session Management Function (SMF) manages the session, allocates and manages UE IP address, DHCP functions, and routing, forwarding, and inspecting packets. The User Plane Function (UPF) routes, forwards, and inspects packets, manages QoS, and serves as the data network's external PDU session point of Data Network (DN). The Network Exposure Function (NEF) secures data transfer from external applications to the 3GPP network and serves as a translator, aggregation point for APIs, or proxy into the Core Network. The NF Repository Function (NRF) maintains profiles of Network Function instances and their network-based supporting services. The Policy Control Function (PCF) implements a uniform policy framework, including the newly-added 5G standardized mobility-based policies. The Unified Data Management (UDM) maintains subscriber information and profiles, performs user identification, access authorization, and subscription management. Application Functions (AF) refer to trusted services by the operator and direct access for network functions.

In Fig. 3, a simplified 5G device-based architecture, separating the User Plane (data path) and Control Plane (signaling path). Here's a detailed breakdown:

A- 5G Device-Based Architecture Key Components:

- User Equipment: Connects to the network via radio signals.
- Radio (Uu): Air interface to the gNodeB (5G base station).

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- Radio (gNodeB/NG-RAN): Handles wireless communication with the UE.
- User Plane Function (UPF): Routes user data traffic between the Radio and Data Network.
- Data Network (DN): External networks providing services to the UE.

B- Separation of User Plane (UP) and Control Plane (CP):

- User Plane (Data Path): Carries actual user data.
- Control Plane (Signaling Path): Involves AMF/SMF for session management, authentication, and mobility.

C- Differences from 4G (EPC):

- UP/CP Separation: Enables flexible deployment.
- Modular Functions: AMF (mobility) and SMF (sessions) are split for scalability.

D- Use Cases:

- Ultra-Reliable Low Latency (URLLC): UPF can be deployed at the edge for factory automation/autonomous vehicles.
- Enhanced Mobile Broadband (eMBB): High-throughput data routing via distributed UPFs.
- Network Slicing: Different UPF instances can serve slices.

E- Missing Elements:

- Control Plane Functions: AMF, SMF, UDM, etc., are critical for signaling.
- Interfaces: N1 (UE-AMF), N4 (SMF-UPF), and N11 (AMF-SMF) would complete the picture.

4. Massive MIMO Antenna Systems

Massive MIMO is a technology that is still in its infancy, but it has the potential to revolutionize mobile network deployment. It offers numerous feasible options for heterogeneous deployment with small cells and provides a novel performance upper bound in the form of a general non-linear time-dependent cost function. However, feasibility is not synonymous with immediacy, as massive changes occur in the years leading up to the operationalization of new mobile technologies. The challenges of topology implementation and hardware knowledge gap are summarized, and lessons learned from previous radio access technologies impacting massive MIMO are depopulated. Provisioning Tcp provides a broad and systematic view of the challenges in the forthcoming massive MIMO horizon, allowing for focused solutions in smaller units. A smart integration of massive MIMO technologies into a clear path for economic return on investment is necessary to avoid failures in the deployment of this technology with incredible performance promises. As mobile devices become an integral part of daily life, the user population is increasing due to new capabilities such as smartphones and mobile broadband. The introduction of location-based services, high-definition video streaming, multiplayer gaming, and augmented/virtual reality will lead to an overwhelming increase in data traffic and traffic density, resulting in a significant traffic volume surge. Mobile operators will require a tremendous increase in network capacity to provide high-quality user experiences and accommodate 1.5-2 billion new subscribers.

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Wireless communication systems will need to support throughput close to this capacity limit to enable next-generation mobile services.

A- MIMO Antenna Configurations

MIMO antenna techniques have been crucial in increasing the capacity of wireless communication systems over the past twenty years. These techniques are applied in base-stations and terminals to achieve a spectral efficiency greater than possible with one antenna. However, as the number of antennas grows, finding the best precoding or combining weights becomes computationally expensive, requiring a multi-user detection algorithm with a complexity of O(N2Nt·NR) per time slot. MIMO systems use multiple antennas at transmitter and reception ends to optimize signal energy for specific users, enhancing throughput and efficiency. This system, which can contain radio transceiver components and is individually controlled, boosts sector throughput and capacity density (MU-MIMO). MIMO can boost performance by 4 to 10 times when used in the right frequencies and configurations. The 5G New Radio (NR) uses three bands: low-band (600-850 MHz), mid-band (2.5-3.7 GHz), and high-band (25-39 GHz, mmWave). Phased array antennas are used to perform beamforming, improving energy efficiency, spectral efficiency, and security.

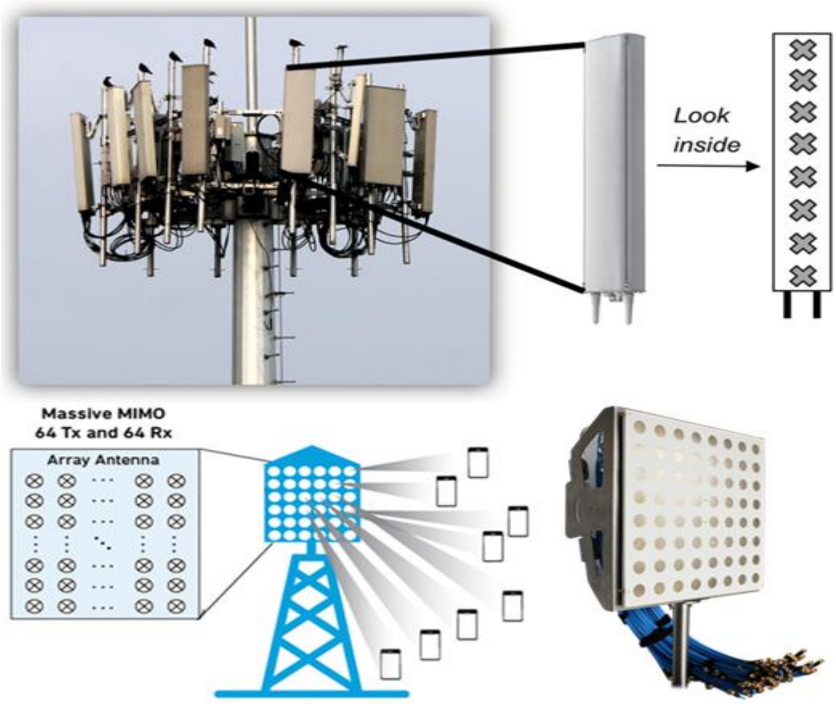

Fig. 3: Photo of an LTE site with three 8TX-sectors [17].

5. Key Features of 5G Networks

5G networks are characterized by technological trends towards massive MIMO and large-scale antenna systems, higher capacity gains compared to NLOS channels, required

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system support for more frequency bands/sub-bands, and expected operation under extreme environments. Recent research on 5G mobile communication systems has shown that spectral and energy efficiencies in 5G systems should be ten-fold higher than those in the fourth generation (4G). To meet these spectral efficiency performance targets, it is crucial to exploit the potential of spatial multiplexing of multiple antennas. MIMO antenna techniques have been considered key techniques to increase the capacity of wireless communication systems in the last twenty years. With the rapid development of large-scale integration technology and higher circuit performance, it has been possible and cheaper to install hundreds or thousands of independent hardware elements on a single chip. By taking advantage of large-scale antenna systems at base-stations (BSs), it can deliver improved capacity and coverage of services in cellular networks. In modern 5G and advanced 4G networks, a centralized Baseband Unit (BBU) pool handles baseband processing for multiple remote radio units, allowing efficient resource sharing and scalability. The fiber-based mobile backhaul connects BBUs to the core network, ensuring high-capacity, low-latency communication. The fiber-based mobile fronthaul connects BBUs to Remote Radio Units (RRUs) in various scenarios, such as Massive MIMO (M-MIMO) and Coordinated Multi-Point (CoMP). This architecture reduces operational costs, improves resource utilization, and supports advanced technologies like M-MIMO and CoMP.

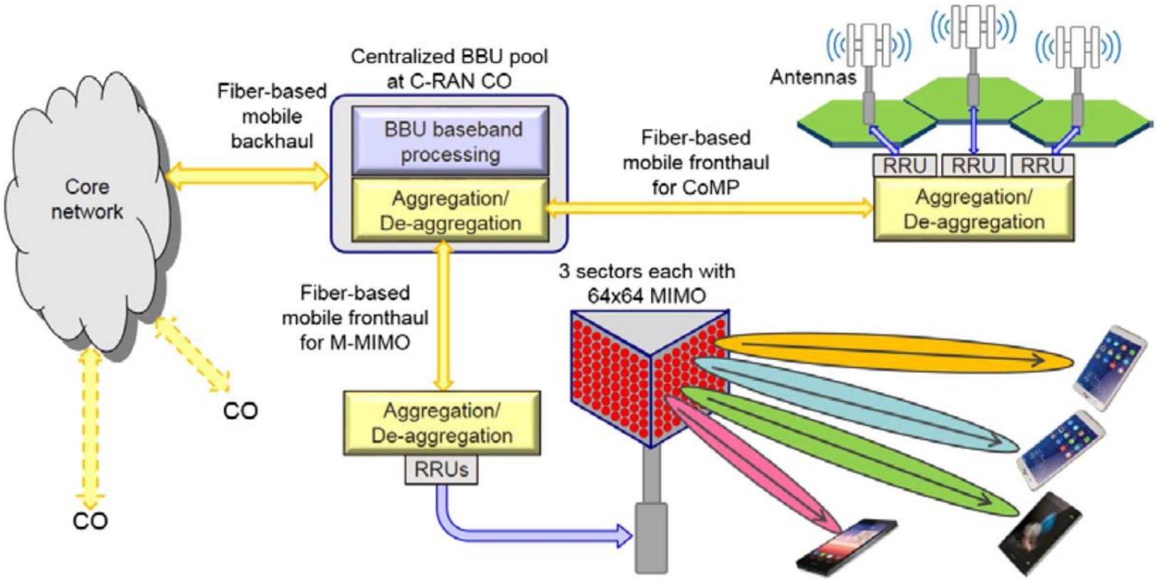

Fig. 4: The optical-fiber-based mobile fronthaul supporting CoMP and M-MIMO, as well as a mobile backhaul transporting baseband data to/from core networks, originating from the central office.

6. Massive MIMO vs. Traditional MIMO

Massive MIMO is a multi-element antenna system with a large number of antennas at the base station (BS) communicating with relatively few active users. This technology offers

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array gains that can be exploited for improving the block error rate (BLER), allowing for new users and technology that can increase the offered traffic, just like a classic macro-cellular network. Energy efficiency is defined as the ratio of the spectral efficiency to the total system power, while energy saving means that an increase in offered traffic reduces the number of active elements (antennas or BSs) to meet the required service level. A major point of concern regarding massive MIMO is its maturity. Macro-cellular base stations have been deployed since 1980 and are already well matured, while other candidate technologies for higher capacity, roaming, and improved service level do not exist yet. For massive MIMO to be deployed, both the technology and related practical implementation must be matured. The future 5G network will consist of a two-tier infrastructure of a relatively small number of large-scale (macro-cells) BSs and a large number of low-power and low-cost access points (micro-cells) employed to service high density areas. Two major paradigms are massive MIMO antennas at the BSs, allowing for spatial multiplexing of user feeds, and access point densification, allowing for more uniform spatial service coverage and larger path loss exponents, offsetting some of the new interference energy generated.

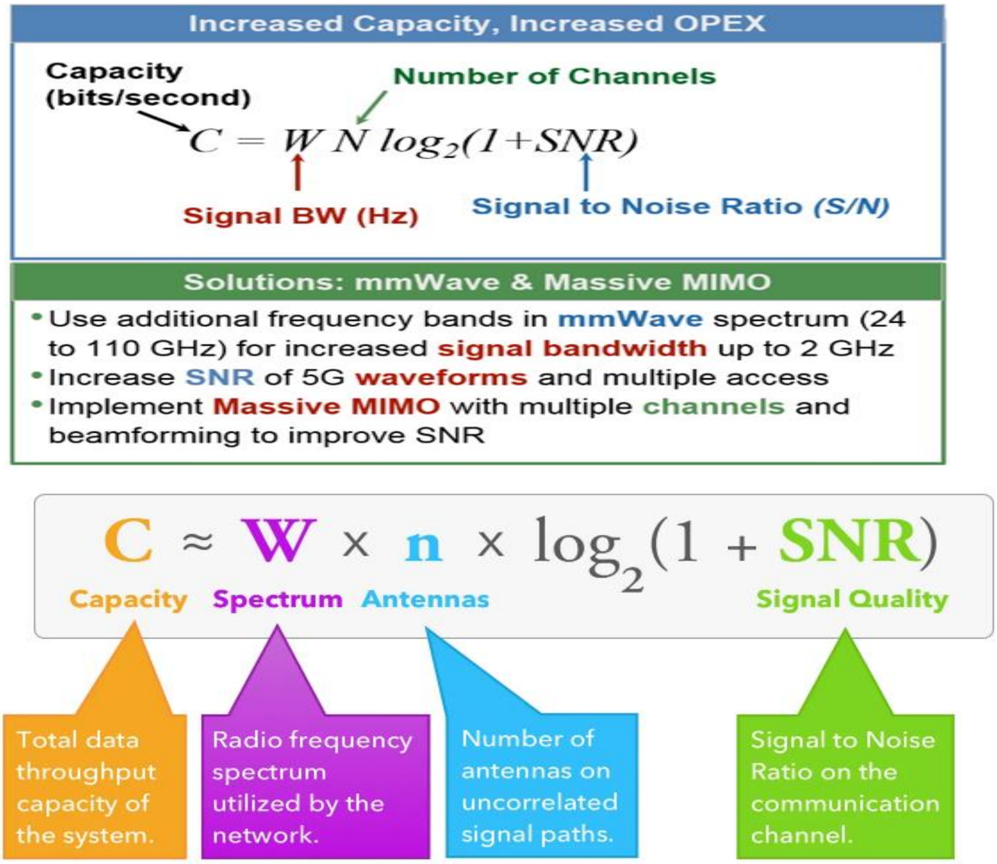

Fig. 5: The image discusses the relationship between increased network capacity and operational expenditures (OPEX) in the context of 5G technologies, focusing on solutions like mmWave and Massive MIMO [18].

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Some 5G application services are presented in Fig. 6 [19] as in the following:

1. **enhanced Mobile Broadband (eMBB):** This technology offers high data rates to support services that need a fast connection, high throughput, and high capacity, such as high definition (HD) video streaming, virtual reality (VR), and augmented reality (AR). Additionally, eMBB offers unmatched end-user experiences in congested settings like stadiums or airports, enabling consumers to enjoy high-quality streaming services wherever they are.
2. **Ultra-Reliable Low-Latency Communications (URLLC):** This term refers to the use of the network for mission-critical applications that demand robust and continuous data exchange.
3. **Massive Machine-Type Communications (mMTC)** is used to link a massive number of devices.

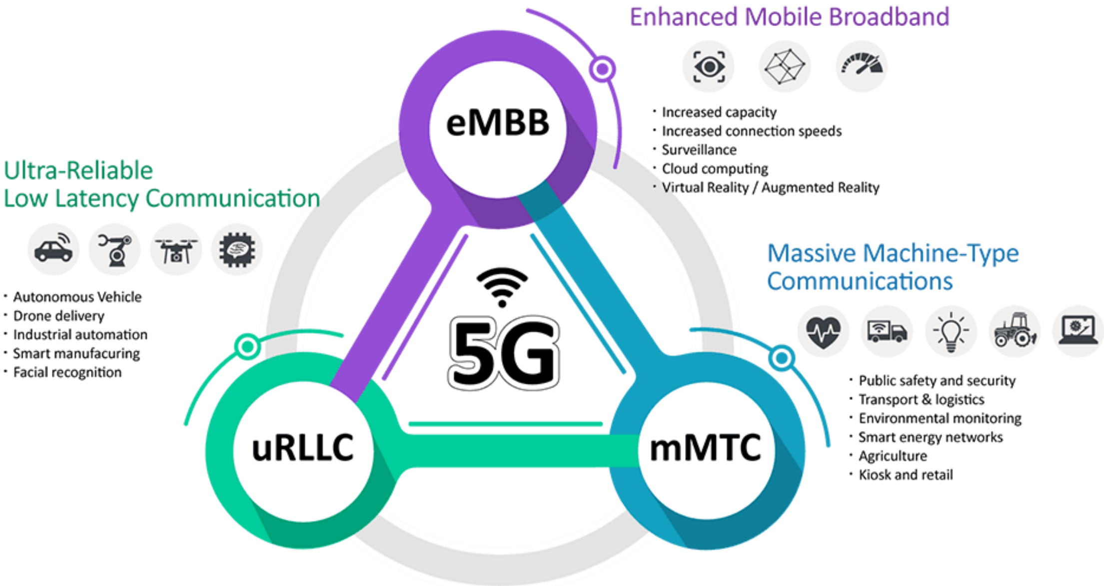

Fig. 6: Some 5G application services.

- These use cases will offer a variety of applications, including augmented reality, self-driving cars, and smart cities. In comparison to fourth generation (4G) communications, 5G communications offer improved spectral efficiency and capacity thanks to the extensive usage of millimeter wave (mm-wave) communications and massive multiple-input multiple-output (m-MIMO) technologies [20]. whereas 4G can only accommodate up to 100,000 devices per square kilometer, 5G can support up to one million.
- Since millimeter waves can travel farther than microwaves, they can only be used in small-sized cells. Additionally, building walls present more of a challenge for millimeter waves [21]. Compared to the massive antennas used in earlier cellular networks, millimeter wave antennas are smaller.

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We must examine Shannon's Law to learn how to address each of the limitations from earlier generations if we are to understand how 5G achieves the increased data speeds.

By directly addressing the first two elements of Shannon's Law, 5G increases data rates:

- **More Spectrum (W):** To communicate between devices and towers, 5G employs a larger spectrum of frequencies.
- **More Antennas (n):** To achieve spatial diversity, 5G employs arrays of antennas in both devices and towers.

When the signal-to-noise ratio (SNR) is high, 5G also employs higher-order modulation schemes methods to boost data speeds, enabling real-world data rates to approach the theoretical Shannon Capacity.

Other advantages of 5G [22]**:**

- connects people to IoT devices.
- supports disaster recovery operations by giving emergency responders access to real-time data.
- Remote surgeries.
- Remotely controlled robots, heterogeneous sensors, and a web of connected autonomous vehicles are all connected to serve a variety of purposes.
- multipurpose wireless network (World-Wireless World Wide Web)

7. Benefits of Massive MIMO

Massive MIMO is a crucial technology in 5G that aims to handle a larger number of simultaneous connections, data traffic, and challenging environmental conditions. It uses a large number of antennas at the base station (BS) to improve spectral efficiency, energy efficiency, and reliability. This is because with a larger number of antennas, propagation can be better resolved in different paths to different users. The BS's capability can be further enhanced economically by increasing the number of antennas. The spectral efficiency can reach M/ln(2) bits/s/Hz per user, with sweeping potential even greater than 10 bits/s/Hz using ultra-reliable low latency or non-orthogonal multiple access techniques. An ever-densifying base station position can compensate for attenuation of propagation channels in millimeter-wave frequencies. Massive MIMO techniques can also be used to increase the robustness of remote Nordic regions with low reliability. However, BSs with a larger number of antennas tend to use distributed architecture and coherent combining-over-times. A practical approach for ubiquity is placing a smaller number of antennas at each BS and making the accumulation coherent. This will process a round-up of wireless traffic load and BS power efficiently by implementing massive MIMO algorithms and fewer arrays efficiently at base-band units in the clouds.

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7.1. Enhanced Spectral Efficiency

Spectral efficiency is the throughput of a communication channel normalized by its bandwidth, which can be expressed in bit/s/Hz. Higher-order modulation schemes increase the bits per symbol of transmitted information, helping to increase throughput. Techniques such as higher-order modulation schemes, massive MIMO, and beamforming contribute to the effective SNR and allow the same SNR to achieve a higher achievable spectral efficiency. The throughput of a communication channel is determined by four parameters: bandwidth, modulation scheme, code rate, and the number of MIMO layers/streams. Any enhancement of those parameters will result in an enhancement in network throughput.

The physical-layer techniques integrated into the 5G new radio will increase spectral efficiency, given the bandwidth remains unchanged. The currently considered candidate technologies for 5G NR include high-order modulation schemes, massive MIMO, advanced OFDM, enhanced channel coding, and highly flexible air interface. High-order modulation schemes have been standardized in 3GPP Release 15 on top of 256 QAM, using higher-order constellations in signal modulations to encode bits. However, the enhancement in spectral efficiency from 16 QAM to 256 QAM decreases, as expected.

Beamforming is a digital signal processing technique used in adaptive MIMO antennas to broadcast various bitstreams of data simultaneously. It creates narrow, high-gain beams for transmitting signals, focusing on user devices to improve signal quality and minimize interference. The base station computer determines the optimal path for radio waves to reach wireless devices and arranges numerous antennas as phased arrays to produce millimeter waves.

Beamforming works by focusing energy towards intended users, enhancing the Signal-to-Noise Ratio (SNR) and reducing cross-user interference. Applications in 5G include Massive MIMO, compensating for high path loss at 24-100 GHz frequencies, enabling higher data rates and more concurrent connections.

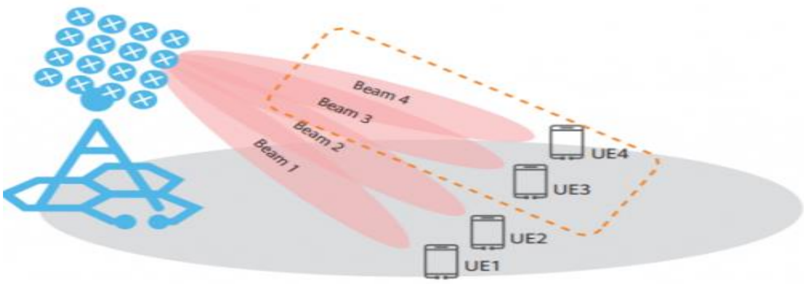

Fig. 7: The image illustrates beamforming in a wireless communication system, likely in the context of 5G Massive MIMO.

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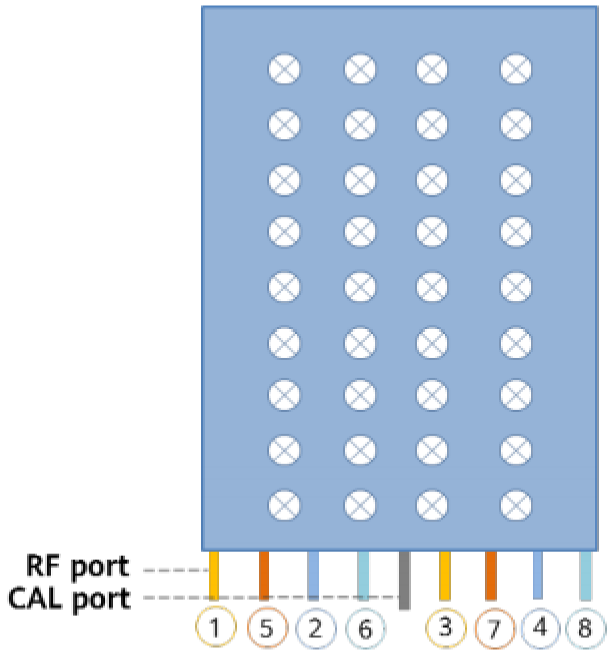
For Example: Antenna 8T8R

Consider a typical 8T8R antenna as shown in Fig. 8. Eight RF ports and one calibration port are corresponding to four dual-polarized antenna columns. The antenna's 8 RF connectors are linked to 8 distinct RF channels. The equivalent single column beam is used by each RF channel for output energy [23].



Item	FDD+TDD Converged Antenna	TDD antenna (8T8R only)
Antenna Model	AOC4518R8v06	ATD4516R8
Antenna Bottom Cap		

Fig. 8: 8T8R Antenna Structure examples (Huawei Antenna Models).

Each RF channel uses a single column beam to radiate energy, with different weights configured using 8T8R beamforming in the baseband. This modifies the amplitude and phase of signals for each of the eight RF ports as seen in Fig. 9. Broadcast and service beams are formed by radiation from combined weighted antenna columns. RF ports can use 8T8R antenna signal weighting to vary features like coverage of broadcast and service beams.

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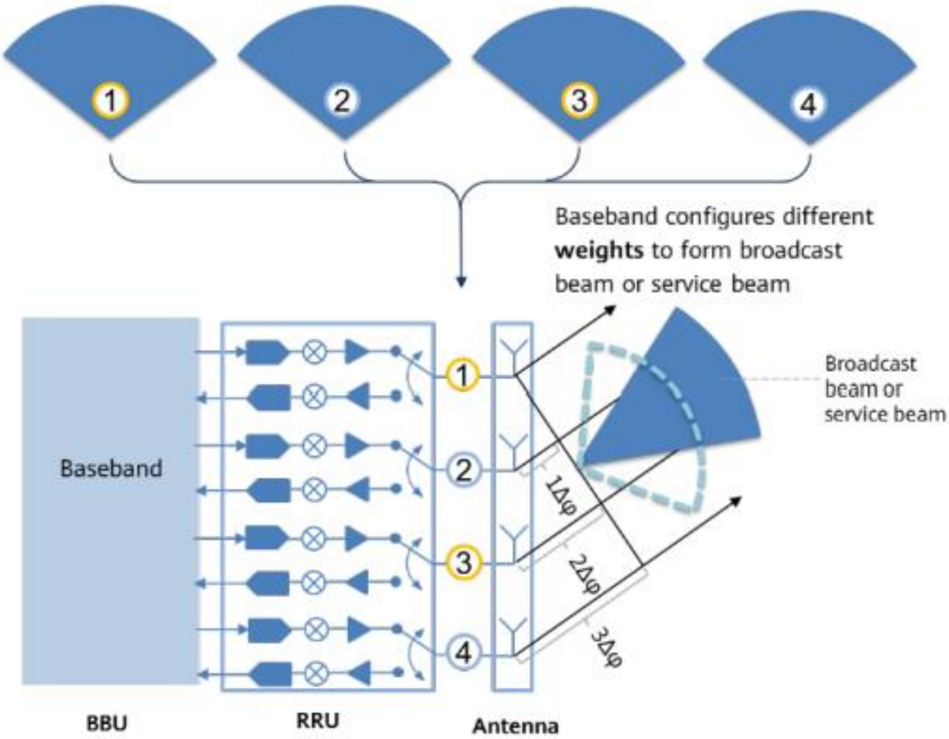

Fig. 9: Single Column Beam.

7.2. Improved Coverage

High-frequency millimeter wave (mmWave) bands are crucial for 5G systems, but their area coverage performance can be compromised by small antenna apertures and high propagation loss. Massive MIMO technology offers a solution by providing spatial diversity and high order spatial multiplexing gain. These technologies are likely to be combined in the 5G mobile communication system. However, increasing the number of antennas requires more energy consumption for data signal transmission, making massive MIMO energy inefficient in low-power domains. Therefore, the trade-off between cell size and system performance is a significant topic for further study. Beamforming types include digital, analog, hybrid, and non-orthogonal multiple access (NOMA). Digital beamforming offers flexibility but is heavy and complex, making it infeasible for large-scale applications. Analog beamforming uses one baseband port but can cause interference in multi-user environments. Hybrid beamforming partitions between digital and RF domains, balancing flexibility and cost while meeting performance parameters. NOMA is a multiple-access technique for future cellular systems, enhancing spectrum efficiency, reducing latency, and offering massive connectivity. It is used in millimeter wave radio and next-generation mobile networks, mainly 5G.

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7.3. Energy Efficiency

The industry should consider new approaches in its next-generation standards to improve energy efficiency (EE) and provide higher capacities when needed. Adaptive waveforms can reduce the peak to average power ratio (PAPR) while avoiding complex digital pre-distortion (DPD), which may not be met due to the increased digital circuit complexity required for MIMO transmission. Orthogonal waveforms can improve PAPR by up to 10 dB, but complex DPD is difficult to avoid. Frequency domain shaping or coding techniques can reduce PAPR while exploiting unused bandwidth. Techniques should have minimal applications changes and no decision feedback multi-user detection is needed. Facilitating antenna muting by ensuring coverage solutions for different/irregular array sizes is crucial for future extreme MIMO systems. Tight bounds on coverage probabilities are needed. Beamforming application in massive MIMO systems offers several advantages, including improved energy efficiency, enhanced spectral efficiency, and enhanced system security. By calculating the right number of antenna elements, these techniques can lower power consumption and improve signal quality. Additionally, beamforming directs transmitted signals to the intended user, ensuring only the receiver can extract the desired signal from the overlay signal. Overall, beamforming techniques contribute to the overall efficiency and security of massive MIMO systems.

Fig. 10: The spectra and energy efficiency.

8. Challenges in Implementing Massive MIMO

Massive MIMO (mMIMO) communication systems face numerous challenges in hardware and algorithm designs. Recognizing the restrictive conditions affecting each mMIMO and understanding its optimality conditions is crucial for most developments. However, due to the larger demands of 5G systems than LTE systems, mMIMO systems may face similar

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underwhelming spectral-efficiency and energy-efficiency scaling in their initial implementations. The performance-limit of mMIMO quantization, namely "channels-in-cones" and "channels-outside-cones" properties, reveals its surprisingly robust nature. The quantization of mMIMO signals scales similarly to other deterministic random designs, indicating that some limiting conditions for quantization-mMIMO hinder the performance of switching systems, especially if implementing Connect-and-Forward (CF) protocols. The punching-holes and bottleneck-angles quantization schemes outperform all others, indicating the many-close-users and dispersion characteristics of performance-limiting scenarios. A simple description of quantization MSI would be useful in directing future research efforts towards understanding their generic properties. In practice, uncertainties may occur in the effective noise covariance matrix due to imperfect channel estimation and/or hardware imperfections. A solid mathematical understanding is key to facilitating insightful developments. Clarifying the substantial difference among the basic components of 5G about use cases, scenarios, performance metrics, and KPIs is not just a matter of pragmatism.

8.1. Hardware Limitations

Massive MIMO (Multi-band Interference) is a significant advancement in wireless technology, requiring a paradigm shift in hardware, wireless channels, and data processing. Modern implementations rely on integrated circuits (IC) manufactured within high integration degree technologies, such as plastic, ceramic, or CMOS chips. Scaling massive MIMO requires large-scale front-ends that can bear hundreds to tens of thousands analogue signal processors per 6G base station. However, the evolution of wireless devices and data processing by the end of 2020s and early 2030s is still not well-understood. Increasing the multiplicity of analogue processors will not only increase temperature rise but also require compacting and optimizing higher rate RF to IF up-converters or down-converters with larger voltage/gain comparisons and higher power consumption. High performance turbos, quantizes, and peak mitigation will be needed to cope with the large data, high sampling rates, and the evolution of low latency and ultra-reliable transmission codes. A paradigm shift in data processing hardware is needed to scale transceivers needed to provide broadband services to everyone everywhere at once under any conditions. Current research considers MIMO arrays in the hundreds and the need for a complete MIMO de-packetisation. The sheer performance of hardware data processing needs to be probed, and the potential of hardware scaling down and novel data processing chips of very high parallelism is explored. 5G and beyond will see unprecedented loadings.

8.2. Software and Algorithm Development

Massive MIMO, or large antenna array systems, are gaining attention due to the growing demand for next-generation wireless communication systems like 5G and 6G. These systems offer significant spatial freedom, spectrum, and energy efficiency, surpassing the Shannon limit. They are widely used in wireless base stations due to their capacity and anti-jamming capabilities. However, the number of antennas in single base stations is expected to grow to

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terahertz MIMO (TMIMO) scale, presenting challenges for radio frequency (RF), analog domain user equipment (UE), and channel estimation algorithms. Terahertz (THz) band systems are recognized as a compelling option for 5G and beyond due to their wider bandwidth and ability to serve multiple users simultaneously. These systems can effectively use all available radio bandwidth, but the design of RF circuits at these frequency bands presents additional challenges. Novel MMIC implementations are required for baseband transmitting/receiving systems with thousands of output signals [24].

8.3. Cost Implications

Millimeter-wave (mmWave) bands are often considered the best solution for empty spectrum range in 5G and future cellular systems. Wireless infra-red (IR) signals in the terahertz band offer gigabits per second data rates for 6G and beyond. However, severe path loss undermines the fundamental increase in capacity, and massive antennas are considered to proactively steer radio energy towards users of interest. Massive MIMO holds promise for a cost-effective remedy to the capacity crunch with substantial noise and interference suppression at increased spectral efficiency more than 100x compared to existing systems. The use of mmWave or infrared systems over terahertz band or massive antennas is largely different from traditional systems built upon low frequencies and a few tens of antennas. This has major implications on systems' design, prototyping, and deployment. Low-cost and high-performance transceivers are urgently needed to overcome the significant gap dictated by Moore's law. Three paradigms have been studied: cloudified cell-free Massive MIMO, cloud-RAN, and self-backhauling relays. The transmission modes under consideration differ across the node architectures, leading to different architectures fulfilling different purposes in different ecosystems.

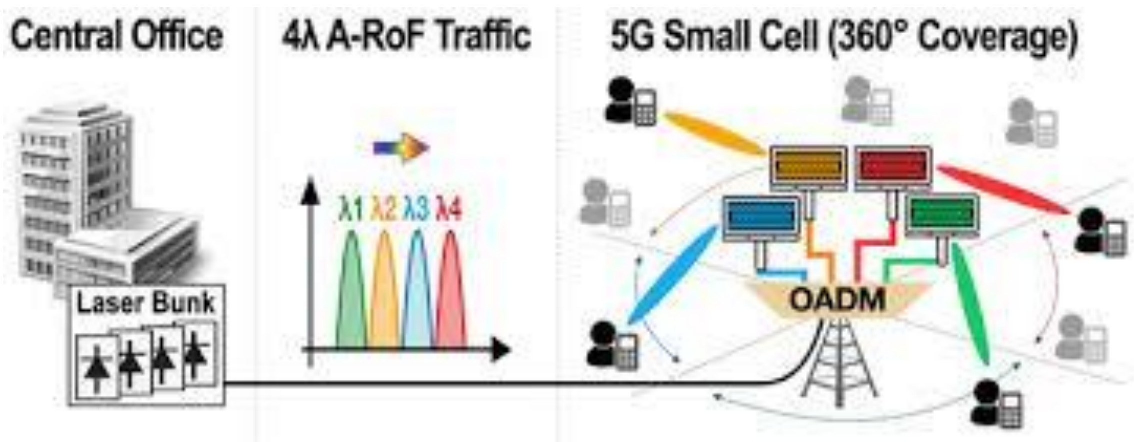

Fig. 11: 5G systems spectral-efficiency and energy-efficiency scaling.

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9. Evolution of RANs

In 5G RANs, including 5G cloud-based RANs, the BBU is divided into two physical entities, the distributed unit (DU) and the central unit (CU). The RAN evolutions show diverse technological developments.

❖ **D-RAN** D-RAN, which stands for Distributed-RAN, is one of the earliest versions of radio access network in which each cell site's physical location houses both the RRU and BBU. As a result, the RAN is dispersed over the region. The same vendor must supply both the hardware and the software.

❖ C-RAN, commonly referred to as Cloud-RAN, stands for Centralized-RAN. It is a developed form of D-RAN. The BBU won't share space with the RRU at the cell location. BBU of many cell sites will be in the same physical location, allowing for dynamic resource sharing (called as BBU Pool or BBU Hotel). That is a well-executed strategy with several benefits. The same vendor must supply both the hardware and the software.

❖ **vRAN (virtualized RAN):** It is similar to C-RAN but no longer depends on some key elements of the RAN architecture's hardware. On top of Commercial-Off-The-Shelf (COTS) servers, BBU is a software package. The same vendor must supply both BBU and RRU.

❖ **O-RAN (Open RAN)**, is the most recent improved RAN system. It retains all of the advantages of vRAN and C-RAN solutions with open interfaces. There won't be a vendor lock-in and dependency in this situation. Any entity may receive supplies from different vendors.

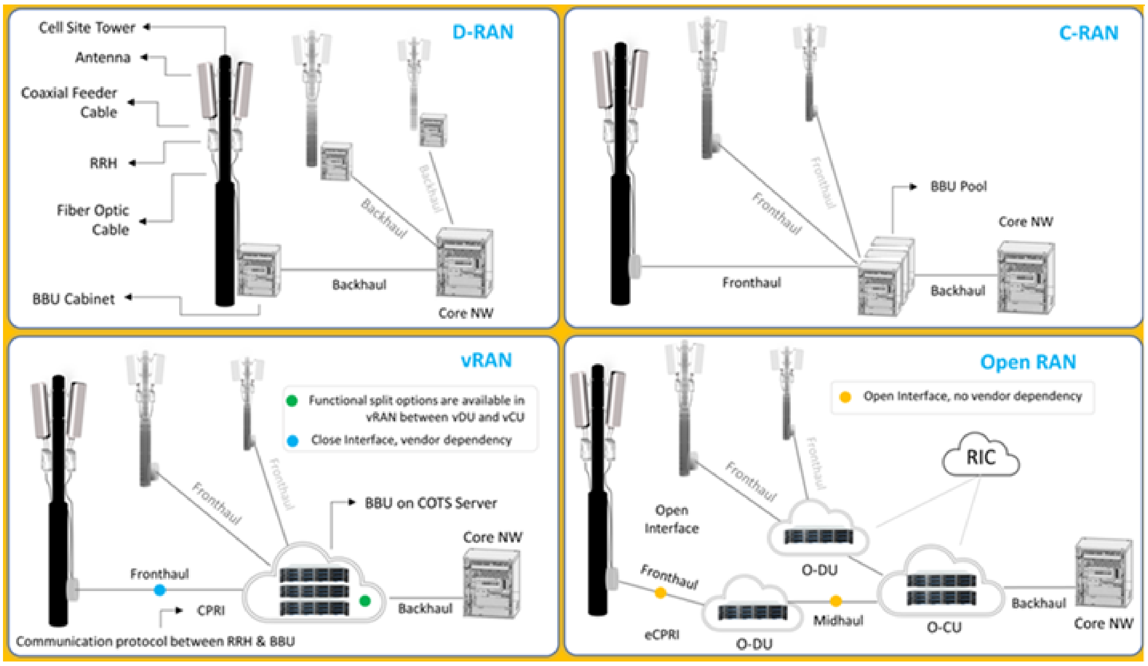

Fig. 12: Different types of RAN.

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The 5G technology is expected to significantly impact various industries, with speeds exceeding 10Gbps and increased uplink and downlink throughputs. This will lead to transformative changes in service delivery models, particularly in the video industry. Profits are currently derived from high definition video streams over fixed and mobile telephony and from content studios producing content [25]. However, ultra-high definition video capture creates a significant uplink burden, leading to increased bit rates and stringent network requirements. In the near future, [26] allowing catchup viewing of very high definition video on telephones will likely be impossible without substantial network expansion. Similar adjustments will be necessary for streaming 360-degree video feeds [27], especially at ultra-high definitions. New content studios will emerge to produce extreme video data streams, with a complex path connecting origination points to the network [28]. The end-to-end environment is only feasible if networks and service providers develop extensive collaborations and business models that make service diversification profitable on network economies of scale [29]. Network providers driven by commoditization will have to be meek in capturing high service barriers raised by video:

9.1 2G RAN (GSM RAN, GRAN)

The Global System for Mobiles (GSM) RAN transmits and manages radio links for circuit- and packet-switched core networks using base stations and controllers. With the introduction of newer mobile networks by network operators, more advanced RAN standards have been implemented throughout time.

9.2 GSM EDGE RAN (GERAN)

Enhanced Data Rates for GSM Evolution RAN provides improved upload and download connections to the internet, improved Voice over IP (VoIP) and cellular conversations, constant connection to the most appropriate base station, and higher bit rates in general.

9.3 3G RAN (UMTS RAN or UTRAN)

Universal Mobile Telecommunications System RAN, here, the base station is known as Node B and Radio Network Controller (RNC) as seen in Fig. 13. The location of the RNCs are between the Node B and the network core. A Node B is different from a GSM base station because a Node B uses WCDMA, whereas GSM base station uses basic CDMA. Radio frequencies received at a Node B are turned into a data stream, which is forwarded to the RNCs to be sent to the core network. For the reverse, the Node B turns the data stream into radio frequencies to be transported to UE.

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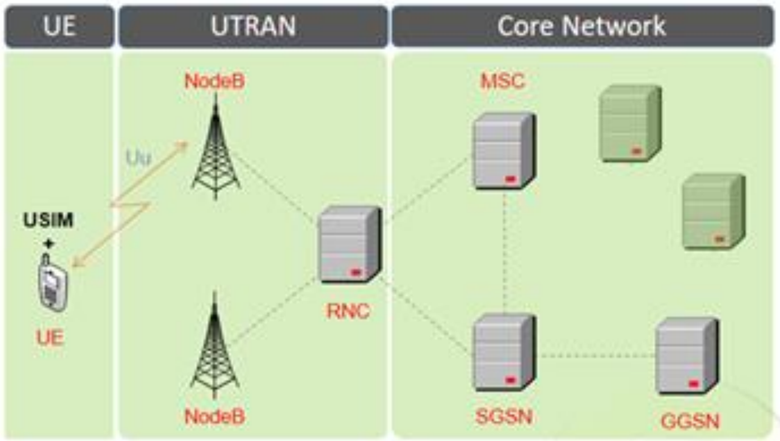

Fig. 13: Universal Mobile Telecommunications System.

9.4 4G RAN (E-UTRAN)

The Evolved Universal Mobile Telecommunications System RAN, Fig. 14, is a 4G LTE network designed with features such as OFDMA for downlink connections and SC-FDMA for uplink, a peak data rate of 100 Mb/s downlink and 50 Mb/s uplink, reduced latency, scalable bandwidth, and support for devices moving up to 500 km/hr. The BS, eNodeB, is responsible for these functionalities, ensuring they are obtained through RNC, making it a self-contained controller.

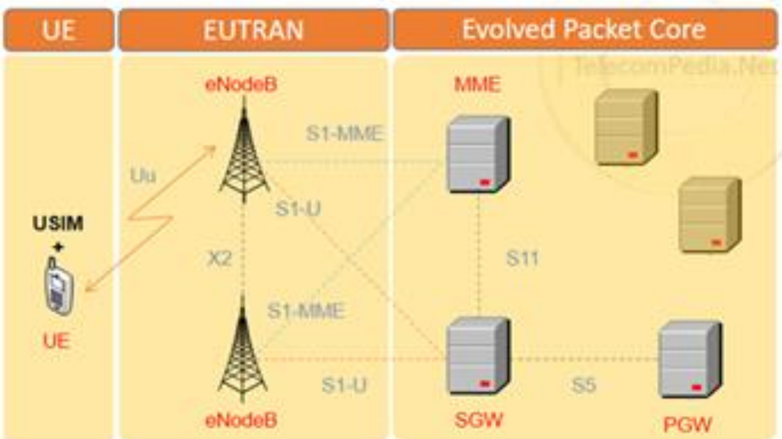

Fig. 14: Evolved Universal Mobile Telecommunications System.

9.5 5G RAN (Cloud RAN, C-RAN)

C-RAN is a centralized, cloud computing-based architecture consisting of three main components: RRU networks, a centralized BBU, and a transport network. RRU networks connect wireless devices to the internet, while the centralized BBU provides resources to RRUs

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based on network needs, similar to a cloud. The transport network uses optical fiber, cellular communication, or mmWave radio frequencies as its connection type. Here, the BS are known as Next generation NodeB (gNodeB). The difference between gNodeB, eNodeB, and NodeB, see Fig. 15, are as follows:

Node B	eNodeB (eNB)	gNodeB (gNB)
Node B	Evolved Node B	Next Generation Node B
Radio base station in 3G networks	Radio base station in 4G networks	Radio base station in 5G networks
3G – UMTS (Universal Mobile Telecommunication System)	4G – LTE (Long Term Evolution)	5G – NR (New Radio)
Wideband Code Division Multiple Access (WCDMA)	Orthogonal Frequency Division Multiple Access (OFDMA)	Orthogonal Frequency Division Multiple Access (OFDMA)
Part of UTRAN (UMTS Terrestrial Radio Access Network)	Part of E-UTRAN (Evolved UMTS Terrestrial Radio Access Network)	Part of NG-RAN (Next Generation Radio Access Network)

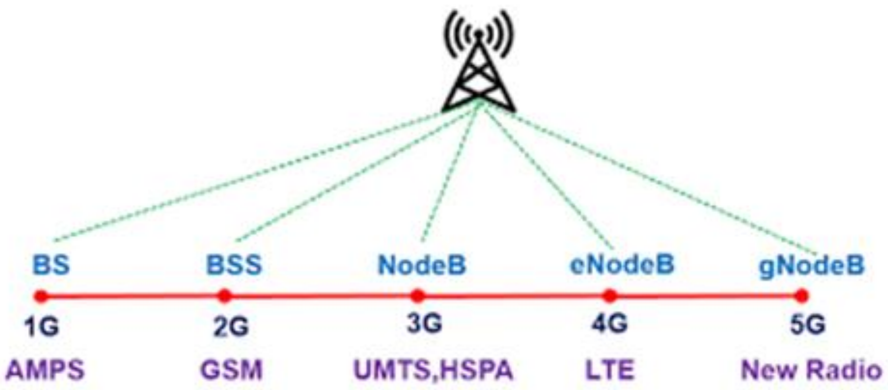

Fig. 15: The differences between different generations.

In 5G RANs, including 5G cloud-based RANs, the BBU is divided into two physical entities, the distributed unit (DU) and the central unit (CU) as seen in Fig. 16.

1. **DU** provides support for the lower layers of the protocol stack such as RLC, MAC, and physical layer.

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2. **CU** provides support for the higher layers of the protocol stack such as SDAP, PDCP, and RRC;

The BBU is connected to the gNB using fiber optic cables.

5G structure can be operated as non-standalone (with 4G LTE network) or as standalone modes.

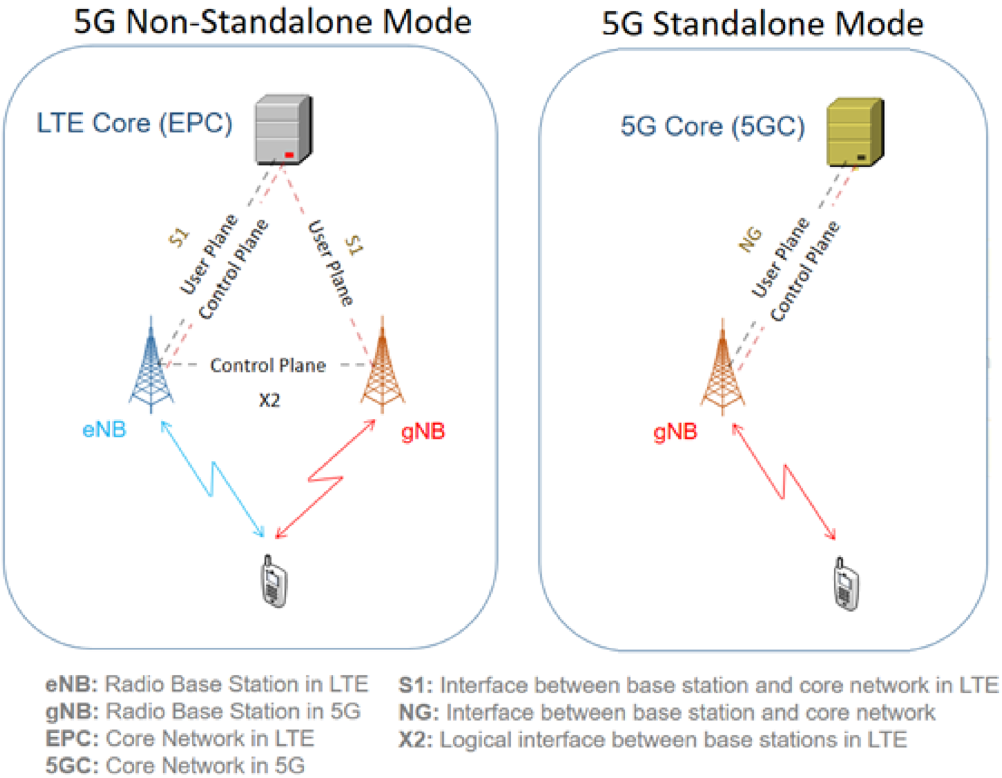

Fig. 16: The BBU physical entities.

The evolution of mobile networks and MIMO technology has led to improvements in data rate, latency, and reliability from 1G to 5G. MIMO technology, initially introduced in 3G and expanded in 4G, has evolved into Massive MIMO in 5G, featuring 2x2 or 4x4 antennas, improved throughput, and improved interference mitigation. This has resulted in higher signal quality and improved spectrum reuse. Traditional base stations have a frequency range of 0.45 to 1.9 GHz and 8 dual-polarized passive antennas, with a peak data rate of 114 kbps. Distributed base stations have a frequency range of 0.7 to 3.6 GHz and 8+ dual-polarized passive antennas, with a peak data rate of 150 Mbps. Centralized base stations have a frequency range of 3.4 to 6 GHz and a millimeter wave of 20-60 GHz, with 128 to 512 active antennas (Active Antenna System, AAS). Key features include integrated antennas with transceivers, virtual BBU Cloud for centralized processing, fiber fronthaul over long distances, and simplified backhaul.

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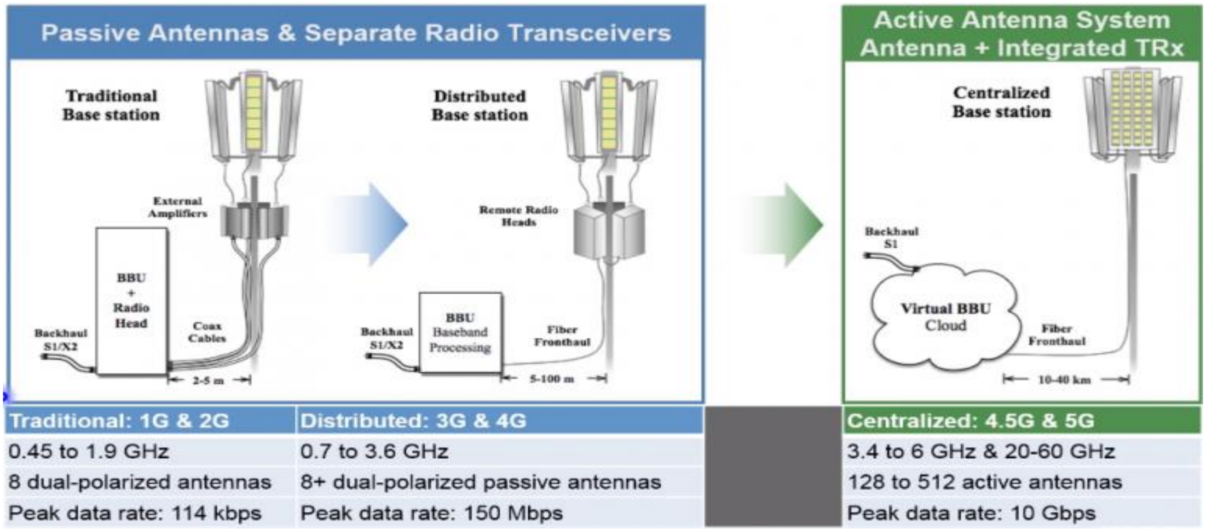

Fig. 17: an overview of the evolution of base station architectures and antenna systems from traditional (1G/2G) to modern (4.5G/5G) technologies.

1. **Earlier generations (1G and 2G)** of cellular base station architectures (Traditional Network): Long lengths (< 200 feet) of thick coaxial cable are used to connect the antenna to a remote radio unit (RRU). RRU is co-located with BBU and the connection between them is through short fiber-optic. Significant coaxial cable losses were introduced as a result of the radio processing being separate from the antenna system. In order to overcome system losses, this required power-hungry power amplifiers with the required cooling and battery backups. This decreased energy efficiency, cost-effectiveness, and system scalability [30]. The deployment of numerous base-band units is necessary. Hardware RRH/BBU and software must come from the same vendor under vendor lock-in.

2. **Later generations (3G and 4G)** of cellular base station architectures (Distributed Network): the fronthaul splitted the RRU from the BBU container to the antenna structure. RRH is connected to BBU through a long fiber-optic connection via CPRI protocol; this allows the BBU to be located a larger distance from the RRH [31]. A single remotely connected BBU or several remotely connected BBUs can operate several cell towers by the CPRI-enabled C-RAN. In consequence, this permits fronthaul distances of up to 40 km and much higher bandwidth. Replacing the lossy high-power cables with a fiber front-haul increases the power gain.

3. **Latest generations (4.5G and 5G)** Introduced Active Antenna System (AAS) which is RRU + Antenna System) and centralized BBU that can be located in a remote DC (Data Center) C-RAN, this will reduce the CAPEX, less power consumption, real time functions, fast

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deployment roll-out, more connections from IoT devices, and lower latency. This allows the RRU to be located closer to the antenna, while the BBU can be located more centrally [32].

10. 5G Applications

5G wireless technology is revolutionizing a wide range of industries and applications thanks to its high speed, ultra-low latency, massive device connectivity, and enhanced reliability. Here's a categorized overview of key 5G applications as seen in Fig. 18.

Fig. 18: The 5G applications.

10.1. Healthcare

The 5G technology is a solution for massive connectivity and high data rates, with potential applications in vehicular applications and the Internet of Things. However, firefighting, sensing, and agriculture are few early harbingers for potential usage. The advancement of nodes' affordability is crucial for increased global device penetration. To meet the soaring demand for connectivity, 5G is expected to have a completely revamped architecture, integrating various technologies like software-based and cloud-based architecture with existing 3G and 4G architecture. The offset of the backbone architecture allows dual deployment of infrastructure as a network operator of low latency millimeter-wave networks. The 5G radio access architecture will use existing spectrum more effectively, partly in lower frequency regions, to expand wireless coverage and comply with earlier standards. The text presents major features of 5G architecture affecting healthcare provision and identifies migration paths for industrial users towards 5G networks. The main technology trends for 5G networks include low-cost and low-complexity architectures, self-organizing network architectures, cognitive architectures, dense deployments with femtocells, network function virtualization, and mobile SDN.

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10.2. Transportation

Railway cars, with their metallic bodies and low emissivity coated glass windows, cause high signal attenuation, requiring advanced Doppler compensation algorithms and careful network dimensioning and optimization. However, the deployment of 4G has increased demand for high-capacity mobile connectivity, with users expecting unlimited access to video and music streaming services, instant access to social media services, and reliable connectivity for gaming services. With over one million commuters daily using 720 km of railway tracks in Switzerland, network and train operators are trialing next-generation solutions. Service providers and railway operators use on-board equipment like signal repeaters or Wi-Fi routers backhauled via the cellular network, but this strategy is threatened by the use of MIMO systems and the difference in life-cycle duration between the railway and telecommunications industries. Upgrading railway infrastructure with the latest wireless communications infrastructure every three to five years is a costly mission. Service providers will serve broadband applications with 5G and future railway mobile communication services.

10.3. Manufacturing

The multi-chip module for a GaAs chip with filters and a silicon chip with CMOS ADCs is being manufactured in Israel, with the GaAs chip cooled to -40°C for testing and increasing yield. The main components were specified for bulk fabrication by well-known foundries, with run-times in the order of months for production and testing of typically 2–4 systems. Four chips per wafer are manufactured in Israel at the common foundry Vortex, while a second chip with PCM filtering has been designed and sent for fabrication. The output of the GaAs is connected via a laser-written waveguide on OFS fibers to a Si CMOS ADC chip at DTU, Denmark. Grating couplers were included for down-conversion from 1550 nm to 1310 nm. Several systems were built for high-speed testing of each chip on the reel, including 40G Ethernet and 1550 nm test-beds using fiber-pig-tail packages. Massive MIMO is recognized as a key technology to support unprecedented data rates in forthcoming wireless generations.

10.4. Entertainment

The entertainment market is increasingly crowded, with more channels for distribution, media formats, IP to monetize, ways to connect with audiences, and companies focused on maximizing audience engagement. As choices proliferate, so do points of view, and the value of content continues to grow. In the television space, these competitive dynamics have led to a race to produce more original scripted programming than any other era in history. Content co-existence and consumption is a fact of life now, with more households having subscriptions to multiple VOD providers. Outside of television, there is more competition for attention and viewing time in social media, eSports, and gambling. In cellular infrastructure, more competition leads to more devices aimed at maximizing engagement and productivity. The

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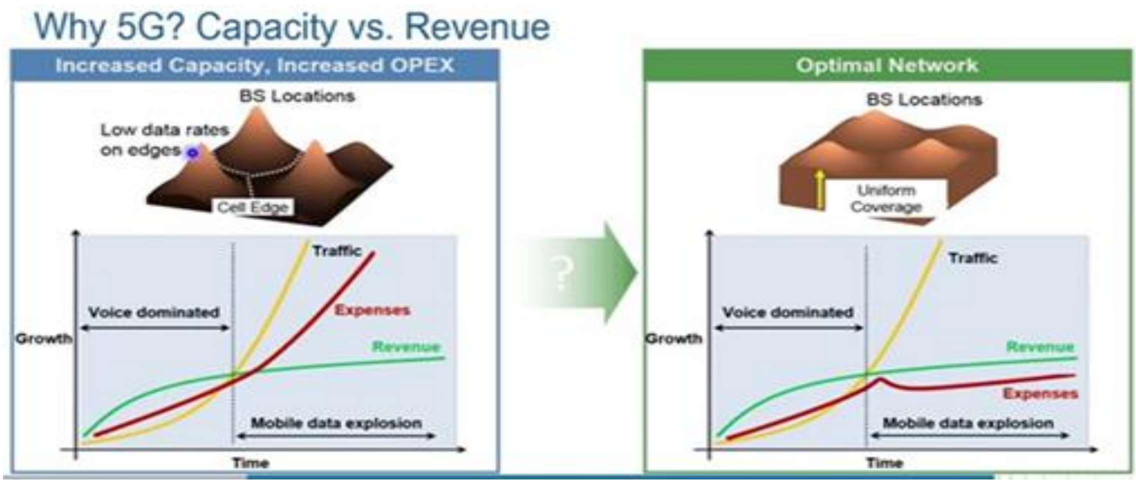
building blocks of such competitive dynamics come from distributed systems of consequence, which traditionally had base stations as the centerpiece of cellular systems. With an adjustable antenna array, machines are freed from trade-offs like orientation, height, capacity, or redundancy, and can be placed nearly anywhere, such as WiFi-like, randomly through cities, or on rooftops of buildings on dense urban thickets. Only a couple are actually needed for service.

11. Economic Implications of 5G Deployment

5G is expected to surpass 5G services, connecting over 50 billion devices. However, a gap in new cell standard radio architecture (Massive MIMO) could delay commercially viable devices for up to a decade. To ensure the viability of these targets, discussions on the big picture drivers are needed. Most telecommunication experts plan deployment based on basic 5G technology tenets, but many factors drive, impede, or shape the target market. Arguments on drivers and impediments need to be quantified, such as need, testing, implementation speed, and the big picture. Governments worldwide have agreed on broadband for the fourth industrial revolution, with private transport, communications, and payment becoming the norm. Low in-data, high latency methods are needed for access, and regulation may be necessary. Smartphones that best accommodate everything are the platform that allows work to connect and thrive even while physically separate. As 5G subforms, fixed access would be achieved, opening huge scope for applications and value creation. However, fixed access would require slow government effort and could fractally implode. New tech is now fitted, granting unthought-of access for faster, better, and infinite data flow. Targets of tens of Gbps from MNOs appreciating decreasing marginal returns would be the best strategy for profits. Outputs ready for scalability include LED light sources augmenting waste RF signature, candle hexagonals supplementing video, dish satellites, and hosted bandwidth of LTE core nodes.



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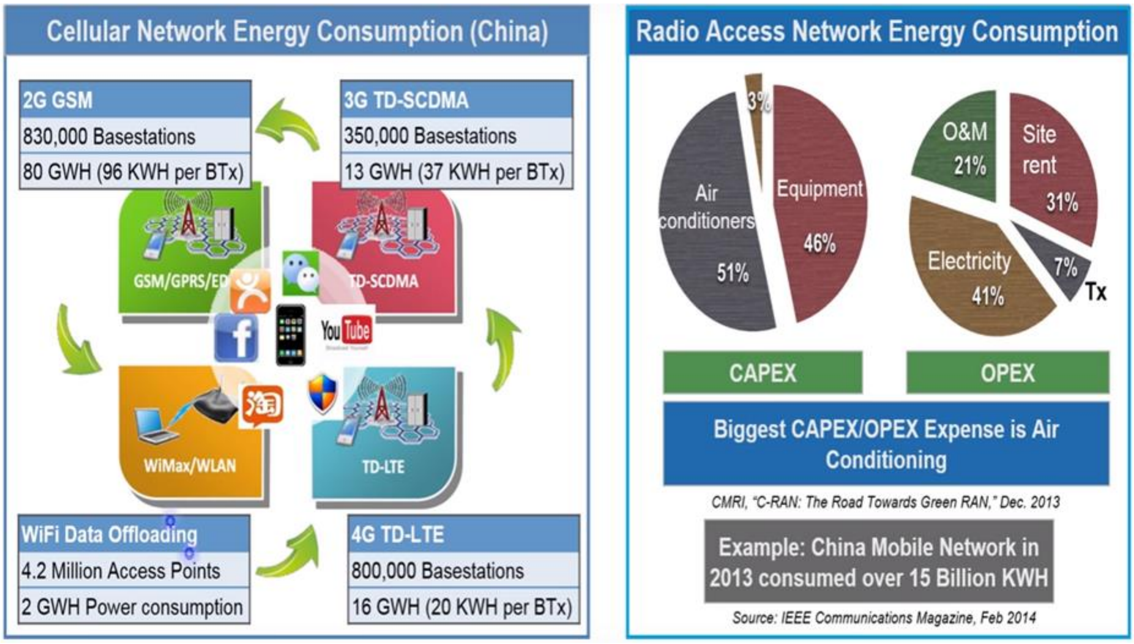

Fig. 19: The effective CAPEX and OPEX of 5G systems.

10.1. Investment Opportunities

Investing in network infrastructure with a diverse set of shares will yield maximum profits for shareholder's long term. This diversification must include participation in many network businesses. Global returns with smaller security funds can be achieved with suitably diversified global network investments. 5G will rank number three amongst shared network infrastructure share sectors but offer greater growth prospects than other sectors. The population growth momentum for 5G is due to the acceleration in smartphone and GBit/s growth, which will increase ubiquity in population growth rates. 5G has higher top-level growth prospects than other network infrastructure share sectors. By extrapolating growth rates and price earnings ratios from the years up to 2020 up to the end of 2030, it is estimated that 5G will be ranked third in global number of users and share sector market capitalisation. It will be ranked first in top-level growth rate of both numbers of customers and share sector earnings per share rates. When fully rolled out, 5G will be orders of magnitude cheaper per and through numerous other measures than any other considered infrastructure.

10.2. Job Creation

The employment impact of 5G cell networks augmented by MIMO antenna technology is significant, with various sectors experiencing job creation and displacement. Construction, engineering handset manufacture, and licensing sectors are expected to see significant growth, while mobile telecoms with lower MOs are predicted to lose jobs due to the construction phase. As infrastructure comes online, MNOs and service providers will need to hire staff for ongoing 5G operations and maintenance, creating permanent jobs. However, many mobile telecoms

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jobs will be displaced, particularly in rural areas with lower MOs. Rural ISPs will face greater competition with new similarly priced services, leading to decreased demand for current services and a thinning of operator payroll. WISPs will also lose the highest pre-MNO profit margins nationwide, and older workers may struggle to re-skill for new technology. In southern regions, it is suggested that the economic sector involved with 5G network deployment should be fostered based on existing regional expertise and infrastructure. This would allow local regions to access 5G quickly without large fixed cost expenditures, allowing new services to be adopted and accessed arbitrarily locally. The employment impact of 5G cell networks augmented by MIMO antenna technology is significant, with potential employment opportunities in sectors such as construction, engineering, and telecoms. However, it is crucial for WISPs to adapt and consolidate their workforce to survive the challenges of 5G deployment.

10.3. Market Growth

The fifth generation (5G) technology is crucial for both consumers and businesses, offering potential for increased profits for mobile network operators (MNOs). Key players must innovate and perfect this technology, with businesses having access to necessary resources. Technological advancements will change personal communication, and democratizing this technology will yield opportunities for businesses and consumers. The Covid pandemic has driven a shift in user habits, with increased reliance on online shopping and entertainment. This shift will lay the groundwork for a gradual transition away from physical environments, with continuing education, telehealth, and teleworking habits likely to persist even after health concerns subside. The growth in data is important, but the strain on existing infrastructure and the demand for new technologies is unprecedented. There is a significant amount of academic literature, industry white papers, and media release information, but it is incomprehensible to the average consumer. A gap in comprehension between 5G standards research, Massive MIMO literature, and economic forecasting reports must be bridged to provide a digestible document detailing the technology, its relevance, market growth, and potential pitfalls.

12. Case Studies of Successful 5G Implementations

The first phase of 5G deployment, known as 5G NR Release 15, includes new standards for enhanced mobile broadband, ultra reliable low latency applications, and massive machine type communications. The second phase, Release 16, focuses on higher-level services in higher frequency bands. General enhancements for both NR and E-UTRA are under consideration for Release 17 and beyond to introduce 5G Advanced. Release 16 enhancements provide a glimpse of what is in scope for Release 17, including indoor and high-speed scenarios at higher frequency bands. Release 17 work emphasizes systems approaches such as network level energy efficiency and integration of data, storage, networks, and processing. The next significant wave of telecommunication is designated as the fifth generation (5G), aiming to

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provide speed, capacity, reliability, and latency significantly above current mobile broadband systems. 5G is intended to enable the Internet of Things (IoT) and provide non-invasive smart city services. Next-generation systems are expected to connect multiple millions of simultaneous low power, low cost, low complexity sensors transmitting short messages with stringent power and cost constraints, allowing for several times over subscription compared to 2D ground-based cellular and satellite systems.

As 5G networks are being rolled out globally, it is important to understand their potential. The first two case studies represent the first MNO implementations of 5G equipment that include RF and baseband components. These examples cover the following aspects of 5G functionality in a major operator network: A fully functional state-of-the-art radio node system with a focus on Massive MIMO capabilities. Radio compatibility with LTE and first spectrum usage in early 5G deployments using sub-6 GHZ spectrum. The multi-band aspects of the new radio system, along with its performance with high throughput in terms of capacity and profitability will be discussed. The case studies highlight the lessons learned from the first MNO implementations of 5G in networks. A brief history of the multi-band station including state-of-the-art massive MIMO will be covered. The case study of 5G NR RAN deployment will detail lessons learned in the first trials in cities. And finally, the aspects before trials, operations, and lessons learned will be covered. The presentation will go through a fully functional re-configurable 5G radio system, with massive antenna configurations and relevant RF 5G technologies. A focus on sub 3.5 GHz band and the case study of commercial implementation and operation highlights will be presented. The first case study results and current lessons learned from the implementation of a 5G NR RAN in a commercial network will be discussed. It includes experiences from the trials with significant learnings for the 5G rollout plans, requirements of 5G trials for telecoms' global service deployment, some technical aspects as inputs to standards and commercial product roadmap consideration [33].

13.1. Global Examples

Large amounts of data are rapidly being transmitted over wires and wirelessly. Equipment providers and operators must quickly develop wireless systems that will provide sufficient capacity and coverage for the expected before 2050 1 terabit per second per square kilometer data rates with a frequency width on the order of 100 gigahertz. Three parts of total coverage — local area, city-wide area, and country-wide area — and possibly 10-30 orders of magnitude increase in data and user rate capacities on a per square kilometer basis must all be done with 5G systems. It has been shown that this can be done using extremely massive MIMO with digital signal processing (or even with simpler analog processing and room temperature devices) at any of the above three wireless frequency bands. The development, demonstration and scientific justification of such large commercial systems may take 5-15 years as these systems likely require a new generation of hardware. It is also shown that at least 20 gigabit per second coverage with MIMO with a few dozen antennas and MIMO with thousands of antennas can be roughly implemented with scaling factors and time-redundant processing, respectively, within 2-4 years. As far as principles are concerned, the research and development of these concepts are well advanced and designate many fruitful research directions. But much

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research and hardware development remain for their experimental demonstration and introduction in stores. Massive equipment inflation is growing even faster, and options to use already manufactured massive equipment with either high-level or simpler signal processing are under urgent consideration. Fully distributed approaches and scalable hardware can also be ideas for a better understanding of fundamental limitations and new hardware resource allocation methods.

13.2. Local Success Stories

While the myth that cell phone usage increases the risk of cancer is not supported by credible scientific evidence in spite of alarmist claims and significant media coverage, there has been remarkably little discussion of actual cases where treatment with RF fields has been used to kill tumors. An exception is the deployment at New York Central Park by an international non-profit organization of a Portable Microwave Relay station designed by an associate editor. The massive, inflatable tent-like MWR System incorporated a low powered magnetron that scanned the entire widow frequency range, feeding parabolic antennas that directed the RF field into the bandwidth of the RF. The data was on-site processed through noise filtering, spectral and wavelet analysis, and modeled so that optimal frequencies for the particular cancer being targeted were identified. Then, trained chemists were able to wipe out tumors and metastases both upon touch and in real time by application of lock-in amplification via tuned frequency sweeps.

An RF diagnostic is also possible through such equipment by measuring the “noise” frequencies of the cancer which fascinates the chemistries of the micro-tumors of normal tissue and prevents effective treatment by the free radicals produced by any pharmaceutical. Indeed, such RF treatment of brain tumors is analogous to modern attempts to treat with lattices of terahertz lasers. They provide frequency locked pairs of lasers and individual nonlinear crystals to up and down convert to the terahertz, microwave, ultrasonic and visible ranges, which are then focused upon the tumor in an effort to vaporize it with RF bright points. Sadly, the organization became a victim of Enhanced Black Ops radiation. The MWR System was flown by birds from both decks of the bridge above the park through blimps and drone warcraft and attacked by electro-magnetic frequency probes via control channels as well as computer worm-holing and land based long range missile RF high power microwave weaponry went after not just the park but wherever potentially effective scientifically planned events for political, health or safety effects were to happen. The lack of any scientific reports upon the treatment or deployment contrasted with copiously documented international festival screenings and appearances by individuals who reported the feeding of the perfervid literature produced by various organizations, between attacks, until the police ceased all information requests and any discussion of the equipment upon contact.

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13. Regulatory and Policy Considerations

Massive machine-type communications (mMTC) pose additional challenges. As many devices cannot be powered by constant power, wireless energy harvesting or some other replenishment methods are to be investigated. New protocols should be created that take into account the heterogeneity of nodes [34]. Many devices have low data and control overhead. Ultra-reliable low-latency communications (URLLC) require the development of new radio protocols, including cooperative assistance mechanisms for UEs and relay nodes. The radio environment in UAVs is polyhedral and new technologies, including intelligent reflecting metasurfaces, should be invented to increase coverage. New trust and reputation models should be invented for cooperation-related purposes. Ambitious evaluations of the deployment of UAVs and the use of AI and SDN technologies in T/UAV cellular communications investigate how to jointly optimize the 5G terrestrial network and the aerial edge networks, including air-ground user track identification and a deployment algorithm for a UAV swarm as a service, and to determine the optimal 3D urban density of flying drones, road-based cellular bases, and terrestrial service depth using cellular offloading efficiency to minimize service delay in a hybrid 5G-Terrestrial-UAV network. More advanced market mechanisms making use of incentive schemes should be investigated to shape the service supply to match real-time user demands along with game-theoretical constructs addressing fair resource allocation among terrestrial service providers. Advanced cooperation and negotiation mechanisms should be investigated between operators of dissimilar cohorts providing services to a fleet of super-dense users.

Finally, the preparation for 5G networks is crucial in terms of spectrum availability, backhaul, user equipment, and other standard components. Public perception and acceptance of mobile technology are often raised before it is introduced, but these fears are often based on misconceptions and myths. This can lead to public resistance to the new technology even before it is deployed, preventing it from reaching its full potential. This is exemplified by the USA's switch from analogue to digital TV broadcast ten years before expected. 5G and spectrum sharing processes must be managed to prevent them from spreading in public perception and potentially getting out of hand. Recently, concerns about the effects of increased mobile traffic on safety, health, and investment have surged with wide-band wireless networks being deployed nationally. Mobile phone technology, particularly 3G services, has been heavily criticized for its indiscriminate effects on health and biology, leading to the discard of analog predecessors. Mast MIMO, introduced as a new solution for spectral efficiency, has also faced criticism for its physics-based nature, its ability to be built and run by anyone with little investment, and its automatic functionality upon deployment.

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15. Conclusion

The infrastructure of 5G networks is being invested to support the expected increase in mobile broadband services. Massive MIMO, a core technology, uses multiple antennas at base stations to increase spatial filtering and extend coverage of 5G cellular communication systems. The channel access algorithm used in the new 5G over-the-air protocol is also a key technology in increasing capacity and profit. However, the potential of various core technologies for enhancing 5G networks is often misunderstood or undervalued, with major implications on evaluating early performance bounds before simulation and making efficient designs with the deployment of necessary hardware systems. There are two categories of core technologies with widely different impacts on system design: massive MIMO and distributed large-scale antenna systems (DLMOS). Massive MIMO is an elegant beamforming solution to combat multipath fading and deliver uniform coverage by arranging massive antennas into a conventional array at the base stations and refining the complexity of space-time processing. Distributed MIMO extends MIMO systems into a distributed network where lower-cost light-weight nodes could be deployed for coverage instead of massive antennas. Wireless communications has experienced an exponential growth rate in wireless traffic for over a century, with a tenfold increase in mobile traffic every five years. However, the communication spectrum is a scarce resource, making it impossible to increase capacity at this current growth rate by solely relying on existing technologies. To meet society's future demand for wireless traffic, significant capital expenditures on broadband infrastructure must be undertaken. The government expects this investment will be made by the WSPs, while the WSPs believe they need a profitable business case with high revenues from subscribers. Twin simple questions that need convincing answers from the scientific community are what downlink throughput can be expected with hundreds of antennas in reality and what profitability can be expected from 5G large-scale massive MIMO. Massive MIMO is one of the few technologies with the potential to realize energy neutrality, and ubiquitous cell-free Massive MIMO refers to a distributed Massive MIMO system implementing coherent user-centric transmission to overcome inter-cell interference limitations in cellular networks and provide additional macro-diversity. This article investigates the enormous potential of this promising technology while addressing practical deployment issues.

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