सत्यमेव जयते

TRAI
20 Glorious Years
(1997-2017)

Enabling 5G in India

February 2019

TELECOM REGULATORY AUTHORITY OF INDIA

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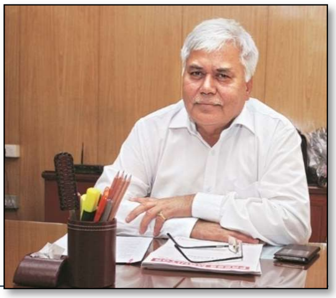
A White Paper on

Enabling 5G in India

22nd February 2019



PREFACE

The telecom sector is one of the most dynamic sectors. With the advent of new technologies and technological advancements, things keep on changing and to be more precise, things keep on getting better, may it be consumer experience, spectrum utilization, development of new services etc. The telecom sector has grown rapidly in the past two decades and has brought with it many innovations in other allied sectors and the economy as a whole.

5G is the latest technological development in the telecom sector which will provide enhanced connectivity not only to the individual but will also help in digitalizing various industrial verticals.

Globally, full scale deployment of 5G networks is expected to start by late 2019 or early 2020 for which pilots have already commenced. India is also not far behind. The India's 5G High Level Forum envisages 5G to be deployed in India by 2020 along with the rest of the world.

In order to create an enabling environment for timely rollout of 5G in India, TRAI has come up with a White Paper. This White Paper highlights the specifications of the 5G technology, discusses the potential use cases and architecture of 5G network, deliberates those areas that will require investment for 5G deployment, covers the spectrum requirements for 5G networks, and tries to identify regulatory challenges that need to be addressed for the deployment of 5G in India.

The purpose of this White Paper is to identify the probable challenges in the deployment of 5G Networks in India and to initiate a discussion with all stakeholders for finding implementable solutions.

I am sure that this White Paper will open the flood gates for the industry and the technocrats to kindle their thought process and bring about transformation by removing the barriers for the smooth launch of 5G technology in India.

(R. S. Sharma)
CHAIRMAN, TRAI

New Delhi
Date: 22/02/2019

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Disclaimer: This White Paper from TRAI discusses potential benefits of 5G and tries to identify regulatory challenges that need to be addressed for the deployment of 5G in India. No inference or statement or proposition made in this document should be taken as the recommendations or endorsement of TRAI.

CHAPTER 1
INTRODUCTION

1.1 5G is the latest iteration of cellular technology that will provide seamless coverage, high data rate, low latency, and highly reliable communications. It will increase energy efficiency, spectrum efficiency, network efficiency as well as efficiency of other systems. Besides providing faster & reliable access, it will act as an information duct built to connect billions of Internet of Things (IoT) devices.

1.2 New capabilities of mobile communication networks enabled by 5G technology will allow higher quality video services with mobility at high speed, business automation delivered through billions of connected devices, delivery of critical services such as tele-surgery and autonomous cars assured by low latency and ultra-reliable networks, and improved productivity assisted by high quality, real time data analytics. Unlike existing mobile communication networks, 5G networks will allow tailoring of requirements for each of these different use cases within the same network.

1.3 The commercial deployment of 5G was earlier expected in 2020. However, the completion of the first 5G New Radio (5G NR) standard for a Non-Standalone (NSA) solution in December 2017 and for Stand Alone (SA) standard in June 2018 has set the stage for the global mobile industry to start full-scale development of 5G NR for large-scale trials and commercial deployments as early as in 2019. Figure 1.1 shows the 5G development[1] around the world.

[1]https://www.gsmaintelligence.com/research/?file=8535289e1005eb248a54069d82ceb824&download

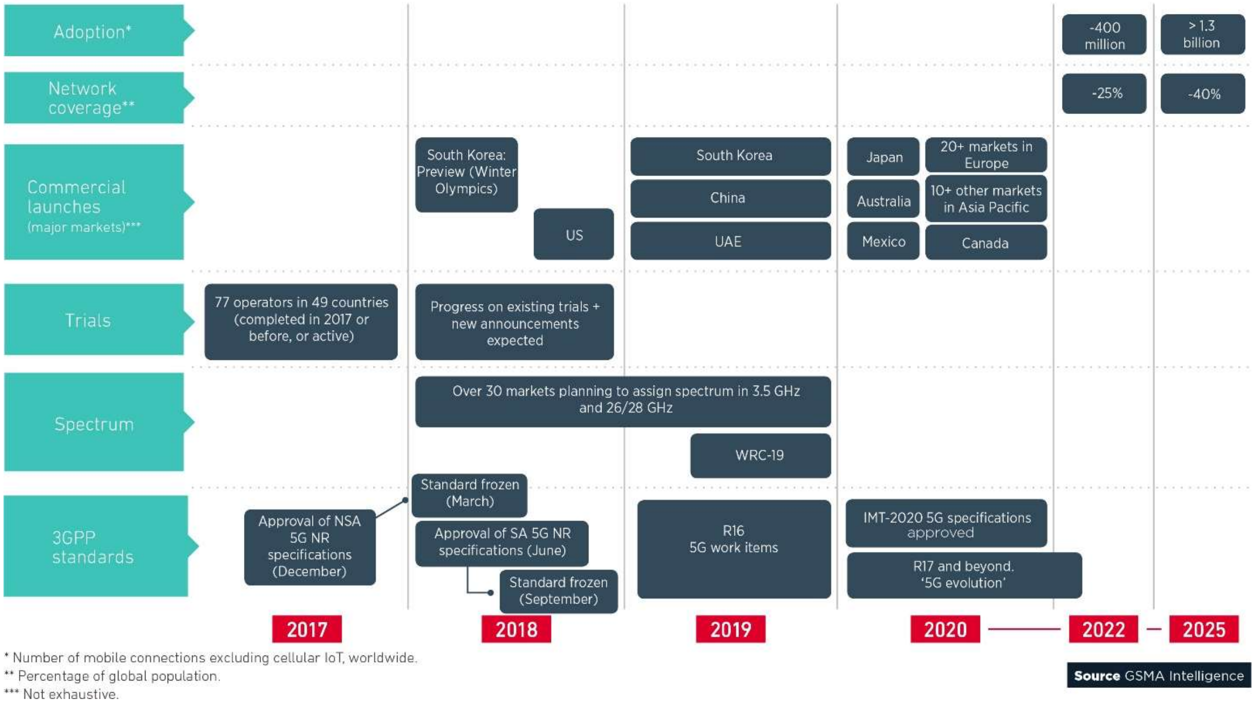

Figure 1.1: Global 5G development (Source: GSMA)

1.4 In the past it is observed that technological deployment in India has not been concurrent along with that of the most developed countries in the world. However, India is planning meticulously to launch 5G abreast with rest of the world.

Government's initiatives

1.5 A 5G High Level Forum (5G HLF) was set up by the Government in September 2017 to articulate the vision for 5G in India and to recommend policy initiatives & action plans to realize this vision. The 5G HLF has released a report[2] in August 2018 titled "Making India 5G ready" suggesting measures in the area of Spectrum Policy, Regulatory Policy, Education and Awareness Promotion Program, Application & Use Case Labs, Development of Application Layer Standards, Major Trials and Technology Demonstration and Participation in International Standards.

[2] http://dot.gov.in/whatsnew/national-digital-communications-policy-2018

1.6 The Government has launched a program[3] titled 'Building an End-to-End 5G Test Bed'[4] to advance innovation and research in 5G. This three-year program began in March 2018, with a budget authorization of Rs 2,240 million. The program has been awarded to Indian Institutes of Technology (IIT) Madras, IIT Hyderabad, IIT Delhi, IIT Kanpur, Centre of Excellence in Wireless Technology (CEWIT), Society for Applied Microwave Electronics Engineering & Research (SAMEER) and Indian Institute of Science (IISc) Bangalore. The program envisages close collaboration between the universities and small technology companies. The goal of the program is to build proof-of-concept 5G prototypes that are broadly compliant with the 3GPP standards. Several academic R&D programs around 5G themes have also been funded by Department of Science and Technology (DST) and Ministry of Electronics and Information Technology (MEITY).

1.7 On the standards front, Department of Telecommunications (DoT) and Telecommunications Standards Development Society, India (TSDSI) in collaboration with the IITs have been successful in getting the Low Mobility Large Cell (LMLC) use case accepted in the International Mobile Telecommunications-2020 (IMT-2020) requirements. LMLC reflects the needs of rural India and other similarly placed countries. TSDSI is currently working with 3GPP to include specifications in Release 15 standard that support the LMLC use case.

Industry Initiatives

1.8 Ericsson has installed the first public access 5G test bed at IIT Delhi in July 2018 for developing applications in the broadband and low latency areas and has provided access to the industry and institutions to work on India specific usage scenarios and applications.

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[3] As mentioned in the High-Level Forum report

[4] http://5gindia.co.in/img/5GTestBedWriteUp.pdf

Impact of 5G in India

1.9 Mobile data usage per month[5] in India has increased from 39 Petabytes in June-2016 to 4178 Petabytes in September-2018 (Figure 1.2), thereby showing an increase of many folds. With the exponential growth in data usage, India has become one of the countries with highest mobile data usage.

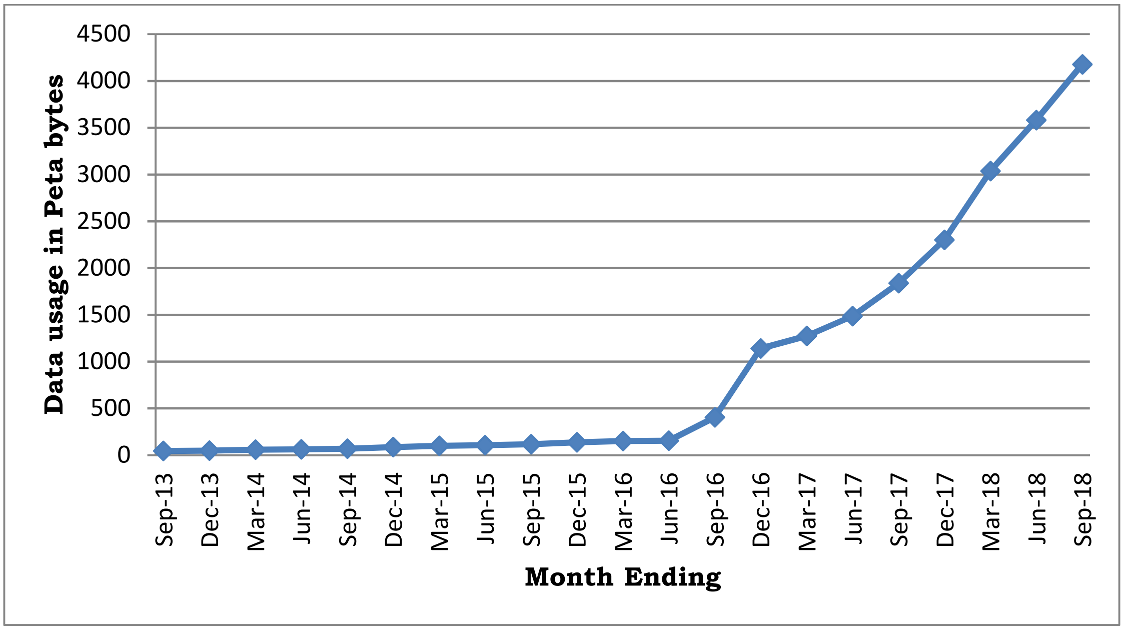


Figure 1.2: Data Usage trend in India in last five years

1.10 According to GSMA intelligence (GSMAi)[6], 208 million new subscribers will get connected in India by 2025, accounting for a quarter of global and half of regional [Asia-Pacific (APAC)] new subscribers over 2017-2025 period. By this time, smartphone connections in the country will account for three quarters of total connections.

1.11 5G will help to cater the growing demand for high speed internet. Moreover, it will unleash new business opportunities and bring substantial socioeconomic benefits through increase in productivity, improvements in

[5] As per the reports submitted by the service providers to TRAI
[6] https://www.gsmaintelligence.com/research/?file=28401018963d766ca37d014fa9cbffb1&download

service delivery, optimum use of scarce resources as well as creation of new jobs.

1.12 According to 5G HLF[7], 5G is expected to be launched in India by 2020 and is predicted to create a cumulative economic impact of USD 1 trillion in India by 2035. As per Ericsson, 5G enabled digitalization revenue potential in India will be above USD 27 billion by 2026. GSMAi projects that after initially launching in 2020, 5G connections in India will grow to almost 70 million by 2025, equivalent to around 5% of total connections (excluding cellular IoT).

Objective of the report

1.13 The National Digital Communication Policy-2018 (NDCP-2018), released on 26th September 2018[8], envisions supporting India's transition to a digitally empowered economy and society by fulfilling the information and communications needs of citizens and enterprises by establishment of a ubiquitous, resilient and affordable Digital Communications Infrastructure and Services. With respect to the rollout of 5G services, NDCP-2018 envisages the following-

> *"2.2 …(d) Enabling Hi-speed internet, Internet of Things and M2M by rollout of 5G technologies:*
> *i. Implementing an action plan for rollout of 5G applications and services*
> *ii. Enhancing the backhaul capacity to support the development of next-generation networks like 5G*
> *iii. Ensuring availability of spectrum for 5G in 6 GHz bands*
> *iv. Reviewing industry practices with respect to traffic prioritization to provide 5Genabled applications and services*
> *v. Developing framework for accelerated deployment of M2M services while safeguarding security and interception for M2M devices*

[7] http://www.dot.gov.in/sites/default/files/5G%20Steering%20Committee%20report%20v%2026_0.pdf?download=1
[8] http://pib.nic.in/newsite/PrintRelease.aspx?relid=183711

vi. Defining policy for EMF radiation for M2M devices, with accompanying institutional framework to coordinate government-funded and India-specific research in this regard"

1.14 Timely deployment of 5G in India is very essential for achieving the objectives envisaged in NDCP-2018. 5G will further push the Digital India program and will help in making governments' digital services available to all. 5G capabilities will also be needed to support Smart cities project.

1.15 As India's telecom and broadcasting regulator, TRAI has a role to play along with the Government and industry, in creating an enabling environment for the rollout of 5G in India. With this in view, this white paper discusses potential benefits of 5G and tries to identify regulatory challenges that need to be addressed for the deployment of 5G in India.

1.16 For drafting this white paper, various documents available in the public domain, published by government agencies/departments, telecom regulators in many countries, research agencies/institutions, academic institutions, telecom vendors, operators and international agencies/forums etc. were referred with the purpose to make it balanced and comprehensive. Excerpts from certain documents, which had domain relevance, are also included in this white paper.

1.17 The white paper comprises of eight chapters. Chapter-II highlights the specifications of the 5G technology. Chapter–III discusses the architecture of 5G network. Chapter-IV covers the spectrum requirements for 5G networks. Chapter-V deals with the small cell deployment. Chapter-VI gives the insights of the backhaul requirements in 5G. Chapter-VII touches upon the regulatory issues & challenges and Chapter- VIII deliberates those areas that will require investment for 5G deployment.

CHAPTER 2
5G SPECIFICATIONS

A. Technical Specifications

2.1 5G is a system designed to meet the requirements[9] of IMT-2020 set by the International Telecommunication Union (ITU-R) specification M.2083. IMT-2020 (5G) is intended to provide far more enhanced capabilities than those provided by IMT Advanced (4G). It is expected to make available much greater throughput, much lower latency, ultra-high reliability, much higher connectivity density, and higher mobility range. Figure 2.1 shows the comparison of design targets between 4G and 5G.

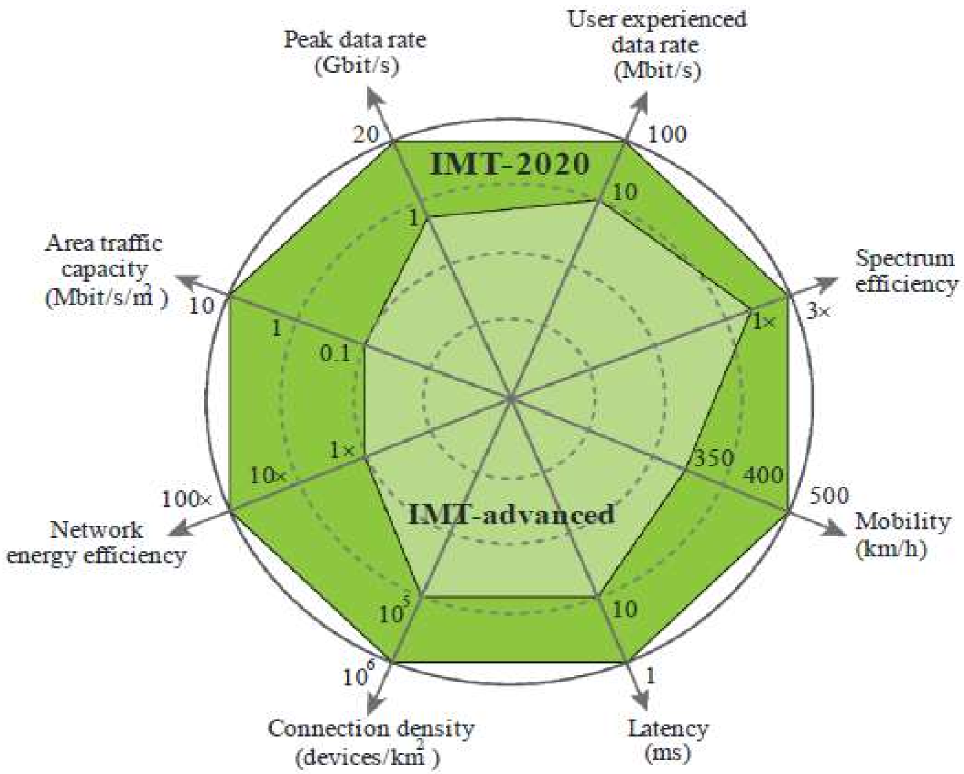


Figure 2.1: Comparison of design targets between 4G & 5G (Source: ITU)

[9] https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

2.2 The 5G networks are envisioned to provide a flexible, scalable, agile, and programmable network platform over which different services with varying requirements can be provisioned and managed within strict performance bounds. The key performance requirements related to the minimum technical performance of IMT-2020 (5G) as defined by ITU[10] in Report ITU-R M.2410-0 is summarized in Table 2.1.

Table 2.1: Key Performance Requirements of IMT-2020

KEY PARAMETERS	VALUES	
Peak Data Rate	Downlink: 20 Gbit/s Uplink: 10 Gbit/s	
Peak spectral efficiency	Downlink: 30 bit/s/Hz Uplink: 15 bit/s/Hz	
User experienced data rate	Downlink: 100 Mbit/s Uplink: 50 Mbit/s	
5th percentile user spectral efficiency	**Indoor Hotspot**	Downlink: 0.3 bit/s/Hz Uplink: 0.21 bit/s/Hz
	Dense Urban	Downlink: 0.225 bit/s/Hz Uplink: 0.15 bit/s/Hz
	Rural	Downlink: 0.12 bit/s/Hz Uplink: 0.045 bit/s/H
Average spectral efficiency	**Indoor Hotspot**	Downlink: 9 bit/s/Hz Uplink: 6.75 bit/s/Hz
	Dense Urban	Downlink: 7.8 bit/s/Hz Uplink: 5.4 bit/s/Hz
	Rural	Downlink: 3.3 bit/s/Hz Uplink: 1.6 bit/s/Hz
Area traffic capacity	Downlink:10 Mbit/s/m^2 in the Indoor Hotspot	
Latency	**User Plane**	1 ms
	Control Plane	20 ms
Connection density	10^6 devices per km^2	
Energy Efficiency	Efficient data transmission in a loaded case Low energy consumption when there is no data	

[10] https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf

KEY PARAMETERS	VALUES
Reliability	$1\text{-}10^{-5}$ success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms
Mobility	Stationary: 0 km/h Pedestrian: 0 km/h to 10 km/h Vehicular: 10 km/h to 120 km/h High speed vehicular: 120 km/h to 500 km/h
Mobility interruption time	0 ms
Bandwidth	100 MHz

B. 5G Use Cases

2.3 5G use cases can be categorized into three different use case classes namely- enhanced Mobile Broadband (eMBB), massive Machine-Type Communication (mMTC), and Ultra-Reliable Low-Latency Communications (UR-LLC). The requirements for the use case classes and the use cases within each class vary significantly. Figure 2.2[11] shows the key performance requirements in different usage scenarios.

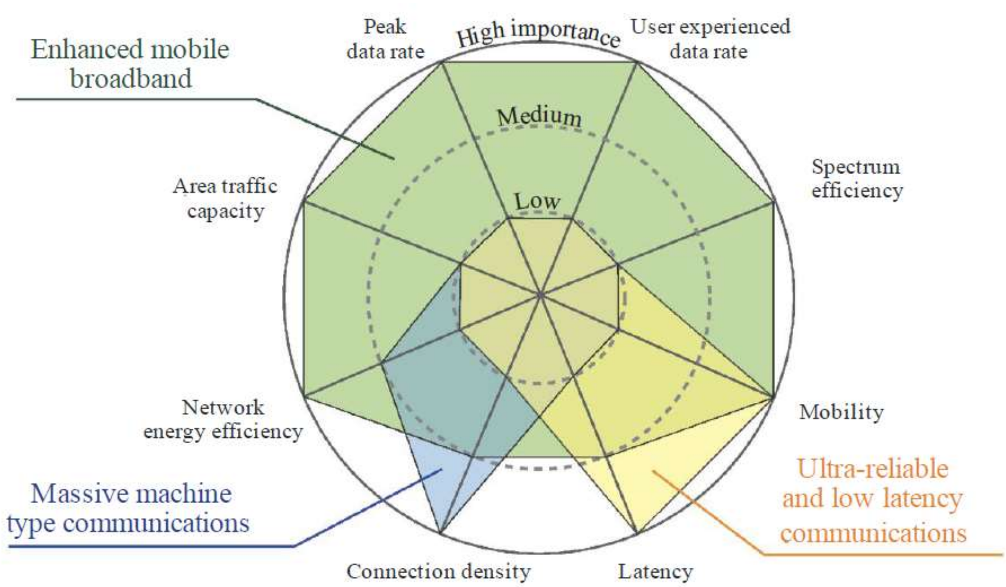


Figure 2.2: Key performance requirements in different usage scenario (Source: ITU)

[11] https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

2.4 eMBB: It addresses the human-centric data driven use cases for access to multi-media content, services and data. This usage scenario comes with new application areas such as virtual reality, video monitoring, mobile cloud computing, 360° Ultra-High-Definition (UHD) video streaming, real-time gaming, etc and new requirements such as hotspot, wide area coverage, etc in addition to existing Mobile Broadband applications.

2.5 UR-LLC: This use case has stringent requirements for capabilities such as throughput, latency and availability. It will support the delivery of critical communications. Some examples include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid, transportation safety, autonomous cars etc.

2.6 mMTC: This use case is characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. Devices are required to be low cost and have a very long battery life. This use case covers IoT applications. Some examples include health monitoring wearables, smart cities with smart grids, smart transport systems and smart homes, etc.

2.7 5G will have impact on many sectors. In 2017, 5G Americas published a report[12] titled "5G services and use cases" highlighting potential 5G use cases (Figure 2.3) in different sectors. Some use cases in key sectors are listed below-

- Healthcare

(i) Remote patient monitoring and communication with sign measuring devices such as blood pressure, ECG, temperature etc, which is possible with immediate, automatic or semi automatic responses.

[12] http://www.5gamericas.org/files/9615/1217/2471/5G_Service_and_Use_Cases__FINAL.pdf

(ii) Remote surgery applications that can provide control and feedback communication technique for surgeons from ambulance, remote areas etc, which requires low latency and highly reliable networks.

- Smart cities

(i) Consistent user experience, hotspot broadband access in highly dense areas, urban city centers etc.

(ii) Access to broadband in public transport system such as high-speed trains by providing communication link and high-quality internet for entertainment or work.

(iii) Can control real and virtual objects like autonomous cars, which requires real time reaction.

(iv) Support safety applications to mitigate road accidents, traffic efficiency etc, which requires ultra low latency for warning signals and high data rates.

- Industrial IoT

(i) Integrate and enable automation process which will be useful for many industries like oil and gas, chemicals and water.

(ii) Communication transfers will enable time critical factory automation across wide range of factories such as metals, pharmaceuticals etc.

- Emergency, disaster and public safety

(i) Highly efficient communication during natural disasters such as earthquakes, floods etc.

(ii) Provides real time accurate location and communication for better safety.

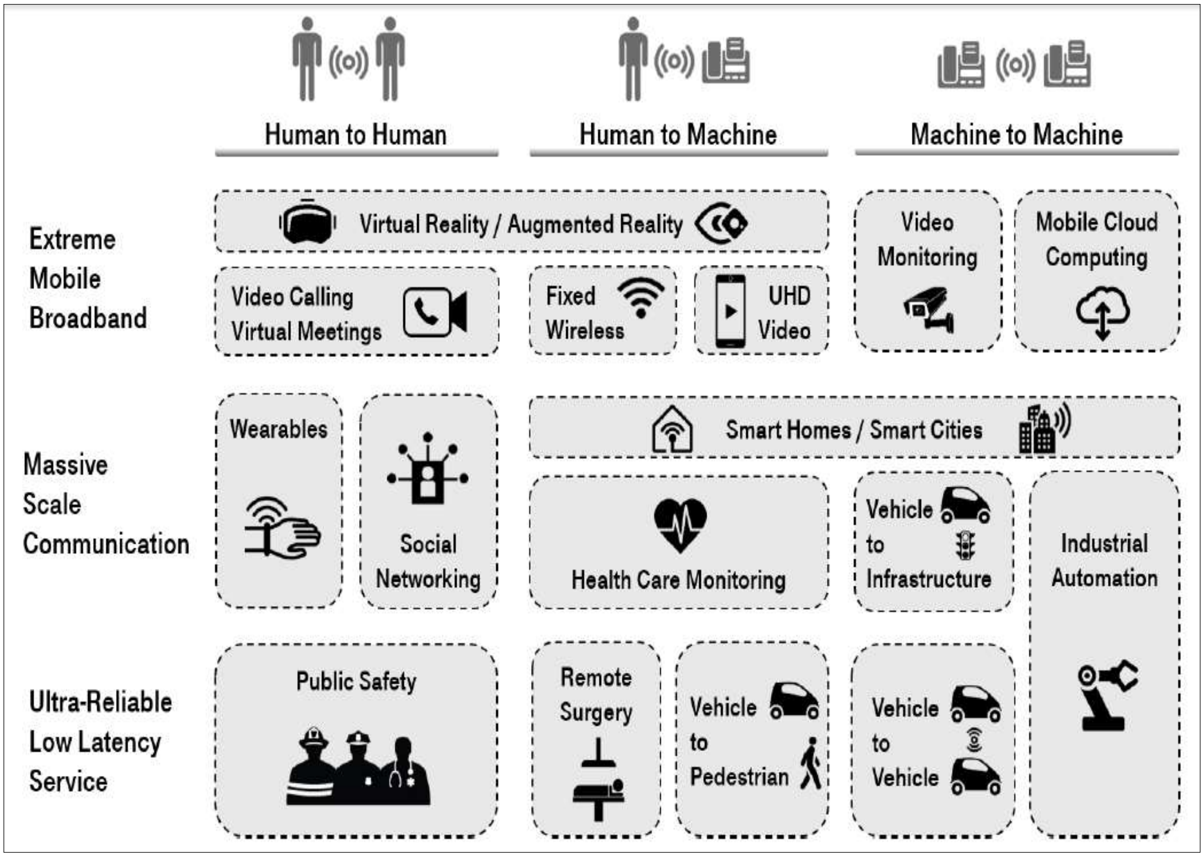


Figure 2.3: 5G Use Cases grouped by type of interaction and different performance requirements (Source: 5G Americas)

C. Key Enablers

2.8 To support different services with varying requirements, a paradigm shift is taking place in the technologies that drive the networks. Innovative techniques (Figure 2.4) are being developed to power the next generation mobile networks. Mobile network functions are being split up, distributed and virtualized to provide the best combination of latency, throughput and cost effectiveness for various potential applications.

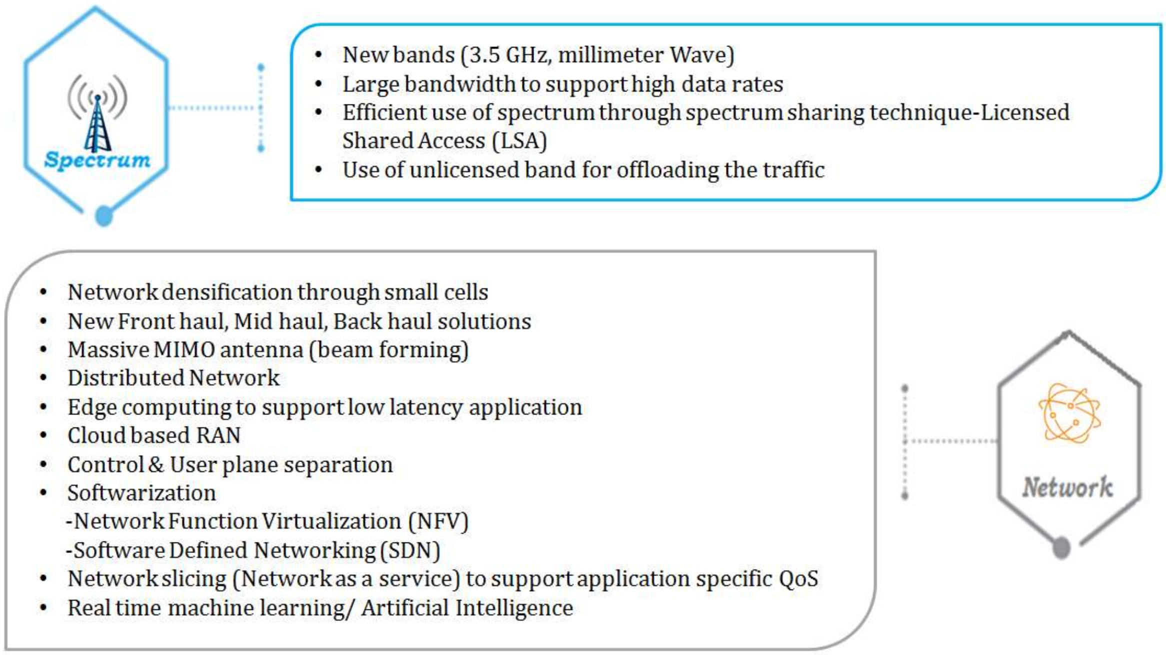


Figure 2.4: Enablers of 5G

2.9 Network Function Virtualization (NFV) and Software Defined Networking (SDN) technologies-based network enable virtual “network slices” for different vertical markets, which provide customized Quality of Service (QoS) and specific functional requirements. Cloud Radio Access Network (Cloud RAN) reduces operators’ Total Cost of Ownership (TCO) and facilities efficient allocation of resources. Deployment of Small Cells increases network capacity and spectrum reuse. New backhaul solutions support the implementation of both traditional and distributed RAN network. Use of edge computing for local analysis and processing of data provides users faster higher-quality experiences with ever-improving visual, audio and potentially tactile interfaces. Massive Multiple Input Multiple Output (MIMO)[13] implementations increase user data speeds and system capacity to meet 5G standards by dynamically transmitting data as highly-focused beams and exploiting multipath propagation and spatial multiplexing to

[13] https://www.ericsson.com/en/networks/trending/hot-topics/5g-radio-access/massive-mimo

simultaneously send and receive more than one data signal over the same radio channel.

2.10 High frequency bands are best suited for technologies such as massive MIMO, super-dense meshed cells and macro-assisted small cells. Furthermore, substantially more bandwidth is available in high frequency bands than in the bands below 1GHz, which is beneficial for providing much wider channels and higher speeds. Use of spectrum within three different frequency range (sub 1 GHz, 1-6 GHz, above 6 GHz) support varying requirements of all use cases. Spectrum sharing technique such as Licensed Shared Access (LSA) improves spectrum utilization. Also, unlicensed spectrum coupled with licensed spectrum increase the access network capacity and improves users' wireless experience.

CHAPTER 3
5G NETWORK ARCHITECTURE

A. Evolution of Mobile Network[14]

3.1 Global System for Mobile communications (GSM) was developed to carry voice services in a circuit switched manner. Data services were also possible over a circuit switched modem connection but with very low data rates. The first step towards an Internet Protocol (IP) based packet switched solution was taken with the evolution of GSM to General Packet Radio Service (GPRS), using the same air interface and access method.

3.2 To reach higher data rates in Universal Mobile Terrestrial System (UMTS), a new access technology namely Wideband Code Division Multiple Access (WCDMA) was developed. The access network in UMTS emulates a circuit switched connection for voice services and a packet switched connection for data services. Incoming data services in UMTS had to still rely upon the circuit switched core for paging. To overcome this shortcoming, pure IP based Evolved Packet System (EPS) was developed.

3.3 In EPS system, both voice services and data services are carried by the IP protocol. A new access solution called Long Term Evolution (LTE) which is based on Orthogonal Frequency Division Multiple Access (OFDMA) is used to achieve high data rates. The LTE access network is simply a network of smart base stations (evolved NodeB) without any centralized intelligent controller, generating a flat architecture. Distributing the intelligence amongst the base-stations in LTE, reduced the time required for setting-up the connection and for handover.

[14] http://www.3gpp.org/technologies/keywords-acronyms/98-lte

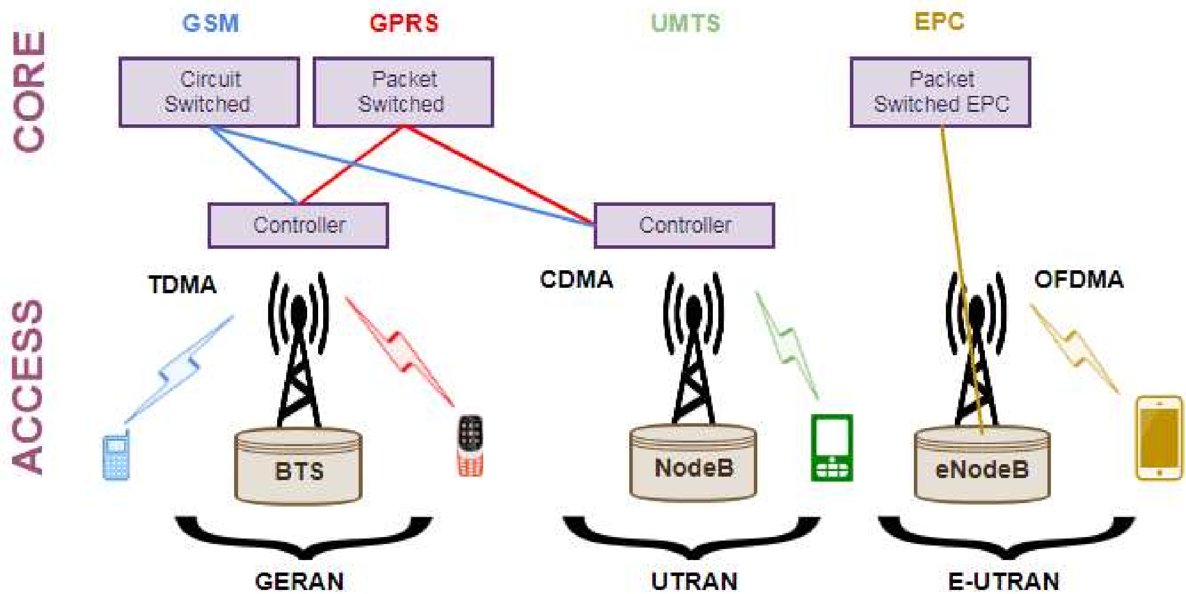


Figure 3.1: Network Architecture from GSM to LTE (Source: 3GPP)

B. Need of 5G NextGen core (5G NGC)

3.4 5G has demanding service and network requirements that will require a fundamental change to the core architecture. Simply upgrading the existing LTE core won't be able to support the varied requirements of all envisaged 5G use cases. The 5G NG core will have the following characteristics:

- Virtualization and NF modularization;
- Service based architecture and interface;
- Control plane and user plane separation;
- Mobility management and session management function decoupling;
- New QOS architecture for introducing the new services;
- Network slicing for supporting the new business domains.

Virtualization and NF modularization

3.5 With software-defined networking (SDN) and Network Functions Virtualization (NFV) supporting the underlying physical infrastructure, 5G comprehensively cloudifies access, transport, and core networks. SDN is about the separation of the network control traffic (control plane) and the user specific traffic (data plane/user plane). It is based on the centralization of configuration and control, while ensuring simple data plane architecture. NFV is about virtualizing network functions (by implementing them in software) and the functions that can run on a range of standard hardware. Cloud- and virtualization-based platform allow many different functions to be built, configured, connected, and deployed at the scale that is needed at the given time. It enables flexible orchestration of resources and controls the network efficiently.

3.6 Cloud adoption allows better support for diversified 5G services, and enables the key technologies of end-to-end network slicing, on-demand deployment of service anchors, and component-based network functions. It also simplifies scaling and management of network infrastructure. Moreover, it offers an increasing number of comprehensive 'Platforms as a Service (PaaS)' to make it easy to develop new applications.

Service based architecture and interface[15]

3.7 3GPP identifies two representation of 5GC architecture- (1) point-to-point (P2P) based and service based (SBA). The P2P architecture has been used in 2G, 3G, and 4G. In P2P architecture, it is difficult to make changes in a deployed system because it contains large number of unique interfaces between functional elements. When a new element is introduced or existing element is upgraded, multiple adjacent functions need to be reconfigured. The SBA decouples the end-user service from the underlying network and platform infrastructure. This enables both functional and service agility.

[15] https://img.lightreading.com/downloads/Service-Based-Architecture-for-5G-Core-Networks.pdf

Control plane and user plane separation

3.8 Control and user plane separation enables independent scalability and decoupled technical evolution. This will also support flexible deployments, such as at centralized and edge locations. It can also be applied to the EPC in 4G. This upgrade enables the EPC to meet increasing traffic demands at lower cost-per-bit, and to serve low-latency applications hosted in edge locations. It also provides an important migration path from 4G to 5G.

Network slicing for supporting the new business domains[16]

3.9 Network slicing permit business customers to enjoy connectivity and data processing tailored to the specific business requirements that adhere to a Service Level Agreement (SLA) agreed with the operator. The customizable network capabilities include data speed, quality of service, latency, reliability, security, services and charging.

3.10 In this concept, an operator set up multiple virtual slices of the RAN, core and transport networks (Figure 3.2) on top of the same physical infrastructure to meet specific service requirements. The operators could deploy a single network slice type that satisfies the needs of multiple verticals, as well as multiple network slices of different types that are packaged as a single product targeted towards business customers who have multiple and diverse requirements.

3.11 Network Slicing provides an industry vertical optimized platform catering in an economical way the various requirements and business needs of each vertical. According to GSMA, the Industry Sectors with high potential for the application of Network Slicing are Government, Utilities, Media & Entertainment, Financial, Smart cities, Consumer, Automotive, Logistic, Industry Internet and Health & Welfare.

[16] https://www.gsma.com/futurenetworks/wp-content/uploads/2017/11/GSMA-An-Introduction-to-Network-Slicing.pdf

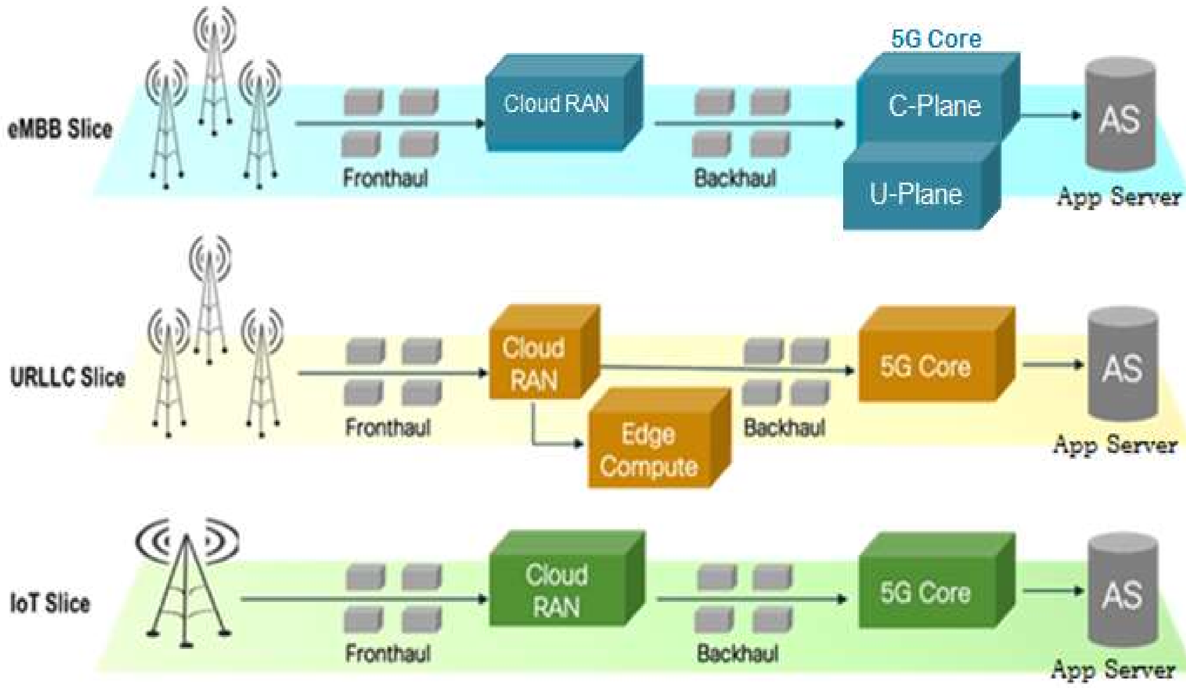


Figure 3.2: Network Slicing

3.12 Network slicing can be used for several purposes: a complete private network, a copy of a public network to test a new service, or a dedicated network for a specific service. For instance, when setting up a private network in the form of a network slice that can be an end-to-end virtually isolated part of the public network, the network exposes a set of capabilities in terms of bandwidth, latency, availability and so on. Thereafter, a newly created slice can be locally managed by the slice owner who will perceive the network slice as his or her own network, complete with transport nodes, processing and storage. The resources allocated to a slice can be a mix of centrally located and distributed resources. The slice owner can initiate applications from his or her management center, and applications will simply execute and store data, either centrally, in a distributed management system or a combination of both.

C. 5G RAN[17]

3.13 Mobile network capabilities are evolving quickly, continuously pushed by new requirements relating to latency, traffic volumes, data rates and need for reliable connectivity. To efficiently meet future demands the LTE RAN architecture will need to support improved resource pooling, capacity scalability, layer interworking and spectral efficiency over various transport network configurations. Cloud RAN architectures (Figure 3.3) support these needs by exploiting NFV techniques and data center processing capabilities, as well as improved radio coordination for distributed as well as centralized RAN deployments.

3.14 Distributed RAN[18] (DRAN): In DRAN architecture, the interface between the RAN and core network is located at the radio site. Today, most LTE networks use a distributed baseband deployment only. DRAN architecture enables quick rollout, ease of deployment and standard IP-based connectivity.

3.15 Centralized RAN (CRAN): In CRAN architecture, all baseband processing (including RAN L1, L2 and L3 protocol layers) is located at a central location that serves multiple distributed radio sites. The transmission links between the central baseband units and distributed radio units use Common Public Radio Interface (CPRI) fronthaul over dedicated fiber or microwave links. This CPRI fronthaul requires tight latency and large bandwidths. Its main use is in dense and ultra-dense urban environment to boost performance.

3.16 Virtualized RAN (VRAN): The Virtualized RAN architecture exploits NFV techniques and data center processing capabilities and enables coordination and centralization in mobile networks. It supports resource pooling, scalability, layer interworking and robust mobility. It increases the flexibility

[17] https://www-file.huawei.com/-/media/CORPORATE/PDF/mbb/cloud-ran-the-next-generation-mobile-network-architecture.pdf?la=en
[18] http://www.tid.es/sites/526e527928a32d6a7400007f/content_entry5321ef0928a32d08900000ac/578f4eda1146dde411001d0e/files/WhitePaper_C-RAN_for_5G_-_In_collab_with_Ericsson_SC_-_quotes_-_FINAL.PDF

of the network by virtualizing parts of the baseband process, making it easier to scale capacity, deploy new services and adopt the network. The increased flexibility of this split architecture will lead to a more diverse range of deployments for the operators, with the possibility of tailoring the networks to meet customer needs from dense urban, high eMBB bandwidth applications to automated factory machine control. VRAN can be applied on both DRAN and CRAN networks.

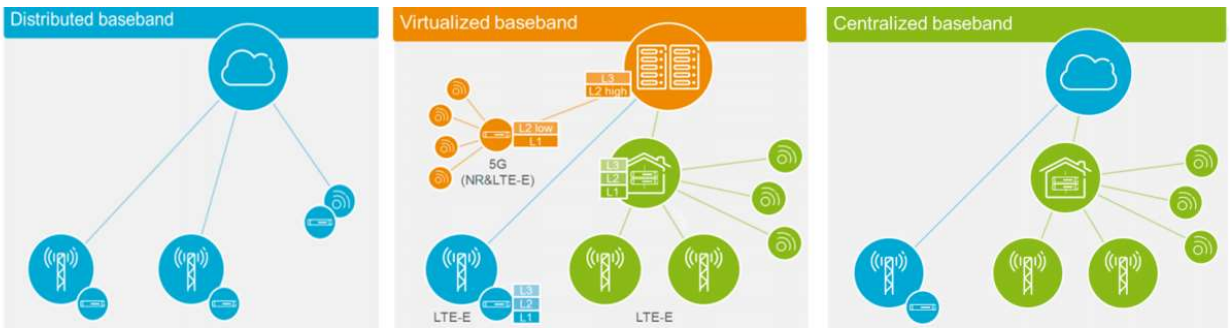


Figure 3.3: RAN Architectures (Source: Ericsson)

D. 5G NR RAN interfaces

3.17 For the new 5G RAN architecture, including the split architecture, new interfaces have been standardized. The CPRI has been replaced by new fronthaul interface eCPRI – a packetized interface for improving bandwidth efficiency and ease of deployment. The new IP-based interface between the Centralized Unit (CU) and Distributed Unit (DU) processing nodes in VRAN, is like the traditional S1 backhaul interface but demands lower latency for optimal performance. S1/NG backhaul will retain most of the characteristics of current S1 backhaul, but with increased bandwidth.

E. 5G Transport Network

3.18 The transport domain delivers connectivity between remote sites and equipment/devices. Backhaul serves both ends of the transmission – for example, to connect a Base Station (BS) to an access network or a central office – while fronthaul is a term used when the BS antennas are connected to a remote integrated Radio Frequency (RF) unit, or to a centrally located baseband (BB) unit. In addition to providing bulk connectivity for the operator's mobile network fronthaul and backhaul, the transport domain may offer different types of customer facing connectivity services, such as a Layer 2 or Layer 3 VPN.

3.19 5G RAN technology puts new requirements on the bandwidth and latency of transport networks. Consequently, a high degree of automation and coordination within and across network domains will be required. A concept known as RAN Transport Interaction (RTI) introduces coordination between the radio, transport and packet core layers of an operator's mobile network, providing network-wide optimization and service assurance. Examples of such coordination include:

- support for various industries extending network resource differentiation into the transport network
- proactive congestion management, enabling transport aware RAN load balancing for improved user Quality of Experience (QoE)
- securing fairness between radio technologies within the transport network.

F. MIMO & beamforming solution[19] for 5G

3.20 Recent technology developments have made advanced antenna systems (AAS) a viable option for large scale deployments in existing 4G and future 5G mobile networks. AAS enables state-of-the-art beamforming and MIMO techniques (Figure 3.4) that are powerful tools for improving end-user experience, capacity and coverage. It significantly enhances network performance in both uplink and downlink.

3.21 MIMO is the ability to transmit multiple data streams, using the same time and frequency resource, where each data stream can be beamformed.

[19] https://www.ericsson.com/en/white-papers/advanced-antenna-systems-for-5g-networks

Beamforming is the ability to direct radio energy through the radio channel toward a specific receiver. By adjusting the phase and amplitude of the transmitted signals, constructive addition of the corresponding signals at the UE receiver can be achieved, which increases the received signal strength and thus the end-user throughput. Applying AAS features to an AAS radio results in significant performance gains because of the higher degrees of freedom provided by the larger number of radio chains, also referred to as Massive MIMO.

3.22 High frequencies are vital for providing high data rates in 5G, however, the propagation in these frequencies is hostile. To combat the challenging propagation conditions at these frequencies, deployment of advanced antennas plays a major role.

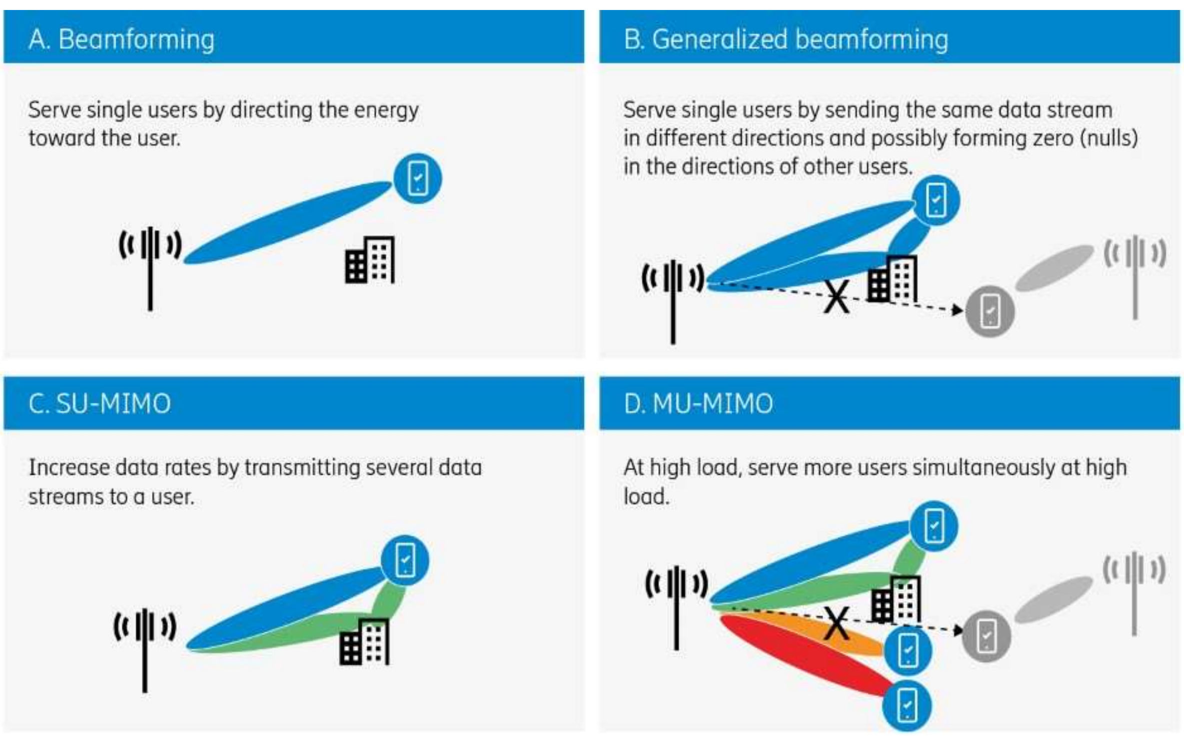


Figure 3.4: Beamforming and MIMO (Source: Ericsson)

G. Integration of Non- 3GPP access networks

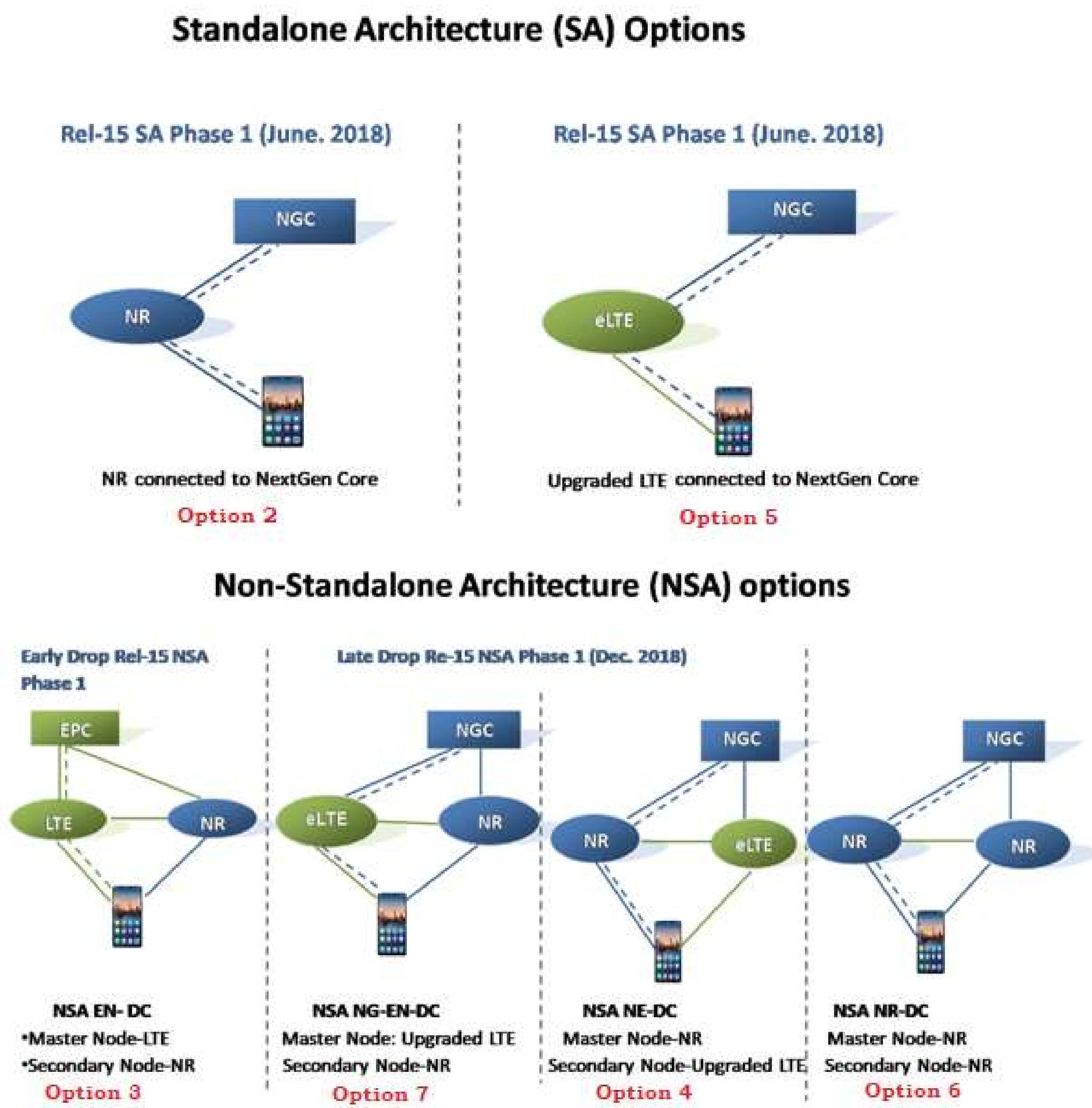
3.23 In IMT-2020 specifications, there is a feature to integrate WiFi access into the 5G core. Non-3GPP access networks (such as WiFi networks) are connected to 5G core network via a non-3GPP Inter-Working Function (N3IWF) Interface. The N3IWF interfaces to 5G core network control plane and user-plane functions via N2 interface and N3 interface respectively. Whenever the User Equipment (UE) is in the WiFi enabled area, the traffic (calls and data) is off-loaded to the WiFi network. However, traffic over the Non 3GPP access is sent through a secure tunnel established between UE and N3IWF; thus, there is no compromise on security. This will help in reducing the load on IMT spectrum.

H. 5G network deployment solutions

3.24 As per the 3GPP specification, 5G will be deployed in two different modes- (1) Non-Standalone (NSA) and (2) Standalone (SA). In NSA, NR and LTE are tightly integrated and connect to either the existing EPC or the 5G NG Core, leveraging Dual Connectivity (DC)[20] toward the terminal. Whereas, in SA, either NR or LTE connects to 5G NG Core. The 3GPP standards provide several architecture options as shown in figure 3.4.

3.25 In order to have speedy deployment of the 5G, initially it is going to be deployed in co-existence with LTE. Gradually, once the technology matures and all the 3GPP specifications get frozen, NSA networks will move towards SA networks with 5G NR as well as 5G Core.

[20] In Dual Connectivity architecture, a Master Node (MN) and a Secondary Node (SN) concurrently provide radio resources towards the terminal for enhanced end-user bit rates.



	Core Network	Master Radio Access Technology (RAT)	Secondary RAT
Option 1	EPC	LTE	-
Option 3	EPC	LTE	NR
Option 2	5GC	NR	-
Option 5	5GC	Upgraded LTE to support 5GC	-
Option 4	5GC	NR	Upgraded LTE to support 5GC
Option 7	5GC	Upgraded LTE to support 5GC	NR

Figure 3.5: 4G/5G RAN Architecture Options (Source: Samsung)

CHAPTER 4
SPECTRUM FOR 5G

4.1 Spectrum is the lifeline for any wireless communication. Low frequencies (less than 1 GHz) provide wide area and deep indoor coverage across urban, suburban and rural areas and support IoT for low data rate applications. Medium frequencies (1–6 GHz) provide good coverage and high speeds. High frequencies (above 6 GHz) offer real promise for the provision of very high data rates and high system capacity in dense deployments. Figure 4.1 compares varies frequency bands based on their physical properties. Technically, spectrum is technology neutral i.e. any spectrum band can be used for deploying any technology. However, while deciding the deployment of a technology, apart from the technical factors, development of eco-system plays a significant role.

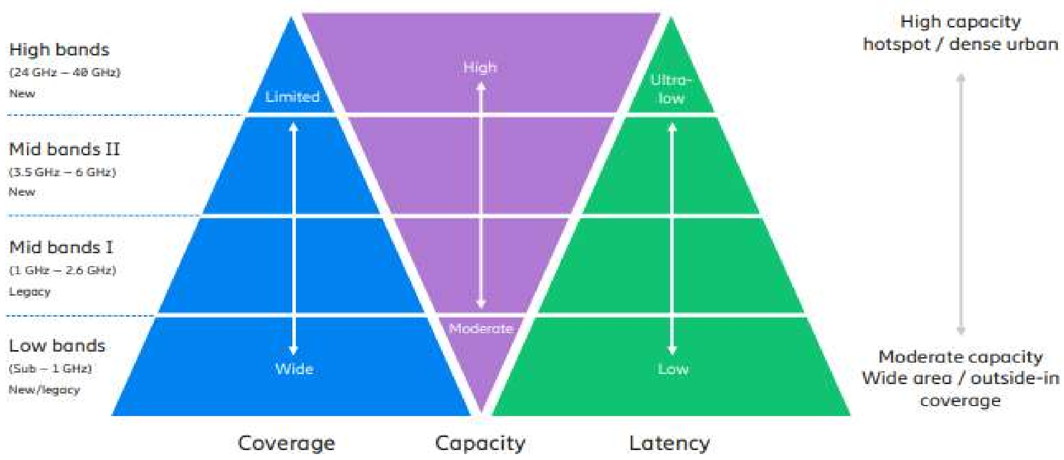


Figure 4.1: Physical properties of different spectrum bands (Source: Ericsson)

A. Licensed Spectrum

4.2 5G is emerging as a technology that will use both low frequencies (f<1GHz), high frequencies (1GHz<f<6GHz) and, for the first time ever in consumer networks, very high frequencies referred to as "millimeter wave" frequencies (f>6GHz). This diverse spectrum is bound to ensure the promises of extended coverage (low frequencies), ultra high speeds (very large channels in very high frequency bands) and low power consumption which are envisaged in 5G. The three key spectrum frequency ranges required for 5G can be summarized as shown in figure 4.2.

Sub-1 GHz Coverage Layer	**1-6 GHz Coverage & Capacity Layer**	**Above 6 GHz Super Data Layer**
Wide area & deep indoor coverage	**mMTC (no deep coverage), eMBB, uRLLC**	Supports high data rates
mMTC, eMBB, uRLLC		**eMBB, uRLLC**

Figure 4.2: Spectrum for 5G

Global Scenario and Developments

4.3 3GPP has undertaken studies to identify suitable bands for 5G. In its Release 15, 3GPP has listed the following 5G NR frequency bands (Table 4.1). Among the identified bands, 700 MHz, 3.5 GHz, 26/28 GHz are the 5G pioneer bands. The figure 4.3 shows the global snapshot of 5G spectrum.

Table 4.1: 5G NR Frequency bands

NR Operating band	Uplink	Downlink	Duplex Mode
< 1GHz (LOW BAND)			
n5	824 MHz – 849 MHz	869 MHz – 894 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
1-6 GHz (MID BAND)			
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n38	2570 MHz – 2620 MHz		TDD

NR Operating band	Uplink	Downlink	Duplex Mode
n41	2496 MHz – 2690 MHz		TDD
n50	1432 MHz – 1517 MHz		TDD
n51	1427 MHz – 1432 MHz		TDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n77	3300 MHz – 4200 MHz		TDD
n78	3300 MHz – 3800 MHz		TDD
n79	4400 MHz – 5000 MHz		TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL
> 6 GHz (HIGH BAND) mmWave			
n257	26.5 GHz – 29.5 GHz		TDD
n258	24.25 GHz – 27.5 GHz		TDD
n260	37 GHz – 40 GHz		TDD

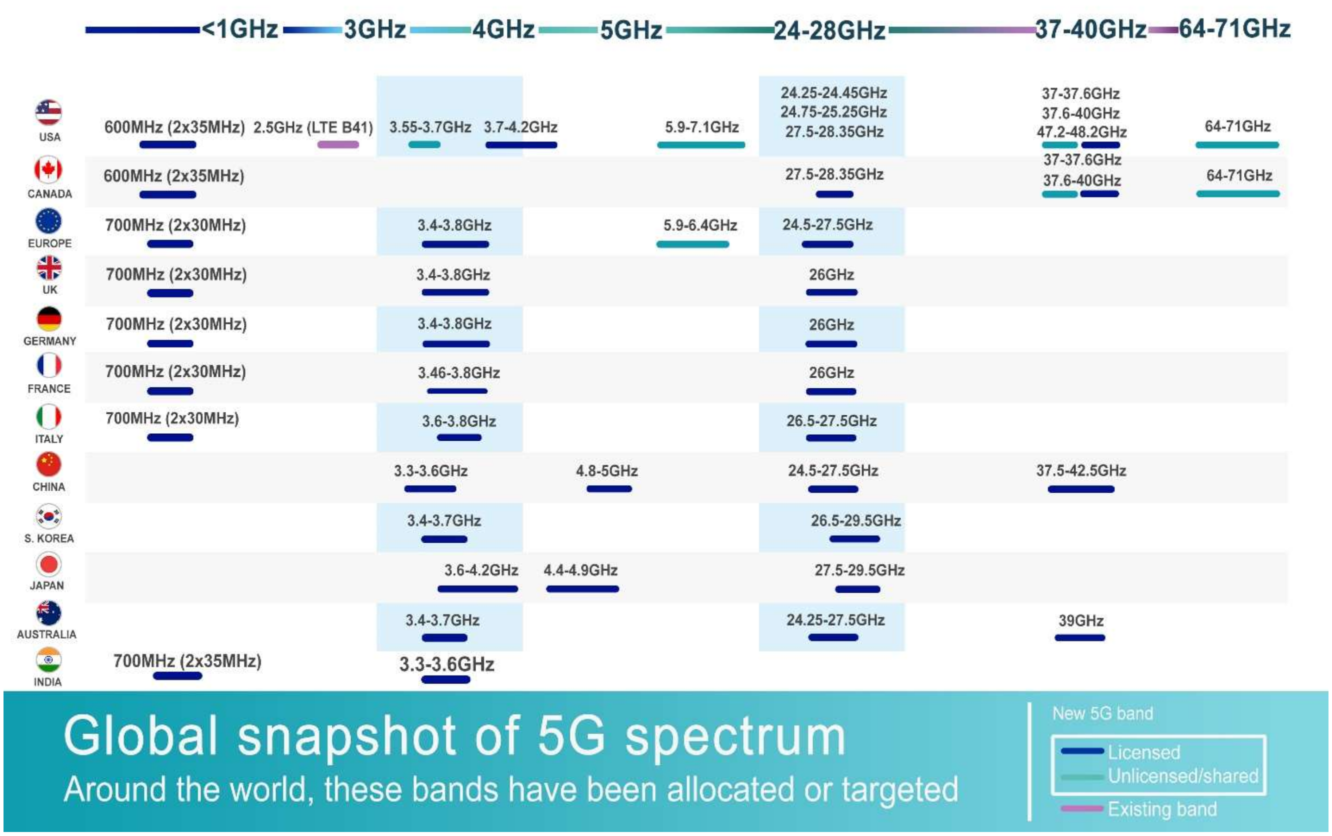


Figure 4.3: Global Snapshot of 5G Spectrum (Source: Qualcomm)

4.4 In the higher frequency bands, eleven candidate frequency bands including 24.25-27.5 GHz (26 GHz), as listed in Table 4.2, are being considered under World Radio Conference-2019 (WRC-19) for evaluation to check whether 5G could coexist with the incumbent services in the same and adjacent bands. The Asia Pacific Telecommunity (APT) Wireless Group (AWG) is also conducting sharing and compatibility studies for IMT above 24 GHz frequencies with the consideration of Asia-Pacific regional relevant status. Table 4.2 lists the frequency bands under study for IMT identification according to Resolution 238 (WRC-15).

Table 4.2: Frequency bands for study and IMT identification according to Resolution 238 (WRC-15)

Frequency Band (GHz)
24.25-27.5
31.8-33.4
37-40.5
40.5-42.5
42.5-43.5
45.5-47
47.2-50.2
47-47.2
50.4-52.6
66-76
81-86

4.5 Based on the spectrum availability and equipment readiness from mobile industry, countries such as US, Canada, South Korea, Japan, Hong Kong, New Zealand, Singapore, Brazil, Taiwan, Colombia and Slovakia have either allocated or are in the process of allocating parts of 26.5-29.5GHz (28 GHz band) for 5G, which is not in the scope of WRC-19.

4.6 Telecom Industry has started developing a strong equipment ecosystem for 28 GHz band. More than 50 trials have been conducted in this band. 3GPP too has developed the specification to support 28 GHz band for 5G with the strong support of mobile industry, expecting to be the first global mmWave ecosystem. Furthermore, global mobile industry organizations such as GSMA and GSA fully support the 28 GHz band as 5G Frontier band.

Indian Scenario and Developments

4.7 Presently, spectrum assignment in India is being done through auction process and the spectrum sold is liberalized (technology agnostic) i.e. the service provider has the freedom to decide the technology to be deployed in the given spectrum band. With the passage of time, several spectrum bands have been earmarked for IMT services in India. Table 4.3 provides the details of these spectrum bands.

Table 4.3: Spectrum bands earmarked for IMT services in India

Band	Uplink Frequency (MHz)	Downlink Frequency (MHz)	3GPP band no.	Duplexing Scheme
700 MHz	703 -748 MHz	758-803 MHz	28	FDD
	(35 MHz has been earmarked for Access services)			
800 MHz	824-844 MHz	869-889 MHz	5	FDD
900 MHz	890-915 MHz	935-960 MHz	8	FDD
1800 MHz	1710-1785 MHz	1805-1880 MHz	3	FDD
	(55 MHz has been earmarked for Access services)			
2100 MHz	1920-1980 MHz	2110-2170 MHz	1	FDD
2300 MHz	2300-2400 MHz		40	TDD
2500 MHz	2500-2690 MHz		41	TDD
3300 -3600 MHz	3300-3600 MHz (25 MHz spectrum (3400 MHz - 3425 MHz) is identified for ISRO's use in Indian Regional Navigation Satellite System (IRNSS)		Not yet auctioned but TRAI has recommended: (i) TDD Duplexing scheme (ii) Barring the specific locations where ISRO is using the 25 MHz of spectrum, the entire spectrum from 3300 MHz to 3600 MHz should be made available for access services	

4.8 As indicated in Table 4.1, 3GPP release 15 covers all the existing spectrum bands identified for IMT in India. Meaning thereby that the service providers can use any spectrum band to provide 5G services. However, development of ecosystem is one of the major deciding factors for deployment of any technology in a particular spectrum band. Since global deployments drive the development of ecosystem, **spectrum harmonization** is very essential to realize this future vision of high speed mobile broadband communications soon. Spectrum harmonization results in greater economies of scale, reduces interference issues across borders, and enables roaming, which in turn results in increased uptake of services by customers.

4.9 In 5G vision, the spectrum availability is one of the most important issues. In order to realize the potential of 5G; it is crucial that **enough spectrum** is made available in appropriate frequency bands. Recognizing this fact, the 5G HLF has recommended three tiers of access spectrum release for 5G based on availability and readiness-

i. Announce Tier – here certain bands are declared as being made available for 5G rollout, providing certainty to the ecosystem. [698-803 MHz, 3300-3600 MHz, 24.25-27.5 GHz, and 27.5 – 29.5 GHz]

ii. Identify Tier – here bands are designated for potential 5G use which can be moved to the Announce Tier after coordination with other domestic users. [617-698 MHz, 1427-1518 MHz, 29.5 to 31.3 GHz and 37.0 to 43.5 GHz]

iii. Study Tier – here bands are designated for exploratory studies for 5G use. These bands should be considered as only of potential availability for 5G networks. [3600-3700 MHz]

4.10 From the Para 4.11, it can be seen that the Announce Tier includes the 700 MHz, 3.5 GHz, 26 GHz - 28 GHz bands. HLF has also suggested the government to announce these bands as candidate bands for 5G and allow its use for research trials.

700 MHz

4.11 The 700 MHz band was put for auction last time but was not sold. The 35 MHz (713-748 MHz for uplink and 768-803 MHz for downlink) paired spectrum is still available for IMT services.

3.5 GHz

4.12 The 3.5 GHz (3300-3400 MHz and 3400-3600 MHz) band has recently been identified in India for IMT services. 100 MHz spectrum from 3300-3400 MHz is available on pan India basis and out of 200 MHz in 3400-3600 MHz band, 175 MHz (3425 MHz - 3600 MHz) spectrum is available for access services and 25 MHz spectrum (3400 MHz - 3425 MHz) is earmarked for ISRO's use in Indian Regional Navigation Satellite System (IRNSS). Considering that ISRO would be using this 25 MHz spectrum at few locations only, reserving the entire 25 MHz on Pan India basis would lead to wastage of this precious spectrum. Therefore, through recommendations dated 1st August 2018, TRAI has recommended that barring the specific locations or districts where ISRO is using this spectrum, the entire 200 MHz should be made available for access services. TRAI has further recommended that 3300 MHz to 3600 MHz should be treated as a single band and Time Division Duplexing (TDD) should be adopted in this band.

28 GHz

4.13 28 GHz is already allocated to MOBILE, FIXED, Fixed Satellite System (FSS), etc. Now, it is also being considered for a new service called Earth Station in Motion (ESIM) at WRC-19, where small sized terminals with satellite communication capabilities are installed on aircrafts, ships and land vehicles.

4.14 Globally, some of the administrations recognize 28 GHz as one of the leading and essential bands for early 5G deployments. India has also proposed a co-existence study for 28 GHz band in APT Wireless Group 24 (AWG#24) meeting of Asia Pacific Telecommunity (APT). The study results in AWG Report will help not only Indian administration but also other Asia Pacific countries to consider the possible allocation of 28 GHz for 5G and also for other services. During the AWG#24 meeting held in September 2018, there was a good support from all countries (S. Korea, Japan, New Zealand, Singapore, Hong Kong, Bangladesh, Australia, Indonesia and others) except China, for conduct of sharing studies for the 3GPP Band n257 (26.5-29.5 GHz) by AWG.

4.15 To offer multi-gigabits mobile broadband services (MBB), 5G would essentially require **large contiguous spectrum blocks** per operator to roll out 5G services. The results of some recent auctions conducted globally in 3.5 GHz band shows that an operator bought around 40-100 MHz. However, the block size prescribed by some of the country's Regulator was as low as 5 MHz.

4.16 While larger block size is beneficial for improving mobile broadband experience and spectrum efficiency of the networks, smaller block size provides greater flexibility. However, the latter increases the chances of fragmentation. Therefore, to provide flexibility and attain greater efficiency and at the same time avoid the fragmentation of these bands, TRAI has recommended a block size as 20 MHz with a cap of 100 MHz in its recommendations to the Government dated 1st August 2018. The block size of 20 MHz would give flexibility to the bidders and a maximum limit of 100 MHz per bidder would help in avoiding monopolization of this band. To avoid fragmentation of spectrum, it has also been recommended that in case a Telecom Service Provider (TSP) is able to win more than two blocks of spectrum, it should be allocated spectrum in contiguous blocks.

4.17 5G has the potential to work as a catalyst in achieving larger overall economic growth of the country. Investment in mobile network infrastructure will be a key enabler of growth and competitiveness in national economies worldwide for the foreseeable future. Therefore, for spectrum pricing and allocations, the administrations are needed to be focused on maximizing long-term welfare benefits, not on short term revenue benefits, by simulating competition and investment. Keeping in mind, the massive impact 5G will have on different industry verticals, and hence on the overall economy, effective spectrum pricing will play a vital role in promoting healthy investment in the networks.

B. Spectrum sharing and unlicensed spectrum

4.18 Licensed spectrum enables wider coverage areas and better quality of service guarantees. However, unlicensed spectrum [21] can play a complementary role by allowing operators to augment the 5G user experience by aggregating licensed and unlicensed bands.

4.19 Access to shared and unlicensed spectrum will extend 5G in multiple dimensions by providing more capacity, increasing spectrum utilization, and creating new deployment scenarios. It will benefit mobile operators with licensed spectrum, but also create opportunities for those without licensed spectrum to take advantage of 5G technologies.

4.20 As a part of LTE Advanced Pro, through 3GPP Release 13, 3GPP introduced **License Assisted Access** (LAA) -a feature that leverages the 5 GHz unlicensed band in combination with licensed spectrum. It uses carrier aggregation in the downlink to combine LTE in unlicensed 5 GHz spectrum with LTE in the licensed band. This aggregation of spectrum provides for a fatter pipe with faster data rates and more responsive user experience. By maintaining a persistent anchor in the licensed spectrum that carries all the control and signaling information, the user experience is both seamless and reliable.

[21] https://www.gsma.com/spectrum/wp-content/uploads/2018/11/5G-Spectrum-Positions.pdf

Indian scenario

4.21 In India, earlier, only 2.400-2.4835 GHz and 5.825-5.875 GHz were unlicensed bands for indoor and outdoor use of low power equipment. Recently, 5150-5250 MHz, 5250-5350 MHz, 5470-5725 MHz and 5725-5875 MHz frequency bands have been included as unlicensed for use in indoor and outdoor environment. The opening of more unlicensed frequencies will facilitate development of 5G ecosystem.

4.22 Though the unlicensed bands are used, the expression “unlicensed” does not mean permission of operating these devices in a free-will fashion. The operation must strictly observe the prescribed power limits and use of type approved equipment. Also, any transmission in unlicensed spectrum is affected by interference. However, Quality of Service still be ensured.

C. Licensed Shared Access (LSA)

4.23 Any amount of spectrum, if not use optimally and efficiently, results not only in financial loss to the Government, but also hinders economic and social development of the country. **LSA** is a concept to dynamically share a spectrum band, whenever and wherever it is unused by the incumbent users. Shared use of the spectrum is only allowed based on an individual authorization (i.e. licensed).

Indian scenario

4.24 All the Government agencies in India are assigned spectrum administratively. Spectrum audit will help in identification of unutilized or inefficiently utilized spectrum. After the identification, LSA can be used for optimal utilization of spectrum.

CHAPTER 5
SMALL CELL DEPLOYMENT

5.1 Technological advancements as well as capacity constraints are driving the network evolution towards an integrated network called HetNet (Heterogeneous Network) consisting of macro cells, micro/small cells and WiFi Access Points.

5.2 5G promises to provide 20Gbps peak data rate & 100Mbps user experience data rate and 100-fold increase in traffic capacity. However, a site capacity increase of x100 is not feasible. Moreover, the use of high frequencies limits the coverage area to a few meters per site. For meeting the network demands of the future, network densification will be required, which involves addition of more macro cells and small cells in the network.

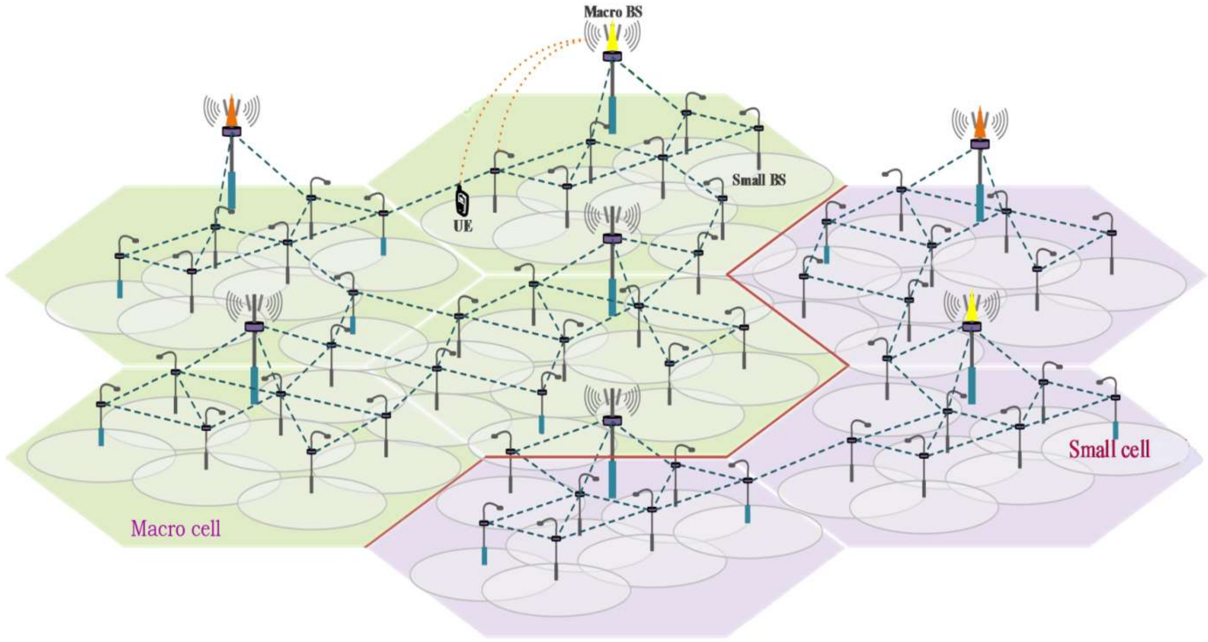


Figure 5.1: Network Densification

5.3 By deploying small cells, operators will be able to support significantly higher capacity in dense areas, as well as improved coverage in areas where building blockage otherwise reduces the signal strength.

5.4 Small cells are a technology shift for operators and are leading to the emergence of new 'as-a-service' business model. This can be a new opportunity for Infrastructure Providers (IP) companies in our country. Small-Cell-as-a-Service (SCaaS) models allow operators to avoid much of the Capex involved in massive small-cell roll-outs and enable cost savings through multi-operator deployments. SCaaS providers may seek to leverage existing asset ownership of sites, backhaul connections, etc. to deliver cost savings to operators.

5.5 Since 5G capabilities depend on hyper dense network, small cells will be required to be deployed at every 200-250 meters on many types of infrastructure such as electric utility poles, street light poles, bus stands, roof tops, traditional cell towers, etc. However, telecom operators are experiencing significant challenges in the deployment of small cells. For deploying a macro cell/ small cell, a TSP has to contact varied authorities/institutions for obtaining necessary approvals/clearances such as site acquisition, municipal clearance, RF compliance certification, environment clearance, power supply management, etc. All these processes are time consuming and impose excessive administrative & financial obligations on operators.

Global scenario

5.6 Internationally, a lot of work is being done to address the small cell deployment related issues and foster 5G development. In February 2017, the Small Cell Forum (SCF) in conjunction with 5G Americas issued a report[22] titled "Small cell siting: regulatory and deployment considerations" with the aim to outline ways to increase collaboration between large number of stakeholders (regulators, administrations, municipal authorities, site owners, operators and vendors) for successful delivery of dense HetNets. Table 5.1 highlights core issues in the deployment of small cells and Small

[22] http://www.5gamericas.org/files/9714/9253/4528/SCF-190-Small-Cell-Siting-04.2017.pdf

Cell Forum's recommended solutions based on evolving best practices round the world.

Table 5.1: Small Cell Deployment-Key challenges and potential solutions

KEY CHALLENGE	**SCF RECOMMENDED SOLUTIONS**
Streamlining the regulatory approval for small cell equipment	– Standard industry classifications of equipment with common documentation of compliance and conformity to be used when defining related policies. – Some of the classes can be exempt from approval process or to light regulatory regime.
Scaling the planning application process to support large numbers of cells	– Common rules on which equipment classes can be exempt or subject to fast track approval. – Batch process for groups of cells, to decrease the approval time and reduce workload of local administrations.
Securing sufficient suitable sites with power and backhaul	– Simplified common frameworks to ease the opening up of access to street furniture and other existing assets. – Census of available assets per municipality. – Open access to administrative buildings.
Cost of installation	– Adopt simplified rules of installation that would enable non-skilled workers to deploy (based on classes of equipment and complexity of installation). – Reduce administrative charges (e.g. installation, operation, periodical revision taxes).
Radiofrequency compliance	– Follow international recommendations for installation classes and provide information
Administrative complexity	– Single executive to coordinate all approvals (e.g., in a smart city program). – Streamlined paperwork and filing to minimize the approval processes and reduce the workload of the administration.

5.7 In United States (US), the Federal Communications Commission (FCC, the US Telecom Regulatory body), in order to speed-up the rollout of small cells nationwide, has recently issued guidelines[23] which time limits local officials to make decisions regarding small cell deployments in cities. The guidelines also put limits on how much city officials can charge operators to deploy small cells.

Box 5.1: FCC's guidelines to facilitate the small cell deployment

- State and local governments must charge fees that are based upon how much it costs to process and manage applications and small cell deployments in rights-of-way, but they are prohibited from charging excessive fees.
- Local officials have 60 days to approve or reject a request from a wireless carrier for a small cell being added to an existing structure and 90 days when the service provider wants to put up a new small cell.
- Small cell site deployments are exempt from the historical and environmental assessment reviews that are currently required before a wireless operator deploys a new tower site.

5.8 In Europe, the new European Electronic Communication Code[24] which is under validation by the European Parliament and Council is set to be transposed in to the new telecommunication law by the 28 Member States. The Code, acknowledging the changes in the network architecture, defines the "small-area wireless access points" and set up nationally consistent rules for streaming the deployment of forthcoming 5G networks.

Box 5.2: Rules related to small cell deployment in the European Electronic Communication Code

- Small cells to be rolled out without individual town planning permit or other individual prior permits
- Exceptions are considered for specific sites and areas – historical, natural beauty, public safety
- Easy access to public infrastructure for hosting/ backhaul on fair, reasonable and nondiscriminatory terms
- Costs associated with small cell deployments should be transparent and cover only the administrative costs

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[23] https://www.fcc.gov/document/fcc-facilitates-wireless-infrastructure-deployment-5g
[24] https://www.eumonitor.nl/9353000/1/j9vvik7m1c3gyxp/vkpj78r8ppzi

Indian scenario

5.9 In earlier days, to deploy a BTS in India, a TSP was required to contact many organizations for obtaining necessary approvals. All those processes were time consuming and imposed administrative & financial obligations on TSPs.

5.10 In order to create a unified frame work nationwide and streamline all the processes involved in telecom infrastructure roll out, DoT, in November 2016, issued Indian Telegraph Right of Way (RoW)[25] Rules-2016. The RoW rules provide a framework to give approvals and settle disputes in a time-bound manner, as well as improve coordination between companies and government authorities. To ease the administrative complexities, these rules also mandate the State Governments to develop a single electronic application process, within a period of one year from the date of coming into force of these rules, for all appropriate authorities under its control. The rules also limit the one-time fee charged by the local authority to meet administrative expenses for examination of every application to ten thousand rupees.

5.11 To ease the process, the Wireless Planning & Coordination (WPC) Wing of DoT has also put in place a portal for filing online applications for Standing Advisory Committee for Frequency Allocation (SACFA) site clearance. The facility of online receipts towards 'SACFA siting application registration fee' now exists using Bharatkosh portal. However, the online application process is not completely paperless. In this context, TRAI through its Recommendations on "Ease of doing Telecom Business" dated 30th November 2017, has recommended to make the entire process of SACFA clearance paper-less and execute it end-to-end through an online portal. This would make it more transparent, time-bound and effective.

[25] http://www.dot.gov.in/sites/default/files/ROW_2016.pdf?download=1

5.12 In India, there has always been a public concern on possible adverse health effects due to Electro-Magnetic Field (EMF) Radiation from mobile towers. Due to this people oppose the erection of telecom towers on rooftops of houses and in densely populated areas. For clearing the misconception of public on mobile towers emissions, DoT in May 2017, launched[26] Tarang Sanchar. It is a web portal for Information sharing on Mobile Towers and EMF Emission Compliances.

5.13 According to Small Cell Forum's report titled "Small Cell Forum Densification Summit: Asia Market Requirements" published[27] in December 2017, the predicted compound annual growth rate (CAGR) of new small cell deployments in India, from 2016 to 2022, will be 33% in enterprise environments and 90% in outdoor urban.

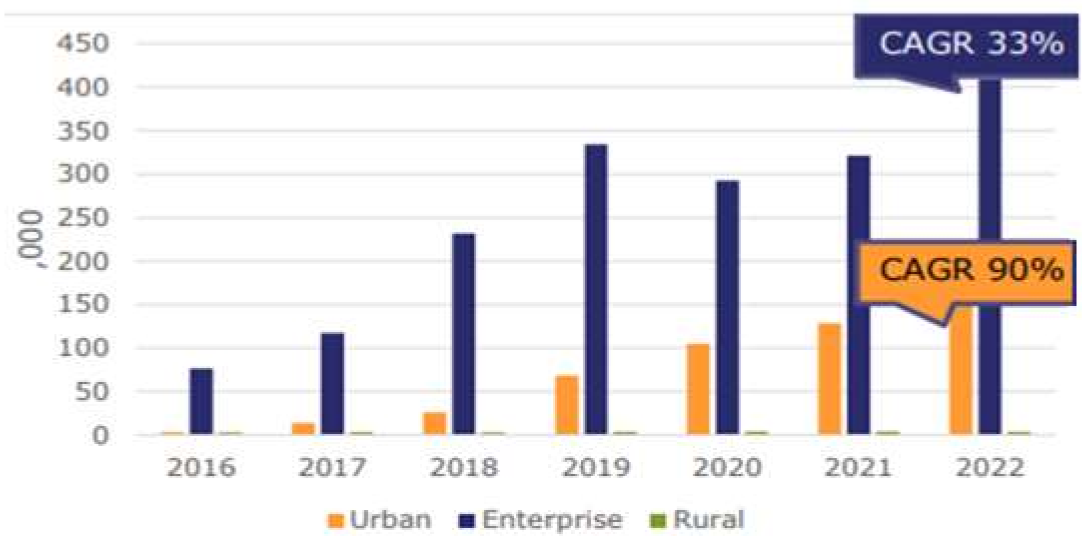

Figure 5.2: Forecast growth in new small cell deployments in India 2016-22 (Source: Small Cell Forum)[28]

[26] http://pib.nic.in/newsite/PrintRelease.aspx?relid=161464
[27] http://scf-releases6.contentdaemon.com/preview/en/documents/202_-_Densification_Summit_Asia_Market_Requirements.php
[28] http://scf-releases6.contentdaemon.com/preview/en/documents/202_-_Densification_Summit_Asia_Market_Requirements.php

5.14 Exact statistics of the small cells deployed in India is not available, however according to TowerXchange, in terms of the number of telecom towers, India is placed at number two position amongst the prominent Asian markets (figure 5.3).

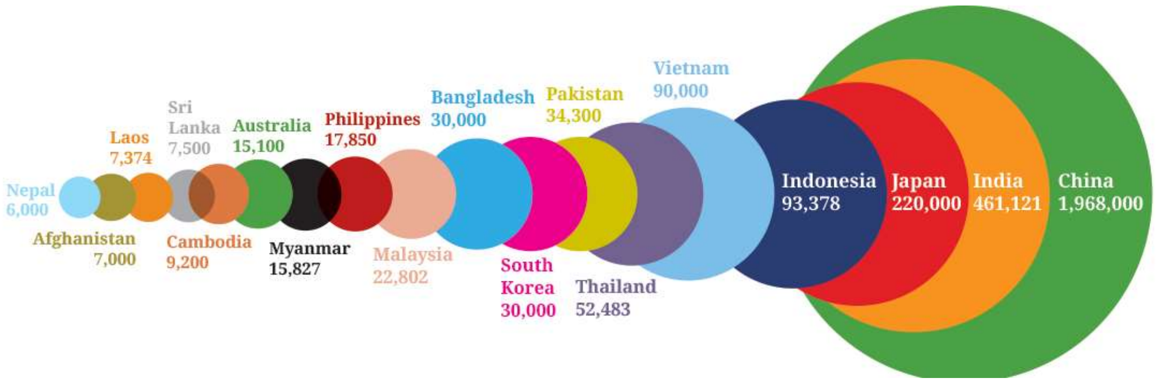

Figure 5.3: Selected Asian tower market size comparisons, Q3 2018 (Source: TowerXchange)[29]

Challenges

5.15 Lengthy and complex processes, excessive fee and outdated policies have slowed the development of small cells in India. If the challenges in deploying small cells are not addressed in a timely fashion, many of the benefits which Indian government, regulator and cities hope to derive from 5G – such as smart city platforms, improved access to healthcare, education & banking and the Industrial IoT – will be severely compromised.

5.16 To start commercial roll-out of 5G services by 2020, Indian TSPs will have to deploy small cells at a faster pace and at greater density. Since public infrastructure such as street lights, traffic lights, metro pillars, electricity poles, public buildings/rooftops are valuable sites for deploying small cells due to their density, it is necessary to ensure that local and national authorities offer **easy access to operators to** such **public infrastructure** for the installation of small cell on non-discriminatory terms. For this, close coordination and collaboration is required between many stakeholders such

[29] https://www.towerxchange.com/towerxchanges-analysis-of-the-independent-tower-market-in-asia/

as licensor, administrations, municipal authorities, site owners, TSPs, vendors, infrastructure providers, etc.

5.17 To **speed up the approval process**, for site locations, where electricity authorities, metro rail corporations or other government organizations are permitting installations of small cells & telecom infrastructure, further permission from municipal corporation and local bodies need not be mandated.

5.18 As large numbers of small cells are required to be deployed, in order to reduce the approval time and administrative burden of local authorities, batch processing for group of small cells will play a crucial role. Also, for making deployment of huge number of small cells **economically viable**, administrative fee for getting approvals/clearances needs reconsideration.

5.19 Though comprehensive RoW rules 2016 have been declared, necessary steps need to be taken to follow up with the state governments for getting RoW rules 2016 implemented properly. Moreover, keeping with the requirements of small cell deployment, suitable **amendment in the RoW rules** will be beneficial.

CHAPTER 6
5G BACKHAUL

Wireless Backhauling requirements in 5G

6.1 Mobile data traffic has grown dramatically in the past few years and is likely to grow further with the advent of IoT, whereby billions of devices would use mobile networks to connect with each other. In order to use IoT, uptake of smartphones will increase rapidly, whereby each new smartphone user will send and receive far more data than they did with their previous handset.

6.2 Rising demand for mobile broadband creates increased capacity requirements in the backhaul network. It is forecasted[30] that, by 2022, the typical backhaul capacity for a high-capacity radio site will be in the 1Gbps range, rising to 3-5Gbps towards 2025.

6.3 5G is expected to provide "4A- anytime, anywhere, anyone, anything" connectivity, which will take mobile data speeds to new limits and will support an immense increase in connections. However, a good 5G network cannot be expected unless a high capacity backhaul is not in place.

6.4 Today's backhaul relies either on optical fibre or microwave radio links. Fibre has limitless capacity but pulling fibre to every cell site is practically not feasible due to cost, time and logistical challenges. In comparison to fibre, microwave is cheaper, scalable option and can be deployed quickly. Moreover, capacity of microwave link has evolved gradually over the years to meet the demand of the new generations of networks. Throughputs of 1-10 Gbps in microwave backhaul are now a reality.

6.5 With the rise of Cloud RAN architecture, the backhaul in 5G (as shown in Figure 6.1) has evolved to a more complex network composed of front haul, mid haul, and traditional backhaul. Speed greater than 10 Gbps and

[30] https://www.ericsson.com/en/microwave-outlook/reports/2017

latency in the orders of hundreds of microseconds, render fibre optics the only front haul viable solution. However, laying fibre to connect envisaged Remote Radio Head (RRH) to the core may be impossible in some cases and certainly very costly otherwise.

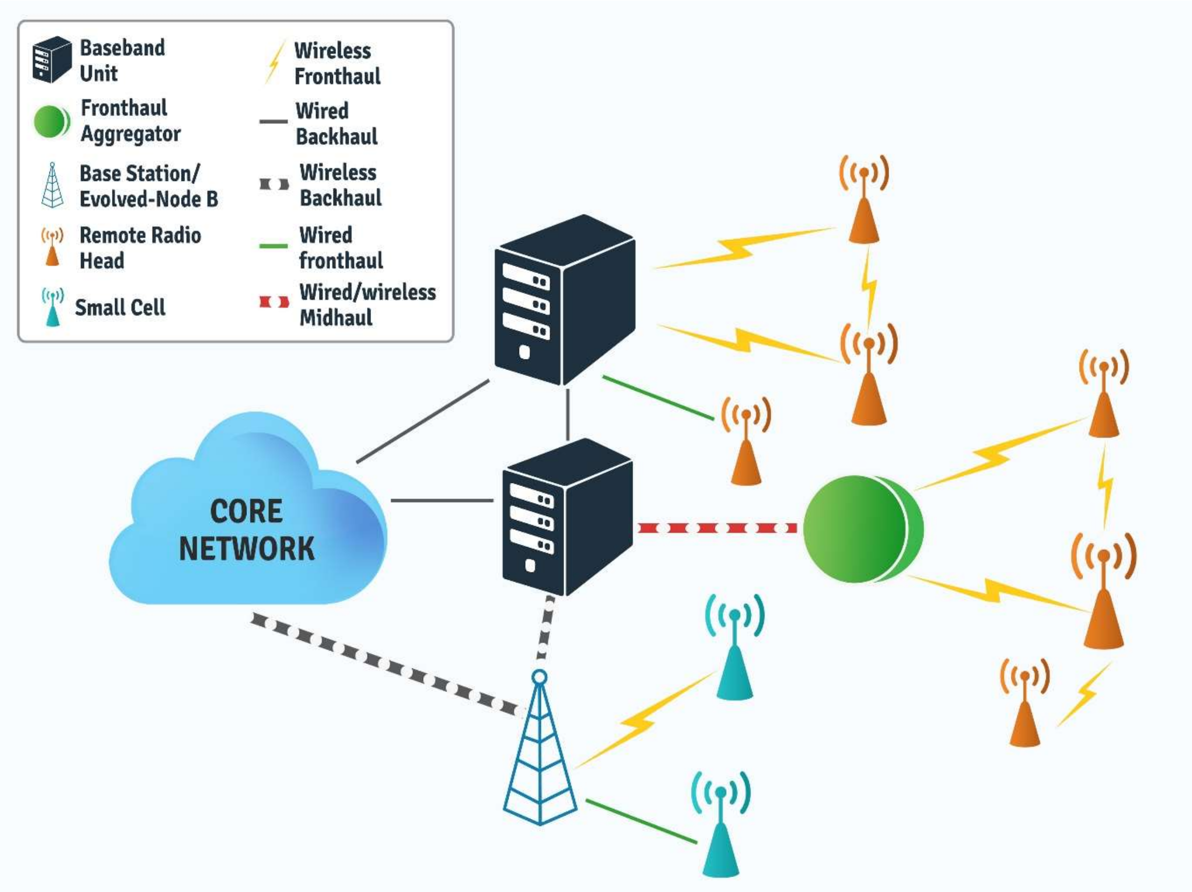

Figure 6.1: 5G Backhaul network

Global wireless backhaul scenario

6.6 The choice between fibre and microwave in backhaul networks is not about capacity, it is about fibre presence and Total Cost of Ownership (TCO). Microwave technology can provide high capacity backhaul for the broadband networks in a cost-efficient way and is more suitable for operations in the cities and difficult terrains where laying fibre is not possible. Due to these reasons, globally, mobile backhaul network is evolving with the mix of both fibre and microwave.

6.7 It is forecasted[31] that by 2022, more than 65% of all radio sites in the world (excluding China, Japan, Korea, Taiwan) will be connected by microwave.

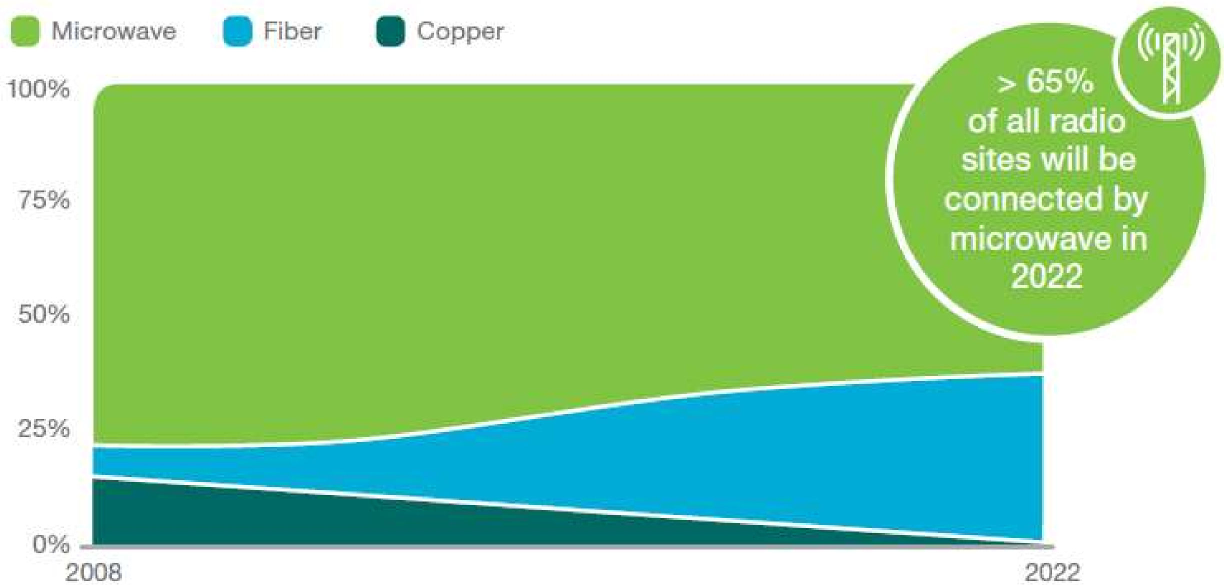

Figure 6.2: Backhaul Media distribution (Source: Ericsson)

6.8 As the dominant backhaul media in today's networks, microwave plays a significant role in providing good mobile network performance. However, the constant pressure to increase performance levels translates into requirement of more bandwidth for microwave backhaul.

6.9 Conventionally, microwave backhaul has used frequencies from the range of 6GHz to 42GHz. Regulators world over are opening higher frequency bands, such as V-band (60GHz) and E-band (70/80GHz) to satisfy the high-capacity backhaul requirements of future networks. According to Ericsson[32], E-band will satisfy the high-capacity demands of today's networks. Moreover, it will be suitable during the coming years when 5G is rolled out. However, in the long term more spectrum will be needed. To cater to the future demand, frequencies beyond 100GHz are subject of wireless communications research

[31] https://www.ericsson.com/en/microwave-outlook/reports/2017
[32] https://www.ericsson.com/en/microwave-outlook/reports/2017

(Figure 6.3). Standardization and prototyping of the W-band (92–114.25GHz) and D-band (130–174.8GHz) is ongoing.

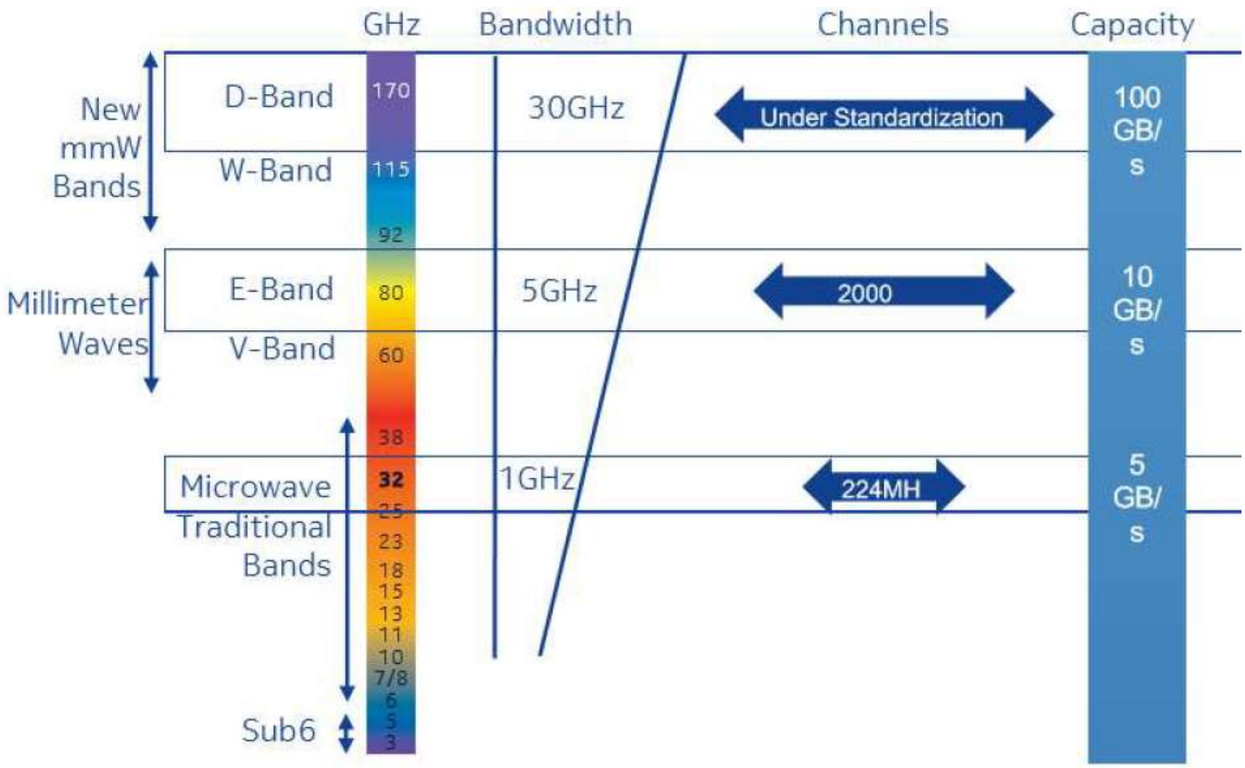

Figure 6.3: Spectrum bands for Wireless Backhaul

6.10 E-band was established in the US over 10 years ago. Since then, E-band has grown steadily. E-band is now open in more than 85 countries.[33] The main drivers for E-band are high capacities and low spectrum fees.

Backhaul requirements in India

6.11 India has about 1.5 million Kms of fiber deployed. However, telecom sites connected through fiber is less than 25%[34]. Most of the telecom sites are backhauled using microwave links. India has the world's largest installed base of microwave links in the traditional bands- 6GHz to 42GHz.

[33] https://www.ericsson.com/en/microwave-outlook/reports/2017

[34] http://dot.gov.in/sites/default/files/DraftNDCP2018_1.pdf?download=1

Challenges

6.12 The expected traffic growth particularly in 4G/LTE and 5G networks will be difficult to manage through existing microwave backhauls despite the best modulation techniques used. To cater the requirement arising due to congestions in these bands and demand for **more capacity**, the backhaul portfolio will need mmWave spectrum.

6.13 The bands above 43 GHz have larger bandwidth. The short links associated with V-band and E-band also caters for greater frequency reuse efficiency. An early policy decision on allocation of carriers in these bands is very crucial for 5G deployment.

6.14 TRAI through its Recommendations dated 29th August 2014 on "Allocation and pricing of Microwave Access (MWA) and Microwave Backbone (MWB) RF carriers" has recommended that E-band (71-76 paired with 81-86GHz) should be on light-licensing and allocated at very nominal price on 'link to link basis'. To facilitate the link registration, WPC make necessary arrangements for an online registration process by developing a suitable web portal.

6.15 The industry analysts believe that once E-band gets open in India with low-spectrum fee approach, like in most countries, India will become the world's largest E-band market.

CHAPTER 7
LICENSING & POLICY ISSUES

7.1 As the technology is changing, new services are opening, and new use cases are blooming rapidly across various industry verticals. It may be a situation, wherein the existing licensing and regulatory norms may not be explicitly supporting/permitting such new services/use cases.

7.2 Moving forward, with the adoption of the latest technologies such as 5G, the networks of older technologies such as 2G and 3G will also witness upgradation or will have to eliminate gradually due to the challenges of non-capabilities and higher costs of maintenance. The uptake and proliferation of the 5G networks is likely to surge during the early years of next decade (after 2020). Convergence of technologies and aggregation of resources such as spectrum will require lesser number of physical installations. Various core networks functionalities will also be enabled in cell/ Node (gNB), thus making the Node intelligent and efficient in 5G which was not possible in earlier technologies.

7.3 The foremost task with Regulators and Licensors is to figure out the changes required on the licensing/regulatory regime to not only permit or support but also facilitate the proliferation of new services and new use cases. There should not be any regulatory or licensing barrier on the path of adoption of newer and better technologies; rather, regulation and licensing framework should be an enabler in fostering newer technologies. 5G will enable new capabilities and use cases, which are set to impact not only consumer services but also many industries embarking on their digital transformations. Combined efforts of industry players and regulators to align on various related aspects such as standards, technology, spectrum, security and RoW will be essential for timely roll out of the services.

A. Policy statement of National Digital Communication Policy 2018

7.4 The Government, among the initiatives through the National Digital Communication Policy (NDCP) 2018, seeks to spur the socioeconomic development up to the bottom of the pyramid by ensuring voice, video and data connectivity for all. It seeks to provide reliable and secured connectivity with assured quality of service, facilitate development of infrastructure and services for new technologies including 5G and IoT, encourage innovation and manufacturing, and develop a large pool of digitally skilled man-power, by aligning regulatory and licensing frameworks impacting the telecom sector.

7.5 The Government has inter-alia envisioned that the major themes of the policy will be regulatory and licensing framework impacting the telecom sector, connectivity-for-all, quality of services, ease of doing business, and absorption of new technologies including 5G and IoT.

B. Present policy on deployment of the Core network

7.6 With the introduction of 4G, the telecom as a sector has shifted from the “voice-centric” to “data centric” market. The convergence of technology and media are enabling efficient content sharing. Major aspect of LTE is the ‘flat’ radio and core network architecture. A key aspect of the ‘flat’ architecture of LTE is that all services, including voice, are supported on the IP packet network using IP protocols.

7.7 Unlike previous systems, which had a separate circuit-switched subnetwork for supporting voice with their own Mobile Switching Centers (MSC) and transport networks, LTE envisions only a single evolved packet-switched core, the EPC, over which all services are supported, which could provide huge operational and infrastructure cost savings.

7.8 The deliberations above indicate that there are substantial changes in network architecture in 4G LTE network with respect to the earlier networks i.e. 2G and 3G. Network Function Virtualization (NFV) has transformed major hardwired switching functions into logical and virtual functions. A soft switch or equivalent server can perform millions of tasks simultaneously without physical expansion. Eventually, upon evolution of newer technologies such as LTE, various network elements in the network have been eliminated and physical location of the servers has become less important for the purpose of operations. Moreover, virtualization of the several functions has enabled the telecom operators to host the servers on the cloud.

7.9 Consequent upon the architectural changes occurred in the cellular networks, DoT on 23rd June 2017 has issued amendment to the respective conditions of clause 'Location of switches and other network elements' under 'Technical and Operating Conditions' in UL and UASL licenses. The amended clause has allowed the licensee to host any of its equipment anywhere in India subject to the interconnection points being located and operated in the respective service area for inter operator, inter service area, NLD & ILD calls and meeting the security conditions as mentioned in the license. Eventually the conditions of mandatory hosting of the Media Gateway Controller/ Soft switch and other common systems in a license service area have been done away with by DoT.

C. Deployment of network elements on the Cloud

7.10 In the recent years, cloud computing is increasingly taking up an integral role in people's daily life, as individuals' functioning in the physical world or in the virtual sphere is shifting to web-based services on the cloud. There are wide ranging benefits such as higher availability, higher scalability & highly secure environment, generally associated with cloud computing, which have played the role of a catalyst in changing business abilities for firms and has accelerated economic, commercial and social innovations. Cloud based services reduce cost of infrastructure, increase collaboration, provide flexibility (work from anywhere), provide back-up and recovery solutions, thereby, increasing efficiency and availability.

7.11 5G is expected to be broadly based on the Service Based Architecture (SBA). The expectation will be high on the part of service providers to allow for fast creation of new service and extendibility without impacting the standards. Technology such as SDN and NFV enable the use of network slicing in 5G networks to meet many different requirements of the consumers, enterprises and industry use cases on the same physical infrastructure. These technologies also enable the programmability, agility of the infrastructure and the applications.

7.12 Keeping in view the scale and functional requirements of the future networks, it can be predicted that NFVs and SDNs alone cannot serve the purpose unless these are taken to next level. There are issues of fault tolerance and scalability in existing virtualized environment which need to be taken care of in order to enhance the required capability of future networks. To eliminate or overcome the infrastructural limitations of the core networks, a cloud-based Network Function Virtualization (NFV) framework will be essentially helpful that gives tenants the ability to transparently attach stateless, container-based network functions to their services hosted in network of cloud.

7.13 Despite numerous advantages, there are certain key challenges in cloud computing such as data privacy, data security, law enforcement and cross border data flow. These aspects become more relevant when the data or network function of a TSP is hosted over the cloud. Besides TSP, there could be several entities involved in providing the services and support to the end user or to a service aggregator in the service-based architecture.

7.14 Security over the cloud is vital for adoption of cloud-based services. Without security, no cloud service could be effectively offered. Specially, the users should have confidence that their data is secure in the cloud. Security is needed not only for data but also for services and applications to avoid their usage beyond trust boundaries. Transfer of data, sharing of information and use of third-party systems are areas of concern.

D. Policy on Regulation of Cloud Services in India

7.15 The Cloud companies and technology start-ups have emerged providing network infrastructure resources for computing, storage and processing as well as network functions such as security, firewall, load balancing, software-defined WAN and big data analytics. TRAI on 16th August 2017 has issued recommendations on Cloud Services. Through the recommendations, light touch approach to regulate cloud services and to lay down a broad framework for registration of an industry association of cloud service providers (CSPs) by DoT has been emphasized. Accepting the recommendations, DoT has asked TRAI for its recommendations on other terms, such as eligibility conditions, entry fee, period of registration, governance structure, etc.

7.16 Further, on the issue of legal framework for data protection, TRAI has issued its recommendations on ‘Privacy, Security and Ownership of the Data in the Telecom Sector’ dated 16th July 2018, covering the following aspects:

a) Adequate protection to sensitive personal information;
b) Adopt globally accepted data protection principles as reiterated by Planning Commission's Report of Group of Experts on Privacy 2012;
c) Provisions governing the cross-border transfer of data;

To address the issue of access to data, hosted by CSPs in different jurisdictions, by law enforcement agencies:

a) Robust Mutual Legal Assistance Treaties (MLATs) should be drawn up with jurisdictions where CSPs usually host their services, enabling access to data by law enforcement agencies.
b) Existing MLATs should be amended to include provisions for lawful interception or access to data on the cloud.

7.17 On the cloud service side, certain Service Level Agreement must be there to be enforced and committed by the cloud service provider to ensure that the mission critical services are not impacted. As the statutory, regulatory, and legal requirements vary with market, sector and jurisdiction, the issue is required to be addressed in future by the policy makers, keeping in view the sector specific or service specific requirement of rules and framework.

E. Policy for sharing of active and passive infrastructure

7.18 Infrastructure sharing provides a healthier competitive environment for the telecom market. It also improves economies of scale, avoiding duplication of networks where unnecessary. The increase of infrastructure sharing in the telecom business has allowed for a more efficient pace of expansion and innovation, for example, a faster roll-out of next generation networks and services have been made possible due to sharing of active and passive infrastructure. The sharing of towers and equipment also translates into sharing of expertise between telecom companies, and an overall reduction in Capex and Opex costs, which are also spread among TSPs.

7.19 BEREC report on infrastructure sharing[35], by Body of European Regulators for Electronic Communications (BEREC), provides a provisional analysis of infrastructure sharing arrangements, which are

[35] https://berec.europa.eu/eng/document_register/subject_matter/berec/download/0/8164-berec-report-on-infrastructure-sharing_0.pdf

currently in place in various individual European markets. The report includes various scenarios of sharing arrangements, benefits and challenges, as well as future evolution of sharing arrangements due to 5G. The analysis could be considered useful for any policy decisions. The report indicates that as per the figures provided by some NRAs, the cost saving is as shown in Table 7.1.

Table 7.1: Infrastructure Sharing- Cost Saving

Passive infra sharing cost savings	16%-35% CAPEX	16%-35% OPEX
Active infra sharing (excl. spectrum) cost saving	33%-35% CAPEX	25%-33% OPEX
Active infra sharing (incl. spectrum)	33%-45% CAPEX	30%-33% OPEX

7.20 For infrastructure sharing, it has been observed that commercially led network-sharing agreements are generally preferred and seem to have gained market traction. In this case, the commercial drivers of infrastructure sharing and the types of infrastructure sharing agreement are likely to differ between countries and according to levels of market maturity.

7.21 Dynamic Spectrum Sharing (DSA) is a useful feature for evolving 4G to 5G; DSA enables deployment of 5G in the same spectrum as 4G. For example, TSP could use 1800 MHz for both 4G and 5G, thereby enabling a natural shift of resources from 4G to 5G over time. This can be achieved through new radio deployments or installing new software. Many networks can be rapidly upgraded to support 5G services in existing LTE frequency bands, for example, in low to mid-bands by using spectrum sharing between LTE and 5G. All the existing LTE bands are also considered as candidate bands for 5G deployments in below 6GHz bands. From a coverage perspective, this type of deployment is similar to existing LTE deployments. The equipment, particularly base stations and cells are designed to support the multiband scenario, therefore, network slicing or hosting of virtual network operators or sharing of the spectrum between two entities would be quite easier in the future. The densification of cells and Right of Way (RoW) issues shall also propel the sharing of active infrastructure by TSPs in 5G scenario.

F. Future use cases required to be supported by the licensing framework

7.22 The speed offered through 5G networks will be of the Gigabit rate and will substitute the requirement of wired Local Area Network (LAN). The enterprises are setting up LAN for their internal requirements such as operation of the plant or internal office communication. This traffic is usually not routed through Internet or any other form of Wide Area Network (WAN) by these enterprises. For the solution to LAN and factory automation, upcoming use cases of platform and services are expected through 5G. In near future, 'Network-as-a-service' is considered to be one of the services offered by the telecom companies where medium and large enterprise will be able to find the replacement for LAN and also minimize the defects etc. with no or minimal investments in their IT network. Such use cases are required to be included in the scope of licensing framework so that the benefits of 5G reaches to the industry. Network as a Service (NaaS) to the Industry 4.0 is to be facilitated in the licensing and regulatory framework to facilitate the orderly growth and migration to Industry 4.0.

7.23 Telecom operator may develop, deploy and operate an integrated solution for the industry as per its requirement and provide most of the computing at edge. The data coming to control plane to be minimal and most of the user plane processing will be at edge, leading to less use of bandwidth and low latency. This may require TSP to deploy 5G network for specific industrial unit and provide the services directly or as an alternate lease the network with control of edge devices to the industrial entity itself.

Further, the M2M Service Provider (proposed to be registered with DoT) may also provide the services to various Industries after obtaining the resources from the connectivity providers.

7.24 There could be plenty of services based on network slicing whereby telecom operators will allocate network resources (slices) in line with complexity of customer requirements. Technology and standards for slicing of the network shall enable the new revenue streams to telecom operator. Use cases having network slicing functionality shall have stringent requirement of Quality of Service (QoS) parameters so that adequate resources are aligned by the telecom operator to provide the services.

G. Aspects related to Sectoral Regulations

7.25 The application of 5G use cases will be across industry verticals though eMBB, uRLLC and mMTC capabilities. It is, however, difficult to predict at this stage that which of the use cases would drive the 5G demand. With the range of 5G use cases across industry verticals requiring different characteristics, for example, low latency and high reliability application for robotics in manufacturing and automotive sectors; high data throughput requirements for augmented reality use cases; the traditional offerings based on connection speed and volume of usage could see a shift. The use cases will be having differentiated services/ applications based on niche industry vertical they want to cater to with suitable tariffs to meet the customer needs along with capability to meet the sectoral regulation, if any.

7.26 The cross-sectoral use cases would require coordinated efforts in managing the 5G ecosystem with cross sectoral involvement. For cross-sectoral cases of M2M/ IoT, in order to bring M2M industry concerns and regulatory bottlenecks, DoT[36] has proactively formed M2M Apex Body, M2M Review Committee and M2M Consultative Committee. Domain experts from every vertical which has been considered as potential M2M/IoT market has to get together to address the concerns and also be in advisory role to the policies making bodies of the government.

7.27 M2M Consultative Committee has been constituted incorporating representatives from Standardizing bodies such as Bureau of Indian Standards (BIS) and Telecom Standards Development Society of India (TSDSI) and sectoral industry representative bodies to bring M2M industry concerns and regulatory bottlenecks to the notice of Apex body. Also, in order to support implementation of actionable points evolved from National Telecom M2M Roadmap, M2M Review Committee has been formed under DoT. The scope of the existing committees can be expanded or broadened for inclusion of all the 5G use cases.

[36] http://www.dot.gov.in/machine-machine-communications

CHAPTER 8
INVESTMENT FOR 5G DEPLOYMENT

8.1 As already discussed in earlier chapters, 5G is going to touch and change our lives like never before. The key features of 5G i.e. ultra high speed and ultra low latency along with the new capabilities will make it possible to use 5G for healthcare (tele-surgery), autonomous vehicles, automated manufacturing so on and so forth. 5G will result into both direct and indirect benefits. It has potential to work as catalyst to higher overall economic growth of the country. However, to bring this into reality, substantial amount of investment would be required to roll-out 5G services in India. In the report on "5G: The catalyst to Digital Revolution in India" by Deloitte[37], it has been mentioned that while the investment for 5G would grow incrementally as advancements on existing 4G/LTE technology, with 5G spectrum and network densification needs, it is anticipated that industry might require an additional investment of USD 60-70 billion to seamlessly implement 5G networks. Ernst & Young has also estimated that India would have to invest USD 60-70 billion for 5G.

8.2 5G is expected to play a major role in digitalization of industries. 5G will bring new level of performance and characteristics to the telecom networks enabling new services and creating new ecosystems. New revenue streams will get open-up for operators as they go beyond mere Connectivity and Infrastructure providers to become service enablers and service creators. As per Ericsson data, 5G enabled digitalization revenue potential in India will be above USD 27 billion by 2026. As per the High-Level Forum report, 5G can create a cumulative economic impact of USD 1 trillion by 2035.

[37] https://www2.deloitte.com/content/dam/Deloitte/in/Documents/technology-media-telecommunications/in-tmt-the-catalyst-report-one-noexp.pdf

8.3 The success of 5G speed and coverage relies immensely upon network diversification which in turn will depend upon network infrastructure, including spectrum, Radio Access Network (RAN) infrastructure, and core network. Figure 8.1 illustrates the areas where investment is anticipated for 5G deployment.

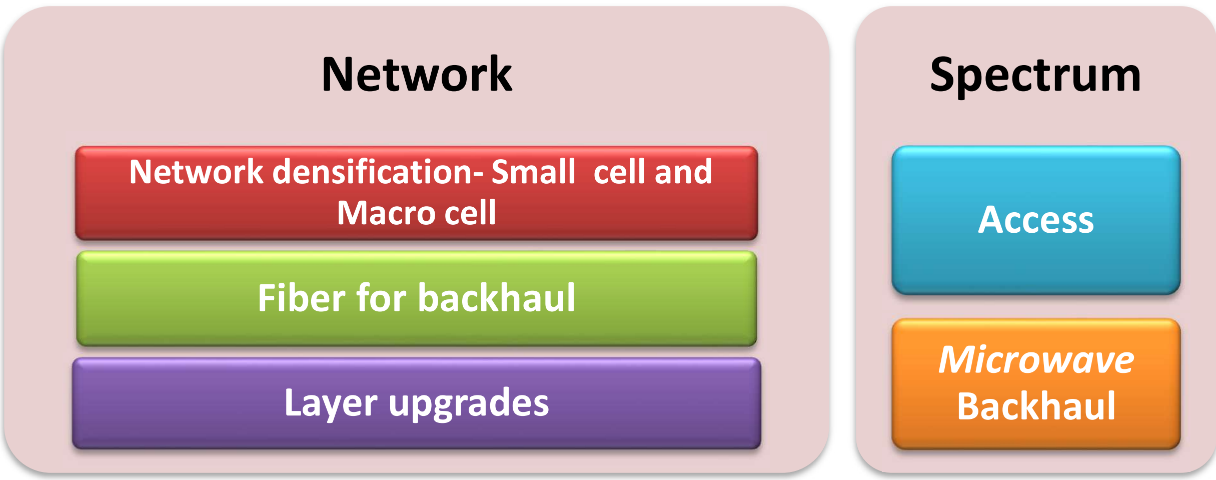

Figure 8.1 Expected investment areas for 5G deployment

8.4 Operators with existing 4G footprints will be able to leverage their 4G infrastructure for providing 5G services and hence their investment requirement will be relatively less. Whereas, a Greenfield operator will need to establish the network from ground level and therefore would require huge amount of investment.

8.5 As per an estimate by Nokia, 5G coverage compared to 4G coverage using 1800 MHz spectrum band would be about 60%. Operators with existing 5G footprints, will be able to leverage 4G UL coverage through concept of dual-connectivity/UL-sharing and hence will be able to cover larger areas with same number of sites. However, a Greenfield 5G operator will need to deploy about 66% more sites to compensate for penetration losses.

A. Access Spectrum for 5G

8.6 5G will support significantly greater data speed and ultra low latency. Therefore, larger chunks of spectrum will be required for 5G as compared to that is required for 4G. As analyzed by Ericson, "deploying the 3.5 GHz and 26 GHz band on existing macro sites can provide a capacity improvement of approximately 10 times compared with the LTE systems in low and mid bands"[38].

8.7 Spectrum requirement for 5G network lies around three key frequencies ranges: Sub-1 GHz, 1-6 GHz and above 6 GHz. The choice of spectrum among these ranges will depend on the capacity and coverage requirement of the region.

8.8 3.5 GHz spectrum band is likely to be the first band to be globally used for 5G deployment. DoT is yet to auction spectrum in the 3300-3600 MHz bands. Therefore, the TSPs are likely to incur initially an additional investment while launching 5G services on account of spectrum cost.

B. Network Densification- Small cell & Macro Cell Deployment

8.9 In the race to rollout 5G services around the world, the key focal point of investment will be the deployment of small cells, especially in the dense urban areas. According to Small Cell Forum, globally, the compound annual growth rate in the deployment of small cell will be 14% and it will reach at 11.4 million by 2025, with 8.5 million of those in non-residential[39].

8.10 Operators can manage the increased traffic in rural and urban areas simply by densifying their existing network. However, for operators having larger chunks of spectrum, the requirement to densify their network via small cells falls.

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[38] https://www.ericsson.com/en/ericsson-technology-review/archive/2018/the-advantages-of-combining-5g-nr-with-lte

[39] http://www.scf.io/en/documents/050_-_Small_cells_market_status_report_February_2018.php

8.11 The marginal cost of small cell equipment is generally lower than deploying a macro base station site. However, as large number of small cells would be required to be deployed to provide additional capacity in densely populated areas, the total expenditure would be quite substantial.

8.12 For India, it is expected that small cell deployment growth would be huge and soon going to outpace global standards also[40]. The rising investment requirement for network densification coupled with the difficulties in site identification and related permissions is likely to lead to increased infrastructure sharing among telecom operators. Further, TSPs will decide 5G rollout based on demand and affordability, which was one of the considerations while recommending no roll-out obligations for 3.5 GHz spectrum band. Therefore, the investment on network densification is also likely to be carried out in phases.

C. Layer Upgradation

8.13 The digital transformation of network infrastructure through Network functions virtualization (NFV) and Software-Defined Networking (SDN) plays a pivotal role in 5G deployment. NFV and SDN based network architecture increases efficiencies across all elements with reduced operational (OPEX) and capital (CAPEX) costs. With virtualization, over-provisioning of resources can be avoided, and existing resources can be utilized more efficiently, thereby reducing day-to-day cost of operations. It also reduces the investment required on estate and environmental resources such as cooling and power.

8.14 The initial one-time cost would have to be incurred in deployment of NFV. Once implemented, virtualization lowers the total cost of ownership (TCO) for the telecom operators. In the long run, these technologies will increase the network's ability to generate new revenue streams for

[40] https://www.smallcellforum.org/blog/indian-densification-sets-high-bar-small-cell-industry/

telecommunication operators by creating virtually dedicated network for different verticals.

D. Backhaul

8.15 Network densification through growth in the number of small cell will increase the traffic pressure on backhaul networks. Traditionally, 2G and 3G networks used wireless backhaul to get data point distributed over the network. With the advent of 4G, the demand for fiber backhauling has increased relatively.

8.16 According to International Telecommunication Union (ITU), investment in fiber backhaul will go beyond $144.2 billion between the years 2014-2019 globally[41]. As fiber backhaul provides almost limitless bandwidth, its use is progressively rising to cater the increasing data traffic. Since fiber investments typically have a depreciation of around 25 years, and 5−8 years for microwave, it becomes important to invest in fiber.

8.17 5G network architecture which allows deploying both traditional and distributed RAN network will need extensive backhaul upgrade. In India, <30% sites are connected on fiber and rest are on microwave links. While fiber-based backhaul can offer unlimited capacity and low latency that are perquisite for 5G applications, microwave frequencies available in India can only deliver backhaul capacity of 250 to 500 Mbps. Thus, presently available backhaul solutions with operators will not be enough. While fiberization is the best solution, the cost of laying and maintaining is high and it may not be feasible to lay fiber everywhere. E-band (71-76 paired with 81-86 GHz) is an important band which can be used for providing rapid and economical deployment of backhaul in dense urban routes for proliferation of wireless services quickly.

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[41] https://www.itu.int/en/ITU-D/Conferences/GSR/Documents/GSR2018/documents/DiscussionPaper_Setting%20the%20scene%20for%205G_GSR18.pdf

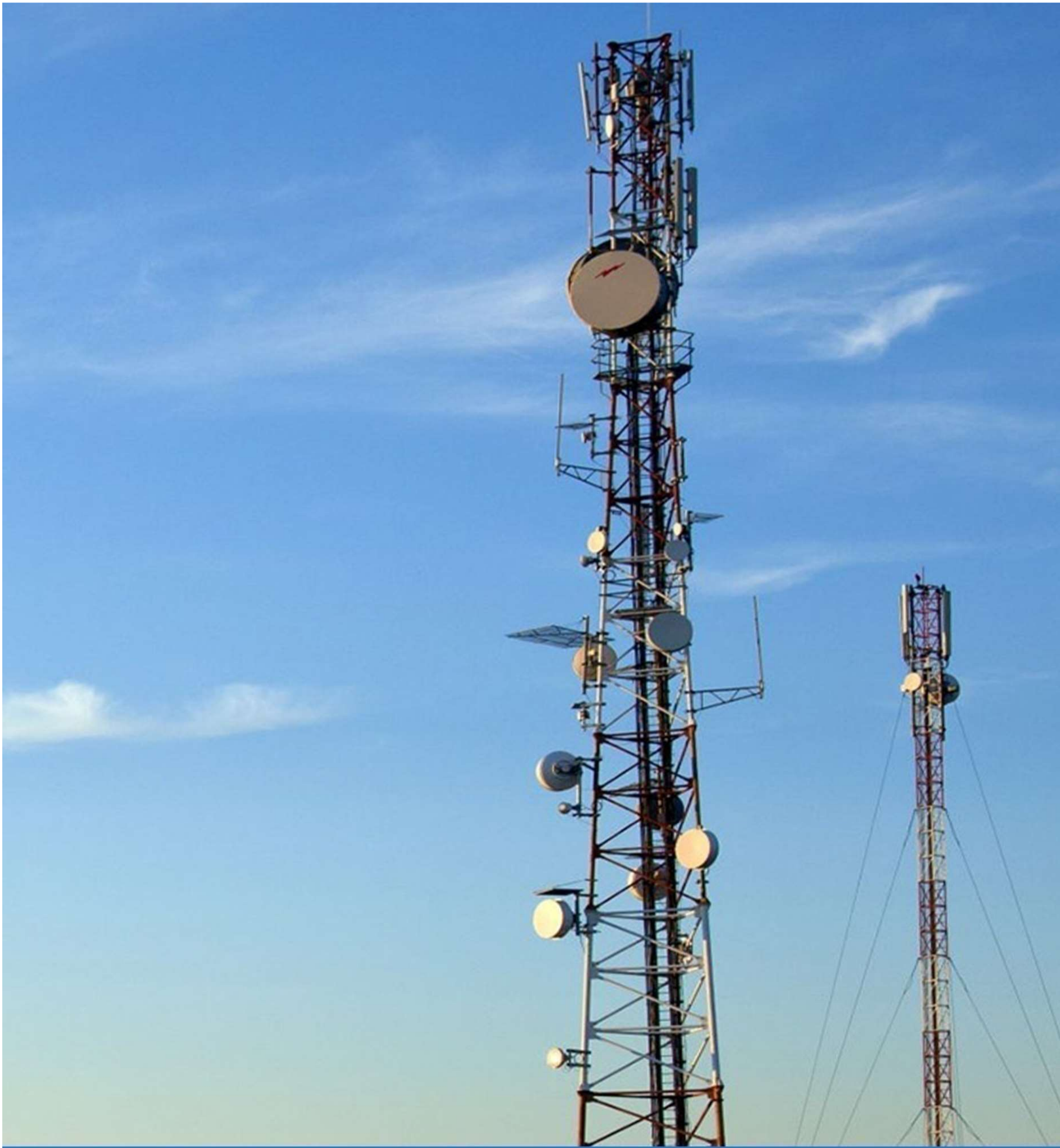
8.18 In summary, deployment of 5G network will require substantial investment in the core, Radio Network and Spectrum. However, the 5G services will open-up many new revenue streams also as it will cater to variety of solutions to new verticals besides enhanced mobile broadband solutions.

List of Acronyms

2G	2ND GENERATION OF WIRELESS TECHNOLOGY
3G	3RD GENERATION OF WIRELESS TECHNOLOGY
3GPP	3RD GENERATION PARTNERSHIP PROJECT
4G	4TH GENERATION OF WIRELESS TECHNOLOGY
5G	5TH GENERATION OF WIRELESS TECHNOLOGY
AAS	ADVANCED ANTENNA SYSTEMS
APAC	ASIA-PACIFIC
APT	ASIA PACIFIC TELECOMMUNITY
AWG	APT WIRELESS GROUP
AWG	APT WIRELESS GROUP
BB	BASEBAND
BBU	BASEBAND UNIT
BS	BASE STATION
BTS	BASE TRANSCEIVER STATION
CAGR	COMPOUND ANNUAL GROWTH
CDMA	CODE DIVISION MULTIPLE ACCESS
CEWIT	CENTRE OF EXCELLENCE IN WIRELESS TECHNOLOGY
CPRI	COMMON PUBLIC RADIO INTERFACE
Cloud RAN	CLOUD RADIO ACCESS NETWORK
CRAN	CENTRALISED RAN
CSP	CLOUD SERVICE PROVIDER
CU	CENTRALIZED UNIT
DoT	DEPARTMENT OF TELECOMMUNICATIONS
DRAN	DISTRIBUTED RAN
DST	DEPARTMENT OF SCIENCE AND TECHNOLOGY
DU	DISTRIBUTED UNIT
eMBB	ENHANCED MOBILE BROADBAND
EMF	ELECTRO-MAGNETIC FIELD
EPC	EVOLVED PACKET CORE
EPS	EVOLVED PACKET SYSTEM
ESIM	EARTH STATION IN MOTION
FCC	FEDERAL COMMUNICATIONS COMMISSION
FDD	FREQUENCY DIVISION DUPLEX
FSS	FIXED SATELLITE SERVICE
FSS	FIXED SATELLITE SYSTEM
GPRS	GENERAL PACKET RADIO SERVICE
GSA	GLOBAL MOBILE SUPPLIERS ASSOCIATION

GSM	GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS
GSMA	GSM ASSOCIATION
GSMAi	GSMA INTELLIGENCE
HetNet	HETROGENEOUS NETWORK
HLF	HIGH LEVEL FORUM
IISc	INDIAN INSTITUTE OF SCIENCE
IIT	INDIAN INSTITUTES OF TECHNOLOGY
IMT	INTERNATIONAL MOBILE TELECOMMUNICATIONS
IoT	INTERNET OF THINGS
IP	INTERNET PROTOCOL
IRNSS	INDIAN REGIONAL NAVIGATION SATELLITE SYSTEM
ISRO	INDIAN SPACE RESEARCH ORGANIZATION
ITU	INTERNATIONAL TELECOMMUNICATION UNION
LAA	LICENSED ASSISTED ACCESS
LMLC	LOW MOBILITY LARGE CELL
LSA	LICENSED SHARED ACCESS
LTE	LONG TERM EVOLUTION
M2M	MACHINE-TO-MACHINE
MEITY	MINISTRY OF ELECTRONICS AND INFORMATION TECHNOLOGY
MIMO	MULTIPLE INPUT MULTIPLE OUTPUT
mMTC	MASSIVE MACHINE-TYPE COMMUNICATION
MWA	MICROWAVE ACCESS
MWB	MICROWAVE BACKBONE
N3IWF	NON-3GPP INTERWORKING FUNCTION
NDCP	NATIONAL DIGITAL COMMUNICATION POLICY
NFV	NETWORK FUNCTION VIRTUALIZATION
NR	NEW RADIO
NSA	NON-STANDALONE
OFDMA	ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS
P2P	POINT-TO-POINT
PaaS	PLATFORM AS A SERVICE
PSUs	PUBLIC SECTOR UNDERTAKINGS
QoE	QUALITY OF EXPERIENCE
QoS	QUALITY OF SERVICE
R&D	RESEARCH & DEVELOPMENT
RAN	RADIO ACCESS NETWORK
RF	RADIO FREQUENCY
RoW	RIGHT OF WAY
RRH	REMOTE RADIO HEAD
RTI	RAN TRANSPORT INTERACTION

SA	STAND ALONE
SACFA	STANDING ADVISORY COMMITTEE FOR FREQUENCY ALLOCATION
SAMEER	SOCIETY FOR APPLIED MICROWAVE ELECTRONICS ENGINEERING & RESEARCH
SBA	SERVICE BASED ARCHITECTURE
SCaaS	SMALL CELL AS A SERVICE
SCF	SMALL CELL FORUM
SDL	SUPPLEMENTAL DOWNLINK
SDN	SOFTWARE DEFINED NETWORKING
SLA	SERVICE LEVEL AGREEMENT
SUL	SUPPLEMENTAL UPLINK
TCO	TOTAL COST OF OWNERSHIP
TDD	TIME DIVISION DUPLEX
TRAI	TELECOM REGULATORY AUTHORITY OF INDIA
TSDSI	TELECOMMUNICATIONS STANDARDS DEVELOPMENT SOCIETY INDIA
TSP	TELECOM SERVICE PROVIDER
UE	USER EQUIPMENT
UHD	ULTRA-HIGH-DEFINITION
UMTS	UNIVERSAL MOBILE TERRESTRIAL SYSTEM
UR-LLC	ULTRA-RELIABLE LOW-LATENCY COMMUNICATIONS
US	UNITED STATES
VRAN	VIRTUALIZED RAN
WCDMA	WIDEBAND CODE DIVISION MULTIPLE ACCESS
WiFi	WIRELESS FIDELITY
WPC WING	WIRELESS PLANNING COORDINATION WING
WRC	WORLD RADIO COMMUNICATION CONFERENCES



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Mahanagar Doorsanchar Bhawan (next to Zakir Hussain College)
Jawaharlal Nehru Marg (Old Minto Road), New Delhi: 110 002