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Optimized Deployment of 5G Network in Pakistan

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Abstract

Pakistan has a rapidly growing mobile industry, with approximately 195 million cellular subscribers in the country, and near 116 million 3G/4G subscribers. Due to massive growth in mobile broadband users, mobile data networks are facing network congestion and spectrum capacity issues that will become the primary cause of service degrading issues.

Hence, the design of 5G network in term of network infrastructure enhancement in the existing digital mobile network, utilizing new spectrum bands can improve the quality of service by minimizing the congestion issues. This approach of network infrastructure enhancement and new 5G spectrum bands introduction in the country can enhance the telecom consumer experience of high speed mobile broadband services.

INTRODUCTION

1.1 Background

The 2nd Generation (2G) mobile communication systems was mostly driven by voice services, while the later 3G and 4G systems witnessed a gradual shift to data and wireless broadband services. The 5G networks through ultra-fast data traffic and high mobility are expected to further accelerate the development of mobile broadband services. Beyond 2020, 5G technology is anticipated to meet potential service and business demands, thus playing a major part in facilitating technological advancement, and playing a major role in enhancement of the economic output. The European Commission as part of its 5G action plan 2016 has given major attention and focus to the digitization of major industries, like health care, agriculture, cellular mobile and others. Industry stakeholders and partners like, telecom service providers, industry and academia have made significant contributions towards the research and development of various features of 5G networks, particularly the technological standards, bandwidth, network design, implementations, and use cases. The 3rd Generation Partnership Project (3GPP), has been vigorously pursuing the standardization process for communication systems. They proposed their 5G specifications first time in Release 15, which has been further improved till Release 18.

The information flow, the various types of consumer equipment and applications, and the expected service cases are expected to quickly grow in the mobile network, with handheld devices accounting for the majority of the traffic. The Fifth Generation Infrastructure Public Private Partnership (5GPPP) released expected goals for the next generation cellular mobile networks, including support for more than 104 devices per sq. kms, high data rates (up to 1 Gbps), and ultra-low transmission delays (1- 10 milli seconds). Mobile network operators (MNOs) need to work out ways to enhance Quality of Service (QoS), maximize spectrum efficiency, while ensuring healthy revenues to meet customer needs. Various technologies have been proposed for the Fifth Generation (5G) mobile networks, especially in the field of Radio Access Networks, to cater for traffic development, develop cost-effective networks, and provide enhanced Quality of Service. In the light of the above, we may classify these as follows.

The spectrum efficiency, beamforming and data power can be increased through advanced transmission techniques like massive Multi-Input Multi-Output (massive MIMO) and Millimeter Wave (mmWave) transmission. While we recently have witnessed significant technological progress in these technologies, major issues exist in the shape of implementation challenges, antenna correlation, radio frequency interference and environmental obstacles.

Using existing network infrastructure to deploy small cells (picocells, femtocells, and microcells) in combination with macro cells. Long Term Evolution - Advanced (LTE-A) networks also employ this method, however heterogeneity level is comparatively higher in 5G RAN as compared to legacy RAN architectures. However, the small cells have serious challenges in the shape of higher power consumption, higher CAPEX/OPEX, higher frequency of handover and a range of interference.

The 5G network architecture is expected to provide major improvement and overall efficiency, including a 1000 times increase in overall system capability, enhanced coverage to minimum Hundred Billion devices, and average 100 Mbps individual user experience, and more. With a 1000-time decrease in power utilization per bit, a ninety percent decrease in network energy use, provision for 500 km/h mobility, three time enhanced spectrum performance, consumer perception of 99.99% network availability, hundred percent service coverage with latency between 1-10 10 msec. 5G requires spatial optimization and rehabilitation compared to existing networks to meet new expected use-cases and high growth expected on the existing network infrastructure.

The 5G network architecture communication is focused on three key issues: enhanced bandwidth, massive networking, and a wide range of services. International Telecommunication Union (ITU) has divided all 5G network networks into three major groups i.e. massive Machine-Type Communications (mMTC), Ultra-Reliable Low-Latency Communications (URLLC) and enhanced Mobile Broadband (eMBB) which are depicted below in figure 1.

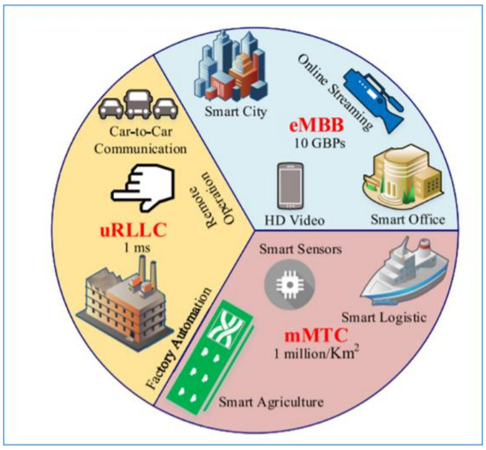


Figure 1. 1. Services categories of 5G mobile communication

The eMBB is designed for common consumer requirements with high bandwidth requirements like virtual reality and high definition video services etc. The mMTC is designed for service provision to big number of connected devices like smart cities, smart health care, banking services, smart metering etc. The URLLC is designed for latency sensitive services like online gaming and factory automation, which require millisecond level latencies coupled with low packet loss rate.

1.2 Evolution of Mobile Communication in Pakistan

Below figure shows the evolution of mobile communication in Pakistan.

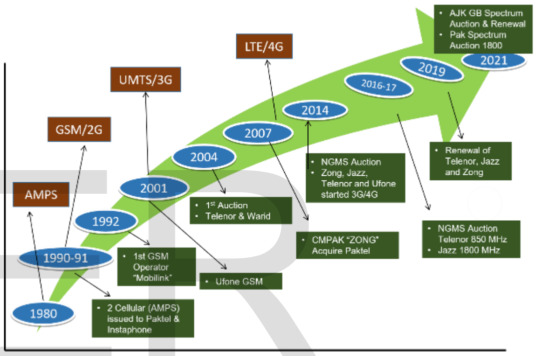


Figure 1. 2 Evolution of mobile communication in Pakistan

1.3 Spectrum Assignment to Mobile Operators in Pakistan

PTA/FAB has currently assigned spectrum to mobile operators in Pakistan, as seen in the diagram below.

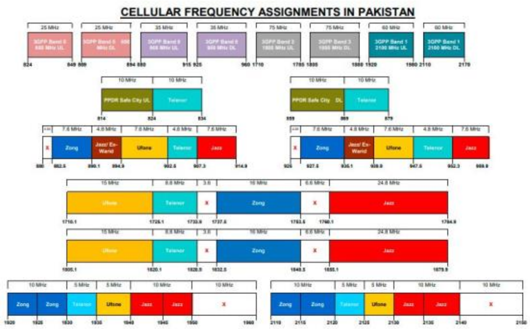


Figure 1. 3 Spectrum Assignment To Mobile Operators In Pakistan

1.4 Problem Statement

Pursuant to high growth in mobile broadband traffic over past 5 years, mobile data networks are facing spectrum capacity and congestion issues, due to which users are facing degraded quality of service (QoS). Existing network infrastructure enhancement is required to resolve the current coverage footprint, increased user demands and QoS requirements.

1.5 Research Questions

- How to improve the spectrum capacity and congestion issues to avoid the problem of degraded quality of service (QoS) facing by the broadband customers of cellular mobile communication in the existing network?
- How to improve the user experience?
- How to enhance the footprint of mobile broadband subscribers?

1.6 Research Objectives

- To design of high speed 5G data networks to build digital Pakistan and achieve Sustainable Development Goals.
- Improved User Experience (> 1Gbps Throughput)
- Enhanced coverage footprints for mobile broadband subscribers
- Introduction of advanced live applications in the field of medicine, remote agriculture, online- education, entertainment, businesses and ICTs.

1.7 Significance of the Study (Academic Perspective)

The critical goal of this research is to contribute knowledge to the body of a particular field (5G Mobile telecommunication industry). This research is among the few kinds of researches that are used to investigate the 5G mobile telecommunication infrastructure and implementation to enhance the spectrum capacity and efficiency to meet the hungry bandwidth requirements of the end users to execute the data applications related to high throughputs.

1.8 Industrial Significance of the Study

This research proposes an implementation of 5G network that helps the mobile telecommunication service industry to enhance its network performance in order to avoid the network congestion and degrading of bandwidth issues. By the implementation of design to be proposed in this research the service provide can improve the throughput which is the most critical and the requirement of end users. This research also help to enhance the business performance by offering the quality of services and innovative solutions required by the end users to access the high bandwidth related applications that are not accessible by the use of legacy 2G, 3G and 4G networks.

LITERATURE REVIEW

2.1 Expectations from 5G

The 5G technology is anticipated to generate spectral efficiency through identification of new frequency bands coupled with wider spectral bandwidth across each frequency channel. The previous generations of the mobile networks have shown significant increase in peak bitrate.

5G is not just about connectivity but is expected to become one of the engines of the economy that will fuel Pakistan's competitiveness over the next decade. The eco system for fifth wave of communications innovation will bring together people, businesses, and sectors that have so far developed separately and put them to work collaboratively.

5G means more than just a whole new experience on the Internet, it is designed to bring along inbuilt connectivity to products and services. Compared to previous generations of mobile networks, 5G is expected to be far above the traditional voice and data services. The driving force behind the need for 5G services is to serve the new innovation technology solutions which are bandwidth intensive and shall be facilitated by the 5G capabilities. The 5G capabilities will contribute substantial value to the current services and shall generate market for new businesses. As compared to existing 3G and 4G cellular mobile architecture 5G is significantly advanced in the following manner

- Significantly high peak bit rate
- Higher capacity with more concurrent connected devices.

- Improved power consumption
- Larger spectral efficiency with higher data volume
- Enhanced connectivity
- More supporting devices and interfaces
- Low development cost
- Low Latency for high speed services

Basic comparison of IMT 2020 with IMT advanced is explained as per below table:

	IMT-Advanced	IMT-2020
Minimum peak bitrate	Downlink: 1 Gbit/s Uplink: 0.05 Gbit/s	Downlink: 20 Gbit/s Uplink: 10 Gbit/s
Bitrate experienced by individual mobile device	10 Mbit/s	100 Mbit/s
Peak spectral efficiency	Downlink: 15 bit/s/Hz Uplink: 6.75 bit/s/Hz	Downlink: 30 bit/s/Hz Uplink: 15 bit/s/Hz
Mobility	350 km/h	500 km/h
User plane latency	10 msec	1 msec
Connection density	100 thousand devices per square kilometer	1 million devices per square kilometer
Traffic capacity	0.1 Mbit/s/sq. m.	10 Mbit/s/sq. m. in hot spots
Frequency bandwidth	Up to 20 MHz/carrier (up to 100 MHz aggregated)	Up to 1 GHz (single or multiple frequency carriers)

Table 2. 1 IMT-2020/5G vs. IMT-Advanced/4G requirements

2.2 Why 5G

4G is almost 10 years old and it is time for a new generation. The mobile and ICT industry needs new generation because the ICT technology (hardware and software) is continuously developing and mobile business needs growth. Hunger for bitrates for mobile broadband never ends, so each generation and each release introduces higher speeds. The timeline of mobile generations is shown in Figure – 2.1.

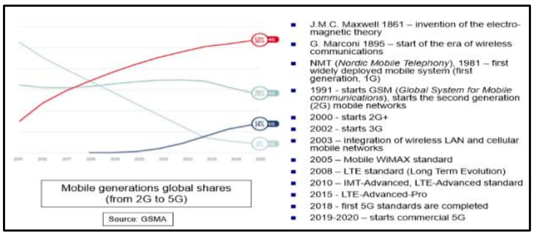


Figure 2. 1 The rise of mobile generations

Focus of 5G is on different vertical businesses besides traditional broadband customers. For that purpose, 5G is developed on the principles of network slicing, which means different logical network slices adapted to different services. The need for 5G is driven by multiple factors. 5G will support Internet of Things (IoT), factory automation, robotics, smart cities, autonomous vehicles and drones, etc.

However, as shown in below Figure-2.2 from Ericsson Mobility Report of 2019, 76% of mobile data traffic by 2025 will be video.

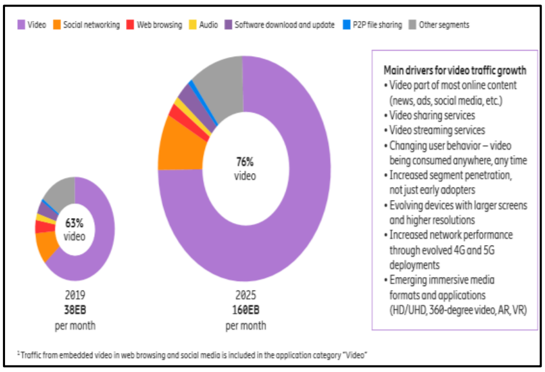


Figure 2. 2 Mobile traffic by application category per month (percent)

Besides Video, the other drivers for rise in traffic includes 'Device proliferation' - each year 1 billion of mobile devices are shipped. Application uptake which includes mobile application acceptance & usage and subsequent upgrades will be the main driver of network traffic, as evident in Figure-2.3.

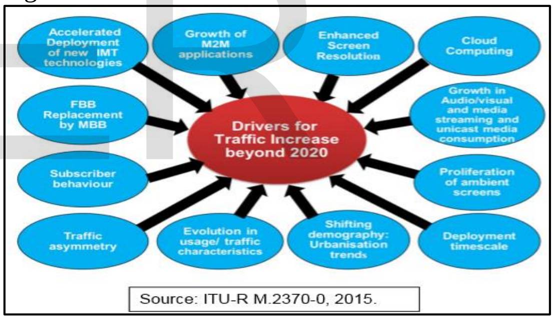
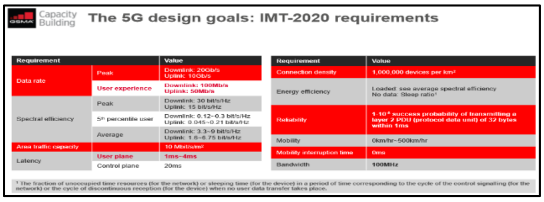


Figure 2. 3: Drivers for traffic increase in 5G era

2.2.1 What Is 5G

5G is the title for a next generation of technologies as envisioned in the IMT 2020 Framework devised by ITU. IMT 2020 mentions specification for 5G cellular mobile architecture, as detailed in Figure-2.4 and bears the timeline for anticipated commercial launch of 5G services with commercial launch expected in 2020. Initial 5G handsets were available in 2019, however today in 2022 there is more demand for 5G handsets are in more demand compared to previous mobile generations in developed countries.



Requirement		Value
Data rate	Peak	Downlink: 20Gb/s Uplink: 10Gb/s
	User experience	Downlink: 100Mb/s Uplink: 50Mb/s
Spectral efficiency	Peak	Downlink: 30 bit/s/Hz Uplink: 15 bit/s/Hz
	5th percentile user	Downlink: 0.12~0.3 bit/s/Hz Uplink: 0.045~0.21 bit/s/Hz
	Average	Downlink: 3.3~9 bit/s/Hz Uplink: 1.6~6.75 bit/s/Hz
Area traffic capacity		10 Mbit/s/m²
Latency	User plane	1ms~4ms
	Control plane	20ms

Requirement	Value
Connection density	1,000,000 devices per km²
Energy efficiency	Loaded: see average spectral efficiency No data: Sleep ratio[1]
Reliability	1-10⁻⁵ success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1ms
Mobility	0km/hr~500km/hr
Mobility interruption time	0ms
Bandwidth	100MHz

[1] The fraction of unoccupied time resources (for the network) or sleeping time (for the device) in a period of time corresponding to the cycle of the control signalling (for the network) or the cycle of discontinuous reception (for the device) when no user data transfer takes place.

Figure 2. 4: IMT 2020 Design Requirements

2.2.2 5G Technology

New Radio (NR) in 5G access, developed by 3GPP is the driving radio access technology, envisioned to be the logical extension of LTE-Advanced Pro. 5G New Radio can operate in very diverse frequencies varying from very low to very high frequency bands. It also offers use ultra-wide bandwidth, like with frequency bands below 6 GHz it offers up to 100 MHz carrier bandwidth and for frequency bands above 6 GHz, its offers up to 400 MHz carrier bandwidth. New Radio employs OFDM techniques for both downlink and uplink. It offers extremely high reliability and low latency while supporting E2E Network Slicing.

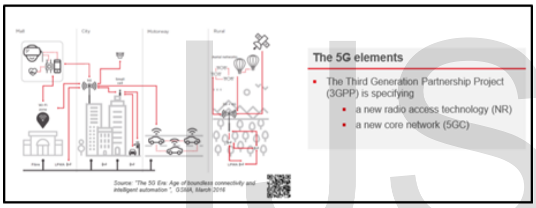


Figure 2. 5: 5G Main Elements

New Radio gives future roadmap for evolution of mobile performance, but at the cost of much higher base station densities, as presented in Figure 2.6 below.

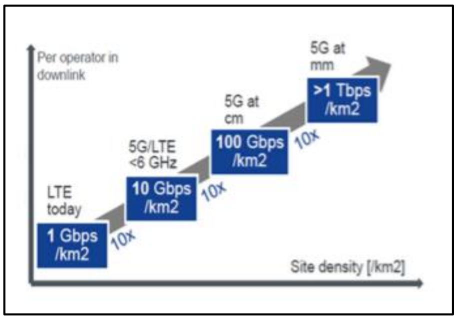


Figure 2. 6: Evolution of Mobile Network Performance

2.2.3 5G Standard Development Timeline

3GPP Release 15 is considered to be the first complete 5G Standard. It supports licensed bands between 600 MHz – 39 GHz. It comes in two variants: LTE-Anchored 5G Non Standalone (NSA), LTE-Anchored 5G Standalone (SA). It supports Ultra Reliable Low Latency Communication (URLLC), Massive Multiple Input Multiple Output (MIMO) and Flexible RAN architecture. Release 15 also fulfills ITU's IMT2020 criteria for 5G. Timelines for evolution of 5G, with 3G & 4G standards is shown in Figures-2.7 & 2.8.

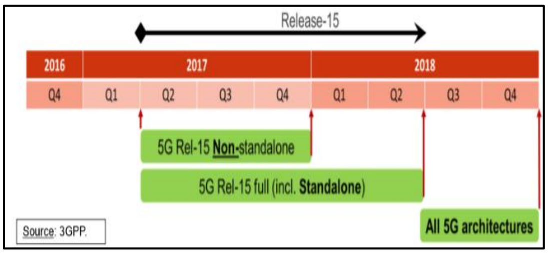


Figure 2. 7: Timelines of 5G (IMT 2020) Standards

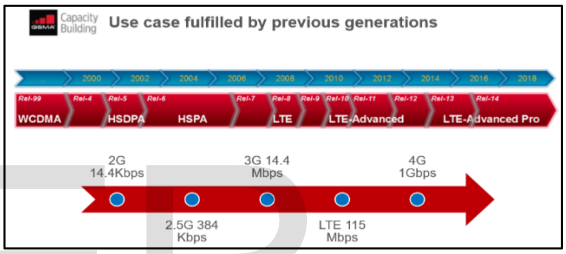


Figure 2. 8: Timelines of 3G & 4G Standards

2.2.4 5G Architecture

The provision of high speed, reliable mobile services to the customers has been main driving objective behind the previous generations of mobile networks. This scope has been enhanced for 5G services which are expected to provide end users with a wide range of mobile services across multiple access platforms as well as multi-layer networks.

5G is a dynamic as well as flexible framework employing multiple technologies which support a broad array of new applications. 5G architecture is more intelligent, wherein the Radio Access Networks (RANs) no longer constrained either by the proximity to the base station and the complexity of the network infrastructure. 5G leads to flexible virtual RAN offering compatibility with new interfaces thus allowing new access points.

2.2.5 3GPP Provided 5G Architecture

The 3rd Generation Partnership Project (3GPP) has shared detailed architecture specifications for 5G networks. These specifications are more focused on service orientation as compared to the previous generations. Services being the main building block are provisioned through a common framework of network functions allowed to use services. Modular and reusable network functions are further deliberations for the 5G k architecture proposed by the 3GPP platform.

2.2.6 5G Spectrum

Various frequency ranges are allocated for 5G services. The Regulatory Authorities across various regions have allocated millimeter frequencies between 24 GHz and 100 for 5G services and are considering auctioning a mix of frequency bands driven by the potential use cases. There is general consensus on three (3) major spectrum bands: Low band which is < 1 GHz, Middle band between 1-6 GHz and finally High band between 6-100 GHz, as detailed below in Figure-2.9.

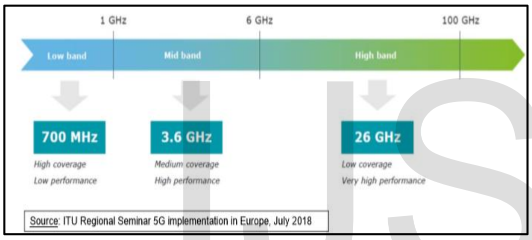


Figure 2. 9: Spectrum for 5G

Besides the UHF frequencies (300 MHz - 3 GHz) are proposed for 5G. The multiple frequency ranges can be customized for the individual applications requiring higher frequencies with higher bandwidth and shorter range. Among the frequency bands allocated for 5G, carriers have begun to carve out separate chunks of the 5G spectrum.

2.2.7 Multi-Access Edge Computing (MEC)

Multi-Access Edge Computing (MEC) is a core building block of 5G architecture and is an advancement in cloud computing technology. MEC is employed for the transportation of key applications between network edge and the centralized data centers. It is thus in close proximity to customers and their allied devices. This thus reduces the path among end customer and host thus leading to reduction in content delivery lead time.

However, MEC is not exclusive for 5G however remains the main driver of the increased efficiency. The reduced path among end customer and host offers low latency, enhanced bandwidth and real time access to Radio Access Network which differentiates 5G from previous generation. The 5G architectures created on the recommendations of 3GPP is very suitable for the deployment of MEC. The 5G recommendations identify the major drivers for edge computing thus facilitating 5G and MEC to jointly route traffic. In addition MEC allows improved sharing of computing power which allows more connected devices with him traffic volumes necessary for the Internet of Things (IoT).

2.2.8 Network function virtualization (NFV) and 5G

Network function virtualization (NFV) replaces serval network elements like firewalls routers and load balancers through software based solution thus creating clear separation software and hardware. This reduces deployment cost and the installation time's thus allowing speedy provision of new services.

The network slicing technology that NFV offers allows setting up multiple virtual appliances and networks that operate concurrently in 5G.

2.2.9 Small Cells/ IBS

The capacity challenges in 5G networks have led to the evolution of integrated networks consisting of macro/ micro cells and Wifi Access Points termed as Heterogeneous Network (HetNet). The future networks designed to meet the traffic challenges incorporate more macro and small cells. The addition of small cells allows improved capacity and covered in dense zones where buildings reduce the signal strength.

Since 5G is based on very thick network, small cells can be deployed at very close proximity of around 250 meters on available infrastructure.

2.2.10 Network Slicing

Network slicing is major driving element behind the efficiencies expected from 5G. 5G network slicing divides one network and creates end to end separate virtual networks based on network virtualization technique and subsequently allocates network resources based on the various categories of traffic.

The latest applications in todays' IoT environment are based on high number of concurrent connected users with bandwidth requirements. In such an environment where each 5G service has its own network requirements Network slicing offers reduced cost, flexible configuration and effective resource management and is thus major consideration in 5G architecture.

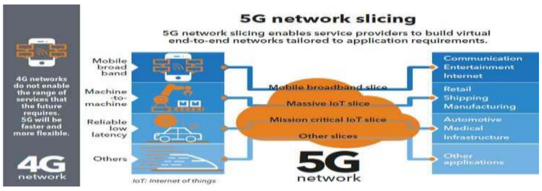


Figure 2. 10: 5G Network Slicing

2.2.11 Beamforming

Beamforming is also very critical technology in 5G evolution. Signals propagate in various directions in traditional base stations. However, 5G utilizes multiple-input, multiple-output (MIMO) technology, where in arrays are formed through a combination of several antennas into a single formation, It then uses signal processing techniques to evaluate efficient transmission to individual subscribers, and transmit similar packets in various directions. The small size of the antenna allows bigger arrays within identical space. Each smaller antenna reassigns its beam many time within each millisecond which makes massive beamforming possible. The massive MIMO technique allows narrow beam formation which offers high bandwidth and throughput required for 5G.

2.2.12 5G Core Architecture

The 5G core network architecture based on 3GPP specifications, employs, service-based architecture (SBA) for all 5G functions. The 5G core architecture design employs NFV along with software based virtual functions managed through MEC protocol.

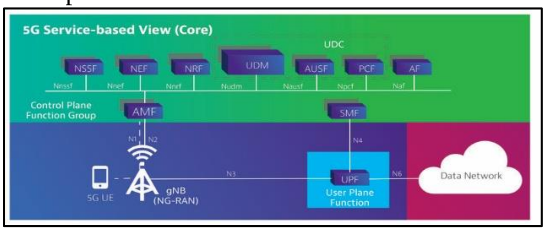


Figure 2. 11: 5G Core Architecture

2.2.13 Difference from 4G Architecture

4G was based on 4G Evolved Packet Core (EPC), however the architecture is much different in 5G. The progression from 4G to 5G is accomplished through significant architectural changes like migration to millimeter wave, beamforming, network slicing and massive MIMO. The 5G architecture uses network virtualization and cloud based software design. It also employs user plane function (UPF) for packet gateway management along with access and mobility management function (AMF) to separate session management functions from connection and mobility management tasks.

2.2.14 5G Architecture Options

The transition from 4G and 5G is managed through incremental steps with steady move towards a standalone 5G network design. The non-standalone 5G standard was concluded in 2017 and is based on existing LTE radio and core networks, along with a 5G component carrier. Although the non-standalone mode thrives on existing architecture, bandwidth increase will be achieved through millimeter wave frequencies.

Standalone 5G design is new core architecture with full deployment of complete 5G hardware and functions.

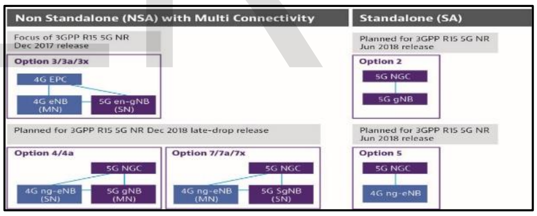


Figure 2. 12: 5G Core Architecture

2.2.15 5G Use Cases

The 5G networks are meant for new technologies requiring low latency and enhanced reliability applications and are expected to coexist with existing 3G/4G networks. The Network Virtualization available in 5G allows flexibility in resource allocation and network control.

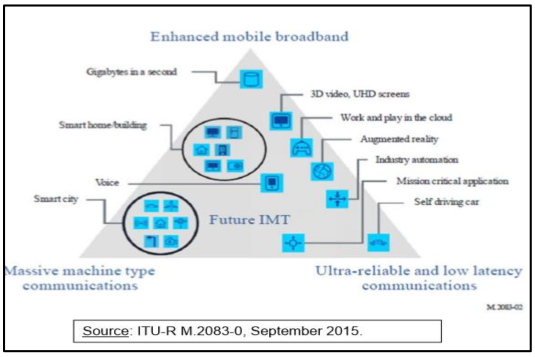


Figure 2. 13: Usage Scenarios for IMT 2020

2.2.16 Fixed Wireless Access

Fixed wireless access is expected to be driving technology for 5G. Industry experts are of the opinion that within a few years' traditional access networks like fixed lines and cellular mobile 5G will be superseded by fixed wireless access. These fixed wireless access networks shall be based on 5G millimeter Wave spectrum coupled with beam forming to meet the growing requirement for wireless broadband services.

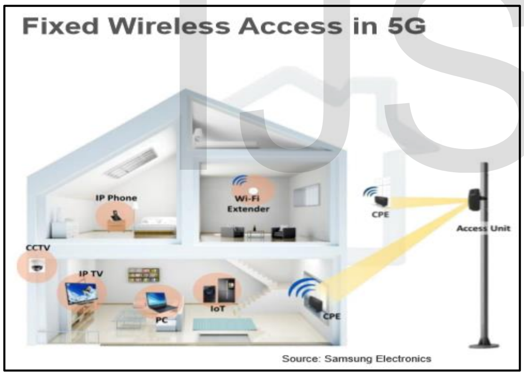


Figure 2. 14: Fixed Wireless Access in 5G

2.2.17 Enhanced Mobile Broadband

The demand for high speed mobile broadband services are on the rise. The higher number of connected IoT devices depend upon provision of high speed, low latency and low cost enhanced Mobile Broadband Solutions. Services like Virtual Reality demand approx. 10 Gbps throughput at peak times. This includes various scenario like hotspots as well as wide-area coverage that operate in separate conditions. The hotspots are suitable for provision of larger capacities in dense condition with limited mobility requirements. On the contrary wide area solutions are suitable in high mobility cases with better coverage and higher data rates.

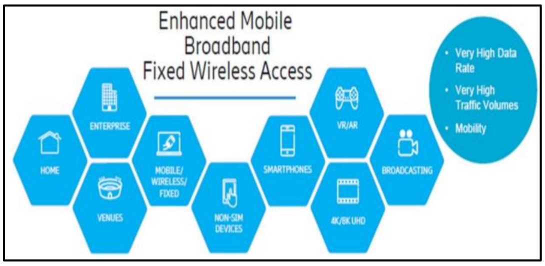


Figure 2. 15: Enhanced Mobile Broadband

2.2.18 Critical Machine Type Communication (Mtc)

Critical Machine Type Communications is suitable for industrial solutions like manufacturing concerns, automotive controls, remote health care and surgery services etc that are extremely dependent on critical network parameters like network availability throughput as well as high latency. It is thus also called as Ultra reliable low latency Communications (URLLC)

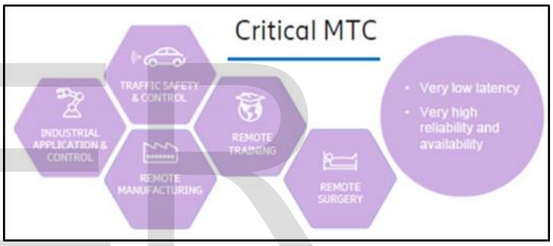


Figure 2. 16: 5G Usage Scenarios – Critical MTC

2.2.19 Massive Machine Type Communication (MMTC)

Massive Machine Type Communication (MMTC) is suitable for high connected devices which have low volume requirements and are not delay sensitive. The MMTC devices are normally low cost with large battery time.

Since MMTC users demand service access anywhere and anytime, so it employs interworking of many access technologies. In order to ensure seamless coverage, each technology in this interworking of many access technologies, needs to be integrated as well interoperable.

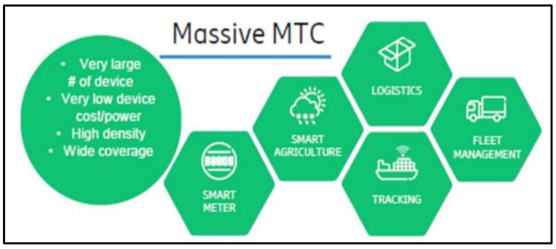


Figure 2. 17: 5G Usage Scenarios – Massive MTC

2.2.20 5G Standardization and Rapid Takeoff

3GPP Release 15 is considered to be the first complete 5G Standard which supports licensed bands between 600 MHz – 39 GHz. It comes in two variants including LTE-Anchored 5G, and Standalone 5G. It supports Ultra-Reliable Low-Latency Communication (URLLC), Multiple Input Multiple Output Massive (MIMO) as well as Flexible RAN architecture. Release 15 also fulfills ITU's IMT2020 criteria for 5G. Timelines for evolution of 5G, with 3G & 4G standards is shown in Figures-2.16 & 2.17.

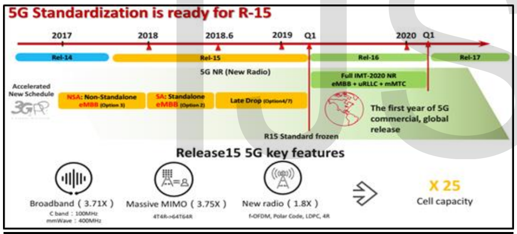


Figure 2. 18: 5G Usage Scenarios – Massive MTC (Source Huawei)

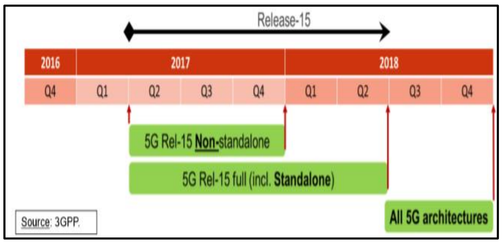


Figure 2. 19: Timelines of 5G (IMT 2020) Standards (Source Huawei)

5G is even growing faster than expectations and as compared to 3G and 4G technologies. As per Huawei it has shown a rapid take off in only 3 years with standardization in multiple bands as per the following figure-2.20:

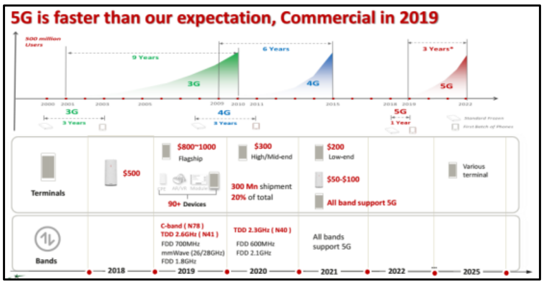


Figure 2. 20: 5G Growth (Source Huawei)

METHODOLOGY / RESULTS

3.1 5G Network Trial

5G delivers many folds' superior performance compared to 4G as depicted in Figure-3.1. I carried out 5G demo with the intention to showcase aspects of 5G pertaining to throughput, latency and reliability through test cases explained in part 4 in detail.

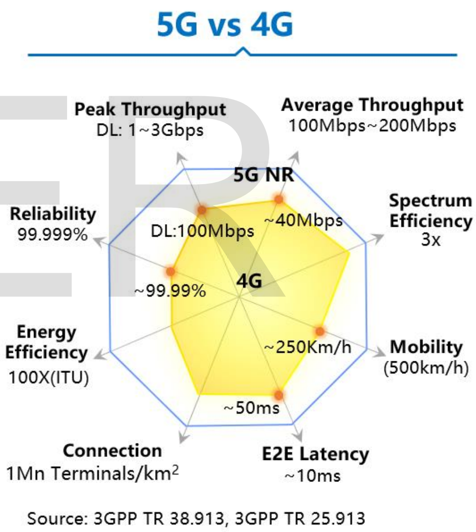


Figure 3. 1 4G vs. 5G Performance Requirements

3.2 5G Step Wise Implementation

- Non-Standalone Architecture NSA (Option 3x)
  - Cell creation using L1800 layer as 'Anchor Layer' for 5G gNodeB signaling.
  - A new Public Land Mobile Number Identity was used for the 5G Network.
- 2.6 GHz (n41 band) was used for the 5G New Radio (NR) interface
  - 100 MHz Channel Bandwidth with TDD duplexing mode

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  - Frequency Range = 2,500 MHz to 2,600 MHz.
- Use of 64T64R Massive MIMO Active Antenna Unit for 5G NR.
- A new standalone 5G virtualized core deployed for the Demo.

Core Site
• 1x Huawei 5G 5G Virtualized Core consisting of ○ vUSN (MME) ○ vUGW (S/PGW) ○ vSDM (HSS) ○ OSS

Table 3. 1 - Core Equipment Plan for 5G Demo

5G Demo Site
• 1x AAU5613 (64T64R Massive MIMO) • 1x BBU5900 configured with: ○ 1x UMPTg2 Control Card ○ 1x UBBPg2 Baseband Card

Table 3. 2 - Access Equipment Plan for 5G Demo

- RF planning & Link Budget analysis

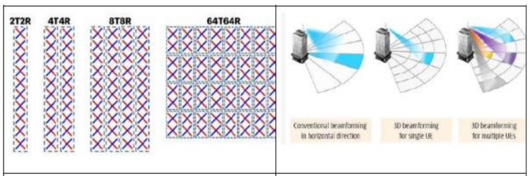
3.2.1 Non-Standalone Architecture NSA (Option 3x)

Anchoring was done on 4G network by sharing same TAC as of 4Gas signaling plane is of 4G however different cell id was used to communicate between different layers.
2.6 GHz (n41 band) was used for the 5G New Radio (NR) interface

3.2.2 Overview of the RAN Equipment

Use 64T64R Massive MIMO Active Antenna Unit for 5G NR

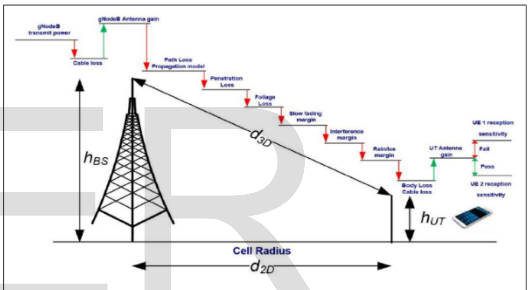
Trial was conducted implementing static beam 64T64R on AAU 5613. Highest throughput of 1Gbps+ was achieved in good coverage scenario and good SINR.



Advance MIMO	Beam forming multiple users
https://www.rfwireless-world.com/Terminology/Difference-between-conventional-8T8R-and-64T64R-Massive-MIMO-Antenna.html	

3.2.3 RF planning & Link Budget Analysis

RF planning & link Budget analysis was conducted analyzing the different frequency behaviors & later studied it with actual results achieved. Google Earth tool was used to identify the cell for launching for 5G.



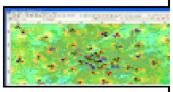
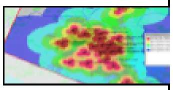
Link Budget(at receiver) = Sum of all system gains- system Losses- path loss(Propagation model)

Figure 3. 2: Deployment principal

Link Budget	Typical Cell Range	
Results Achieved	2600 MHz	900 MHz
Urban	0.54	1.46
Rural	1.07	2.99

Table 3. 3

The tools used for coverage prediction and analysis were Mapinfo and Atoll RF planning tool.

Capacity Modeling	Capacity modeling is used for analyzing high traffic zones	
Coverage Predictions	Network coverage predictions is very useful for specially in hilly areas for new site planning	
Neighbor Planning	In this 5G pilot test project anchoring was done at 4G so neighbor cells are of 4G layer once mobile switches to 4G.	
Coverage & Throughput Static testing Results Using markers in TEMS software and post processing in TEMS analyzer	 	

3.2.4 5G Demo Network Architecture & Construction

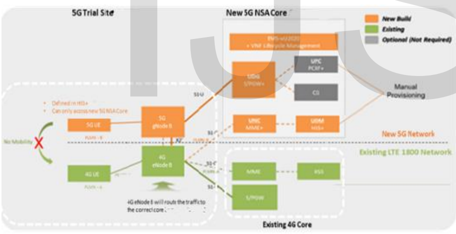


Figure 3.3 - Logical Non-Standalone (NSA) Architecture for 5G Demo

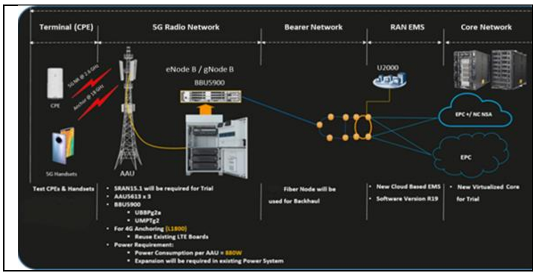


Figure 3. 4 Figure - E2E Network Construction Solution for 5G Demo

3.2.5 Challenges in Future Deployments

Maintaining multiple RAN networks increase OPEX and brings installation complexities with lesser tower sharing options. Major constraints will be observed in AC/DC power, radio frequency transmit power, multiple antenna, tower loading, antenna space.

Solution to these is using Multi RAN radio transmitter with appropriate power settings between 2G,3G,4G& 5G & feeder less connectors.

	Software defined antennas with electrical tilts				300W
Technology wise Power distribution of RF transmitter	TRX 1	TRX 2	TRX 3	TRX 4	2G
	Carrier 1				3G
	Beam 1		Beam 1/2		4G

Multiple trials are conducted in industry to enhance 4G capacity using 5G supportive equipment and Massive MIMO technique which is FDD based.

Having TDD & FDD networks running simultaneously, especially when frequency will be re-farmed and utilized for 5G will create challenges for radio frequency engineers. Which would be catered by FDD only network or enabling TDD/FDD carrier aggregation.
High Transmission backhaul requirement will create another challenge as fiber to the site has its own challenges in Pakistan.

Controlling SNR is the key and to be ensured through tool based planning & ensuring good RSRP levels. 3D maps and improved indoor simulation model is recommended for commercial launch.

DETAILED DISCUSSION OF RESULTS

Following Test cases were demonstrated in the Demo:

4.1 High speed Video Download

A 4K UHD movie 'The Aeronauts' with a file size of 0.72 GB was simultaneously download from Amazon Prime Video Cloud Entertainment Portal using 4G & 5G handsets demonstrating the very significantly (10x) higher download speeds of 5G compared to 4G.

Figure 4. 1 - Logical Diagram for FTP Download Test Case

The test case demonstrated that 5G is at least 10x faster than 4G for an equivalent channel size with the video download on 4G achieving less than 10% completion by the time download over 5G finished.

4.2 Cloud Gaming

In this demo Test case, a NVidea Shield Android Set Top Box connected to a 5G CPE was used to access and play a high-performance game (Need for Speed) hosted in Cloud. This test case requires high download speed in access of 30 Mbps to deliver 4K content at low latency with a Round Trip Time less than 20 milliseconds.

In the demo, it was observed that the 5G Radio link was easily able to deliver the necessary technical requirements to deliver a gaming experience with no compromise on quality comparable to a game hosted on a local High-Performance Computer or LAN Server.

Figure 4. 2 - Logical Diagram for Cloud Gaming Test Case

4.3 Remote Surgery

This test case leverages the latest functionalities and features of 5G which improve the technical performance of the communication link such as throughput, latency, availability and reliability to an extent suitable for delivery of mission critical applications such as Remote Surgery.

This demo successfully demonstrated how a Doctor in one location may be able to perform highly complex and precise surgery on a patient at a remote location by running a thin metal wire through a tiny needle hole. The metal wire was a proxy for the surgeon's scalpel or laser and the needle hole represented a tiny blood vessel or tumor that may need to be operated upon. During the demo an operator (Doctor) manipulated a set of joy sticks on equipment at the surgeon's location (e.g. a big hospital in major city) to precisely control robotic arms holding the wire and needle on equipment at the patient's location (e.g. far-flung remote area). The surgeon saw multiple high resolution 4K streams beamed from the patient's location over the 5G link while the surgeon's control instructions for the robotic arms were also transmitted over the same very highly reliable Ultra-Low latency High Throughput 5G link.

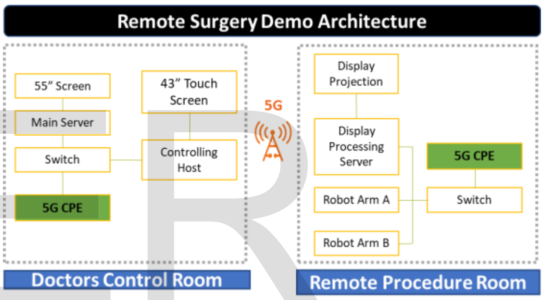
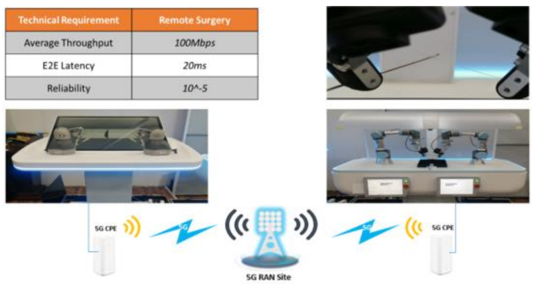


Figure 4. 3: Remote Surgery Demo Architecture



Technical Requirement	Remote Surgery
Average Throughput	100Mbps
E2E Latency	20ms
Reliability	10^-5

Figure 4. 4: 5G Remote Surgery Setup & Technical Requirements

4.4 Interactive Simulation for 5G Smart City Applications

An interactive simulation based on Huawei IdeaHub platform was used to demonstrate how 5G enables connectivity and productivity in a smart city with applications such as Remote Education, Remote Mining, Security Surveillance, Smart Grid, Smart Port, Manufacturing, 5G Live Broadcast etc.

In this demo Test case, a NVidea Shield Android Set Top Box connected to a 5G CPE was used to access and play a high-performance game (Need for Speed) hosted in Cloud. This test case requires high download speed in access of 30 Mbps to deliver 4K content at low latency with a Round Trip Time less than 20 milliseconds.

In the demo, it was observed that the 5G Radio link was easily able to deliver the necessary technical requirements to deliver a gaming experience with no compromise on quality comparable to a game hosted on a local High-Performance Computer or LAN Server

Figure 4. 5: Interactive Simulation for 5G Smart City Applications

CONCLUSION AND FUTURE WORKS

Conclusions

The above results of 5G trials depict that with deployment of 5G networks in Pakistan, consumers will be benefitted by high speed and low latency data networks. Due to tremendous growth in mobile broadband users and higher bandwidth requirements, mobile data networks are facing network congestion and capacity issues that is the primary cause of service degrading issues. Hence, the design of 5G network in term of network infrastructure enhancement in the existing digital mobile network, utilizing new spectrum bands can improve the quality of experience by minimizing the congestion issues. This approach of network infrastructure enhancement and new 5G spectrum bands introduction in the country can enhance the telecom consumer experience of high speed mobile broadband services and can lead us to a Digital Pakistan.

Coverage analysis suggested that lower frequencies are required essentially to be used for Rural coverage improvements and mid bands to be used for Urban centers. However, it is evident from complexity & transmission backhaul requirements that 5G will be more focused on the urban capacity management, spectrum re-farming and carrier aggregation, which will be used to enhance the speeds and improve user experience. In Pakistan, spectrum assigning bodies must make available spectrum in Low Bands like 700 MHz for coverage expansion, mid bands for capacity enhancement; however, it appears that it will be too early for Pakistan to look at mm wave bands for low latency applications due to its attenuation characteristics in monsoon season.

An additional bandwidth of at least 50-100 MHz is required in above mentioned mid bands by each Cellular Operator in Pakistan to provide quality 5G services in at least urban areas of the country before 2024.

Future Recommendations

I have carried out the Non-Standalone Model trial, making use of 2.6 GHz spectrum, however, future trials of standalone models can be carried out in other bands like 3.5 GHz band. Additionally, use cases in mm wave bands is also now becoming common in advanced countries, later researches and trials could be considered for utilizing higher bandwidths in 24GHz band, as identified for Region 3 by ITU, that will guarantee for ultra-reliable low latency applications in Pakistan.

References

[1] European Commission. (2016). 5G for Europe Action Plan. Accessed: Apr. 11, 2019. [Online]. Available: https://ec.europa.eu/digital-singlemarket/en/5g-europe-action-plan.

[2] Cisco. (2017). Cisco Visual Networking Index: Forecast and Methodology 2016–2021. Accessed: Sep. 5, 2018. [Online]. Available: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/ visual-networking-index-vni/complete-white-paper-c11-481360.pdf

[3] M. Maternia. (2014). 5G PPP Use Cases and Performance Evaluation Models. Accessed: Sep. 5, 2018. [Online]. Available: https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-use-cases-andperformance-evaluation-modeling_v1.0.pdf

[4] J. Rodriguez, ''Small cells for 5G mobile networks,'' in Fundamentals of 5G Mobile Networks. Hoboken, NJ, USA: Wiley, 2015, pp. 63–104

[5] J. Lorincz, T. Garma, and G. Petrovic, ‘‘Measurements and modelling of base station power consumption under real traffic loads,’’ Sensors, vol. 12, no. 4, pp. 4281–4310, Mar. 2012

[6] I. F. Akyildiz, S. Nie, S.-C. Lin, and M. Chandrasekaran, ‘‘5G roadmap: 10 key enabling technologies,’’ Comput. Netw., vol. 106, pp. 17–48, Sep. 2016

[7] N. Bizanis and F. Kuipers, ‘‘SDN and virtualization solutions for the Internet of Things: A survey,’’ IEEE Access, vol. 4, pp. 5591–5606, Sep. 2016.

[8] P. Rost, A. Banchs, I. Berberana, M. Breitbach, M. Doll, H. Droste, C. Mannweiler, M. A. Puente, K. Samdanis, and B. Sayadi, ‘‘Mobile network architecture evolution toward 5G,’’ IEEE Commun. Mag., vol. 54, no. 5, pp. 84–91, May. 2016

[9] HUAWEI. (2012). 5G: A Technology Vision. Accessed: Dec. 1, 2018. [Online]. Available: www.huawei.com/ilink/en/download/HW_314849

[12] 2015. 5G Network Technology Architecture. Accessed: Dec. 15, 2017. [Online]. Available: www.imt-2020.org.cn/zh/documents/download/8

[13] 2015. Massive MIMO & beam forming ure. Accessed: Accessed: Dec. 06, 2021. [Online]. Available: www.rfwireless-world.com/Terminology/Difference-between-conventional-8T8R-and-64T64R-Massive-MIMO-Antenna.html