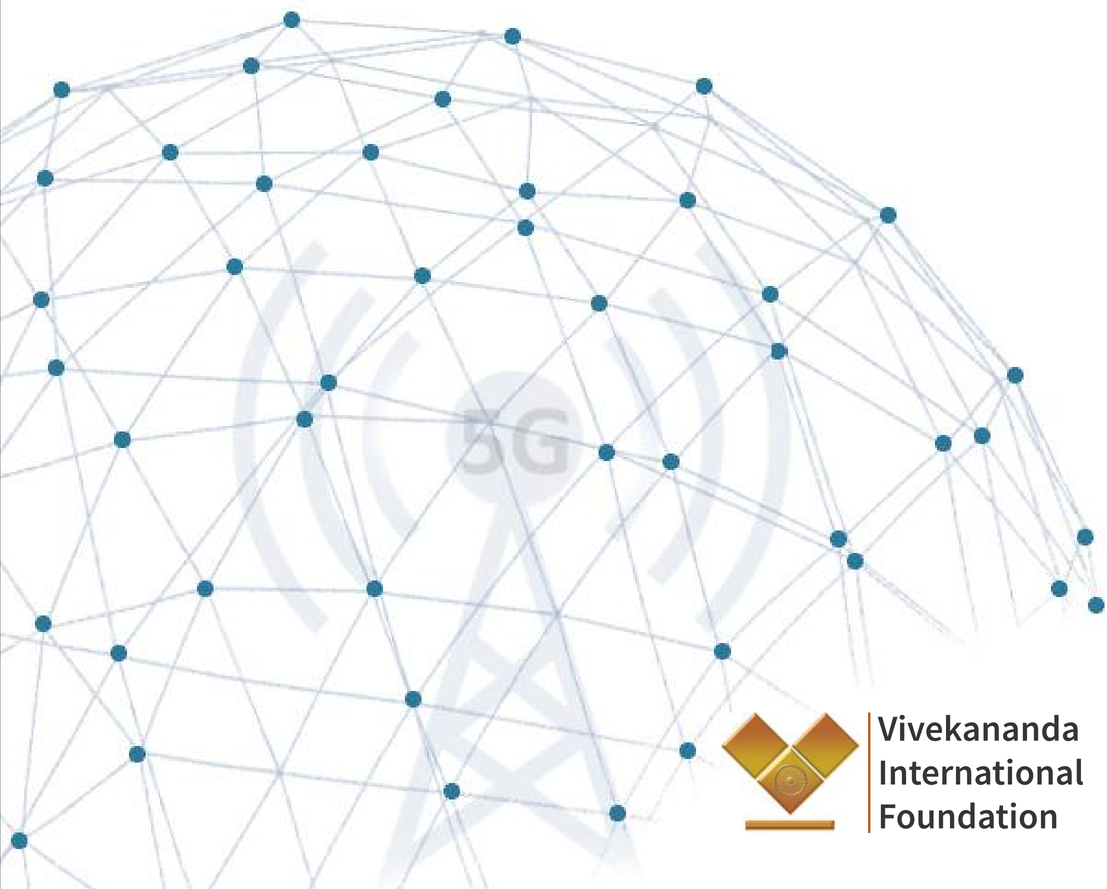
Compendium

TECHNOLOGY, ECONOMICS AND GEOPOLITICS OF 5G CELLULAR

A BRIEF ANALYSIS TO FACILITATE POLICY MAKING IN INDIA

Dr. Kamlesh Bajaj & Team VIF



Vivekananda International Foundation

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CONTENTS

FOREWORD

The introduction of 5G technologies will usher the era of the Internet of Things (IoT). Data will play an even greater role in our daily lives when billions of devices will be interconnected. 5G will have a huge impact on the economy, policy, security and society. 5G technologies differ fundamentally from 4G and the earlier generation of communication technologies. The promise higher greater speed, latency, and bandwidth. 5G is not a single technology. It is a combination of core and peripheral technologies. 5G technologies can be used for higher industry automation, self-driving cars, health, education, workplace and entertainment etc. Cybersecurity will become even a greater concern in the age of hyper-connectivity. Quite understandably, Indian policymakers are keen to develop 5G technologies in India at the earliest possible. India, unfortunately, lags behind in the indigenous development of 5G technologies. It will need to rely on foreign technologies for this purpose. This will have a serious cybersecurity implication for India. Having invested billions of dollars in R&D, China has made rapid strides in the development of 5G technologies. It is acknowledged to be a world leader in this area. Chinese companies like Huawei & ZTE are on the verge of launching their services across the world. However, the prevailing suspicion of the Huawei about its links with Chinese security agencies has made many countries cautious towards Chinese companies.

Dr Kamlesh Bajaj, with the assistance of the team VIF, has compiled data and reports on various facets of the 5G revolution. This compendium based on reports from EU, the UN, ITU, Tech Companies and other stakeholders explains the economic, technologies and geopolitics of 5G focusing, inter-alias, on the implications for cybersecurity. In context of India, he makes several recommendations on how India can emerge as a world leader in this area. He argues that to compete globally in 5G infrastructure rollout, the Indian government may consider giving free spectrum to Indian companies in the initial years. On the question whether India should allow Chinese companies to enter the Indian market, the author recommends that India should make a careful risk assessment of such an action. In his view, only trusted suppliers of technologies should be chosen for the Indian market. India should also include homegrown start-ups in the 5G trials. He also points out that there is still a lot of scope in India to improve 4G infrastructure to get higher speeds. Therefore, there is still time for India to catch up with the 5G revolution.

Dr. Bajaj is a noted expert on cybersecurity, having the credit for setting up of India's Computer Emergency Response Team (CERT). He was also the Chief Executive of the Data Security Council of India (DSCI). He is well qualified to write on the subject of 5G. I hope that this compendium will be found useful.

Dr Arvind Gupta
Director VIF

New Delhi

ABSTRACT

5G is an investment for the next decade. It is not just a game changer; it is likely emerge as a General Purpose Technology (GPT). 5G mobile will move from being a consumer device to an industrial productivity and efficiency tool, with billions of IoT devices connected seamlessly for transformative applications in all sectors of economies and governance models. Smart cities, hospitals, manufato cturing, agriculture, and transport will get transformed with ultra-fast data throughputs, and near zero latency, which will unleash the potential of AI and ML in all these sectors. 5G infrastructure will be the backbone for digital economies throughout the world. Potential global sales activity across multiple industry sectors enabled by 5G could reach $12.3 trillion in 2035. This represents about 4.6% of all global real output in 2035. Global 5G value chain will add $3.8 trillion, with 22 million jobs by 2035. However, cyber security issues in 5G have been linked to the national security challenges, leading to global trade issues, which threaten to divide the world into two blocs. Nations have to decide on the basis of geopolitical risks they perceive. This paper analyses the technology, economics, and geopolitics of 5G in the global context. Finally, the technology, regulatory and other policy challenges facing India that stand in the way of faster rollout of 5G infrastructure in the country, along with geopolitical considerations are discussed.

ACKNOWLEDGEMENTS

The author is grateful to Dr Arvind Gupta, Director, Vivekananda International Foundation (VIF) for reviewing the manuscript and giving his suggestions and advice to make it more readable. He also thanks Lt. Gen. Ravi Sawhney, VIF for his constructive comments on the paper.

The author also places on record the critical comments and suggestions of three industry experts, who wish to remain anonymous, to improve the paper. He is grateful to them for sparing their valuable time.

LIST OF ABBREVIATIONS

3GPP	3rd Generation Partnership Project
5GCN	5G Core Network
AI	Artificial Intelligence
AGV	Automated Guided Vehicle
ANSSI	Agence Nationale de la Sécurité des Systèmes d'information (French)
API	Application Program Interface
AR	Augmented Reality
ASIC	Application Specific Integrated Circuit
ATCF	Access Transfer Control Function
ATGW	Access Transfer Gateway
AuC	Authentication Centre
BGP	Border Gateway Protocol
BRI	Belt & Road Initiative
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CAD	Computer Aided Design
CAICT	China Academy of Information and Communications Technology
CapEx	Capital Expediture
C-RAN	Cloud-Radio Access Network
CCDCOE	NATO's Cooperative Cyber Defence Centre of Excellence
CDMA	Code Division Multiplexing Access
CDR	Charging Data Record
COAI	Cellular Operators Association of India
CP	Control Plane
CTIA	Cellular Telecommunications and Internet Association
CUPS	Control and User Plane Separation
DPI	Deep Packet Inspection
eMBB	enhanced Mobile Broadband
eNodeB	evolved NodeB
EDGE	Enhanced Data Rates for GSM Evolution

EIR	Equipment Identity Register
EPC	Evolved Packet Core
EPS	Enhanced Packet System
ET	Envelope-Tracking
ETSI	European Telecommunications Standards Institute
EU	European Union
EVA	Economic Value Added
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FM	Frequency Modulation
FTTP	Fibre-To-The-Premises
FWA	Fixed Wireless Access
GCHQ	Government Communication Headquarters
GDP	Gross Domestic Product
GMSA	Global Mobile Suppliers Association
GPRS	General/Generic Packet Radio Services
GPT	General Purpose Technology
GSM	Global System for Mobile Communication
GSMA	GSM Association
GSMC	Gateway Mobile Switching Centre
GVA	Gross Value Added
HCSEC	Huawei Cyber Security Evaluation Centre
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
IAB	Integrated Access and Backhaul
IBCF	Interconnection Border Control Function
IC	Integrated Circuit
ICT	Information and Communication Technology
IMEI	International Mobile Equipment Identity
IMS	IP Multimedia Core Network Subsystem/IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IIoT	Industrial IoT

IP	Internet Protocol
ISG	Industry Specification Group
ITU	International Telecommunications Union
KPI	Key Performance Indicator
LAN	Local Area Network
LSI	Large-Scale Integrator
LTE	Long-Term Evolution
mMTC	massive Machine Type Communication
MAP	Mobile Application Part
MCC	Mobile Country Code
MCS	Mission Critical System/Services
ME	Mobile Equipment
MEC	Mobile Edge Computing
MIMO	Multiple-Input and Multiple-Output
ML	Machine Learning
MME	Mobility Management Entity
MNC	Mobile Network Code
MS	Mobile Station
MSSC/MSC	Mobile Services Switching Centre
MTSO	Mobile Telephone Switching Office
MWC	Mobile World Congress
NSA	Non-Stand Alone
NFV	Network Functions Visualization
NTT	Nippon Telephone and Telegraph
OFMD	Orthogonal frequency-division multiplexing
OS	Operating System
PSTN	Public Switched Telephone Network
PDN GW	Packet Data Network Gateway
PDCP	Packet Data Convergence Protocol
QoS	Quality of Service
RAN	Radio Access Network
RF	Radio Frequency
RNC	Radio Network Controller
SAE	Service Architecture Evolution
SA	Stand Alone
SGW	Serving Gateway

SDN	Software Defined Networking
SIGINT	Signals Intelligence
SIM	Subscriber Identification/Identity Module
SMIC	Semiconductor Manufacturing International Corporation
SoCs	System on Chips
tpm	terabytes per minute
TLS	Transport Layer Security
TSMC	Taiwan Semiconductor Manufacturing Company
TRAU	Transcoding Rate and Adaptation Unit
TDMA	Time Division Multiple Access
TrGW	Transition Gateways
UE	User Equipment
URLLC	Ultra-Reliable Low Latency Communication
UHD	Ultra-High Definition
UNCTAD	United Nations Conference on Trade and Development
UAVs	Unmanned Aerial Vehicles
UP	User Plane
USIM	Universal Subscriber Identity Module
UMTS	Universal Mobile Terrestrial / Telecommunication Systems
UTRAN	UMTS Terrestrial Radio Access Network
VR	Virtual Reality
VoIP	Voice over Internet Protocol
VM	Virtual Machine
VNF	Virtual Network Functions
V2X	Vehicle-to-Everything
VLR	Visitor Location Register
VHE	Virtual Home Environment
WAP	Wireless Application Protocol
WAN	Wide Area Network

EXECUTIVE SUMMARY

Digital economy is contributing much more to the GDP of nations, than any other sector. It is not only the western world that is seeing their digital economies grow 6-10 percent of economic value (compared to their annual GDP growth of 2-4 percent), China, too, is growing its digital economy very significantly, and very fast. In fact, faster than rest of the world. It expects nearly half of its GDP to come from digital, create more jobs, and innovations to power its knowledge economy, and take its digital platforms, products and services, to the rest of the world.

Critical to the growth of digital economies is digitization of more and more business and governance processes; collection of more data and its use to develop Artificial Intelligence (AI) and Machine Learning (ML) applications to increase productivity and efficiency; build talent to develop AI and ML in areas of interest to a country; cloud data centres; and build data protection frameworks. Most critical is the network infrastructure that enables more apps – entertainment, productivity and transformational – through connectivity of billions of devices for real time response and action in health care, robotic surgery, driverless cars. 5G infrastructure is the key to achieving that potential along with AI and ML to deliver more value to society.

5G is the next generation of wireless technology. The generations are technically defined by their data transmission speeds; and in encoding methods, or "air interfaces." It promises greater speed, lower latency, and the ability to connect a lot more devices at once. It will launch the era of Industrial Internet of Things (IoT).

IHT Markit predicts that 5G will soon be a General Purpose Technology (GPT), in league with the printing press, electricity, steam engine, telegraph, and the Internet, because of its ubiquity, and transformative effects on the individual, industry, and the society. Its research concludes that 5G will enable $12.3 trillion of global economic output in 2035; the global 5G value chain will generate $3.5 trillion in output, and support 22 million jobs in 2035; the 5G value chain will invest $200 billion annually in R&D to continually expand and strengthen the 5G technology base within network and application infrastructure base. 5G will fuel sustainable long-term growth to global real GDP. From 2020 to 2035, the total contribution of 5G to real GDP will be equivalent to an economy the size of India – currently the seventh largest in the world.

Today, India is not among the top seven countries which are investing heavily in 5G R&D, rollout of networks, launching use cases to be there for first mover advantage. Projections over the next 16-years period, up to the year 2035, count India in rest of the world. With its aim of growing digital to a trillion dollars, and GDP to five trillion dollars by 2024, India can ignore 5G only at peril to itself!

This paper is divided into sections on technology, economics, and geopolitics of 5G, followed by an analysis of the challenges that are unique to India, especially in the light of geopolitical security scenarios. **Section 1** on 5G technology traces the journey from 4G to 5G networks. Core technologies of 5G cellular networks, spectrum bands, 5G rollout, chipsets and devices, power consumption and health risks of RF risks are also touched upon.

In **Section 2**, on the Economics of 5G, we examine the use cases proposed by various technology companies, the projections made by a number of global studies, and research publications on the potential impact of 5G on national economies. From 5G being a consumer use technology to one affecting industry and transforming into a GPT.

The technical aspects of cyber security are getting linked to national security challenges, which, in turn are morphing into trade wars, and geopolitical challenges. We analyse this issue in **Section 3**, starting with cyber security challenges in 5G networks. How different is security in 5G from 4G? Does it really become a national security challenge, or is it a supply chain risk as is the case with another ICT? Trade related and geopolitical challenge is also part of this section. The US concerns about national security with deployment of Chinese technology from Huawei are specially examined to see whether it is a trade issue, or a supply chain risk, or a technology supremacy risk.

Section 4 is devoted to India, in the context of technology, geopolitics, and economics. We can ignore the global developments at peril to our economy, national security and sovereignty. Some policy options are examined.

1 TECHNOLOGY OF 5G

In this section, we will review 4G cellular networks, followed by evolution of 5G networking technology. Core technologies, Spectrum challenges, 5G rollout, devices and chipsets; power consumption and health risks of RF radiation are briefly discussed.

1.1 PRE-4G ERA

The first two generations of cellular networks (1G and 2G) were driven by technology vendors, and network operators with their own standards. 3G standards were formulated by 3rd Generation Partnership Project (3GPP), under the umbrella of International Telecommunications Union (ITU). The network standards for 4G and 5G are also driven by it. For the sake of completeness, and for the benefit of inquisitive readers, a brief introduction to the earlier era is provide in Appendix 1.

1.2 4G NETWORKS

4G is an Internet Protocol (IP) data digital network with high mobile broadband, which launched the Video Streaming Era. The key technological difference between 4G and 3G lies in its use of an all-IP network. No circuit switching as in 3G; 4G treats voice-calls just like any other type of streaming audio media, utilizing packet switching over the Internet, LAN (Local Area Network) or WAN (Wide Area Network) networks via VoIP (Voice over Internet Protocol).

While 3G provided four times the data transfer rates of 2G, to begin with, the speeds were much higher towards the end in 2008. But the industry continued its march forward to 4G, with the objective of creating more bandwidth. It led to offering of services such as high-quality audio/video streaming over end-to-end Internet Protocol.

4 Cell Phone Generations Compared

	Standards	Technology	SMS	Voice Switching	Data Switching	Data Rates
1G	AMPS, TACS	Analog	No	Circuit	Circuit	N/A
2G	GSM, CDMA, EDGE, GPRS	Digital	Yes	Circuit	Circuit	236.8 kbps
3G	UTMS, CDMA2000, HSPDA, EVDO	Digital	Yes	Circuit	Packet	384 kbps
4G	LTE Advanced, IEEE 802.16 (WiMax)	Digital	Yes	Packet	Packet	up to 1 Gbps

Figure 1. Four Cell Phone Generation Compared with Characteristics [Image Source: https://support.chinavasion.com]

The first two commercially available 4G technologies were WiMAX and the Long-Term Evolution (LTE) standards. The LTE emerged as the dominant standard. Simultaneous transmission of voice and data became possible with LTE system, with significantly improved data rates. All services including voice services can be transmitted over IP packets. The complex modulation schemes and carrier aggregation are used to multiply uplink/downlink capacity. Data speeds soon reached 100Mpbs.

3GPP introduced **Evolved Packet Core (EPC)** as a standard in its Release 8, as a "flat architecture", to handle the data traffic efficiently from performance and costs perspective. In this architecture, few network nodes are involved in the handling of the traffic, and protocol conversion is avoided. It was also decided to separate the user data (also known as the **user plane**) and the signalling (also known as the **control plane**) to make the scaling independent. This functional split allows the operators to design their networks easily per their requirements.

A basic architecture of the **Evolved Packet System (EPS)** when the **User Equipment (UE) is connected to the EPC over E-UTRAN – the LTE Radio Access Network (RAN) -** as shown in the following figure. The **Evolved NodeB (eNodeB) is the base station for LTE radio**. In figure 2, the EPC is composed of four network elements: the Serving Gateway (SGW), the Packet Data Network Gateway (PDN GW), the Mobility Management Entity (MME), and the Home Subscriber Server (HSS). The SGW is a critical network function for the 4G mobile core network— the EPC. The SGW resides in the user plane where it forwards and routes packets to and from the eNodeB and PGW. The EPC is connected to the external networks, which can include the IP Multimedia Core Network Subsystem (IMS).

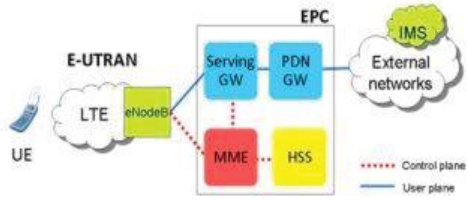


Figure 2. Basic Architecture of EPS. [Image source: www.3gpp.org]

The 4G LTE data transfer speed can reach peak download speed of 100Mbps, peak upload 50Mbps; WiMAX offers peak data rates of 128Mbps downlink, and 56Mbps uplink. 4G was first deployed in Stockholm, Sweden, and in Oslo, Norway in 2009 on LTE. It was introduced in other countries thereafter. With this, the High-quality video streaming became a reality. 4G offers fast mobile web access, up to 1Gpbs for UE at rest, i.e. stationary users which facilitates gaming services, HD videos and HQ video conferencing. The current 4G architecture, as per the International Telecommunications Union (ITU), is shown in the figure below. It is based on the 3GPP recommendations.

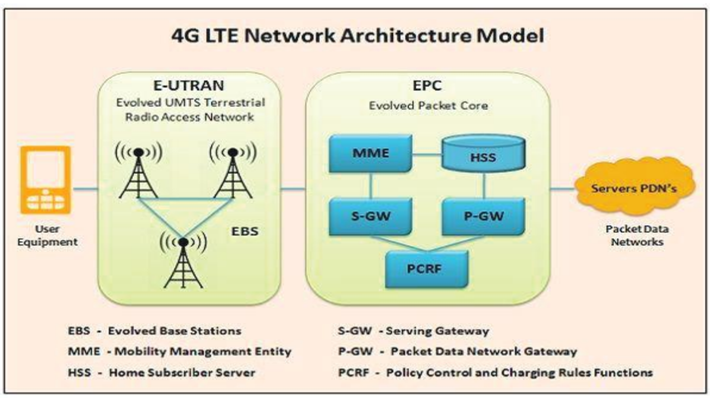


Figure 3. 4G LTE Network Architecture Model [Image source: www.techdifferences.com]

Interestingly, while transitioning from 2G to 3G was as simple as switching SIM cards in existing mobile phones, whereas 4G required new mobile devices specifically designed to support 4G technology. It is this transition that was a factor in Apple's rise to become the world's first trillion-dollar company.

The hardware and infrastructure are expensive; costly spectrum; high end mobile devices compatible with 4G technology are expensive; and wide deployment and upgrade is time consuming. Even though 4G was referred to as **MAGIC**: **M**obile multimedia, **A**nytime anywhere, **G**lobal mobility support, **I**ntegrated wireless solution, **C**ustomized personal service; its implementation has been tardy. Despite 4G being the global standard, many regions suffer from network patchiness and have low 4G LTE penetration for the above reasons.

As an example, 4G penetration in India will reach 82 per cent only by 2024.[1] Moreover, the average 4G data transfer rate is only 6 Mbps, which is significantly low compared to 45 Mbps globally. Even in the UK, according to Ogury— a mobile data platform, UK residents can only access 4G networks 53 percent of the time. So, much remains to be done to rollout 4G. To sum up, its key features are: data rate up to 1Gbps (maximum promised but not achieved); enhanced security and mobility; reduced latency for mission critical applications; high definition video streaming and gaming; voice over LTE network VoLTE (use IP packets for voice). Fully digital IP-based network, with radio and core networks separated.

1.3 5G NETWORKS

5G is referred to as the network for the era of IoT. It has been years in the making. **5G is the next generation of wireless technology.** The generations are technically defined by their data transmission speeds; and in encoding methods, or "air interfaces." It promises greater speed (to move more data), lower latency (to be more responsive), and the ability to connect a lot more devices at once (for sensors and smart devices). Latency is the amount of time it takes for a packet of data to get from one forwarding point to another. Users want faster data speeds and more reliable service. 5G promises to deliver that, and much more. With 5G, users should be able to download a high-definition film in under a second, a task that can take 10 minutes on 4G LTE. Wireless engineers are building technologies to support hitherto not-possible applications such as autonomous vehicles, virtual reality, and the Internet of Things.[2]

The telecommunications companies (telcos) are expected to launch commercial 5G networks in 2020s. Over the last few years, the differences between 4G and 5G have become clearer, and the new technologies that need to be developed have crystallized. As the number of mobile users and their demand for data rises, 5G is becoming a necessity to handle far more traffic at much higher speeds than the 4G base stations in current cellular networks. The suite of technologies under development, will deliver data with less than a millisecond of delay (compared to about 40-60ms on 4G networks) and bring peak download speeds (compared to 1 Gbps on 4G, claimed though not yet achieved) to users.[3]

2G used Global System for Mobile Communications (GSM) standard, and Code Division Multiplexing Access (CDMA) technology; it was not a single standard. Its evolution to 3G followed different routes – General Packet Radio Services (GPRS), Enhanced Data Rates for GSM Evolution (EDGE). Although the global standards community came together with 3GPP, which set the standards adopted by the ITU, vendors and countries continued to push their technologies as the standard, as was seen in the evolution to 4G. Competing standards, namely WiMAX and LTE were supported by two major groups of practitioners. LTE emerged in the race for global supremacy. The 5G standardization effort is an attempt to ensure a single standard. It is being led by 3GPP, under the ITU. But technology developers, vendors and countries keep pushing their standards within 3GPP. Each participating country such as China, Russia, South Korea, the United States (US), and the European Union (EU) wishes to maintain its own definition of 5G networks, its own concepts of frequencies and data speeds, and its own regulations for where 5G transmissions may take place. It's a race to stay ahead. But the good news is that it is only 3GPP that specifies which technologies constitute 5G wireless in its Release 15, Release 16, and Release 17. Work is in progress in the later releases. The 5G wireless standard aims to be global, which will have to be adopted and followed by all vendors and countries. While 2G focused on massive mobile device communication; 3G, starting in 1998, enabled mobile broadband, feature phones, and browsing; 4G networks, starting in 2008, saw the launch of smartphones which popularized video consumption. Data traffic on mobile networks really exploded. **All these networks primarily catered towards consumers.** But the next generation of mobile networks, is very unlike the previous generations. **5G is truly an inflection point from the consumer to the industry.**[4] The era of IoT, and industrial productivity is emerging.

By the early 2000s, developers knew that 4G networks wouldn't be able to support a network with billions of devices – IoTs, which are nothing but a number of network-connected sensors that help do all tasks from navigation, to communication, to photography, to industrial control, surveillance and much more. Even a mobile phone with a camera, location indicator through GPS, voice assistants and more, is but an IoT device. The IoTs generate data which moves out of servers to 'edge devices' such as Wi-Fi enabled appliances like fridge, washing machines, and cars. As 4G's latency of between 40ms and 60ms is too slow for real-time responses, research began to develop the next generation of mobile networks.

5G networks use orthogonal frequency-division multiplexing (OFDM) encoding, with the air interface designed for much lower latency and greater flexibility than LTE, the 4G technology. 5G will have data transfer speeds of up to 100 Gbps; latency of only 1-3ms, which is much lower than 40-60ms in 4G; and will enable a video film to be downloaded in 1 sec. It will support more connections on a broad range of frequencies 300 MHz-90 GHz, and a million devices per sq. km. While most 4G channels are 20MHz, 5G channels can be up to 400MHz (in frequency bands of 28-37GHz). Data will move 100 times faster; it will handle far more data, with far lower lag times. It is about machine-to-machine communications, with billions of IoT devices connected - from refrigerators to self-driving cars to entire "smart cities."

5G network architecture supports the following three service categories:

1) eMBB (Enhanced Mobile Broadband) – entertainment, smart home;
2) mMTC (Massive Machine Type Communication) – smart city, IoT devices;
3) URLLC (Ultra-Reliable Low Latency Communication) – driver-less cars, e-heart surgeries, virtual reality, augmented reality.

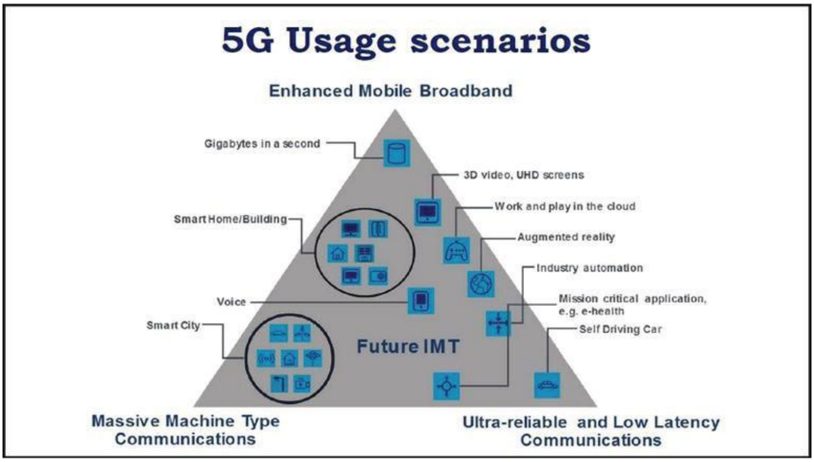


Figure 4. 5G Usage Scenarios[5]

It was during 4G implementation that the telcos realized **the need for different grades of infrastructure to support different classes of service.** 5G is being designed for precisely these three services to enable telcos to cater to their own different business models, and those of other network operators.

In 4G, radio access and core networks were conceived as a single system. With 5G, operators will need to combine elements of 4G and 5G, since 4G is likely to coexist with 5G for a long period of time. The **RAN has been defined in two ways: Non-Stand Alone (NSA), and Stand-Alone (SA).** Devices will be able to access radio via NSA if 4G and 5G are both deployed by the mobile operator, while for pure 5G it will be via SA. The RAN, with components of a base station and antennas that cover a given region, depending on their capacity, has been an essential component of 3G, 4G; and it will be so in 5G too except that it will require a major step forward.

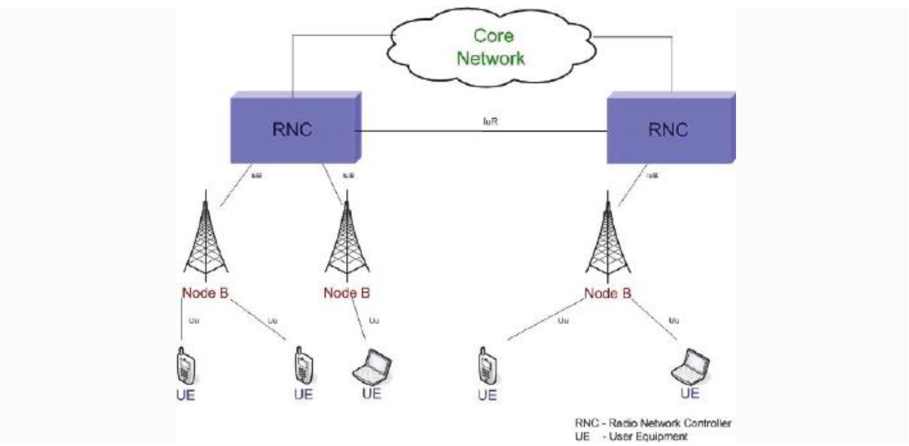


Figure 5. Radio Access Network (RAN)[6]

3GPP has added functions to the RAN and core networks to support new network elements and applications. 2G RAN network was affected by the introduction of packet-switched data in the core network, which helped support higher traffic rates. In 3G, lower redundancy and schemes for higher spectral efficiency improved data ranges on the RAN, which resulted in mobile broadband. The **3GPP 4G system introduced Long-Term Evolution (LTE) as the RAN.** In 4G the LTE core network separates the packet-switched domain from the circuit-switched voice service, which carries as data via voice-over-IP (VoIP).

5G networks require that the RAN network architecture be reworked beyond this evolution of the 3GPP LTE releases. The radio access network requires a new approach in light of the new use cases, services, and traffic types that 5G will introduce, particularly when it comes to configurability and flexibility. It will be far more intricate and complex, but with flexibility to configure and reconfigure, on the fly, for enabling services for enhanced broadband, ultra-reliable low latency, and massive machine-to-machine communications, making use of an array of enabling technologies: Software Defined Networking (SDN), Network Functions Virtualization (NFV), frequency bands such as millimetre Wave (mmWave, 28-37 GHz), small cell, full duplex, massive MIMO, and beam forming. RAN network will leverage virtualization (vRAN) and Cloud (C-RAN) technologies.[7] These will be discussed next. We will briefly touch upon their impact on power consumption, and health of people too.

1.3.1 CORE TECHNOLOGIES FOR REALIZING 5G: (IEEE SPECTRUM)

These include millimetre waves, small cells, massive MIMO, full duplex, and beam forming. To understand how 5G will differ from today's 4G networks, it's useful to see what these will mean for wireless users. The existing radio-frequency spectrum bands are clogged with massive data generated by the devices, which means less bandwidth for everyone, causing slower service and more dropped connections. Operators have to move to new frequencies of the spectrum, which have not so far been used for mobile services. Service providers are experimenting with broadcasting on **millimetre waves**, which use higher frequencies than the radio waves that have long been used for mobile phones. Millimetre waves are broadcast at frequencies between 30-300 GHz, compared to the bands below 6 GHz that were used for mobile devices in the past. They are called millimetre waves because they vary in length from 1 to 10 mm, compared to the radio waves that serve today's smartphones. So far, these are used only by operators of satellites and radar systems.

A major drawback to millimetre waves is that they can't travel through buildings or obstacles and can be absorbed by foliage and rain. To overcome these hurdles, 5G networks will need to use another new technology – **small cells** – to augment traditional cellular towers. These are portable miniature base stations that require minimal power to operate and can be placed every 250 meters or so throughout cities. Thousands of these stations in a city will form a dense network that acts like a relay team, receiving signals from other base stations and sending data to users at any location.

While traditional cell networks have deployed an increasing number of base stations, 5G performance will require an even greater infrastructure. But, antennas on small cells can be much smaller than traditional antennas if they are transmitting tiny millimetre waves. This size difference makes it even easier to stick cells on light poles and atop buildings. The new network structure should provide more targeted and efficient use of spectrum.

In addition to broadcasting over millimetre waves, 5G base stations will also have many more antennas than the present base stations —to take advantage of another new technology: **massive MIMO**. 4G base stations have a dozen ports for antennas that handle all cellular traffic: eight for transmitters and four for receivers. But 5G base stations can support about a hundred ports, which means many more antennas can fit on a single array. That capability means a base station could send and receive signals from many more users at once, increasing the capacity of mobile networks by a factor of 22 or more. This technology is called massive MIMO: Multiple-Input Multiple-Output; it features dozens of antennas on a single array. It promises high spectral efficiency, a measure of how many bits of data can be transmitted to a certain number of users per second.

But like with other technologies above, massive MIMO too comes with new problems in its wake. Many more antennas to handle cellular traffic also cause more interference. So, a new technology - beam forming needs to be incorporated in 5G stations. It is like a traffic-signalling system for base stations that identifies the most efficient data-delivery route to a particular user, and it reduces interference for nearby users in the process. Beamforming can help massive MIMO arrays make more efficient use of the spectrum around them. The primary challenge for massive MIMO is to reduce interference while transmitting more information from many more antennas at once. At massive MIMO base stations, signal-processing algorithms plot the best transmission route through the air to each user. For millimetre waves, beam forming is primarily used to address a different set of problems: cellular signals are easily blocked by objects and tend to weaken over long distances. In this case, beam forming can help by focusing a signal in a concentrated beam that points only in the direction of a user, rather than broadcasting in many directions at once.

An additional technology - **Full Duplex -** is used to achieve higher throughput and low latency, which modifies the way antennas deliver and receive data.

Today's base stations and cell phones rely on transceivers that must take turns if transmitting and receiving information over the same frequency or operate on different frequencies if a user wishes to transmit and receive information at the same time. With 5G, a transceiver will be able to transmit and receive data at the same time, on the same frequency, using full duplex. It could double the capacity of wireless networks at their most fundamental physical layer.

Radio waves travel both forward and backward on the same frequency—a principle known as reciprocity. Engineers have recently assembled silicon transistors that act like high-speed switches to halt the backward roll of these waves, enabling them to transmit and receive signals on the same frequency at once. But it also creates more signal interference, through a pesky echo. This is solved by use of special **echo-cancelling technology**.

1.3.2 NETWORK DESIGN

3GPP introduced the Generic Packet Radio Service (GPRS). A further evolution of this system occurred with the introduction of 4G: the **Enhanced Packet System (EPS)**, whose core network is called the **Enhanced Packet Core (EPC)**. The 5G architecture features a new **5G Core Network (5GCN).**

The key components of EPC are: Mobility Management Entity (MME) – manages session states and authenticates and tracks a user across the network; Serving Gateway (S-gateway) - routes data packets through the access network; Packet Data Node Gateway (PGW) - acts as the interface between the LTE network and other packet data networks; manages Quality of Service (Q0S) and provides Deep Packet Inspection (DPI); Policy and Charging Rules Function (PCRF) - supports service data flow detection, policy enforcement and flow-based charging. The standards for EPC operation were specified by 3GPP in 2009. EPC is the core component of Service Architecture Evolution (SAE), 3GPP's flat LTE architecture.

1.3.3 FACILITATING 4G EPC TRANSITION TO A CENTRALIZED CLOUD

Vendors are moving the 4G EPC to the cloud. This lowers the network deployment and maintenance cost. Moving to the cloud, however, increases the user plane latency. All user plane data must be carried all the way to the cloud provider before it hits the Internet.

Figure 6. 4G LTE data plane in the cloud with SGW/PGW integrate control and data plane functions.[8]

Separating the control and data plane functions of PGW and SGW into separate entities gives the service providers more flexibility in dealing with user plane latency. The following figure shows that the SGW/PGW control functions have been moved to the cloud. The data plane has been separated out giving the service provider flexibility in routing data plane traffic.

- A distributed SGW-PGW user plane function may be placed closed in an edge cloud that is located very close to the radio network. Latency sensitive traffic can take this route.
- Regular traffic can still be routed via the SGW-PGW user plane functions located in the centralized cloud.

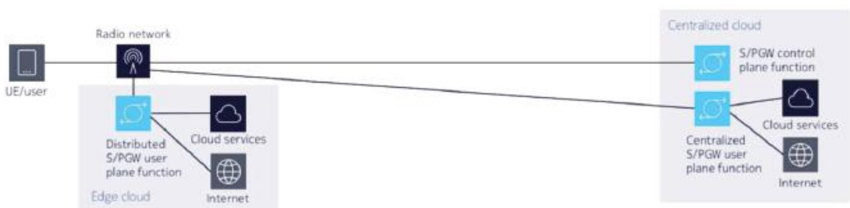


Figure 7. 4G LTE data plane is simplified by separating out the control plane functions—CUPS.[9]

1.3.4 CUPS — CONTROL AND USER PLANE SEPARATION

The EPC architecture separated the primary control plane functions in to the MME. However, SGW and PGW still perform many control plane functions during session establishment. The 3GPP standards for 5G assume separation of the Control and User Planes as a mandatory (and basic) network feature. The purpose of the network system is to efficiently provide User Equipment (UE), with access to services (voice, text, data, etc.) available in data networks. UE access to the Data Network involves two distinct networking domains: the Access Network (e.g. Radio Access Network) and Core Network (GPRS, EPC or 5GC.)

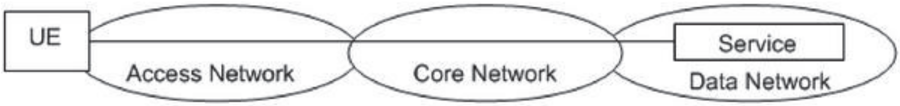


Figure 8. A simple model of service access using the 3GPP system

Control plane functions exist throughout the system: in the Core Network, in the Access Network, as well as end-to-end, between the UE and the Service. The 'control plane' is the term used for all signalling used to support the functions in the mobile telecommunications system that establish and maintain the user plane. Signalling in this sense means exchange of information to enable, but not to provide the end-to-end communication service itself. (In some cases, services are delivered in part by means of control plane mechanisms, e.g. SMS messages are delivered to the UE by means of control messages.) The control plane is itself a forwarding path to exchange information for operation of the service.

The delivery of service generally occurs via a data forwarding network or 'user plane.' The Core Network establishes and maintains this forwarding path, which requires the Core Network to support various capabilities. The mobile telecommunication system supports data forwarding even as the UE moves, transitions to and from the 'idle' state, intermittently becomes unreachable over the Access Network, and as services delivered to the UE change over time. The user plane is not a merely a packet data forwarding path: it supports many capabilities and constraints, for example monitoring, service level guarantees, charging and a wide range of network capabilities that require authorization. The Core Network supports several functions, most essentially access control, data packet routing and forwarding, mobility management, radio resource management and UE reachability functions. All these functions are part of the control plane functions.

Through successive generations, the Core Network has evolved and advanced with respect to how the above functions are supported.

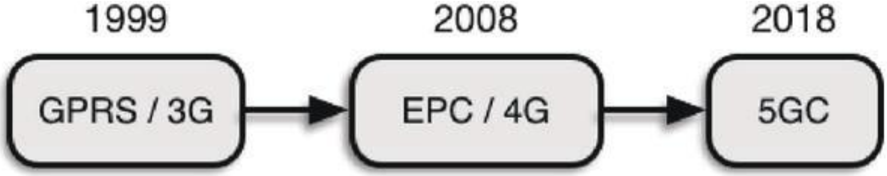


Figure 9. Core network evolution through generations

CUPS provide for the architecture enhancements for the separation of functionality in the Evolved Packet Core's SGW, PGW and TDF. This enables flexible network deployment and operation, by distributed or centralized deployment and the independent scaling between control plane and user plane functions - while not affecting the functionality of the existing nodes subject to this split.

As the penetration of mobile and other IoT devices increases worldwide and the interest in content-rich multi-media services (e.g. OTT video streaming services, person-to-person video, content sharing) rises, data traffic continues to accelerate. But, the consumers' demand for better user experience, with lower latency is also rising. These two requirements – higher data traffic and low latency - are thus among the critical Key Performance Indicators (KPIs) which need to be met. CUPS enable that; it allows for:

- Reducing Latency on application service, e.g. by selecting user plane nodes which are closer to the RAN or more appropriate for the intended UE usage type without increasing the number of control plane nodes.
- Supporting Increase of data traffic, by enabling to add user plane nodes without changing the number of SGW-C, PGW-C and TDF-C in the network.
- Locating and Scaling the CP and UP resources of the EPC nodes independently.
- Independent evolution of the CP and UP functions.
- Enabling Software Defined Networking to deliver user plane data more efficiently.

The split architecture of control plane, as a concept, appeared in 3GPP Release 4. The MSC/VLRs got replaced with the MSC Servers serving the Control Plane (CP) and Media Gateways acting as specialized routers on the User Plane (UP). The trend continued, with the functionalities of the SGSN from the 2G/3G environment ending up in an MME for CP and the User Plane gateways (SGW/PGW) carrying the traffic. As the next step, the PGWs themselves also got divided, into a PGW-C and PGW-U. SIP-based IMS networks use Interconnection Border Control Functions (IBCFs) on CP and Transition Gateways (TrGW) on UP at network borders, for VoLTE an CP Access Transfer Control Function (ATCF) and UP Access Transfer Gateway (ATGW) handle SRVCC.

The functionalities involved in the exchange of signalling messages between the network entities, and those for transport network that carries user/application traffic, are different. Consequently, separate network functions are defined for these two types of roles, making it possible to plan the hardware and software equipment separately for CP and UP. A bigger number of subscribers requires an increase in capacity of the CP entities that store their subscription data or handle their attachment procedures, while a big growth in the throughputs required by some new, bandwidth hungry applications results in demands on the capacity of the UP routers. Scalability of networks becomes much easier – and the costs of purchasing, deploying and maintaining the network elements fall dramatically. With the current pressing need to optimise network costs, the use of CP/UP splitting concept when standardizing the architecture for any new telecommunication network seems an absolute necessity.

The network deployment and running cost factor, though always important, are becoming crucial in the current environment. On the one hand, huge amounts of data that needs to be transported; on the other hand, pricing models that force the operators to offer low price tags on the volume of data transferred, presents a big challenge to the operators. Any potential tools that help reduce network costs are very much in demand. UP/CP splitting falls neatly into that category – and together with virtualizing network functions, network slicing, hosting content closer to the users – provide the mobile network operators with designing and operating cost-effective telecom networks.

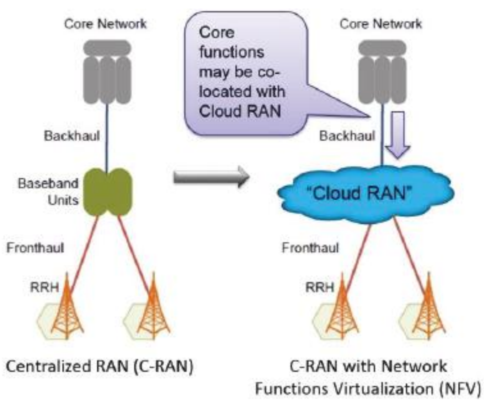


Figure 10. Centralized RAN.[10]

1.3.5 SOFTWARE-DEFINED NETWORKS (SDNS) AND NETWORK FUNCTIONS VIRTUALIZATION (NFV)

As noted above, data speeds have jumped within each generation of the network. But 5G must do more: improve performance, capacity, and speed, and create a network that operates the world over, no matter where or from which device a user connects. Carriers will be working to reduce delays in transmission time. The 5G latency is expected to be less than 1ms; 4G networks have a latency of 40-60ms. Low latency is particularly important for such applications as self-driving cars and robot-aided surgeries, where the slightest delay in transmission time could mean life or death. But simply, updating hardware and software with the latest technologies won't be enough. The new networks will need to handle billions of IoT devices and other new applications. It must provide connections that are 100 times faster than current network speeds. That's where software-defined networks (SDNs) and network functions virtualization (NFV) fit in. They support the flexibility and dynamics of the growing number of advanced terminals and intelligent machines at the networks' edges. SDNs can provide improved speeds and lower latency while eliminating bottlenecks.

SDNs decouple hardware, such as that which forwards IP data packets, from software - the control plane - that carries signalling traffic for routing through network devices. Software is executed not necessarily in the equipment but maybe in the cloud or in clusters of distributed servers. That means networks could be built and reconfigured centrally in an automated fashion, rather than having network managers hop from device to device to make changes manually. SDN is an intelligent, network architecture that minimizes hardware constraints. SDN abstracts lower level functions and moves them to a normalized control plane, which manages network behaviour through application program interfaces (APIs). From a software-based, centralized control plane, network administrators can provide services through the network despite the connected hardware components.

With available spectrum, 5G is going to push the limits of what is achievable. This is where SDN fits into the 5G picture. SDN can be used to provide an overall framework to enable 5G to function across a control plane. It can provide better data flows as data moves across the 5G network. In addition, SDN architecture can minimize network bandwidth and boost latency. Finally, since SDN can be used in 5G networks, it provides a way to manage and automate network redundancy from a centralized control plane, thereby avoiding major outages by determining optimal data flows in real time.

NFV is often paired with SDNs - basic idea behind NFV is to decouple software from hardware. The concept uses CPU and resource virtualization and other cloud-computing technologies such as orchestration, network slicing, and mobile edge computing to migrate network functions from dedicated hardware to virtual machines running on general-purpose hardware. NFV can boost speed, flexibility, and efficiency when deployed with the new services expected to be ushered in by 5G. Components can be upgraded to accommodate a service provider's needs. With NFV, service providers can deploy various network functions, such as firewall or encryption, on virtual machines (VMs). Whenever a customer requests a new network function, service providers are able create one VM for that function automatically. Leveraging this technology, network administrators do not need to invest in high-priced, proprietary hardware to set up a service chain of network-connected devices. And unlike proprietary hardware, these network functions can be installed in weeks instead of months.

With respect to 5G, NFV will help virtualize multiple appliances in the network. Specifically, NFV will enable 5G network slicing, allowing various virtual networks to run on top of a single, physical infrastructure. Moreover, 5G NFV will allow a physical network to be divided into various virtual networks capable of supporting multiple RANs. NFV can also address barriers to 5G by optimizing resource provisioning of the virtual network functions (VNFs) for price and energy, scale VNFs and ensure VNFs consistently operate properly.

1.3.6 NETWORK SLICING AND MOBILE EDGE COMPUTING (MEC)

Network slice is defined as "an isolated set of programmable resources to implement network functions and application services through software programs for accommodating individual network functions and application services within each slice without interfering with the other functions and services on the coexisting slices." Network slicing is considered one of the most important concepts to realize "extreme flexibility" in 5G mobile networks. The current mobile networks are optimized to serve only mobile phones. However, 5G mobile networks need to serve a variety of devices with very different, heterogeneous quality of service (QoS) requirements without interference among one another for all three categories – eMBB, mMTC, URLLC.

5G Use Cases	Examples	Requirements	Mobility
eMBB/xMBB	4K/8K ultra high definition (UHD) video, hologram, Augmented Reality (AR), Virtual Reality (VR)	High capacity, video cache	Yes
mMTC	Sensor Networks (smart metering, logistics, city, home, etc.)	Massive connection covering a very large area of mostly immobile devices	No
URLLC/uMTC	Autonomous driving, smart- grid, remote surgery	Low latency and high reliability	Yes

Table 1. 5G use case examples and their QoS requirements.[11]

SDN and NFV are the two main enabling technologies in creating network slices on physical infrastructure resources. End-to-end network slicing, all the way from user equipment (UE) to cloud data centres for enabling end-to-end quality and extreme flexibility to accommodate various applications, as shown in the figure below. There are two significant aspects of end-to-end network slicing. First, there is the physical infrastructure, that is, a collection of network, computing and storage resources, all the way along end-to-end communication. These programmable resources, embedded along the end-to-end communication paths, are to be used for delivery of services.

Second, it should be possible to logically define an end-to-end network slice from UE to cloud data centres using the programmable resources per application service. This means that we need to enable dynamic creation, modification, and destruction of network slice, coordinated especially across fixed network and radio boundary, called mobile packet core slicing and RAN slicing. Each network slice is made up of a virtualized air-interface, radio access network and mobile packet core network, and transport network combined. The mobile front-haul and backhaul network slicing need to be considered as well in the overall scheme.

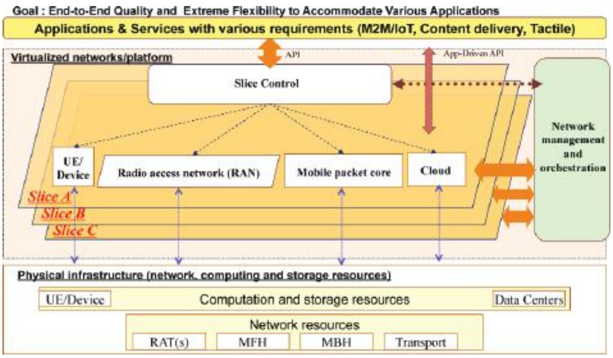


Figure 11. End-to-End Slicing Concept.[12]

In 3GPP, the EPC network has been designed and standardized as a flat architecture, where IP is the only protocol to transport all services. A UE can get Internet connectivity when connected to EPC over RAN. In considering end-to-end network slicing, it is worth recalling that the packet core network slicing is an extension to well-studied transport network slicing, such as transport SDN.

Network slicing as an isolated set of programmable resources to implement network functions and application services through software programs, has two significant features: *resource isolation* and *programmability on resources* that are essential for accommodating individual software defined network functions and application services within each slice without interfering with the other functions and services on the coexisting slices. Network slicing in 5G mobile networking must accommodate applications with very different requirements, such as eMBB, mMTC and URLLC, to avoid interference among those, to guarantee the end-to-end quality of applications.

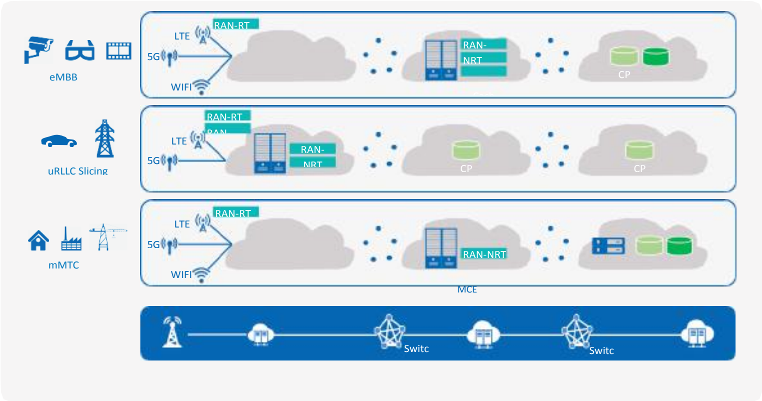
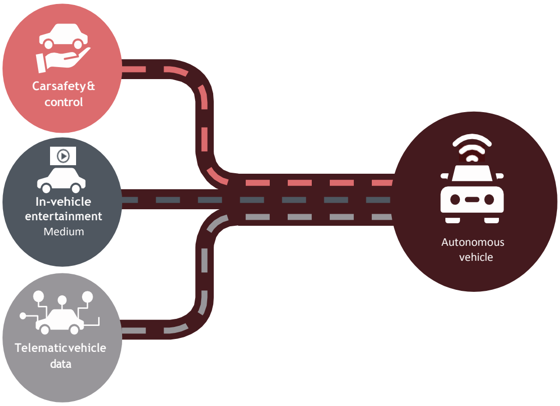


Figure 12. 5G Network Architecture- A High Level View.[13]

In some instances, multiple network slices likely will be required for a single vertical. The automotive sector, for example, may require a low-latency slice for any function related to the piloting of autonomous vehicles, a slice delivering lower priority but high bandwidth for in-vehicle entertainment and still another slice for intermediate collection of telematic data which isn't particularly latency or bandwidth sensitive.



The TM Forum believes that network slicing is the lead 5G technology with great market potential. The ability to deploy any number of virtual end-to-end networks on a single underlying infrastructure – each of those virtual networks being a slice – promises to unlock a new world of enterprise services and revenue for mobile operators. To make this happen, operators must not only deploy 5G technology but also overhaul their back-end operational and business support systems (OSS/BSS).[14]

Network slicing enables networks to be segmented to meet the requirements of specific services, such as guaranteed resilience, bandwidth or low latency. For example, one slice could be configured to support low latency applications such as augmented or virtual reality, while another is created to ensure the highest levels of availability, for applications in healthcare or for autonomous cars. By moving away from the one-size-fits-all approach of current networks, slicing gives operators greater flexibility to meet specific service needs while still using the same underlying network infrastructure. It will enable new business models. 5G will be an enabler for the digital transformation. The role of the operator will vary widely. From simply acting as a connectivity provider – leveraging extensive networks assets – to providing enabling platforms for offering a broad set of value-added services.

Multi-access Edge Computing (MEC), formerly known as mobile edge computing, is a network architecture concept that enables cloud computing capabilities and an IT service environment at the edge of the cellular network[15] and, in general at the edge of any network. The basic idea behind MEC is that by running applications and performing related processing tasks closer to the cellular customer, network congestion is reduced, and applications perform better. MEC technology is designed to be implemented at the cellular base stations or other edge nodes and enables flexible and rapid deployment of new applications and services for customers. Combining elements of information technology and telecommunications networking, MEC also allows cellular operators to open their RAN to authorized third parties, such as application developers and content providers. MEC provides a distributed computing environment for application and service hosting. It also could store and process content near to cellular subscribers, for faster response time. Applications can also be exposed to real-time RAN information.[16]

The key element is the MEC application server, which is integrated at the RAN element. This server provides computing resources, storage capacity, connectivity and access to RAN information. It supports a multitenancy run-time and hosting environment for applications. The virtual appliance applications are delivered as packaged operating system virtual machine (VM) images. The platform also provides a set of middleware application and infrastructure services. Application software can be provided from equipment vendors, service providers and third-parties. The

MEC application server can be deployed at the macro base station EnodeB that is part of an LTE cellular network, or at the RNC that is part of a 3G cellular network and at a multi-technology cell aggregation site. The multi-technology cell aggregation site can be located indoors or outdoors.

Business and technical benefits: By using mobile edge computing technology, a cellular operator can efficiently deploy new services for specific customers or classes of customers. The technology also reduces the signal load of the core network[17] and can host applications and services in a less costly way. It also collects data about storage, network bandwidth, CPU utilization, etc., for each application or service deployed by a third party. Application developers and content providers can take advantage of close proximity to cellular subscribers and real-time RAN information.

MEC has been created using open standards and APIs, using common programming models, relevant tool chains and software development kits to encourage and expedite the development of new applications for the new MEC environment. Some of the notable applications in mobile edge computing are computational offloading,[18] content delivery, mobile big data analytics, edge video caching, collaborative computing, connected cars, smart venues, smart enterprises, healthcare, smart grids,[19] indoor positioning, etc.[20]

1.3.7 NETWORK FREQUENCY BANDS FOR 5G

5G primarily runs in two kinds of airwaves: below and above 6GHz. Low-frequency 5G networks, which use existing cellular and Wi-Fi bands, take advantage of more flexible encoding and bigger channel sizes to achieve speeds 25 to 50 percent better than LTE. Such networks can cover the same distances as existing cellular networks and generally won't need additional cell sites. Some operators are setting up all their new 4G cell sites as 5G-ready. Rural networks will likely stick with low-band 5G, because low-frequency bands have great range from towers.

But to reach multi-gigabit speeds, millimetre waves with frequencies above 28GHz are being used. The existing cellular bands enable only relatively narrow channels because that spectrum is heavily used. But up at 28GHz and 39GHz, broad swathes of spectrum are available that enable big channels for very high speeds. Presently, these bands are used for backhauling, connecting base stations to remote Internet links. But they haven't been used for consumer devices before, because the handheld processing power and miniaturized antennas weren't available. Millimetre wave signals also drop off faster with distance than lower-frequency signals do, and the massive amount of data they transfer will require more connections to landline internet. So cellular providers will have to use many smaller, lower-power base stations (generally outputting 2-10 watts) rather than fewer, more powerful macro-cells (which output 20-40 watts) to offer the multi-gigabit speeds that millimetre wave networks promise.

To make the existing 4G towers 5G-ready, many carriers have already installed those "small cells" in many major cities, to increase capacity during the 4G era. All they need is to add an extra radio access onto the existing site to make it 5G. But in the US, carriers are having trouble convincing towns to let them add small cells to suburban neighbourhoods, because of possible ill effects of radiation at these frequencies. We'll discuss this later. Incidentally, small cells tend to be much less powerful than the macro-cells used for 4G cellular systems: 2-20 watts as compared with 20-40 watts for macro-cells.

There's a third set of airwaves being used in some countries, the mid-band, with frequencies ranging from 3.3GHz to 7GHz. These are slightly above current cellular bands but have quantities of spectrum (and speeds) that start to look like millimetre wave. Mid-band networks won't require quite as many cell sites as millimetre wave, although they'd still be dense; probably every third to half-mile. 5G channels are already in the range of 100MHz to 800MHz. 5G networks need to be more intelligent, since they're handling many more, smaller cells that can change size and shape. But even with existing macro cells, Qualcomm says 5G will be able to boost capacity by four times over current systems by leveraging wider bandwidths and advanced antenna technologies.

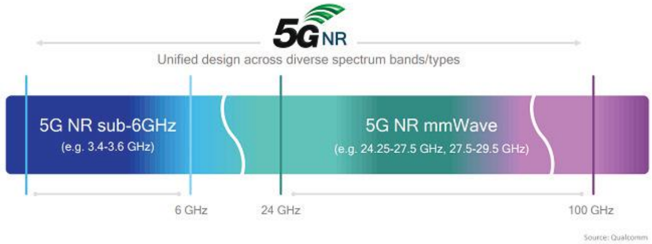


Figure 13. 5G Unified design across diverse spectrum bands/types.[21]

1.3.8 NETWORK ARCHITECTURE

In earlier generations of mobile networks, RANs are located close to the base station. Traditional RANs are complex, require costly infrastructure, periodic maintenance and have limited efficiency.

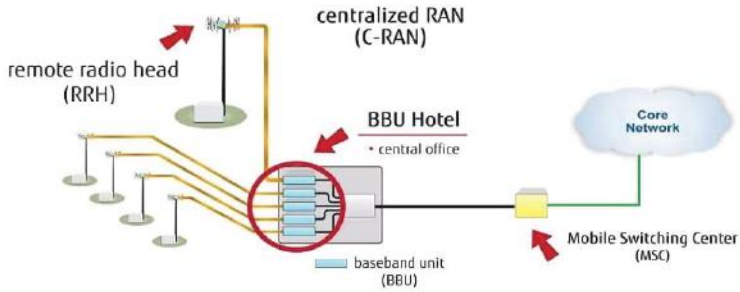


Figure 14. Centralized RAN (C-RAN).[22]

5G technology will use Cloud Radio Access Network (C-RAN) for better efficiency. Network operators can provide ultra-fast Internet from a centralized cloud-based RAN.

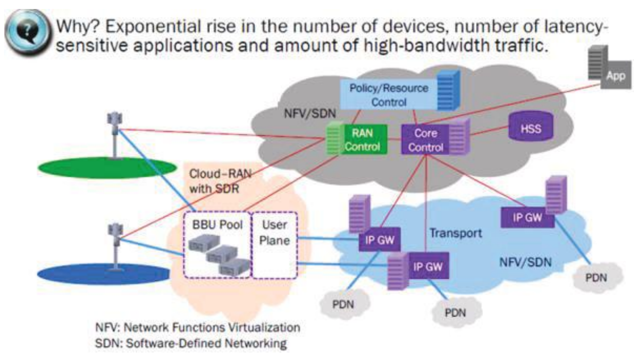


Figure 15. Software Defined Networking 5G.[23]

Narrow Band – Internet of Things (NB – IoT) applications like smart lighting, smart meters, and smart parking solutions, weather mapping will be deployed using 5G network. 5G will be able to handle massive data volume from billions of devices and the network is scalable for upgrades. 5G technologies will be able to address the 4G/LTE limitations of data volume, speed, latency and network scalability. It will provide cost effective solutions to service providers and end users. **Compared to 4G, future 5G devices will offer always connected, ultra-reliable and highly efficient solutions.**

1.3.9 5G ROLLOUT

The figure below shows the basic 4G and 5G architectures.

Both NSA and SA have been defined by 3GPP. There are several options for vendors to move from 4G to 5G in co-existence mode, or standalone 5G SA mode depending upon what kind of applications and services the telcos wish to offer as per their business models. Is it Enhanced Mobile Broadband (eMBB), Massive Machine Type Communications (mMTC), or Ultra-Reliable Low Latency Communications (URLLC)? Cost of spectrum, and that of technology are critical to design and deployment of networks.

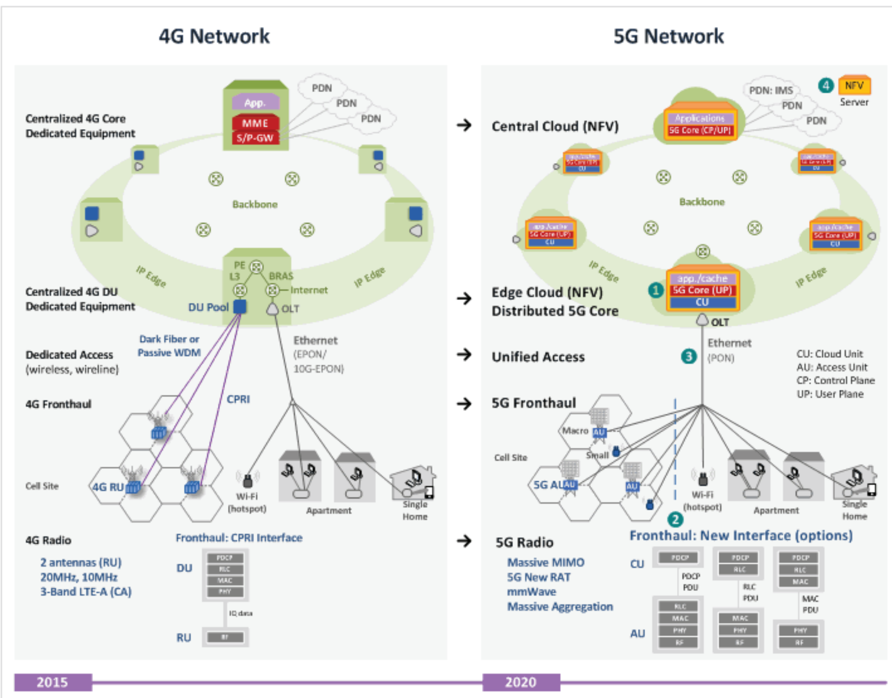


Figure 16. Basic 4G and 5G network.[24]

5G network rollout requires an end-to-end approach to network architecture, not merely getting RF spectrum and building a RAN. Other key components are backhaul (or transport) from the base stations to the core network, plus supporting IT operations. A full 5G deployment requires architecture changes at every stage:

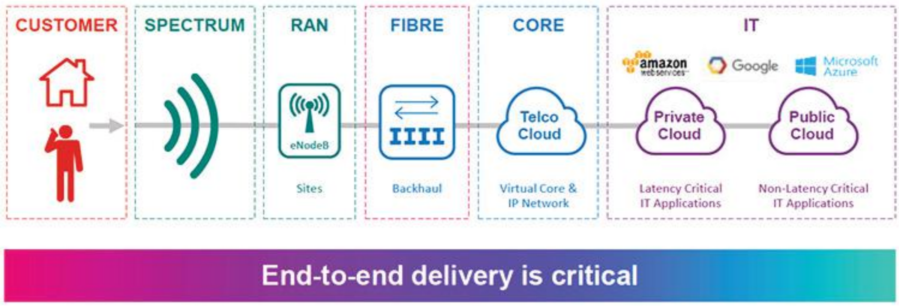


Figure 17. End to End Approach to 5G.[25]

The UK mobile operator Three has taken the following steps to roll out its services after acquiring the 5G spectrum: Acquisition of new cell site technology to prepare target urban areas for the rollout of 5G devices, as well as enhance the 4G service; set up a high-capacity dark fibre network, which connects 20 new, energy efficient and highly secure data centres; deployed 5G-ready, fully integrated cloud-native core network in new data centres, which at launch will have an initial capacity of 1.2Tbps (three times more than existing capacity) and will be easily scalable cost effectively. It will rollout carrier-aggregation technology on 2,500 sites in the busiest areas, improving speeds for customers.[26] The UK Three has committed to spend £2 billion, showing the need for high investments. It also underscores the fact that different 5G use cases (eMBB, URLLC, mMTC and FWA) have different requirements when it comes to bandwidth, latency, mobility, security, reliability and pricing.

Early 5G deployments concentrate on traditional more consumer-oriented areas such as eMBB and Fixed Wireless Access (FWA), based on the finalised 3GPP Rel-15 standard, which can utilise a lot of existing 4G LTE infrastructure. But phase 2 of 5G will be based on the evolving Rel-16 standard and will require new spectrum and infrastructure to support advanced business use cases like URLLC and mMTC. Enabling all this requires a cloud-native, service-oriented architecture that supports network slicing to drive multiple virtual networks on the same physical infrastructure, leveraging SDN and NFV.

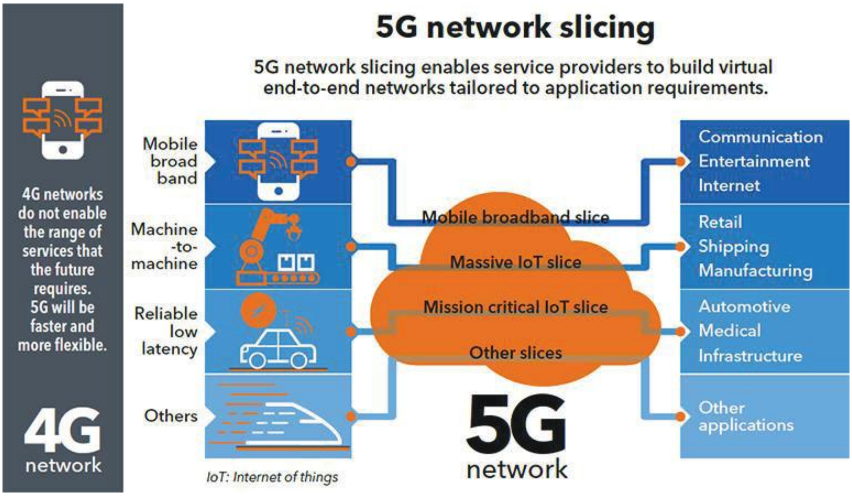


Figure 18. 5G Network Slicing.[27]

Network slicing, though crucial to full 5G deployment, is still a work in progress. As per GSMA November 2018 report, only 26 out of 524 of 5G demos or tests had showcased this technology. The telecommunications service providers, the transmission equipment makers, the antenna manufacturers, and even the server manufacturers – promise that once all of 5G's components are fully deployed and operational, everyone will be wireless. No wire or cable will be required to deliver communications, or entertainment service to a mobile device, or to any of the fixed devices (HDTV, security system, smart appliances), or to any automobile. 5G would be both – long distance and the "last mile" – for a user. It will deliver complete digital connectivity from the tip of the carrier network to the customer, for all apps, at high speeds, with nearly zero latency and ultra-reliability, connecting millions of devices in highly dense areas.

Summary of 5G Infrastructure

Core network RAN components such as base stations and antenna arrays constitute 5G networks. Core network components comprise the central part a cellular network, which presents a consistent user experience, by weaving together mobile, fixed, and converged connectivity. 5G has enabled hardware disaggregation from computing and storage platforms, as well as software programmability over LTE networks. No wonder, standard servers from HP, Dell, EMC etc. have significant presence in telecom, and are responsible for disruption from cost and easier deployment perspective. AI, ML, SDN, and NFV are some of the new capabilities in core networking, which have brought with them benefits like faster time to deployment, self-healing for improved uptime, and network slicing to deliver quality of service at lower costs. RAN components enable smartphones, IoT, and other mobile devices access cellular network seamlessly. Base stations are designed, as fixed points of communication, to cover a specific geographic area. Macro-cells cover a wide area, micro-cells are used for densification of coverage in highly populated areas, while pico-cells boost coverage within buildings. They connect to the core network on one side, while connecting to smartphones and mobile devices on the other side.

Antenna Arrays are attached to base stations, with new features to deliver lower latency and improved throughput over LTE with Massive MIMO technology. Large number of antennas combine to enhance broadcast efficiency. Base stations and antennas combine to form RAN, which connects devices to a core network.

1.3.10 5G SPECTRUM CHALLENGES

Radio spectrum is the lifeline of the mobile network. More the spectrum, more the capacity. But it is a finite resource, and very expensive. Mobile operators need right frequencies with adequate bandwidth to deliver services in eMBB, mMTC, and URLLC categories to their customers at affordable and competitive price in the market. Experts underline the need for its allocation internationally in a harmonized way. This alone can ensure economies of scale, enable global roaming, and mitigate against equipment design complexity. Moreover, it will help prolong battery life and improve spectrum efficiency. The spectrum should be priced such that the telcos may continue investment in infrastructure, as the customer base expands, without worrying about delays in return on investment. It should be made available in right timeframes.

Spectrum volume: To meet growing demand for cellular data and enable key use cases, 5G spectrum needs to be allocated in significantly larger quantities than has been the case for previous generations. For example, more downlink spectrum will be released in the UK between 2017 and 2020 than was made available during the past three decades for all previous generations of cellular technologies.

It will also be allocated across a far wider spread of frequencies than has been the case so far. No single frequency range can support all 5G use cases. This will make global harmonization – which is important for the cost-effective development of network and device technologies – more challenging than in previous generations. Allocations have been made and/or are planned in three broad ranges: sub-1GHz, 1GHz - 6GHz and above 6GHz, in the millimetre wave range above 24GHz.

Addressing a wide variety of use cases: (TM Forum Report April 2019)

Sub-1GHz: this range delivers wide area coverage and in-building penetration. Thus, it will underpin eMBB services both within and beyond dense urban areas and offer essential support to mMTC and URLLC use cases. Key brands include 700MHz in Europe and 600MHz in the US. However, availability of spectrum in this range is limited, and it offers peak data rate of only 100Mbps.

1GHz - 6GHz: this range offers a combination of coverage and capacity well suited to dense urban deployments. The initial focus is on 3.3GHz - 3.8GHz; though 3.8GHz - 4.2GHz; and 4.5GHz - 5GHz are also in line. With peak data rates of 1Gbps it will support initial eMBB use cases, by adding more capacity to the existing networks, with existing number of base station sites. Markets in Europe, North America and Asia are all committed to allocations. Massive MIMO antennas and beam forming are helping address the propagation limitations of spectrum in this band.

Above 6GHz: 5G will take mobile networks into the millimetre wave spectrum which stretches from 24GHz to 100GHz. Spectrum in this range is easily available in large bands and at 10Gbps offers the highest peak data rates of the three 5G ranges. It will therefore support full eMBB.

Initial allocations are focusing on spectrum in the 26GHz and 28GHz bands, but much work remains to be done. The ITU World Radio Communication Conference taking place in Egypt during October and November 2019 will, among other things, focus on driving international harmonization for 5G bands above 24GHz. Capacity and throughput will be high enough to enable the most demanding 5G performance requirements, positioning mmWave spectrum as the enabler of FWA, which can truly rival fibre for performance. However, range, mobility and indoor penetration are limited, and network deployments in the mmWave will require a high density of small cells. As with spectrum in the 3.5GHz range, massive MIMO and beam forming technologies will be essential to maximizing the performance potential of networks operating in mmWave spectrum.

Existing spectrum: Finally, 3GPP bands already in use around the world for mobile services, including 600MHz, 700MHz, 800MHz, 850MHz and 900MHz in the sub- 1GHz range and 1.5GHz, 1.7GHz, 1.8GHz, 1.9GHz, 2.1GHz, 2.3GHz and 2.6GHz in the mid-band range are under consideration for future 5G usage. As 3G services near the end of their second decade, operators are likely to begin shutting them down.

1.4 5G CHIPSETS AND DEVICES

5G chipsets for consumer mobile devices are different from those that go into IoT or Industrial IoT (IIoT) devices. There is also another group of 5G chipsets that go into 5G infrastructure. Due to high R&D costs and low returns, many vendors have exited from this field. Forbes defines leadership "*in the space as one that is first and foremost defined by commercial availability and chipset capabilities*."[28]

According to Electronic Products, the 5G chipsets range from wireless network infrastructure and base stations to smartphone and IoT device applications. It is these chipsets that help transition to 5G communications, and to deliver a fully connected mobile world that spans markets from connected cars and smart cities to smartphones and IoT devices. The acceleration of 5G adoption will require a strong commitment from device and chipset vendors. Chipsets include radio frequency ICs (RFICs), system-on-chips (SoCs), application-specific integrated circuits (ASICs), cellular ICs, and millimetre-wave (mmWave) ICs. Many of these players are building modems, RF front ends, or both, with many designing for sub-6GHz spectrum and supporting 100MHz envelope-tracking (ET) bandwidths.[29] Forbes confirms that there are few players in the mobile chipset space - some building only modems, or RF-Front-end components, while some players like Qualcomm, Samsung and Huawei are doing both to address the increasing complexity of cellular networks and tighten integration and improve time to market. The industry is split between those that can do mmWave and those that cannot. mmWave is harder to do in terms of RF and device design. Mobile handsets in this frequency range are more difficult to deliver. Presently very few players can do this commercially. But their requirement will increase, because of the capacity and bandwidth that they will deliver when dense deployments take place. The biggest market for 5G modems right now is in Sub-6GHz. Forbes lists the following companies as makers of 5G smartphones and RF chipsets. Huawei Technologies (HiSilicon) both modem and RF ICs – Mate X, Mate 20X; Media Tek for Sub 6GHz 5G modem only, no RF; Intel modem XMM8060 for Sub-6GHz and XMM8160 for mmWave, with RF IC announced for 2020/21.

Huawei claims that its Balong 5000 - a 7nm, multi-mode 5G modem – supports both standalone and non-standalone networks. Mate X foldable device will be the first to use this modem. However, Huawei later announced a Mate 20X 5G which is a version of last year's Mate 20 Pro paired with a Balong 5000 modem. The Balong 5000 is not yet commercially available in any devices. Huawei claims to also be a leader in 5G mmWave, though Forbes doubts the claim. But Huawei has big network infrastructure business.

Qualcomm has been the leader in making modems since CDMA; long history with cellular communications and has been a key player in developing the 3GPP 5G standard. Qualcomm was first with its 5G modem - Snapdragon X50 chip – and it was shipped in commercial devices as well. The X50 is not a multi-mode 5G chip; it must be paired with a Qualcomm Snapdragon 4G SoC platform which was designed for early NSA and Sub-6GHz or mmWave 5G network deployments. The second-generation Snapdragon X55 has, both SA and NSA network support for mmWave and Sub-6GHz frequencies. Qualcomm is expected to integrate a 5G modem into an SoC in early 2020. It has also launched two generations of 5G mmWave RF front-end modules. The second generation of these modules, the QTM525, is so small that it could be integrated into virtually any kind of device, which further helps to improve the adoption of mmWave 5G. The new QTM525 also adds support for more bands of mmWave including 24 GHz to 27 GHz, which is in addition to the already supported 28 GHz and 39 GHz bands.

Samsung builds modems only for its own handsets. It has a big network infrastructure business, so it is also involved in 5G in more ways. Samsung's Exynos Modem 5100 - Exynos is the brand for Samsung's in-house SoCs – enjoys the same branding, similarly to Qualcomm's Snapdragon branding. Samsung's modem is both Sub-6GHz capable as well as mmWave and supports LTE as well as 5G; it is paired with Samsung's own RF IC for mmWave. Exynos 5100 refers to the entire platform, which includes the modem, RF, ET (envelop tracking) and power management IC. Samsung is building the Exynos Modem 5100 on a 10nm process node. Other players include Unisoc, Skyworks Solutions and Qorvo. But Forbes lists Qualcomm, already with two generations of 5G modems, with both Sub-6GHz and mmWave commercially shipped products, as the leader in 5G mobile phone chipsets. A list of Top 5G chipmakers for all categories is provided by Electronic Products. They include: Analog Devices, Media Tek, Qualcomm, Samsung, u-blox, Xilinx, SkyWorks, Marvell, and Broadcom.

According to TM Forum, the timelines for 5G smartphones depend upon the availability of the cellular baseband chipsets. It quotes Strategy_Analytics, that at the close of Q1 2018, Qualcomm – with a dominant position in the Android smartphone market – held 52% of the global cellular baseband processor market by revenue. Samsung's semiconductor unit occupied second place with 14%, followed by MediaTek with 13%. HiSilicon (owned by Huawei) and Unisoc (Spreadtrum and RDA) completed the top five. Some of the recent 5G silicon announcements include the following: **HiSilicon**, owned by Huawei, the world's second-largest smartphone manufacturer, claimed the world's first commercially 3GPP- compliant 5G chipset, the Balong 5G01, in February 2018. It does not support previous cellular generations, and Huawei reportedly will not license the chipset to rival vendors.

Samsung LSI launched its Exynos 5100 in August 2018, with the claim of supporting 5G NR and being backwards compatible as far as 2G. **Qualcomm** unveiled its Snapdragon X50 modem in December 2018. In its initial format it will need to be paired with a separate LTE modem and processor in order to operate on 4G and 5G networks. **MediaTek**, a Chinese company launched its M70 multimode chipset in December 2018 in a close partnership with China Mobile in its press release. **Intel** announced in November 2018, its intention to bring the XMM8160 chipset, which also supports LTE, 3G and 2G, to market in the second half of 2019, with devices expected in 2020. The firm decided not to commercialize a 5G-only modem. There has been speculation that Intel's chip will support the first 5G iPhone from Apple. But other reports suggest that after recently setting a contentious legal dispute over royalties and licensing fees with Qualcomm, Apple will begin buying Qualcomm chips , to launch a 5G iPhone in 2020. The dynamics of the chipset market are complex. Samsung's own silicon development suggests a desire to reduce its reliance on the market leader – Qualcomm.

1.5 5G SMARTPHONES ROLLOUT WITH TELCOS

Apple plans to launch a 5G iPhone in 2020, based on Qualcomm chipsets. Samsung planned launch of its 5G phone S10, with Verizon, AT&T and Sprint in 2019. Oppo was ready with its 5G prototype of its Find X device at a China Mobile event in December 2018; and announced to launch a commercial 5G smartphone in 2019. Motorola has developed a modular approach to 5G, with a snap on 5G module compatible with its Z3 device that is to be launched on Verizon's network in H2 2019.

Huawei, the global No. 2 after dislodging Apple during 2018, has announced the launch of its 5G smartphone - expected to be the Mate 30 - before the end of 2019. It is unique in occupying leadership positions in both networks and devices; (However, operators in several markets have banned the company from participation in 5G network deployment because of national security concerns and possible links to Chinese state intelligence. US has led global cry against Huawei and has banned it from being used.) LG was expected to launch its V50 ThinQ 5G smartphone in April 2019, with Sprint in the US. Mi announced a 5G version of its Mi Mix 3 device in October 2018, while one-plus (1+) has confirmed a 5G smartphone release during before the end of 2019.

1.6 POWER CONSUMPTION

Questions have been raised on high power consumption and the effect of radiation in high frequencies on the health of people. In a paper "A technical look at 5G energy consumption and performance" Ericsson examines the energy saving features of 5G NR which enable operators to build dense networks to meet performance demands - high capacity, low latency, more connected devices - while keeping energy consumption low.[30] 3GPP standard for NR is designed to enable denser network deployments, but with more energy efficiency than obtained in 4G. This helps in reducing both operational costs and environmental impacts. Before we explore the new technical features, let's look more closely at how the existing 4G LTE radio networks function.

The 4G LTE networks continue to expand exponentially to meet the high data demands. The energy consumption in radio networks is contributing significantly to the electricity usage and operational expenditures of operators. In a study conducted by Ericsson with network operator Telia, in 2015, it examined the operational carbon emissions of ICT network operators. They found that ICT networks consumed 1.15% of the total electricity grid supply globally and contributed to 0.53% of the global carbon emissions related to energy. A major part of energy consumption comes from the radio base stations, which in 4G are always on whether there is any data traffic. And for significant durations in the day, they are idle, but consuming power. Even when there are bursts of data traffic, short gaps of idling are observed. This is because most of the hardware components must remain active so as to transmit mandatory idle mode signals that are defined in the 4G standard such as synchronization signals, reference signals, and system information. It is this knowledge of the typical traffic activity in radio networks as well as the, need to support sleep states in radio network equipment that has helped create features for energy saving in 5G NR standard. By putting the base station into a sleep state when there is no traffic to serve i.e. switching off hardware components, it will consume less energy. The more components that are switched off, the more energy we will save. So, if new devices and use cases which demand increased capacity in 4G networks, more base stations would mean more power consumption.

In a 4G/5G network, Ericsson observed a clear decrease in energy consumption when it used NR deployments. It found that every addition of an LTE micro node made for a considerable increase in the power consumption, whereas with NR in a base station, each addition of a NR micro node resulted in a very small increase in the energy consumption. The reason for this is that the added capacity with more micros open for the possibility of offloading traffic between the nodes, and each single node can stay idle for long periods. The NR technology takes advantage of this idle time and uses it for deep sleep and low energy consumption. It is estimated that the power consumption in base stations as we move to 5G will be less than that in 4G, with more devices and more capacity of networks. This is a result of 3GPP NR standard.

1.7 HEALTH RISKS IN 5G

In a big definitive survey of research work and reports of scientists on the effects of RF signals on the health of humans "5G Is Coming: How Worried Should We Be about the Health Risks?", published in Scientific American on September 16, 2019, the author Kenneth R. Foster concludes that "So far, at least, there's little evidence of danger".[31] People and a few scientists, have expressed concerns about the possible health effects of RF energy transmitted by 5G base stations. The focus is on two characteristics of 5G networks: First, 5G systems will operate in several frequency bands, including one in the millimetre-wave part of the RF spectrum that extends from 30 to 300 GHz. These mm waves have been used for many applications, including airport security scanners, anti-collision radar for automobiles, and to link present-day cellular base stations, but not in cellular communications. Many 5G networks will operate at frequencies in bands that are already in use by present cellular networks, and some may use millimetre waves to handle high data traffic where needed.

Second, the concern is about large number of small cells mounted close to subscribers, on poles along the streets. We have seen this in previous section that they have antennas that transmit multiple beams (massive MIMO - up to 64 with present designs, more in future), which can be independently steered to individual subscribers. They operate at much lower power levels than the macro cells used by present systems, which are typically located on tops of buildings in urban areas. In future, these will be supplemented by Pico cells mounted inside buildings, operating at still lower power levels. So, 5G will have many more RF signal transmitters in our neighbourhood, homes and offices. Environmental exposure to RF signals will likely increase. The author notes that public exposure to RF fields from future 5G networks has not been surveyed in detail but states that they are unlikely to be different than those from existing cellular networks. This is because the fundamental role of the technology is the same: "to provide a signal that is strong enough to communicate with an individual subscriber but not strong enough to cause interference to users in adjoining cells."[32]

The existing 4G networks are adding many small cells (densification) to manage the increasing data traffic. The author believes that "by allowing faster transmission of data and steering beams toward individual users, 5G may, in fact, work to reduce the overall levels of RF signals in the environment, but that will eventually be offset by the rapidly growing data traffic on cellular networks and by the eventual flood of wireless-connected devices that 5G will make possible.” He cites a 2019 review of environmental levels of RF signals, which did not find an increase in overall levels since 2012 despite the rapid increase in use of wireless communications, in part because of "improvements in efficiency of these technologies and improved power controls of all emitters."[33]

So, as of now there is no evidence on possible bad effects on human health. But health agencies have not directly carried out any assessments. The Swedish Radiation Safety Authority, in its 2018 review, concluded that "despite the lack of established mechanism[s] for affecting health with weak radio wave exposure there is however need for more research covering the novel frequency domains, used for 5G." But in August 2019, FCC decided to maintain its current RF exposure safety standards (adopted in 1996), quoting a statement from the Director of the U.S. Food and Drug Administration Centre for Devices and Radiological Health that "[t]he available scientific evidence to date does not support adverse health effects in humans due to exposures at or under the current limits."[34] Most countries around the world have adopted RF exposure limits that are roughly similar to present FCC limits. The author states that “FCC and similar limits are designed to avoid established hazards of RF energy that result from excessive heating of tissue. A few countries, including India, Italy, and Belgium have adopted lower limits” as a measure of abundant caution.

Health agencies will need to conduct studies to examine the bioeffects of millimetre waves and the projected increase in use of this part of the spectrum. But so far there are no negative findings. But it is known that an individual's greatest exposure to RF energy is when he or she uses a cell phone.

2 ECONOMICS OF 5G: USE CASES AND IMPACT ON ECONOMY

In this section we review the use cases through the analyses of industry leaders and some other research agencies. **These include Huawei, TM Forum, IEEE, Gartner, and IHS Markit.** There are several others like Deloitte, PwC, Ericsson, Qualcomm too. While the projections vary, they are unanimous in that 5G is a game changer, that will transform society. The **IHS Market predicts that 5G will emerge as a General Purpose Technology (GPT), in the league of printing press, steam engine, electricity, telegraph, and the Internet. Mobile will be as ubiquitous as any of these GPTs.**

2.1 DIGITAL ECONOMY – 5G, AI, ML AND MORE

The UNCTAD (United Nations Conference on Trade and Development)'s Digital Economy Report 2019 estimates that the digital economy is anywhere between 4.5 to 15.5 percent of world GDP. It does acknowledge that there is no widely accepted definition of digital economy, and that the data, especially from developing countries, on key components and dimensions, is not all that accurate. Yet, this estimate is fare. Also, value added in the Information and Communications Technology (ICT) sector, the United States (US) and China together account for 40 percent of the world's total.[35] In the last decade, global exports of ICT services, and that of services that can be delivered digitally, grew faster than those of overall services exports. In 2018 digitally deliverable services exports amounted to $2.9 trillion, which was 50 percent of global services exports.

That, the digital economy is growing more rapidly than the overall GDP in several countries, is clear from this. In its report of March 2018 *"Defining and Measuring the Digital Economy",* the US Bureau of Economic Analysis (BEA) estimated that from 2006 to 2016, "digital economy real value added grew at an average annual rate of 5.6 percent, outpacing the average annual rate of growth for the overall economy of 1.5 percent. In 2016, digital economy was a notable contributor to the overall economy – it accounted for 6.5 percent of current-dollar GDP, 6.2 percent of current-dollar gross output, 3.9 percent of employment, and 6.7 percent of employee compensation".[36] Therein lies the importance of digital economy – faster growth than any other sector, and higher contribution to the national GDP. Digital economy in 2016 contributed $1.2 trillion to the US GDP.

European Union estimates that digital Information and Communications Technology (ICT) market revenue in Europe - the digital economy in terms of computing technologies, and tech businesses – will touch nearly 1,085 billion euros by 2019.[37] The Department of Digital, Culture, Media & Sport (DCMS) of the UK government published digital economy estimates in August 2016. The digital sector Gross Value Added (GVA) figure was placed at GBP 118.4 billion in 2015, which was 7.1% of the UK GVA, which was GBP 1661.1 billion.[38] The digital sector grew by 6.1% in a year, while it grew by 21.7% from 2010-2015. This is to be compared with the overall economic growth of only 2.3% in a year, and 17.4% since 2010. The digital sector employed 1.5 million people in 2017, which was 4.6% of total UK jobs. This number was 3.1% more than that in 2016, and a 16.1% increase over 2011.[39]

China today is at the forefront of using the Internet to power its economy, create jobs, develop high end skills for the data driven knowledge economy. Be it robotics in manufacturing, smartphones, telecommunications technology development, e-commerce, social media, Artificial Intelligence (AI), Machine Learning (ML) - China is innovating. It is not merely copying, but developing advanced technologies – 5G mobile routers and phones, quantum computing, quantum encryption; and much more. It has realized the potential of cyberspace for economic growth – by 2021 it is estimated that half of its GDP will come from digital economy. The government has a grand vision for digital China that will be powered by generous government funds for R&D; unleashing the potential of private sector through partnership and regulation that enables easy access to domestic market for experimentation, and for its further growth through exports to markets in Europe, Asia and Africa as well.

China Academy of Information and Communications Technology (CAICT) under the Ministry of Industry and Information Technology, estimated the digital economy at 16 trillion yuan ($2.32 trillion) in the first half of 2018, which was 38.2 percent of GDP, while it was 32.9-percent in 2017.[40] Growing digital economy is key to faster growth of GDP. It is a direction that other countries, especially India, too must take. McKinsey Global Institute report predicts that digital economy of India will grow to $355 to $435 billion of GDP in 2025, from $200 billion in 2017-18, which was 8 percent of GDP.[41] India is aiming to grow the ICT sector to a trillion dollars, with overall GDP of five trillion by 2024. Would it happen?

Critical to the growth of digital economies is digitization of more and more business and governance processes; collection of more data and its use to develop AI and ML apps to increase productivity and efficiency; build talent to develop AI and ML in areas of interest to a country; cloud data centres; and build data protection framework. Most critical is the network infrastructure that enables more apps – entertainment, productivity and transformational – through connectivity of billions of devices for real time response and action in health care, robotic surgery, driverless cars. 5G infrastructure is the key to achieving that potential along with AI and ML to deliver more value to society. To understand the importance of the 5G infrastructure for the digital economies, and the economic growth of nations, it is prudent to begin with a report *"The 5G economy: How 5G technology will contribute to the global economy?"*, published in January 2017 by IHS Economics and IHS Technology, commissioned by Qualcomm Technologies for independent assessment of the importance of 5G technology to the global economy through 2035. The authors predict that 5G will act as a catalyst that will thrust mobile technology into the realm of General-Purpose Technologies (GPT) through the pervasive adoption of the mobile across all sectors of economy and governance. It will not be merely a useful communication or entertainment device for individuals all over the world. Earlier GPTs include The Printing Press, The Steam Engine, Electricity, The Telegraph, and The Internet. "GPTs often are catalysts for transformative changes that redefine work processes and rewrite the rules of competitive economic advantage".[42] Based on evaluation of 21 unique 5G use cases, across different industry verticals, for impact on productivity and efficiency, the report studied the impact of 5G value chain on strengthening and expanding the current mobile technology platform. Key findings of the report include:

1. "5G will enable $12.3 trillion of global economic output in 2035.
2. Global 5G value chain will generate $3.5 trillion in output, and support 22 million jobs in 2035.
3. The 5G value chain will invest $200 billion annually in R&D to continually expand and strengthen the 5G technology base within network and application infrastructure base.
4. 5G will fuel sustainable long-term growth to global real GDP. From 2020 to 2035, the total contribution of 5G to real GDP will be equivalent to an economy the size of India – currently the seventh largest in the world."

These are very far reaching predictions for economies around the world. There are several other studies which underline the importance of digital to the GDP of nations. For example, adoption of AI by advanced economies is predicted to increase their GDP by over 2-4 per cent by 2035.[43] Digitalisation of existing processes in business and governance lend themselves to algorithmic machine learning as more and more data accumulates, thereby increasing efficiency and productivity. Fast compute power is available in the clouds that can be taken advantage of by AI and ML. Likewise, widespread use of Internet of Things (IoT) in industrial applications and home appliances, with faster networks, contribute to productivity, and hence to GDP. The intersection of 5G with AI and ML will be critical to the growth of GDP. India can ignore these technologies only at peril to its economy, and national security.

2.2 OPPORTUNITIES OF 5G

Huawei lists top 10 use cases, along with 14 more in the second category. These are given below.[44] It analyses various business models for their take off, using the cloud computing and cloud-RAN access scenarios. For example, it believes that the revenue model for VR Apps in cloud servers will be Ad-based, subscription-based, or usage-based.

1. Cloud Virtual & Augmented Reality – Real-time Computer Rendering Gaming/Modelling.
2. Connected Automotive – ToD, Platooning, Autonomous Driving.
3. Smart Manufacturing – Cloud Based Wireless Robot Control.
4. Connected Energy – Feeder Automation.
5. Wireless eHealth – Remote Diagnosis With Force-Feedback.
6. Wireless Home Entertainment – UHD 8K Video & Cloud Gaming.
7. Connected Drones – Professional Inspection & Security.
8. Social Networks – UHD/Panoramic Live Broadcasting.
9. Personal AI Assistant – AI Assisted Smart Helmet.
10. Smart City – AI-enabled Video Surveillance.
11. Hologram.
12. Wireless eHealth – Remote Surgery.
13. Wireless eHealth – Ambulance Communication.
14. Smart manufacturing – Industrial Sensors.
15. Wearable – UHD Body Camera.
16. Drone – Media.
17. Smart manufacturing – Cloud Based AGV.
18. Home – Service Robotics (Cloud AI Assisted).
19. Drone – Logistics.
20. Drone – Fly Taxi.
21. Wireless eHealth – Hospital Nursing Robot.
22. Home – Home Surveillance.
23. Smart Manufacturing – Logistics & Inventory Monitoring.
24. Smart City – Trash Bin, Parking, Lighting, Traffic Light, Meters.

The SoftBank and Huawei jointly demonstrated some of the potential use cases for a 5G network, which provide ultra-high throughput, ultra-low latency transmission, and edge computing, to SoftBank's business partners.[45]

The demonstration (*details are mentioned in the Appendix 2*) included real-time UHD video transmission using ultra-high throughput, remote control of a robotic arm using ultra-low latency transmission and remote rendering via a GPU server using edge computing. The real-time UHD video transmission demonstrated throughput of over 800 Mbps. Also, the remote control of the robotic arm demonstrated an ultra-low latency one-way transmission of less than 2ms. SoftBank is planning various experiments to study 5G technologies and is planning to launch 5G commercial services around 2020. In edge computing, servers are located nearby base stations, i.e. at the edge of a mobile network, distributed across at required locations. As seen in the previous section, this architecture enables realization of ultra-low latency transmission between the servers and mobile terminals. Also, it is possible to process a huge amount of data gathered by IoT devices to decrease the load of the mobile network.

2.3 TM FORUM PREDICTIONS (TM FORUM APRIL 2019 REPORT)

TM Forum believes that the greatly expanded capacity, lower latency and higher throughput, along with significant advances in the core network, will make 5G truly transformational in terms of the services delivered by telcos to their customers. While 5G has been positioned as essential to driverless cars, remote medical and surgical applications, automated industrial and manufacturing processes, haptic bodysuits that deliver full tactile internet, and a great many more headline-friendly and futuristic applications, its first targets are consumers. Smartphone-based mobile data consumption will rise, largely because of demand for higher-quality video leading to growth in mobile broadband subscriptions.

Quoting Ericsson forecasts, TM Forum says that the global mobile data traffic will grow five-fold between 2018 and 2024, to reach 136 Ebps per month. Smartphones data share is set to increase from 90% to 95%, of this total data, over the same period. (FWA not included in the forecast) Ericsson predicts that 5G will account for 25% of smartphone data by 2024, while GSMA expects regional variations in the 5G uptake. 5G will account for almost half of all mobile connections in the US in 2025, compared to 31% in Europe, and 13% in

Asia Pacific. 5G will not become a globally dominant technology within this timeframe; it's worth recalling that LTE has become the dominant mobile technology only a decade after its launch. Ericsson expects 1.5 billion 5G subscriptions by the end of 2024, which represents just 17% of total subscriptions. GSMA, on the other hand forecasts a lower share - only 14% of global mobile connections for 5G by 2025 (excluding the IoT). Accordingly, the surge in data consumption per active smartphone is expected to be most dramatic in North America, where Ericsson forecasts it to grow almost six-fold from 8.6Gbps per month in 2018, to 50Gbps per month in 2024. Western Europe will see growth of more than five times to 32Ebps per month, with North East Asia seeing almost tripled growth to reach 21Ebps per month. Ovum has forecast less than 1 million 5G connections globally at the end of 2019 - 37 million by end 2020 and 136 million at the close of 2021.

How will the business plans based on unlimited data for consumers, transform to handle such large data requirements? Though popular as a means of stimulating migration to new networks with surplus capacity, most plans now have usage limitations, such as data consumption, and/or download speed. However, 5G promises a huge capacity boost and improvements in the cost efficiency of delivering mobile data. It is expected that truly unlimited data plans will emerge to fulfil the projections for data consumption noted above. But, while data consumption will grow by 500%, revenue growth will be only 5% between 2017 and 2025, with most of it in China, whereas the Europe and North America will be flat.

More revenue can be generated by telcos through the delivery of breadth of services enabled by 5G, by tapping the market for niche services in verticals, in partnership with the industry leaders. TM Forum predicts that telcos alone cannot target this market. They must consider specializing in certain verticals, or offering horizontal cap. Early market for 5G FWA is likely to be domestic broadband in dense urban areas where the last mile (the most expensive part of a fixed broadband connection to deploy) represents a key challenge to provisioning fixed lines. Rural areas lacking in fixed broadband coverage and small and medium enterprises are also targets. There are also opportunities in developing markets where fixed broadband networks are limited.

Significant gains offered by 5G in terms of capacity, latency and throughput are likely to position cellular to compete with Fibre-To-The-Premises (FTTP) solutions, also known as FWA. Therefore, 5G FWA has potential for multiple operators that will benefit from an additional last-mile connectivity option, as well as pure mobile operators looking to expand their portfolio with a domestic and/or enterprise on-premise broadband solution.

A survey of 71 executives from 53 unique telcos by TM Forum found widespread acceptance that they will not be able to deliver 5G and IoT use cases on their own. These verticals include: Agriculture (AR, VR and drones for crop inspection, autonomous vehicles for harvesting, predictive maintenance), Energy (Smart grid with dynamic routing of electricity, smart meter), Entertainment (Immersive entertainment using AR and VR, online gaming), Health Care (Remote diagnosis of disease, emergency response, robotic surgery), Industrial Automation & Manufacturing (Smart factory, process automation, control of robots, sensor networks, AR & VR), Retail (AR and VR shopping, warehouse automation), Smart City (Sensor networks to enable smart energy, smart transportation, air-quality monitoring, smart streetlights, real-time video and drones for public safety), and Transportation (Driver assistance, enhanced safety, autonomous driving, traffic management, predictive maintenance). Partnerships are in the making in these verticals.

Market potential for 5G and IoT

Industry	Size by year	% of CSPs using partner or joint venture strategy
Industrial automation	$239 billion by 2023	69%
Remote monitoring and control	$27 billion by 2023	62%
Global smart grid	$70 billion by 2024	58%
Smart city technology investments	$158 billon by 2024	67%
Digital health	$379 billion by 2024	60%
Global connected car	$219 billion by 2025	48%

Netcracker & TM Forum, 2018 (sources for data: Global Market Insights, IDC, Markets and Markets, Research & Markets)

Figure 19. Market potential for 5G and IoT, industry-wise is as given below (Source: TM Forum 2019)

2.4 IEEE ON 5G APPLICATIONS: AR &VR, AUTONOMOUS VEHICLES, IOT

Augmented Reality & Virtual Reality: The 5G technology demonstration by Samsung, Intel, and Korea Telecom in the 2018 Winter Olympics is cited by IEEE as an example of things to come. One hundred cameras set up in the ice-skating area gave attendees the chance to experience of being on the ice using Virtual Reality (VR). Augmented Reality (AR) was used to display what cross country skiers were seeing in real time overlaid with biometrics like heart rate and other statistics like speed. The Olympic example shows that viewing sports will change in the future – it will be 360 degrees view from the living room. AR and VR are thought to be the “killer” 5G applications.

VR has the potential to make a big impact in healthcare and education too. Paired with mechanicals like special haptic gloves, the low latency of 5G has the potential for touch to be transmitted over a mobile network. Real-time virtual surgery could be performed. It could also be used as a training tool to teach surgeons in remote locations new skills and give them a way to practice and learn the required muscle memories. It could revolutionize education for students of any age.

Autonomous vehicles: Transmission of a full 360-degree view of the world over a mobile network opens up possibilities for self-driving cars. Presently, self-driving cars use cameras to capture a 360-degree view of the car using a combination of cameras and other sensors. This data is then processed and turned into instructions for the car. Self-driving cars in the future will need all of this, and more data to be able to communicate with one another, in real-time without any latency, on the road. The environmental data can be shared, messages relayed, and “smart traffic” can be created from vehicular communications. Some of this data will be processed on the car’s hardware and some will be streamed back to a base station, with MEC capabilities. But no matter where the data is processed, the low latency 5G aims to deliver is key to create a safe, reliable car. Self-driving cars will have a huge impact on the economy and reshape the transportation system. Personal ownership of vehicles likely to give way to autonomous vehicles for rides using services like Uber, Ola or Lyft.

Internet of Things: Industrial Internet of Things (IoT) devices will generate huge volumes of data that will need 5G for mission critical applications. In smart factories of the future, every machine will be networked together to communicate with one another, as well as with the human operators who will interact with them. Together with AR, this data can give humans a real-time view of the status of jobs, health of machines, and offer troubleshooting recommendations when needed. Smart factories of the future will have humans and machines working seamlessly together aided by 5G technologies. They will not be purely robotic.

2.5 GARTNER PREDICTIONS: (REPORTED IN IE, 18 OCTOBER 2019)

- Outdoor CCTVs to be the largest market for 5G IoT over 3 years;
- 70% of the 5G IoT endpoint installed base in 2020 will be represented by CCTV cameras;
- Million by 2020, 6.2 million in 2021, 11.2 million in 2022; and
- Connected cars will surpass outdoor CCTV cameras by 2023.

5G connected cars actively connected to a 5G service will grow from 15% in 2020 to 74% in 2023, and 94% in 2028. At that time 5G technology will be used for enabling messages to be sent and received within and between vehicles. Connected cars will offer the biggest opportunity for 5G IoT in the long term. Around 53% of the overall 5G IoT endpoint opportunity in 2023 will be represented by the automotive industry. Embedded connected-car modules are the major use case for 5G – growing faster than the overall growth in the 5G IoT sector. 5G IoT Endpoint installed base to grow from 3.522M in 2020, to 48.59M units in 2023.

2.6 IHS MARKIT

IHS Markit assessed the technological diffusion cycle, adoption, and potential long-term economic contribution of 21 foreseeable 5G uses cases, which fall into the three broad classifications of eMBB, MIoT (mMTC), and Mission Critical System (MCS) via ULLTC. This list of likely 5G use cases is merely representative of what the technical innovations of 5G will make possible.

eMBB: The mmWave promises high data speeds in office buildings, industrial parks, shopping malls, and large venues; and improved capacity to handle a significantly greater number of devices using high volumes of data, especially in localized areas. Immediate use cases include: Enhanced indoor wireless broadband coverage, Enhanced outdoor wireless broadband, Fixed wireless broadband deployments, Enterprise teamwork/ collaboration, Training / education, AR & VR, Extending mobile computing, Enhanced digital signage.

The eMBB use cases are an extension of the existing 4G value, hence they will be the first to arrive. As soon as 5G networks become commercially available, these apps will see quick adoption. While there are going to be significant impacts to global economic activity as a result of the eMBB use cases, the net economic impact of 5G will be less transformative than with the MIoT and MCS cases.

mMTC*:* Massive Internet of Things (MIoT)

The M2M and traditional IoT applications enable significant increases in economies of scale that drive adoption and utilization across all sectors. 5G builds upon that with improved low-power requirements, the ability to operate in licensed and unlicensed spectrum, and improved coverage. It will lower costs within the MIoT. This will in turn enable scaling of MIoT apps, which will drive much greater uptake of mobile technologies to address more MIoT applications, such as: Asset tracking, Smart agriculture, Smart cities, Energy / utility monitoring, Physical infrastructure, Smart homes, Remote monitoring, Beacons and connected shoppers.

The MIoT use cases are where we start to see the transformative impact of 5G. Many of these applications are being serviced today by a mix of previous generations of cellular technologies as well as low-power wireless technologies operating in unlicensed spectrum. LTE is creating purpose built cellular technologies such as Cat-M1 (eMTC) and Cat-NB1 (NB-IoT), which are starting to incorporate low-power improvements to address the growing cellular IoT market. These technologies are establishing the foundation for 5G MIoT, which will continue to improve upon the extended low-power operation capabilities, as well as the ability to utilize both licensed and unlicensed spectrum. IHS Markit believes that 5G has the potential to address a much larger segment of the M2M and IoT markets, as well as reducing costs because of economies of scale.

URLLC: Mission Critical Services (MCS)

The MCS represents a potentially huge growth area for 5G to support applications that require high reliability, ultra-low latency connectivity with strong security and availability. These include: Autonomous vehicles, Drones, Industrial automation, Remote patient monitoring / telehealth, Smart grid. The use cases show new applications for mobile technologies. The potential to support applications with high reliability, ultra-low latency, widely available networks with strong security creates significant growth opportunities. But the growth will be dependent on market innovation and development of appropriate regulation as well as the deployment of 5G networks. Hence, it's likely to take longer, but the overall impact to society is expected to be tremendous.

2.6.1 5G MOBILE TO GPT – IHT PREDICTIONS

The IHT predicts that with many new innovative applications in manufacturing and other fields under development, 5G is poised to become a GPT. Investments in new infrastructure will be needed, since with finalization of new 5G standards by 3GPP, there will be continuous evolution. However, government regulations conducive to the growth will have to be put in place. Areas of interest and future study items for 5G New Radio Phase 2 include Vehicle-to-Everything (V2X) communications, coexistence with and licensed access for unlicensed spectrum, and Integrated Access and Backhaul (IAB) for more efficient backhaul infrastructure. The first phase of 5G commercial deployment will be followed by continued research in technology improvement and new use cases for several more years.

Over the last three decades we have seen the impact of the Internet, from being merely a communication tool via email, to becoming a part of our daily lives to engage in e-commerce, social media, governance, AI, ML and much more. As a technology it emerged as a GPT, with much more transformational, and disruptive impact on society in the last decade, than was anticipated when email was launched in the 1960s, and e-commerce in the 1980s. The Internet became internet!

5G is predicted to hit an adoption tipping point soon, that is likely to lead to transformational, and disruptive changes to industries and entire economies. IHS Markit anticipates that as 5G technology advances and becomes embedded within devices, machines and processes, wireless communication will similarly have a transformative effect across industries and geographies and help spur a new age of innovation and economic advance. Uber, Ola and Lyft are examples of companies that are spearheading sharing using mobile technologies. However, despite media and investor hype they have to yet to cross the regulatory and legal challenges. This shows that mobile technologies have yet to make significant inroads in radically transforming the industrial or public sectors of economies. But uber and many industrial applications – MCS and MIoT – are harbingers of transformations in society and are redefining economic competitiveness. The IHS Markit predicts that 5G will put mobile technology solidly into the realm of GPTs.

2.6.2 5G NETWORK DEPLOYMENTS

There are multiple classes of radios that can be used in a wide range of end devices, to accomplish diverse set of tasks. The standard has the potential to utilize not only licensed and unlicensed spectrum, but also shared spectrum, as well as operating on private and public networks. The diversity of use cases and device types; understanding of the different industries and use cases they are trying to address; partnership with industry verticals, are likely to help telcos succeed in the marketplace. 5G will be able to address an unprecedented number of industrial use cases, with new devices. Others may have network requirements that necessitate either a private network, or a guaranteed slice of spectrum. Telcos will have to be flexible. At the end of a decade of LTE networks, the Global Mobile Suppliers Association (GMSA) reported in October 2016 that there were 537 total commercial networks. 5G will use 4G with LTE-A and LTE-A Pro, as a foundation for future 5G network upgrades, to improve the user experience, but it will target the industry. Mobile network operators and other 5G ecosystem players will need to engage industry verticals like manufacturing, energy, healthcare, transportation etc., to drive interest in 5G so as to encourage network upgrades.

However, as noted in section 2.9, high investments are required by operators on 5G spectrum, upgrading cell site technology in target urban areas for the rollout of 5G devices, as well as enhancing the 4G service; setting up a high-capacity dark fibre network to connect a number of new, energy efficient and highly secure data centres; deploying 5G-ready, fully integrated cloud-native core network in new data centres, with high initial capacity, and scalable cost effectively. Plus carrier-aggregation technology on thousands of sites in the busiest areas, for improving speeds for customers are some of the important investments. As an example, the UK telecom operator— Three has committed to spend £2 billion (GBP), underscoring the fact that different 5G use cases (eMBB, URLLC, mMTC and FWA) have different requirements when it comes to bandwidth, latency, mobility, security, reliability and pricing.

Moor Insights & Strategy (MI&S) estimated in its 2018 report that the new IT hardware infrastructure spending attributable to 5G will grow to be approximately $326 billion by 2025, including data centre, edge computing, network transformation activities, and modems.[46] This does not include 5G smartphones, or other endpoints. Cumulatively, this represents $1,197 billion of investment from 2017. Its projections include that by 2022 there will be roughly Nine billion connections with 500 million of them on 5G. The average user will consume 12 GB of data and in total globally will generate 71 Exabytes of data. Clearly, there will be significantly greater demand on existing infrastructure.[47] Early and fast adoption of 5G is driving carriers to increase their forecasts for 5G subscriptions. Ericsson's June 2019 Mobility Report increased its original forecast of 1.5 billion 5G subscriptions in November 2018 to 1.9 billion subscriptions by the end of 2024. GSMA predicts that the number of 5G connections will reach 1.1 billion, 12% of total mobile connections, by 2025; this will account for about 30% of connections in China and Europe and about 50% in the United States. New 5G connections are expected to boost overall operator revenues to $1.3 trillion in 2025.[48]

In mainland China alone, the Chinese Ministry of Industry and Information Technology (MIIT) believes that 5G expenditures of the three domestic operators will hit a peak of $47 billion in 2023. MIIT believes that there will be 588.3 million 5G subscribers in China alone by 2022, up from 31.9 million in 2019.[49] The GSMA estimate of 1.1 billion 5G connections globally by 2025, bears this out. Bloomberg reported on October 30, 2019 that China's three state-owned wireless carriers, China Mobile, China Telecom, and China Unicom Hong Kong launched 5G mobile phone services on October 31, 2019.[50] This was a strong statement of its intent to become a technology power. China Mobile will provide its services in 50 cities including Beijing, Shanghai and Shenzhen, with packages priced as low as 128 yuan ($18) a month. The other two telcos too introduced their services at comparable rates. Interestingly, the operators advanced the rollout by several months. With this, China will quickly become the largest provider by virtue of its huge population and investment by the companies, though the US and South Korea too have introduced 5G to parts of some cities. Is it a message of its resolve to push back the US boycott of China-based 5G equipment supplier and technology giant— Huawei?

More than 10 million subscribers had pre-registered for 5G, for faster access to videos and games, more virtual reality applications and for improved performance for mobile videoconferencing. China Mobile's 5G packages for the heaviest users are priced similar to 4G plans that go as high as 588 Yuan (approx. $83) a month. The largest cities including Beijing, Shanghai and Shenzhen will get full coverage first. The three operators have projected a combined capital spending of 302 billion Yuan (approx. $42.5 billion) in 2019. The scale of 5G infrastructure rollout across China by Huawei, points to its continued dominance in the domestic market – the largest market in the world. This is helping it in other markets; Huawei claimed in July, 2019 that it had signed more than 60 commercial contracts to supply 5G networks around the world, including at least 28 in Europe.[51]

Ericsson also announced that it had signed 78 commercial 5G agreements or contracts with unique operators. 31 of these have been publically announced with customers around the world, such as AT&T, Sprint, Verizon, GCI, T-Mobile, RINA Wireless, U.S. Cellular in the US; Telia Norway; Vodafone UK and Germany; Telenor Sweden, and Denmark; SK Telekom, LG+ in South Korea; Telstra in Australia.[52] Nokia too announced 42 commercial 5G contracts around the world which includes T-Mobile, Telia and SoftBank.[53]

2.6.3 ECONOMIC CONTRIBUTION

The 5G economy will be characterized by strengthening of the infrastructure and technology base in the next few years, followed by large scale global deployment of the 5G use cases. It is clear that the early deployments are likely in eMBB applications. MIoT (mMTC) and MCS (URLLC) applications will gain traction in the medium-to-long term as 5G drives mobile deeper into industrial applications. It estimated that Global output is a $12.3 trillion global opportunity.

The economic impact of 5G, based on analysis of 16 major industry sectors, and modelling with academic experts, is given below. Some excerpts from the IHT Markit's report are presented in Appendix 3.

5G deployments will positively affect virtually every industry sector. The adoption speed, economic and regulatory structures in different verticals, success of new business models that 5G will enable, will take long, for transforming 5G into a GPT. It is because of this reason that IHS Markit focuses on the longer term horizon and the choice of 2035 as the analysis year. IHS Markit estimates the potential global sales activity across multiple industry sectors enabled by 5G could reach $12.3 trillion in 2035. This represents about 4.6% of all global real output in 2035. Manufacturing will see the largest share of 5G-enabled economic activity in 2035—almost $3.4 trillion or 28% of the $12.3 trillion in sales enablement. The information and communications sector will see the second largest share of 5G-enabled economic activity, at more than $1.4 trillion. Implementing any of the 5G use cases will require spending on communication services. Sector-wise contribution to economy is presented as a table in the Appendix 4.

The study estimates that 5G may enable about 4.6% of global real output in 2035, with the ICT sector as high as 11.5%, and hospitality at a low of low of 2.3%. Even though the manufacturing sector will account for nearly 30% of global real output in 2035, the 5G-enabled manufacturing sales will lead to 4.2%, slightly below the overall average. But 5G could enable 6.5% of public service (government) and 6.4% of agricultural output in 2035, supported by smart city and smart agriculture deployments, respectively. The availability of autonomous vehicles and drones, driven by 5G, will stimulate sales of driverless cars and Unmanned Aerial Vehicles (UAVs) to consumers. Deployment in agricultural and mining applications ranging from surveillance of remote natural resources to autonomous transport of ores to self-driving tractors.

2.7 5G VALUE CHAIN IN 2035: $3.5 TRILLION IN OUTPUT AND 22 MILLION JOBS

The 5G value chain will include technology firms, such as network operators, providers of core technologies and components, OEM device manufacturers, infrastructure equipment manufacturers, and content and application developers. 5G R&D and Capital Expenditure (CapEx) investments over 16-year time horizon till 2035 was estimated by IHT Markit. Seven countries that are expected to be at the forefront of 5G development are: The United States, China, Japan, Germany, South Korea, the United Kingdom, and France. Over 16 years, collective investment in R&D and Capex by firms that are part of the 5G value chain within these countries will average over $200 billion annually. US at $1.2 trillion, will account for about 28 per cent of global 5G investment, followed by China at $1.1 trillion, which will be 24 per cent. Spending beyond the seven core countries will make up about 23 per cent of the global 5G investments.

From foundational R&D investments in early period, the next phase will help bring the 5G use cases online, thereby enabling sales across virtually all industry sectors while also driving sales throughout the 5G value chain and its associated supply networks. By 2035, the countries will see results commensurate to the investments made. Many developing and emerging economies that are mobile oriented will adopt 5G and see its significant economic impact. IHT Markit estimates of the value country-wise is given below:

- Global 5G value chain output and employment in 2035
- China: Gross output: $984B; Employment: 9.5M
- United States: Gross output: $719B; Employment: 3.4M
- Japan: Gross output: $492B; Employment: 2.1M
- Germany: Gross output: $202B; Employment: 1.2M
- South Korea: Gross output: $120B; Employment: 963K
- France: Gross output: $85B; Employment: 396K
- United Kingdom: Gross output: $76B; Employment: 605K
- Rest of the world: Gross output: $800B; Employment: 3.6M
- Global total in 2035: Gross output: $3.5T; Employment: 22M

Like previous generations of mobile technologies, 5G will have a profound effect on how people live, work, and interact, but 5G will transcend the communications field and help fundamentally alter how a vast and diverse group of industries operate. It views 5G as a catalyst that will thrust mobile technology into the realm of GPTs.

2.8 GSMA REPORT FEBRUARY 2019: RELEASED AT MOBILE WORLD CONGRESS (MWC) BARCELONA 2019

A 2019 report from the GSMA, predicts that 5G will account for 15 per cent of global mobile connections by 2025. The report states that another 16 major markets worldwide will switch on commercial 5G networks in 2019, following on from the first 5G launches in South Korea and the US in 2018. The operators worldwide are currently investing around $160 billion per year (capex) on expanding and upgrading their networks. GSMA believes that 5G will usher an era of Intelligent Connectivity, which along with IoT, big data and AI, will drive economic growth over the next few years. More than a billion new people will connect to the Mobile Internet, spurring adoption of mobile-based tools and solutions in areas such as agriculture, education and healthcare, which will improve livelihoods of people around the world.[54]

Its key predictions are the following:

- The number of 5G connections will reach 1.4 billion by 2025 – 15 per cent of the global total. By this point, 5G is forecast to account for around 30 per cent of connections in markets such as China and Europe, and around half of the total in the US;
- 4G will continue to see strong growth over this period, accounting for almost 60 per cent of global connections by 2025 – up from 43 per cent last year;
- The number of global IoT connections will triple to 25 billion by 2025, while global IoT revenue will quadruple to $1.1 trillion;
- One billion new unique mobile subscribers have been added in the four years since 2013, bringing the total to 5.1 billion by the end of 2018, representing about two thirds of the global population;
- More than 700 million new subscribers are forecast to be added over the next seven years, about a quarter of these coming from India alone;
- An additional 1.4 billion people will start using the mobile internet over the next seven years, bringing the total number of mobile internet subscribers globally to Five billion by 2025 (more than 60 per cent of the population).

The report says that mobile technologies and services generated 4.6 per cent of GDP globally in 2018 (amounting to $3.9 trillion of EVA); forecast to grow to 4.8 per cent of GDP ($4.8 trillion) by 2023 as a result of the improvements in productivity and efficiency brought about by proliferation of mobile services. The mobile ecosystem supported almost 32 million jobs in 2018 (directly and indirectly) and contributed to the funding of the public sector, with more than $500 billion raised through general taxation. 5G will contribute $2.2 trillion to the global economy over the next 15 years, with key sectors such as manufacturing, utilities, and professional and financial services benefitting the most from the new technology.

3 GEOPOLITICS OF 5G: CYBER SECURITY AND NATIONAL SECURITY

As we have seen above, a telecommunication network comprises: radio access network, core network, transport network, and interconnect network. It is the RAN, which in its fifth generation, has made the mobile and other mobile devices, access services for mobile ultra-high broadband, machine-to-machine (IoT), and mission critical applications that require ultra-reliable low latency access.

3.1 SO, WHAT'S NEW IN 5G? A BIT OF RECAP ON THE KEY DESIGN FEATURES OF 5G

We have noted that there are many types of RANs such as the 3GPP access networks: GSM/GPRS, UMTS, EUTRAN, NR, satellite, and non-3GPP access networks: Wi-Fi or fixed (wired) access network. RAN connects a user to the services such as telephone calls and Internet access over the core network. It is the transport network layer that connects RAN to the core, and the base stations within the RAN connected with each other. The interconnect network connects different core networks with each other. Standardized signalling systems and interfaces help transfer voice and data across the globe with high quality and consistency.

All of these networks carry three types of traffic: signalling traffic, user payload traffic, and management traffic. The signalling plane transports messages that are used to control user sessions, e.g. establishing a call or data session. This is the control plane. The contents of a call or web page is referred to as user plane or user payload. The management plane includes management of monitoring, troubleshooting, configuration and optimization of networks.

All these planes are subject to attacks by cyber attackers for varying reasons:

- Signalling – the metadata which supports the networks is targeted to obtain information such as the geographical position of a subscriber. Modification of signalling traffic can re-route calls or intercept SMS messages of a target for eavesdropping purposes or denying service. Such security risks are similar to those faced by previous generations, but perhaps more developed and complex. Telecom signalling is regularly under attack. In current 5G 3GPP standardization, security takes a central role.

- User payload traffic requires appropriate security measures to protect their privacy, confidentiality and integrity.
- Management layer attack enables hackers to gain access to network resources, which can alter network traffic and data. Security controls such as access control, security monitoring, segregation of network traffic etc. are standard measures to mitigate management related risks and threats.

The cyber security threats are nearly the same in 5G networks, as in the previous four generations. Known malware is still the largest modus operandi since the networks, servers, and devices are not patched in time. Remember the "WannaCry" attack vectors – the vulnerability in the Windows OS was known, but thousands of machines around the world had not been patched. Telecom networks using specialized equipment can be targeted by specially developed malware, if the stakes are very high. For example, Stuxnet targeted Siemens industrial control system to disrupt the centrifuges in the Iranian nuclear reactor. Attacks are easy to carry out since exploits are available for free or as attack toolkits as-a-service. Hence, the frequency of attacks is increasing. Critical information infrastructure attacks can have a larger payoff for a nation against an adversary. For example, the power outage or disruption of financial systems comes with handsome rewards for the attacking nation. Financial frauds, identity theft of millions of users of a service, can devastate a nation.

Telcos are an extremely useful target for nation-state actors and espionage, because the networks store and transfer location data and sensitive information like messages and voice conversations between high value targets, e.g. government officials, decision makers and high-ranking leaders. Such information is of high interest to intelligence organizations from different parts of the world. Industrial espionage, likewise has high payoffs since more and more of the valuable assets a company has, are created, stored and shared digitally. Gaining access to a company's trade secrets like financial records, pricing information, intellectual property like new technology/innovations, and sensitive customer information, results in making the attackers highly competitive without investing time and money in R&D. Nation-states, directly or through rogue non-state actors can track adversaries, since all social, economic and political activities are now in cyberspace, mediated through the public telecom networks. Intelligence gathering is a lot easier now. All these are well known threats. So are the risk mitigation techniques and processes. Risk assessment and due diligence to protect a network, or an enterprise remains the same as in previous generations.

The functionalities involved in the exchange of signalling messages between the network entities, and those for transport network that carries user/application traffic, are different. As a consequence, separate network functions are defined for these two types of roles, making it possible to plan the hardware and software equipment separately for CP and UP. Scalability of networks becomes much easier to cater to bandwidth hungry apps – and the costs of purchasing, deploying and maintaining the network elements fall dramatically. The use of CP/UP splitting concept when standardizing the architecture for any new telecommunication network seems an absolute necessity. Virtualizing network functions, network slicing, hosting content closer to the users, provide the mobile network operators with designing and operating cost effective telecom networks. And this is where SDNs and NFV fit in. They support the flexibility and dynamics of the growing number of advanced terminals and intelligent machines at the networks' edges. SDNs can provide improved speeds and lower latency while eliminating bottlenecks.

SDNs decouple hardware, such as that which forwards IP data packets, from software - the control plane - that carries signalling traffic for routing through network devices. Software is executed not necessarily in the equipment but maybe in the cloud or in clusters of distributed servers. That means networks could be built and reconfigured centrally in an automated fashion, rather than having network managers hop from device to device to make changes manually. From a software-based, centralized control plane, network administrators can provide services through the network despite the connected hardware components.

NFV is often paired with SDNs - basic idea behind NFV is to decouple software from hardware. The concept uses CPU and resource virtualization and other cloud-computing technologies such as orchestration, network slicing, and mobile edge computing to migrate network functions from dedicated hardware to virtual machines running on general-purpose hardware. NFV can boost speed, flexibility, and efficiency when deployed with the new services expected to be ushered in by 5G. Components can be upgraded to accommodate a service provider's needs. With NFV, service providers can deploy various network functions, such as firewall or encryption, on Virtual Machines (VMs). Network administrators no longer need to invest in expensive, proprietary hardware to set up a service chain of network-connected devices. And it's easier and faster to install these network functions, since NFV can help virtualize multiple appliances in the network.

NFV will enable 5G network slicing, allowing various virtual networks to run on top of a single, physical infrastructure. Moreover, 5G NFV will allow a physical network to be divided into various virtual networks capable of supporting multiple RANs. NFV can also address barriers to 5G by optimizing resource provisioning of the virtual network functions (VNFs) for price and energy, scale VNFs and ensure VNFs consistently operate properly. Network slicing has emerged as one of the most important concepts to realize "extreme flexibility" in 5G mobile networks. The current mobile networks are optimized to serve only mobile phones. However, 5G mobile networks need to serve a variety of devices with very different, heterogeneous quality of service (QoS) requirements without interference among one another for all three categories – eMBB, mMTC, URLLC. MEC as a tool helps achieve low latency through MEC, and locating clouds closer to users.

In short, 5G is all software-enabled, and software-controlled. It's an IP network. So, all the vulnerabilities kick in. There are few hardware choke points that can be controlled or isolated to handle attacks, as has been the case in 3G and 4G networks. So the attacks, if successful, are likely to be more severe. But the operator will have to do risk assessment while designing the network for specific applications that it's planning to cater to. Standard risk based processes and technology will have to be deployed as is done for existing networks.

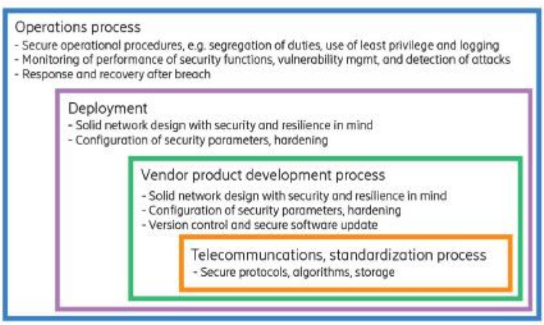


Figure 20. Key security considerations. [Source: Ericsson Inc.]

3.2 SECURITY ARCHITECTURE IN 5G

The 3GPP has standardized the security in 5G to support the following services as was for 4G: VoLTE using the IP Multimedia Subsystem (IMS) for voice services, and Internet connectivity. 3GPP standards also cover some aspects of machine type communications and IoT. But any security issues related to the actual application are not within its scope; these need to be taken care of over the top. Ericsson quotes an example of a temperature controller in a refrigerated goods wagon of a train with IP connectivity, which seen from the general 5G view, requires that the authentication of the management traffic to the controller must be addressed over the top, since the IP address may be accessible via the Internet, so anyone could send messages to the controller.[55]

Huawei also acknowledges the security challenges and opportunities brought by new services, architectures, and technologies, as well as higher user privacy and protection requirements. The diversified use scenarios present different risks, which underline the need for well-defined 5G security standards and technologies. It highlights that the 3GPP security group analyzed threats and risks in 17 security areas in 2018, which include: Security architecture, authentication, security context and key management, RAN security, Security within NG-UE , authorization, subscription privacy, network slicing security, relay security, network domain security, security visibility and configurability, credential provisioning, interworking and migration, small data, broadcast/multicast security, management security, and cryptographic algorithms.[56]

However, 3GPP does not standardize how 5G system functions are implemented and realized. The main purpose of the specifications is secure interoperability between the functions required to provide network connectivity. The standard specifications talk little about virtualization and cloud deployments. Those aspects are handled by other standards organizations, especially ETSI ISG NFV (European Telecommunications Standards Institute, Industry Specification Group, Network Functions Virtualization) and ONAP (Open Network Automation Platform). Some details are not standardized at all and are left for implementations and deployments. Moreover, it should be underlined that industrial IoT devices, and some other aspects of a digitized society like AI and ML, are not related to the radio access connectivity; hence these are not within the scope for 3GPP.

Huawei highlights the use payload data, and network assets that need protection against attackers. These include users' personal data and communication data, hardware and software assets of wireless and core networks, computing resource assets, as well as accounts, passwords, logs, configurations, and charging data records (CDRs) operated and maintained by operators. The successful attacks can tamper with users' personal data and/or compromise the availability of networks or computing resources. According to 3GPP specifications, "The SUPI (Subscriber Permanent Identifier) which is unique for each 5G user, should not be transferred in clear text over NG-RAN except routing information, e.g. Mobile Country Code (MCC) and Mobile Network Code (MNC)".[57] The Packet Data Convergence Protocol (PDCP) can be used for the air interface and IPsec for transmission to guarantee the confidentiality and integrity of users' personal data. 5G nodes, however, face wireless signal interference on external air interfaces and attacks on protocols to compromise service availability. Some 5G core network elements, such as UDM, process and store users' personal data. As a result, 5G core networks face breach of users' personal data as well as attacks to compromise resource.

The 3GPP's 5G security mechanisms provide new enhancements e.g. encryption, authentication and user privacy security mechanisms, in addition to those which are based on well-proven 4G security mechanisms. The security mechanisms provide reliable links for non-malicious bad radio conditions they do not protect against all possible threats, for instance DDoS and radio jamming. Protecting against DDoS attacks and radio jamming is something that is left for implementation and deployment, e.g. to re-route traffic via other base stations if one is jammed, or scaling mechanisms and selective dropping/throttling in case of DDoS. Therefore, the operator has a bigger role to design and configure the 5G network for cyber-resilience appropriate to its needs and use cases. Huawei treats security in five layers (as mentioned below), two of them in network layers (access and domain), and one each in user and application domains, while one is in SBA domain.[58]

i) **User domain security** to secure user access to mobile equipment through internal security mechanisms, such as a PIN code. This ensures security between the UE and universal subscriber identity module (USIM).
ii) **Network access security** enables a UE to securely authenticate and access services via the network, including the 3GPP access and Non-3GPP access, and to protect against attacks on the RAN interfaces. Additionally, it includes the security context delivery from SN to AN for the access security. Specific security mechanisms include bidirectional authentication, transmission encryption, and integrity protection.

iii) **Network domain security** enables network nodes to securely exchange signalling data and user plane data; and for interfaces between access and core networks and between home and serving networks. For the interfaces between RAN and Core, specific security mechanisms, such as IPsec, can be used to provide security separation and protection.
iv) **Application domain security** enables applications in the user domain and in the provider domain to exchange messages securely. Security mechanisms of the application domain are transparent to the entire mobile network and are provided by application providers.
v) **SBA domain security** enables network functions of the SBA architecture to securely communicate within the serving network domain and with other network domains. These features include network function registration, discovery, and authorization security aspects, as well as protection for service-based interfaces. SBA domain security is a new security feature in 5G. An SBA forms the basis of the 5G core network. To ensure security between UEs in the SBA, security mechanisms such as Transport Layer Security (TLS) and Open Authorization (OAuth) are needed.

Ericsson also lists 3GPP security enhancements over 4G networks which include— **mutual authentication:** the end-users of the 5G system are authenticated for user accountability, and Lawful Intercept; the network is also authenticated towards the end-users so that the end-users know that they are connected to a legitimate network; **confidentiality of user data** which is achieved by encryption of end-user data as it passes through the mobile network. But after the data leaves the 5G system and traverses the Internet, the 3GPP standard does not ensure confidentiality; **privacy** that is protected as in confidentiality of user identities, but the 3GPP standards do not mitigate all privacy threats outside the 5G system. The 5G system protects the messages sent by a social media user while they traverse through the mobile RAN and 5G system core network. Once the message leaves the 5G system, it's on the Internet. The application, such as a social media service must ensure that the message is protected end-to-end; **encryption and integrity protection**: 3GPP standards ensure that appropriate encryption and integrity protection algorithm choices are made. 3GPP works with the security algorithm expert group of European Telecommunications Standards Institute, specifically ETSI SAGE—Security Algorithms Group of Experts. For IP layer and above, 3GPP relies on well-proven IETF security protocols; a **false base station:** in GSM it was possible to identify a subscriber via the IMSI. 3G networks prevented the eavesdropping attacks because the network is there authenticated to the user. But, IMSI catching attacks are still possible in 3G and 4G. However, in 5G standards, even IMSI catching attacks are prevented. This is through a technique where the user's long-term identifier is never transmitted over the radio interface in clear text; **compartmentalization**: there is a clear split between the RAN and the core network functions. If a radio base station gets compromised, the core network, which provides global functions and processes more sensitive data, is still secure. Other examples of compartmentalization are cryptographically separated keys used at mobility events, and network slicing. 3GPP standardization also ensures interoperability of security mechanisms between 5G system functions.

Additional security considerations related to deployment scenarios of 5G system include:

- System-wide security (horizontal security)
    - Network level
    - Slicing
    - Application level security
    - Confidentiality and integrity protection
    - Interconnect (SBA)
- 5G function element deployments (vertical security)
    - NFV
    - Distributed clouds

Telcos too confirms that the 5G standards provide more security than has been the case with the previous four generations. The networks design earlier was based on trust among all telcos. For example, every DNS has to trust other DNS. There is no security in Border Gateway Protocol (BGP), which is used to exchange traffic between telcos. Public key encryption proposed for securing DNS and BGP - DNSSIG, BGPSec - considered for some time, but not fully implemented. Likewise, SS7, fundamental to cell phones and operators, relies purely on trust. An SS7 attack is an exploit that takes advantage of a weakness in its design to enable data theft, eavesdropping, text interception and location tracking. Another signalling protocol Diameter also is open to such attacks.

Better authentication is proposed in 5G. Similarly, user data exchanged between telcos when users are roaming, will be encrypted using PKI. Device with a public IoT address potentially hackable. Telcos will have to provide clean pipe to customers as before.

The BroadForward Security Edge Protection Proxy (BroadForward SEPP) enables secure interconnect between 5G networks. The SEPP ensures end-to-end confidentiality and/or integrity between source and destination network for all 5G interconnect roaming messages. It enables operators to achieve an end-to-end confidentiality and integrity between source and destination network for designated message elements. The 5G standards (e.g. 3GPP TS 23.501 and TS 23.502) stipulate that a SEPP is a mandatory function for MNO interconnect for roaming between standalone 5G cores. It's a pure software solution by design. Software driven networks based on cloud, multi-tenanting, and virtualization are all part of 5G. New code in VM generated at run time to create multiple instances of virtual machines, are all software security challenges. Fortunately, Google, Amazon, eBay etc have solved these problems. Telcos are new to this game, using clouds with 5G standards. So, challenges presented by transformation in the core are not difficult to handle. Software in VM, code by a developer can instantiate new machines at run time, containerisation etc, with flexibility to spin multiple machines, provide network slicing to a user can be handled with available knowledge. Compared to Amazon which runs customer heavy load in multi-tenanting environment, telcos challenge is far less. 5G core network being driven by software needs same security as in software – hygiene, hardening, patching, authentication, and authorisation. For example, Microsoft offers authentication solution via an exclusive container in its cloud. Telcos need to secure all layers, all components, and all devices. USIM has good security encryption algorithms. 5G will have even more secure algorithms. So, secure core will not be a problem, but performance will be a challenge. But then separation of CP and UP opens other possibilities for securing data.

The Wall Street Journal interestingly writes that 5G is more secure, because the architecture, specially network slicing, enables building of security upfront by isolating layers such that a compromised slice, say for an application like health-care with thousands of connected IoT devices, will not propagate to another slice catering to, say a gaming or AR/VR app, or a less critical app on another network slice. Strong security controls, and appropriate policies can be implemented for more critical slices. 5G also provides better control of AI tools, which companies increasingly use to solve cybersecurity challenges. High speed and volumes of data flowing through a corporate network could be a boost for AI technology, since corporate security operations centres would gather and analyze much more information collected by sensors and other IoT devices. Moreover, since the 5G mmWaves can't travel long distances which requires augmentation of traditional towers with smaller antennas every 300 metres on buildings and telephone poles, it would enable easier location authentication, and detection of intruders within a couple of blocks.[59]

From the foregoing it's clear that the security mechanisms provided for in the 5G standards of 3GPP are far more than those in 4G networks. There is high level of encryption for the data packets within the 5G core network, as also in the RANs that enable a mobile or a device access the 5G network. But beyond the 5G there are users and the application providers that include innumerable servers, hosts, IoT aggregators and so on. They have to keep their ends secure. Vulnerabilities in their applications, technologies, and sensitive apps such as autonomous vehicles, AR/VR, robotic surgeries are open to breaches as before. So, security is an enterprise-wide effort, not just confined to 5G network alone. An enterprise will have to follow standard risk based assessment of the network and deploy management and technology controls as before. Additionally, it'll need to analyse the use cases, and deploy OTT security controls for services, apps and so on.

All of these are technical challenges and solutions. Technology deployment and processes around them. But what are the security challenges in the context of national security? We'll briefly touch upon these as perceived by the US, France and the European Union (EU).

3.3 NATIONAL SECURITY CONCERNS OF 5G

5G is an investment for the next decade to realize its full potential in all spheres of economy, and in the mobile moving from a personal device to a General-Purpose Technology (GPT). This infrastructure will transform society, industry, automation and be the backbone for digital economies throughout the world. Unfortunately, the race to control this technology has taken a rather ugly turn with the United States linking Chinese technology to a national security concern, and also to trade issues with China. Starting with cyber security concerns in Huawei 5G technology with potential back doors for espionage by the Chinese government, and Chinese security laws that can enable such espionage, global debate on Huawei and national security has surfaced. What is the reality?

NATO's Cooperative Cyber Defence Centre of Excellence (CCDCOE) report on "*Huawei, 5G and China as a Security Threat*" issued in March 2019 observed that 'To date, there has been no evidence, at least publicly, of significant vulnerabilities in Huawei technology.' The report also notes that "Huawei is the largest telecom equipment manufacturer in the world; it passed Apple as the second largest maker of smartphones after Samsung; presently the only company that can produce at 'scale and cost' all the components of 5G network, with its closest competitors Nokia and Ericsson not yet able to offer a viable alternative".[60] This pretty much answers the cyber security concerns voiced by the US. There are none; no more than those in the underlying technologies from the west. We have seen in the previous sub-section that 5G is more secure than 4G. 3GPP standards provide for much more security in 5G. In so far as backdoors are concerned, nothing has been revealed yet. Snowden revelations in 2013 provided enough proof that the US' NSA (National Security Agency) and the United Kingdom (UK)'s Government Communication Headquarters (GCHQ) are no "saints" when it comes to surveillance and espionage. So, it's a matter of securing the global supply chain to enhance trust in countries, companies, and their products.

It needs to be underlined that many countries, including China and the US have been conducting research on hardware Trojans. Notwithstanding Chinese efforts – over 400 papers since 2010 in Chinese language domestic journals with proposals for Trojan circuit designs – it is the US that is still considered the leader in hardware hijacking. Researchers from the University of Cambridge, believe that "a backdoor on Huawei's HiSilicon chip is more likely to be caught than on a chip of American semiconductor company Xilinx." This group works on both detection and planting of Trojans in processor chips. The British government publishes annual report on the security of Huawei products. March 2019 report identifies hundreds of vulnerabilities in Huawei products. A government official said "It does not identify any deliberately planted back doors but lists numerous problems that are very common in commercially developed programs." This was echoed by CTO, FireEye in media briefing in Hong Kong in July 2019 as follows "Speaking strictly from a security perspective, we have seen nothing from Huawei that would give us alarm".[61]

This pretty much sums up the debate on cyber security concerns in Huawei products, but is not likely to close it. However, linking of Huawei to the Chinese government, and the strict cyber security law in China, can't be overlooked. But then, the US and the UK too have national security laws that allow for mass surveillance, which can force operators, and companies to share the desired data. Then why should the 5G technology be not treated as a global supply chain trust issue, as is the case with all other ICT products and services?

3.4 WHY DOES 5G MATTER?

5G is a big opportunity to build global infrastructure, a challenge to the west. Digital economies will ride on these platforms – routers, switches, base stations, smartphones, towers, cloud data centres! This is a fight over who will build and lead innovation for the next generation of internet and telecommunications technology. Is the western reaction a response to "Made in China 2025" plan? China declared in 2016 its plan to build all core technologies – semiconductor chips, 4G/5G telecom equipment; e-commerce and social media platforms; hardware and software for all kinds of digital economy apps including fintech, digital payments, and entertainment; encryption technologies, quantum computing; smart cities connected through IoT devices for increasing productivity and efficient governance. It's another story that technologies such as facial recognition, CCTV cameras are increasing surveillance and control of people in China. But then so are the uses of same technologies increasing the hold of companies like Amazon, Facebook and Google; and of the western governments over people. Through implicit understanding or coercion of laws enacted in the democratic governments. European biometric database is an example of that.

3.4.1 CHINA CONTINUES TO INNOVATE

Does it mean that it's not cyber security or national security concerns about 5G? It's the Chinese political and technological challenge to the hegemony of the west in 5G infrastructure that is the issue. 5G will be critical to the growth of digital economies. From reverse engineering, copying, espionage, forcing global companies to transfer technology as a condition to access its vast market, China, in recent years has emerged as an innovator in many advanced technologies. 5G technology and smartphones constitute only one of these. The AI, ML, digital payments, social media, smart cities and in many more areas its prowess is becoming visible. To highlight the importance of innovation, one example may suffice – processing e-commerce transactions' peak volumes on festivals like single day – a big challenge that companies like Alibaba have taken head on. The peak demand of e-commerce transactions in the US is only three times the off-peak demand, while it's eleven times in China. The challenge is to process peak volumes of transactions in acceptable timeframes. China treated this as an opportunity to scale up its technological prowess.

Alibaba's payment platform processed 120,000 transactions per second, which was three times that of a leading global payment system capacity. Chinese cloud providers created world records in computing efficiency. In a 2016 Sort Benchmark competition on cost efficiency, Alibaba's cloud set the record at $144 for sorting 100 terabytes of data, while it was the US companies that held the record at $155 in 2015, and $451 in 2014. Similarly, in sorting a trillion un-ordered records of size 100-bytes, Yahoo was at the top with 1.4 terabytes per minute (tpm) in 2013.[62] But it was overtaken by Baidu with 8.4 tpm in 2014, Alibaba 18.2 tpm in 2015, and Tencent at 60.7 tpm in 2016. It is obvious that massive computing platforms with cost competitiveness are setting the stage for AI and ML in wide range of applications.

Against the backdrop of Trump order placing Huawei and a few more Chinese companies in the Entity List, China is moving forward to convert the ban into an opportunity to innovate. Threat to cut Huawei's access to Android has made it unveil its own OS, named Harmony (Chinese name HongMeng), in the Huawei Annual Developers' Conference on August 9, 2019, in Dongguan, South China. It will be initially rolled out on devices like smartwatches and smart TVs, not on smartphones. Huawei needs buy in of the global developers to create apps on its platform, to make Harmony acceptable in the world. With advantage of a huge internal market, tacitly backed by the Chinese government, it may not be difficult for Huawei to create a compatible version of WeChat super-app, which is absolutely critical for its success. More so because Tencent Holdings is on the board of Huawei. That alone will enable HongMeng (Harmony) transition to phones from IoT devices. The Android apps will thus run on Harmony. An IDC analyst said "It's not easy to build up a base of developers unless they have a critical mass of users to cater to.....It's difficult to compete with Android and iOS outside China".[63] So from internal market to global will be a big leap of faith for the developers, which will pave the way for Harmony smartphones to appear. Huawei SVP told the global app developers that it'll take them only a day or two to port their apps to Harmony. It's that simple. Till then Huawei will depend on Android, and hence on Trump.

3.4.2 CHINA ADVANCES IN 5G WITH GOVERNMENT SUPPORT

Bloomberg in an article on August 2, 2019, "*China races ahead of the U.S. in the Battle for 5G Supremacy*", pretty much sums up the Chinese government support to its industry in gaining the first mover advantage in 5G technology. It notes that China's telcos are pushing ahead "on the government's mandate, virtually free airwaves and equipment at less than half the price U.S. carriers are paying. Being the first to reach massive scale with the speediest networks could also help the nation in its ambition to dominate industries like factory automation, robotics and autonomous driving".[64] China's operators are probably paying only about $30,000 each for a base station, which is less than half the $65,000 average in other developed-economy markets. With two of China's carriers deciding on leasing the equipment, the upfront cash outlay for an enterprise will be no more than $6,500 each per year – part of opex, with no capex investment.[65] No wonder, analysts believe that the 5G rollout has picked up pace exceeding their expectations. This has made a Hong Kong based analyst to raise its target for base station deployment through 2020 to as many as 400,000 from 360,000.[66] This number is presently ten times the base stations deployed in the US.

Why is the European Union (EU) not rejecting Huawei outright despite pressure from the US? Other than the threat of retaliatory measures by the Chinese to deny access to its market to European vendors, it will cost Europe 55 billion Euros (approx. $62 billion) more if Chinese vendors are banned, and also delay the rollout of networks by 18 months. The estimate is part of GSMA report, which also voices concerns about the consequences of a full ban on Huawei, whose products are widely purchased and used by operators in Europe. Huawei and ZTE have a combined market share of 40 per cent in Europe.

It's usually suggested that operators will have to replace the existing 4G infrastructure before laying the new 5G network, adding to the threat scenario of going with Huawei. The Finland-based Telecommunication and Equipment Company— Nokia said that it was not a true scenario. However, Nokia claims that they have a technical solution whereby it can overlay its 5G equipment on top of another vendor's 4G gear. This could reduce the cost and complexity of vendor changes. Nokia claimed in June 2019, that it had moved ahead of Huawei in total 5G orders and its offering is being favourably considered by the European countries that have been debating the role of Chinese vendors in their networks.[67] A report from the US Department of Defense concerned about China claiming the position of standard-setter for 5G. Huawei leading rival telecom equipment makers, with these standards is considered a risk for the US. More so, if the world accepts Chinese products as the cheaper and superior option for 5G.[68] The Chinese government is helping roll out of 5G in other countries through its Belt & Road Initiative (BRI), and soft loans in Asia and Africa region. Within China, it is helping carriers keep costs down, by providing the bandwidth for 5G networks almost for almost free. "The US carriers, by contrast, bid $2.7 billion at two auctions of 5G airwaves, according to the Federal Communications Commission. In India, the industry group representing carriers says its members can't afford spectrum the government expects to auction for about $84 billion this year".[69] 5G is a foundation and catalyst for reinventing industries, said Paul Lee, UK— based Head of Research for Technology, Media and Telecommunications at Deloitte Consulting. "The fundamental benefit of being the first mover is that you can build business models on the back of that and export them to other countries".[70]

Speaking at ET Telecom's 5G Congress on August 1, 2019, Huawei India CEO said that by the end of 2019, China will have nearly a million 5G base stations, which is way more than that reported by Bloomberg. He felt that the high cost of 5G spectrum was a major challenge in the deployment of 5G network. He stated that network security shall be treated as a technical issue, not a political one.[71] The *Fortune* reported that at a technology conference in Beijing, China, it was announced that China's three major telcos would roll out commercial 5G services on November 1, 2019, two months ahead of plan. The initial launch will be available in major cities like Beijing, Shanghai, Guangzhou, and Hangzhou. China's aim is to bring 5G to over 50 cities by the end of the year. This will put China in race for the world's largest 5G network. Interestingly, it is South Korea that is "neck-on-neck", based on the number of 5G base stations, according to an analyst at IHS Markit. He said that no-one was close to China's 5G footprint. A few cities in the US, and nearly 40 countries around the world already have some version of the 5G in use. But all this pale in comparison to the scale of China's domestic market. Its spectrum allows for the deployment of the technology on a massive scale.[72]

In the US, it's the high-frequency bands being used in base stations. The high-frequency spectrums technically provide the fastest Internet speeds, but they cover a limited physical territory. In China and much of the rest of the world, 5G development has largely focused on low- to mid-frequency spectrums because base stations with lower-level spectrums can reach a larger surface area. A good mix of bands, capacity bands, and coverage is necessary to fully deliver the promise of 5G. "The US market is asking for one frequency while the rest of the world is asking for a common frequency."[73] Does this isolate the US?

3.4.3 US GOVERNMENT TRYING TO REDEFINE THE WORLD ORDER

US Government on 5G: In May 2019, the US government placed Huawei on the Commerce Department's Entity List, banning the tech company from buying critical parts it needs from the US producers. While the current trade war between the US and China is underway, it is this brewing tech war that has the potential to reshape the world order; it is starting with this Huawei development, which is couched in terms of cyber surveillance and espionage, leading up to the national security. The US government is fuelling fears that Huawei, through its 5G networks, will engage in surveillance, on behalf of the Chinese government. In an effort to shape the world order, the US has gone to the extent of using Cold War terms for the next generation networks that nations will be building. The US Secretary of State Mike Pompeo has struck a cautionary note to the world leaders arguing that the Internet ".... has to be a system that has Western values embedded in it, with rule of law, property right protections, transparency, and openness. It can't be a system that is based on the principles of an authoritarian, Communist regime".[74] The world is sought to be divided between US-led or China-led 5G infrastructure.

3.4.4 EU MEMBER STATES REPORT ON EU COORDINATED RISK ASSESSMENT OF 5G NETWORKS SECURITY

The European leaders are viewing this through the prism of their own trade interests with China. The Chinese retaliation can result in job losses in countries like France, Germany and the UK. They [European leaders] believe there are elements of the network that Huawei could build without endangering national security, with western telecom firms such as Nokia, Ericsson, building the "core" of the network— the software-heavy switching systems that govern how machines and humans will talk to one another. Huawei could be assigned the more peripheral parts of the networks - the cellular tower systems that communicate with phones and other devices.

The EU Member States conducted risk assessment of 5G network security in a coordinated way. In a press release of 9 October 2019, a report on this was released which accepts that "5G networks is the future backbone of increasingly digitised economies and societies. Billions of connected objects and systems are concerned, including in critical sectors such as energy, transport, banking, and health, as well as industrial control systems carrying sensitive information and supporting safety systems. Ensuring the security and resilience of 5G networks is therefore essential".[75] The report is based on the results of the national cyber security risk assessments by all EU Member States. It identifies the main threats and threats actors, the most sensitive assets, the main vulnerabilities (including technical ones and other types of vulnerabilities) and a number of strategic risks. This assessment provides the basis to identify mitigation measures that can be applied at national and European level.

In addition to existing security challenges, it states that the security challenges in 5G networks are mainly linked to: software-driven networks— along with other key innovations in wide range of planned services; and the role of the suppliers in building and operating 5G networks— along with the degree of dependency on individual suppliers. This is similar to what we have discussed earlier, including the emphasis on the global supply chain risk.

Specifically, the roll-out of 5G networks is expected to have the following effects:

- An increased exposure to attacks and more potential entry points for attackers: With 5G networks increasingly based on software, risks related to major security flaws, such as those deriving from poor software development processes within suppliers are gaining in importance. They could also make it easier for threat actors to maliciously insert backdoors into products and make them harder to detect.
- Due to new characteristics of the 5G network architecture and new functionalities, certain pieces of network equipment or functions are becoming more sensitive, such as base stations or key technical management functions of the networks.
- An increased exposure to risks related to the reliance of mobile network operators on suppliers. This will also lead to a higher number of attacks paths that might be exploited by threat actors and increase the potential severity of the impact of such attacks. Among the various potential actors, non-EU States or State-backed are considered as the most serious ones and the most likely to target 5G networks.
- In this context of increased exposure to attacks facilitated by suppliers, the risk profile of individual suppliers will become particularly important, including the likelihood of the supplier being subject to interference from a non-EU country.
- Increased risks from major dependencies on suppliers: A major dependency on a single supplier increases the exposure to a potential supply interruption, resulting for instance from a commercial failure, and its consequences. It also aggravates the potential impact of weaknesses or vulnerabilities, and of their possible exploitation by threat actors, in particular where the dependency concerns a supplier presenting a high degree of risk.

- Threats to availability and integrity of networks will become major security concerns: In addition to confidentiality and privacy threats, with 5G networks expected to become the backbone of many critical IT applications, the integrity and availability of those networks will become major national security concerns and a major security challenge from an EU perspective.

Together, these challenges create a new security paradigm, making it necessary to re-assess the current policy and security framework applicable to the sector and its ecosystem and essential for Member states to take the necessary mitigating measures.[76] So, it's clear that security mechanisms have to be deployed as noted in the previous sections – security controls in networks up to 4G, security controls as per 3GPP, security for use cases as OTT. In short, risk-based assessment and deployment of solutions. However, it emphasises supply chain security as a major consideration where dependence on a single vendor appears to be discouraged. Carefully, the report is not rejecting Huawei outright. The EU has to balance security with commercial risks to its economy. It is in part a trade issue.

But Trump makes no bones about Huawei being a lynching horse in its trade war. "We're not going to do business with Huawei. We're not doing business with them," Trump told reporters on August 9, 2019. "That doesn't mean we won't agree to something if and when we make a trade deal". Trump is clear that the US would not do business with Huawei, but that could change if there was a trade deal. So, is it a national security issue? Interestingly, Trump Administration has allowed another 90 day period to its companies to trade with Huawei, so as not to leave its rural areas without cost effective networks, which are presumably using Chinese network gear.[77]

3.4.5 US' APPROACH TO 5G – VOICES OTHER THAN TRUMP

In a Paper from *Brookings,* former US Federal Communication Commission (FCC)'s Chairman Tom Wheeler and Former Chief of Public Safety and Homeland Security Bureau— David Simpson, had highlighted the following five ways in which 5G networks are more vulnerable to cyberattacks than their predecessors:[78]

- The network has moved away from centralized, hardware-based switching to distributed, software-defined digital routing. Cyber hygiene is pushed outward to a web of digital routers throughout the network. Hardware choke points, where inspections could be carried out are no longer available.

- Network functions in physical appliances stand virtualized in software; adding to increased vulnerability, since Internet Protocol and well-known operating systems are known to have cyber vulnerabilities. 5G network infrastructure becomes more prone to attacks by nation-states or criminal actors.
- Networks managed by more software, often AI tools, which makes it even more vulnerable to attacks. A breach in the software managing the networks can lead to entire control of the network in the hands of an attacker.
- Large number of antennas required for expansion of bandwidth, which are low-cost, short range, small-cell antennas are new attack targets. These cell sites will use 5G's Dynamic Spectrum Sharing capability in which multiple streams of information share the bandwidth in "slices." Each slice will carry varying degree of cyber risk. With software allowing the functions of the network to shift dynamically, cyber protection must also be dynamic.
- Connecting billions of hackable smart devices- based on IoT will create huge vulnerabilities. mMTC and URLLC apps using such devices that will create AR/VR, Industry 4.0, new apps in making everything smart: transport, city, surgery, battlefield, logistics and so on, will make any nation vulnerable. It's known that many IoT devices are easy to penetrate. Go-to-market pressures, first mover advantage make companies deliver and install such devices without adequate security. Hackers are having a field day already.

The fifth-generation networks thus create a greatly expanded, multidimensional cyberattack vulnerability. It is this redefined nature of networks that requires a new cyber strategy. The paper observes several factors, including supply chain issues, lack of trust in not only Huawei, but also China as a country to understand the threat scenario in 5G ecosystem. It also notes that the "NotPetya" attack in 2017 caused corporate losses of over $10B. The attacks were successful even without 5G. Massive IoT devices were not connected. Supply chain trust issues were not in the play. So, clearly security is not just a 5G issue as it is sought to be played. The authors come to a different conclusion, namely "under-investment in security by the industry as a key factor that enabled successful cyberattacks.” They conclude that market forces alone will not make the private sector invest adequately in security of infrastructure and applications. Government and regulators need to step in to secure the networks. Overplaying the Huawei threat in 5G will not serve the purpose.

The paper makes two key recommendations:

- Companies must recognize and be held responsible for a new cyber duty of care.

It lists the following measures in this category: Reversing chronic underinvestment in cyber risk reduction, Implementation of machine learning and AI protection, Shifting from lag indicators of cyber-preparedness (post-attack) to leading indicators, cyber security starts with the 5G networks themselves, insert security into the development and operations cycle, NIST Best practices.

- Government must establish a new cyber regulatory paradigm to reflect the new realities.

In this category, given the fast pace of digital innovation and threats requires a new approach to the business-government relationship, it suggests the following: More effective regulatory cyber relationships with those regulated, Recognition of marketplace shortcomings, Consumer transparency, inspection and certification of connected devices, Contracts aren’t enough, Stimulate closure of 5G supply chain gaps, Re-engage with international bodies, whereas the US had withdrawn from 3GPP under the Trump administration.

The authors advise the Trump administration that “We must not confuse 5G cybersecurity with international trade policy. Congress should not have to pass legislation instructing the Trump administration to act on 5G cybersecurity. The whole-of-the-nation peril requires a whole-of-the- economy and whole-of-the-government response built around the realities of the information age, not formulaic laissez faire political philosophy or the structures of the industrial age”.[79]

3.4.6 FRENCH APPROACH

The French government has interestingly opted for increased regulation. In a paper published on 28 July 2019, *While weighing 5G security risks, France predicts it can manage Huawei without banning it,* Mathieu Duchâtel writes that "the French government is creating a regulatory environment that helps reduce its vulnerability to foreign intelligence collection".[80] The author states that 5G infrastructure poses more complex problems, since the distinction between core and edge is no longer as relevant, as many software operations will operate in the cloud. It is recognized that managing sabotage risks is much bigger than the security challenge of protecting data privacy. While underlining that 5G will be the basic infrastructure for a range of industrial applications and a new wave of modernisation of public services, the French government is clear that it does not want to have vulnerabilities that could be exploited during international tensions.[81] But the French assumption is that Huawei can be managed without a ban – this is the aim of legislation that was just passed by the French Parliament, creating a system of prior authorisation for 5G equipment with the aim of addressing the "risk of interference by a foreign state".

In practice, the French Prime Minister is given the authority to authorise equipment in telecommunication networks through ANSSI— the agency in charge of France's information systems' security. The government has prepared a list of equipment that requires prior approval before operators can build the network infrastructure. The legislation only applies to 5G networks and covers hardware and software equipment. The ANSSI may issue authorisations with specific conditions, which, if found to be violated, can punish the guilty with five-year jail terms and fines up to €300,000 (Euros). And here's the most important link to national security. The French Prime Minister's Office reserves the right not to explain decisions to refuse specific equipment when the disclosure of such information could undermine national security. Will the legislation slow innovation and the deployment of the infrastructure? Given the services and business models of operators, they have flexibility in designing and configuring networks. Also, in all software environment, updates will be the norm. Will they require prior approval? Administrative inefficiency is likely to be a risk! Does this law solve the problem, or creates more?

3.4.7 GERMAN APPROACH

Germany has been treating 5G technology from Huawei as purely a cyber security issue – one that can be handled through risk assessment, with appropriate technical mitigation measures. The German Chancellor Angela Merkel has long favoured a free market bid approach for the massive infrastructure project that included Huawei. But, on November 23, 2019, a decision was taken by the parliament that it is the German parliament that would decide on Huawei 5G involvement, instead of the government. Interestingly, Merkel's Christian Democratic Party (CDU) also agreed to the decision taken in the parliament. This was because, nine security and foreign-policy experts with the CDU's coalition partners in Berlin, openly called in a policy paper for Germany to exclude "non-trustworthy manufacturers, especially if unconstitutionally controlled interference, manipulation or espionage cannot be ruled out".[82]

Germany's approach to the Chinese 5G equipment, after the US raised the red flag on Huawei and ZTE as a threat to national security, was only a technical approach. But some of the European Member States are of the view that purely technical measure cannot solve the problem because of the fear that the Chinese Communist Party could pressure the manufacturers, through the Chinese government, to disrupt foreign networks. Even the new IT security requirements for German network operators, recently issued by the German Federal Network Agency (BNetzA), are not adequate, since they address it only as a technical problem. That the government understood it as a strictly technical problem, is not correct.

Neither the Germany's Ministry of Economic Affairs nor the Federal Foreign Office were commissioned to prepare their own risk assessments. The Chinese network equipment providers pose a higher risk than their European competitors - Nokia and Ericsson. This higher risk does not come from Huawei and ZTE providing products of inferior quality, but rather comes from the ability of the Chinese Communist Party to take drastic measures and to exert pressure on Chinese manufacturers. Such a risk can hardly be reduced by technical measures. Whether the Chinese government would want to compromise a foreign telecommunications network, using Chinese network gear is a geopolitical, and not a technical question. This requires a geopolitical answer.[83]

Germany is behind some key European countries in the 5G infrastructure. It is presently a leading market for 5G. It has to decide whether it should be investing in Ericsson and Nokia, leading 5G European technology vendors. It has to address the "Huawei Question" from all angles: IT security, national security, foreign trade and industrial policy. It is not clear that the German parliament will be able to find an answer to this question from all perspectives. It may pass a resolution barring the Chinese equipment altogether.

3.4.8 FIVE EYES AND JAPAN – APPROACH OF US ALLIES

The US has banned the use of Huawei, and ZTE in its 5G networks. It has also leaned on its other four partners in the "Five Eyes"– Australia, UK, Canada, and New Zealand – to not let the Chinese companies build their respective 5G infrastructures. In August 2018, Australia became the first state in this intelligence sharing community—the Five Eyes, that has been in existence since the second world war, to ban Huawei from participating in its 5G project. New Zealand followed suit by raising concerns about Huawei involvement in 5G networks, through the GCSB, its Signals intelligence (SIGINT) agency.

The United Kingdom and Canada are yet to make a final decision on Huawei's involvement, but have indicated a willingness to permit Chinese telecommunications companies' participation in what they deem to be non-core parts of their 5G infrastructure. The UK is somewhat dependent on existing Chinese telecom equipment, specifically Huawei technology. The UK appears to share Canada's view that it may be desirable to have a global set of standards for 5G security that cannot be achieved if one major country or company is completely excluded. But then, as discussed earlier, it's not the security of products or supply chain risks that are under debate. It's the lack of trust in Chinese government, which could disrupt foreign networks under the orders of the Chinese Communist party, which presents geopolitical risk. This risk has to be addressed through national security assessment by National Security Agencies, Ministry of Foreign Affairs.

The SoftBank Corporation selected Nokia as a strategic partner for its 5G rollout and Ericsson as a supplier of radio access network equipment, excluding its earlier supplier— Huawei, in May 2019. Even though Huawei and ZTE had participated in 5G trials, they were not selected. The Japan has said it will exclude equipment with security risks without making an official decision on Huawei. According to the news release, Japanese media has reported that the country's top three carriers - NTT Docomo, SoftBank, and KDDI - will shun

Huawei and ZTE. The companies are also scrapping plans to sell Huawei handsets as the impact of a US supply ban spreads.[84]

3.5 5G INFRASTRUCTURE – NATIONAL SECURITY OR TRADE WARS

From the foregoing, it's clear that 5G security is no different than security in previous generations. In fact, 3GPP standards provide for more secure data communication between RAN and Core networks, within the core network. As an IP based, software driven network, it's exposed to vulnerabilities as any IP network or device. There are many more of such vulnerabilities. So, the attack surface is bigger. But, that doesn't alter the security basics of risk assessment, and mitigation of risks in a network. Applications in outer layers must be secured. The 5G infrastructure vendors are Nokia, Ericsson, Samsung, Huawei, and ZTE. So, it's essentially a global supply chain trust issue!

If global supply chain is not trusted, should one conclude that countries should make their own technologies? Not everyone can have their own chips, operating systems, semiconductors, encryption codes, search engines, social media, 5G phones/base stations/routers, cloud platforms and much more. But poles will emerge – US and China – around which countries will have to gravitate. How long will it take? Today, China produces only 16% of semiconductors it consumes. It wants to be self-reliant in semiconductors in a decade or so – 40% by 2020 and 70% by 2025 – along with other core ICT technologies as part of its Make in China 2025 project. West thinks it's a declaration of its intent to dominate all emerging technologies to be a superpower in the tech world. Critics question whether it's worthwhile, since as a manufacturing base it consumes more than half of world-wide production, which it then re-exports to the global markets. So, why try to be self-reliant in one area, namely semiconductors, since global market can or may become even more distrustful of China as a country because the products will then include nearly all components made in China; but China has a different take on this.

China believes that the US actions of putting Huawei on the Entity List have shown fault lines between the two economies, especially in the global supply chain which has exposed China's dependence on American technology for key pillars of its economy. This threat is most evident in semiconductors; Huawei can no longer buy chips from American companies like Intel and Qualcomm. The trade war has shown that the Trump administration is willing to block

Chinese access to everything from software to semiconductors and much more to contain China's rise.

But in the context of cyber security of 5G infrastructure, it's worth reiterating Tom Wells' advice to Trump administration as noted before, "We must not confuse 5G cybersecurity with international trade policy. The US Congress should not have to pass legislation instructing the Trump administration to act on 5G cybersecurity. The whole-of-the-nation peril requires a whole-of-the-economy and whole-of-the-government response built around the realities of the information age, not formulaic laissez faire political philosophy or the structures of the industrial age".[85]

4 WHERE DOES INDIA FIT IN THE GLOBAL ORDER, AND WHAT IS THE WAY FORWARD?

4.1 WHY DOES 5G MATTER TO INDIA?

What are the economic imperatives for India, and use cases that leave us with no other option but to plan for 5G deployment? Then we can try to understand where we stand in terms of technology, and who are the global technology players, and where do our start-ups fit in? Who can address our security concerns better?

In section 2, specially 2.8, we saw that 5G-enabled economic activity has the potential to generate $12.3 trillion output, which will be 4.6% of the global GDP, in 2035. 5G value chain will generate $3.5 trillion, and 22 million jobs. Over the next 16 years, the US will invest 28% ($1.2 trillion), China 24% ($1.1 trillion), five other countries 25% (Japan, Germany, South Korea, UK, France), with the rest of the world 23% in global 5G investments – average of $200 billion will be invested globally in the 5G infrastructure. The economic output, and jobs will be shared by them in almost similar proportions. So, India is counted in the 23% that will be shared in rest of the world, excluding seven countries. Our ambitions to grow into a digital economy, and to be the third largest in a few years, alone should push us into adopting 5G.

Clearly, India cannot afford to be counted in rest of the world. It must move in the bracket of 'Top Eight'. For this to happen, the government must push the establishment of 5G infrastructure, in partnership with the private sector. It must work closely with the industry to develop policy and regulatory framework; work with user industries to develop 5G use cases; create right spectrum price keeping in view that large swathes of 5G spectrum will be required for different use cases. It's worth noting here that China has allowed sustained trials of 5G ecosystem by giving free spectrum! Can the government and the regulator be this bold in India? While eMBB use cases to provide HD video to home users, and industries are an extension of 4G, and the low hanging fruit to energize the use of 5G, these are not likely to make investments by operators viable. Likewise, AR/VR apps demonstrated by South Korea, for 360-degree view of Olympic games, may not be much revenue generating. These will have to be provided though, even for recovering investments in cities where high density of mmWave antennas will be installed for achieving the promised throughput of up to 100 Gbps.

It's worth recalling Gartner prediction (section 5) that 5G IoT Endpoints installed base will grow from 3.522 million in 2020, to 48.59 million units in 2023. Of these, 70% will be CCTV cameras for security/surveillance in 2020 (2.5 million by 2020, 6.2 million in 2021, 11.2 million in 2022). By 2023, 53% of the overall 5G IoT endpoint opportunity will be represented by the automotive industry. Clearly, automotive manufacturing industry, and CCTV endpoints need attention of the Indian industry and the government (smart cities, safe travel in buses and trains, airport and railway stations for security) for creating 5G use cases. The Cellular Telecommunications and Internet Association (CTIA) estimates that 5G Smart City solutions could produce upwards of $160 billion in benefits and savings.[86] An obvious application is for city-wide surveillance to help with crime prevention and investigations. The TM Forum Report 2019 also notes the market potential for 5G and IoT by 2023 to be $239 billion in industrial automation; $154 billion by 2024 for smart cities; and $379 billion by 2024 for digital health.

The promise of 5G becoming a GPT is based on the mobile turning from a consumer device to an industry device. So, it's such transformational use cases that must be explored. Those which can transform smart cities, smart Power Grids, CCTV traffic monitoring to secure cities. Industrial automation examples using robotics that need to connect large number of IoT devices, and need low latency at the same time, must be discovered. The advantage of network slicing for mMTC and URLLC of 5G can be combined. All of this is possible if telcos work closely with the industry verticals to demonstrate value to the users. The mMTC use cases abound in manufacturing, agriculture, and mining. Likewise, URLLC use cases must be identified that make sense to our economy, along with business models that will work. Government will have to fund initial use cases.

The IHT Markit estimates that 5G will enable $12.3 trillion economic activity, with some sectors as follows: 11.5% in ICT; 6.4% in agriculture; 6.5% in public service; 5.6% in transport; 4.6% in financial services. Utilities, hospitality and construction too are in the league of 4.5% each.[87] It is these core areas that India may target. As application developers of the world, through our booming ICT industry, it should not be difficult to do so. It's only the talent that has to be unleashed through innovative support of start-ups, and low-touch regulatory controls. Long rope has to be given for trials of 5G, AI and ML apps, the way China is doing.

While test beds for driverless cars may be set up to use network slicing for creating multiple networks on the same physical layer for broadband and low latency and connecting large number of IoT devices, it’s the rural areas and mining apps that should engage the country more. Rolling out 5G in these areas, without the need for mmWave and huge density of small cells, will likely have better payoffs. But the users and telcos need to put their act together.

We wish to note some papers produced by various agencies for adopting 5G networks in the country, though none of them has given a list of specific use cases in India to help digital economy grow, which, in turn will increase GDP. Also, none of these papers seem to have touched upon cyber security and national security challenges. The papers are as follows:

a. “5G-Key Capabilities & Applications” by FN Division, TEC, India.
b. “Enabling 5G in India”, by TRAI, India.
c. “Making India 5G Ready” by the Steering Committee Report of the 5G High Level Forum, DoT, India.
d. “5G India 2020” by the TCOE, India.
e. “Roadmap for 5G in India” by the Broadband India Forum.

4.2 CYBER SECURITY CHALLENGE FOR INDIA

The cyber security challenge is universal for all countries. It has been so when the cellular networks did not exist, and it continued to be so through their four generations. It is the vulnerabilities in the basic TCP/IP protocol stack, and the underlying computing platforms that are insecure. New vulnerabilities continue to be discovered and exploited both by the criminals, and the intelligence agencies of almost all the countries. The risk-based assessment along with standard cyber security frameworks, and security controls to mitigate risks are used to address the threats faced by an organization.

It is the same process that has to be followed in 5G. The network is software driven. So, more software vulnerabilities need to be handled. Risk assessment, and security controls are required to secure the networks and applications as before. This was discussed in section 3. But the cyber security challenge has been linked to national security by raising trust issues with respect to Huawei, a Chinese company which has emerged as a major 5G technology global player. So, the standard security frameworks are not considered adequate to address this challenge, since Huawei is deemed to be linked to the Chinese government, and under its control. Even though the Brookings paper of the former FCC Chairman states that the hype around Huawei is unnecessary, and that it’s the underinvestment on security by the private sector that is the major reason for cyberattacks on the US infrastructure, the Huawei distrust continues to be at the centre stage. Is it then a mere supply chain trust issue?

Supply chain trust issues have been addressed in detail in a paper on Technology Nationalism by the *EastWest Institute*. The EWI Technology Nationalism paper proposes some trust measures such as ‘Self-attestation by industry or Third-party assessment’ plus contractual clauses for procurement requirement. Huawei has offered to do so, but not found acceptable by the US. The paper also proposes ‘Global Regional Testing Centres’ based on mutually agreed testing criteria, objectives and methodology; process for testing organisations. But the question is how different will this be from Common Criteria (CC) Labs? The ICT community has to come forward with reasons as to why CC Labs haven’t worked?

The CC’s focus is on security specs, not on whether a product is secure; it reviews documentation but does not conduct source code inspection. However, where a vendor such as Microsoft offers source code inspection, does it enhance trust level in that product or the entire company? The EWI paper has proposed ‘Transparency Centres’ where code inspection of larger companies like Microsoft, Kaspersky, Huawei, Cisco may be conducted by experts of governments with their own tools on vendor source code. Huawei’s Cyber Security Evaluation Centre (HCSEC) is an example. In addition, Declaratory Letter of Management/Board guaranteeing that no hidden or harmful functions are present in the ICT product, has also been proposed.

In this context, it is worth reviewing the experience of Microsoft which offered Windows Operating System (OS) source code, both to China and India. It requires creation of massive infrastructure with an army of operating system developers, recruiting and retaining them since new upgrades are released by Microsoft almost every day, given the discovery of new vulnerabilities, and development of patches to fix them. But then the patches could hide backdoors. So, it requires continuous testing by the national centre. India never took the offer, while China is reported to have set up such a centre. Did it help China increase trust in the Microsoft OS code? Did it also help China steal code and Intellectual Property Rights (IPRs)?

Yet another part of the EWI proposal is to establish the Global Conformance Program – for product testing & certification with a global reach. The EU cybersecurity certification network is in the works, and presents a good option.

4.2.1 IS IT A NATIONAL SECURITY ISSUE?

While there will be normal cyber security challenges because of vulnerabilities, the key question is whether 5G presents a bigger national security challenge? How different it is for India with technology from Huawei and others? Do we have to choose 5G technology from either of the two camps: US-led or China-led. Its importance for our digital economy, and for our armed forces does not need any reiteration. But what is it that we need to do while upgrading our telecom infrastructure? India has developed technological capability in 4G and 5G to some extent and can be ready with our own technology in 4-5 years, in niche areas, provided the government supports the industry. We need not be caught in a bigger global trade war that is reshaping the world order. But given the hype around 5G globally, India has to start trial runs if we have to be at the forefront of building 5G for five trillion-dollar economy. We don't have any cyber security testing labs for testing telecom equipment. Given the surveillance history of the US' NSA, India has to test equipment whether from Nokia, Ericsson or Huawei; no shortcuts. Some immediate short-term measures are required.

4.2.2 INVEST IN R&D, OR ALIGN WITH A BLOC AS A MARKET ONLY?

Does a country like India have a choice to choose a bloc to align with? Or should it attempt to build some of the platforms itself by encouraging start-ups, and investing in R&D? With our market size, increasing Internet penetration, and focus on digital economy, this option has to be supported by government policies, at least in a few niche areas. It may be noted though that in semiconductors, R&D investments are huge, and chances of failure are equally huge. An expert in China noted that the country's current expenditure level was a drop in the ocean compared with global industry leaders like Intel, which spends US$13 billion a year on the R&D. That compares with the 140 billion yuan (approx. US$19.5 billion) in the 13th Five-Year Plan that runs through 2016 to 2020 and the 200 billion yuan that the state-backed China Integrated Circuit Industry Investment Fund is raising. "Without matching the investment levels, it's hard to believe we can close the gap in technology," says Xie, former VP, Semiconductor Manufacturing International Corporation (SMIC), headquartered in Shanghai.[88]

It might be relevant to analyse the China story to be reliant in semiconductors. Despite being one of the world's top five semiconductor foundries in the world, SMIC only began to produce 14 nanometre (nm) semiconductors in

2019, which is three generations – or at least six years – behind its rivals. Whereas Taiwan Semiconductor Manufacturing Company (TSMC) is at the frontier of semiconductor process manufacturing technology, and as an independent foundry, TSMC produces chips based on designs provided by its clients. At present, firms like TSMC and South Korea's Samsung are already manufacturing 7nm chips and planning a shift to 5nm technology. "Over the years China had been misled by the idea that all it takes is equipment to produce a generation of semiconductor fabrication process technology," said Jackson Hu, who helmed Taiwanese semiconductor foundry UMC as chief executive from 2003 to 2008. "They emphasised the importance of equipment investment, but the truth is that equipment is only one of the necessary conditions." He believes that China's lack of talent and experience were the primary reasons for its failure.[89] But with the recent banning of Huawei and ZTE, by the Trump Administration, denying them access to chips from Intel and Qualcomm, has put a question mark on the global supply chain and have exposed China's dependence on American technology for key pillars of its economy. These chips are critical to the function of consumer electronics, communications and computing products, as well as increasingly sophisticated equipment in a range of sectors, from aerospace and financial services to health care and retail. The industry is capital-intensive, however, and currently based around a complex global supply chain.

Even with massive investments by the government and industry, chip design and fabrication are not a problem that can be solved simply without talent and experience. The debate between buy versus make chips continues. The "buy" camp points to the futility of trying to be self-reliant in all aspects of the manufacturing process, from the specialist production equipment to design software, to advanced materials. There are lessons for India here. India should not consider taking up semiconductor chip manufacturing. A better option is to design some specific 4G and 5G chipsets, and get them fabricated by TSMC in Taiwan, and Samsung in South Korea. However, a bigger opportunity is in software development, in which India has proven capabilities. With core networks, cloud computing, NFV, MEC etc all being software driven, India can exploit its competence to develop strength in some of the key software technologies in 5G. The start-ups should be encouraged in niche areas.

So, the choices for R&D and start-ups for indigenous development of technology, if any, have to be wisely made by the industry and the government working closely. But India should take up the design and development of the end-to-end holistic architecture of the national digital communications and computational infrastructure, that will act as a blue-print to decide the critical components that need to be controlled and regulated strategically, components can be supplied by global players, and components that need to be indigenously developed and deployed. It should also include encrypting the transport layer with our own encryption technology, so that irrespective of the underlying physical layer and 5G technology deployed from any vendor, our communications are secure. This blue-print should act as the guiding principle for making all policy decisions regarding the relevant technologies. Sadly, we do not have one as outlined below.

4.2.3 LACK OF FRAMEWORK TO DEVELOP AND INDUCT INDIGENOUS TECHNOLOGY:

Several start-ups have created innovative technologies in the country. However, there are no mechanisms to induct them into military, and government due to archaic norms of tendering, RFP, proven examples, and L1. A start-up cannot have proven sites. Government has no ability to evaluate innovations; officers play safe by choosing existing solutions from abroad. Start-ups lose steam against the bureaucracy and move to Singapore or the US. This trend must be arrested. How are the biggest investors in 5G, namely the US and China approach innovation?

- In the US, military funds innovative research by framing its requirements at high level. The technologies thus developed by companies – big and small – are deployed in test beds, sandbox environments, and then get rolled out on a large scale. And the tested technologies find global markets.
- In China, it is very different. Government lays out a blue-print for the industry to collaborate – it gives large funds, industry too invests – to develop technologies. For example, scores of initiatives under the 'Made in China 2025' to develop core technologies are taken up by the industry and deployed nation-wide. Developments are proven, and ready for the global markets.

4.3 GOVERNMENT ROLE IN BUILDING 5G TECHNOLOGY

India is a unique nation, therefore does not 'fit' into any of these models. Before getting into this, it's worth recalling the stories of China and the US. 5G is perhaps not merely a national security, but a global trade issue, and also a technology supremacy race. And this is obvious from the way the Chinese government is supporting its industry in rolling out 5G, almost free spectrum, subsidies to network carriers in keeping the cost of base stations at half the level of that in the US. China is out to capture the 5G markets globally. Yes, the Chinese government is supporting and subsidizing, but it's the industry led by Huawei which has been working on a long-term plan to set the standards in global bodies like 3GPP and ITU, develop its technology, and commercialize it. It's a technology race to capture the world. Chinese government and Huawei have been and continue to be partners. The smartphones from OnePlus, and Xiaomi too are 5G ready, in addition to those of Huawei. So how do we handle the challenge of building some components of 5G core technology ourselves, and deploy the same through market driven, but government supported business models. It should be clear from this paper that India is nowhere in the global race of 5G technology development, notwithstanding a few start-ups who are ready with some 4G/5G chipsets. Creating R&D capacity, and cyber security and testing labs in the private sector are the immediate tasks for the government, if we have to focus on rolling out 5G networks. Some of the policy initiatives in this regard are mentioned below:

1. **Government should fund R&D in 4G and 5G in the private sector for long term goals**, say matching funds invested by private sector, with the condition that the licence for IP developed with grant, will be retained in India. It should provide start-ups with test beds in military for trial runs, and for telcos to deploy on trial in sandbox environment under the watch of TRAI, before large scale acceptance of indigenous platforms.
2. **Cluster of Cyber labs:** Initiate the setting up of a cluster of labs across the country in a PPP model, that can focus on development of the next generation communications and computing infrastructure, so that we don't play catch-up and are ready with the required core technologies for the future. In the immediate future, the government can extend the usage of lab facilities given to academic institutions under 5G test bed and other nanoscience activities to the start-ups doing R&D in 5G. This should also include creation of a semiconductor post silicon test and bring up ecosystem: RF and communication protocol testing lab, ESD testing and failure analysis lab and open it to Indian industry. Today not only one has to

go out of country for fabrication, even to do some of these IC test and debug activities one has to send chips out of the country incurring delay and expense.

3. **Cyber security lab** in Hyderabad, set up by Wipro for its global clients, can be mandated by the government to test and certify components and products from 4G/5G vendors. However, the government has to notify standards for this to happen. For testing various components of the network including firmware chips etc for vulnerabilities and finding back doors, the government should require the global companies to share firmware code and other relevant details for testing by this lab.
4. **Encourage and Incentivise adoption of Indian semiconductor chips:**
   4.1. Mandate usage of Indian semiconductor chips in defence and strategic network equipment wherever Indian chips are available/feasible within reasonable time. Clearly identify and promote the indigenized core technologies critical to the systems in programs like "Make in India",
   4.2. Incentivise the telecom operators to use Indian made equipment (maybe subsidy on license money or some other method),
   4.3. Indigenous products in core technology face tremendous price pressures in the market from incumbents. As an example, owning Wi-Fi chipsets would mean significant technology ownership in India. But these chips are being sold as commodities, at very low prices, since the R&D expenses have been recovered by incumbents over decades. But a policy such as the government subsidizing, say, the first million units of any indigenously developed and owned chip/system sold by an Indian company, can help ward off the pricing pressures and establish a market. Lessons of STPI can also help,
5. **Electronics company for fabless chips development and for setting up a fab**: Needs to be set up in the private sector for fabless chip design and development for myriad applications in military and commercial space. Funding by the government is essential, which can be tied up to a roadmap of deliverables. Such a company can enlist participation of start-ups, use their technologies, create patents, participate in setting up of global standards in 4G, 5G, cloud infrastructure, chip standards etc. It may leverage Japan, Taiwan and/or South Korea as a partner for fab technology. Key objective is to ensure that IPRs belong to Indians and shall stay within the country.
6. **R&D in Software-Defined Networking for 5GC**: In consultation with major telcos – Airtel, Jio, Vodafone – 5G areas in cloud date centres, MEC, SDN and NFV, which are all software modules, be identified for R&D. India has expertise in software development. Start-ups and other private sector

should be funded by the government, for testing and deployment by the telcos. But, the process of identifying challenge areas, and manner of funding start-ups and private sector be transparent, and easy, without government control. Industry association should take the lead, with government funding the effort, without dominating it.

7. **Some other challenges such as the absence of a standards and compliance body, and indigenous encryption technologies for sovereign data control.** Above all, the absence of a framework to help induct indigenous 4G/5G technology developed by start-ups in the national telecom infrastructure. There are some options like a Large-Scale Integrator (LSI) that maybe the face of a complete integrated solution for the military and other critical infrastructure applications, built around technologies developed by start-ups or a consortium of start-ups be recognized as a national effort to roll out these technologies.
8. **Spectrum Pricing challenges:** The government is yet to announce the auction of spectrum for 5G. However, before the Indian Mobile Congress was held during 14-16 October 2019, the government released spectrum to all telco operators, on shared basis, in the frequency bands of 3.3-3.6 GHz, and 26-28 GHz. Bharti Airtel, Vodafone Idea, and Reliance Jio were asked to demonstrate India specific 5G use cases, along with technology providers like Nokia, Ericsson, Huawei, Samsung, ZTE; and IIT Chennai, IIT Delhi. The Cellular Operators Association of India (COAI) coordinated the demonstration.[90]

   All governments like to treat spectrum as a resource, and wish to maximize revenue from its sale, usually through auction. But the spectrum that will underpin the 5G networks needs to be reasonably priced for telcos and operators to flourish. To date, there has been significant variance in prices paid for 5G spectrum, as the table below shows (price per MHz of spectrum per head of population is a commonly used valuation metric for radio spectrum):

Price paid for spectrum varies

Market	Date	Spectrum band	Spectrum volume	Total spend	Population	Price/MHz/Population
UK	April 2018	3.6 - 3.8GHz	150MHz	$1.48 billion	66.95 million	$0.15
South Korea	June 2018	3.5GHz 28GHz	280MHz 2400MHz	$2.7 billion $600 million	51.34 million	$0.19 $0.005
Spain	July 2018	3.6 - 3.8GHz	200MHz	$512 million	46.44 million	$0.06*
Finland	October 2018	3.4 - 3.8GHz	390MHz	$87.85 million	5.56 million	$0.04
Italy	October 2018	700MHz 3.7GHz 26GHz	60MHz 200MHz 1000MHz	$2.3 billion $4.99 billion $187 million	59.22 million	$0.65 $0.42 $0.003
Australia	December 2018	3.6GHz	125MHz	$611 million	25.09 million	$0.20
Switzerland	January/ February 2019	700MHz 1400MHz 3.5GHz	80MHz 75MHz 300MHz	$380 million in total for all spectrum**	8.42 million	$0.10

*Winners in the Spanish auction are required to pay substantial annual usage fees of up to $25 million
**The Swiss regulator did not publish a price breakdown by spectrum band

TM Forum, 2019

Figure 21. Price Paid for Spectrum [source: TM Forum 2019]

It is against this global background that India has to fix the auction floor for 5G spectrum, so that it's viable for the telecom players. That spectrum is a national resource, is well understood. But it should be remembered that the resource has to be made available to the citizens at large, since the services that it enables are also taxed. It is a challenge both for the government, and the telcos. In view of the issues of spectrum charges, ongoing court cases of 2G, recent court order of spectrum payments to be made by telcos to the government, and the precarious financial position of all the big telcos, the regulators must proceed cautiously. The objective should be to enable telcos to deploy the best technology at affordable costs. Revenue maximization should not be the sole aim. Long term objective of digitalization of all private and government processes, developing AI and ML apps, building our own apps to solve our own problems, and using 5G to enable it to grow into a GPT, as envisaged by IHT Markit, should be the guiding principle for the regulators.

The auction for 5G spectrum in 3.3-3.6 GHz is yet to begin since the reserve price of Rs 492 crore per MHz, set by the TRAI, has been considered by the industry to be too high compared to elsewhere in the world. Also, it has been recommended that the spectrum be sold in chunks of 20 MHz. Therefore, each operator will have to shell out Rs 9,840 crore. Telcos say that this price per MHz is seven times that of South Korea. Such a steep spectrum price makes it unviable for them.

Auction for 4G in the spectrum range of 700MHz, 800MHz, 900MHZ, and 1800MHz, 2300MHz, and 2500MHz will also likely take place together with 5G. This will be the first auction after the last sale that began on October1, 2016. For the 700 MHz band, TRAI had suggested a 43 per cent reduction to Rs 6,568 crore per unit as the spectrum went unsold in 2016 due to high reserve prices. Operators would still have to pay Rs 32,840 crore for a Pan-India 5 MHz block.[91]

CII does not agree with TRAI that the spectrum pricing model should be based on the metric of dollars per MHz per population, since the revenue per user in India is very low. Instead it has proposed spectrum pricing on dollars/MHz/revenue, or dollars/MHz/GDP as a metric for comparing spectrum price across markets. “The population level of the country does not translate into proportionate revenues, resulting in lower cash flows for mobile operators”, says CII. High competition in the market has led to lower revenues, which in turn has lowered the revenue to the government by about 37% during the last two years. However, spectrum liabilities have remained high. With the recent Supreme Court judgement asking operators to pay Rs 94,000 crore spectrum cost within three months, there will be tremendous pressure on them to stay afloat.

The base price of auction is expected to bring Rs 5.6 lakh crore revenue to the government. TRAI is sticking to its position and wants the government to take a call on reducing the spectrum price. The Digital Communications Commission, in its meeting that was to be held in mid-September, was expected to take safe bet in accepting the TRAI recommendation, saying it had no expertise to decide otherwise. That’s buck passing, without examining the harsh realities that telcos are facing. Industry recommendations in solving their financial problems be accepted. Nobody talks about how China is accelerating its 5G rollout, with almost free spectrum, and base stations leased by Huawei and ZTE with the government support! It should be remembered that India is not among the seven countries that are investing in R&D, and in rollout of 5G networks. These countries will have significant growth in their economies, over the next 16-year period leading up to 2035. Also, they will add more jobs to their economies.

To compete globally in 5G infrastructure rollout, government could take a bold step by announcing free spectrum for a couple of years. This could be progressively increased to the base price of auction over the next couple of years. This single step will go a long way in creating huge 5G infrastructure in the country. 5G chipsets developed by start-ups, and software modules for segments of the network, be appropriately inducted into the infrastructure. Telcos will innovate for specific use cases, along with industry verticals for the country.

9. **Market challenges facing telcos**: Broadband subscriber base in India is 600 million, second only to China. GSMA expects India to have 88 million 5G connections by 2025. By 2024, India will only have five per cent of 5G phones, compared to 30 percent in China and Europe. We need to change this. Besides the spectrum challenges, telcos are facing financial difficulties. Over the last decade the industry has gone through consolidation via several mergers & acquisitions, as has happened in other countries. Market presents its own challenges, but ultimately the government has to step in, keeping the interests of users, and national development foremost in its policy measures.

   Aggressive campaigns by telcos, especially the new entrant— Reliance Jio, have increased competition, but brought down the subscription charges to rock bottom levels, which appear unsustainable. The charges are the lowest in the world, with Average Revenue Per User (ARPU) in the range of Rs 88 to 100, which may touch Rs 130 by the end of December 2019. This figure was Rs 200 in 2014-15. With data consumption going up from 1.5 to 2 GB, users are expected to be willing to pay more to bring ARPU back to 2015 level, say USD$3 per user per month. This may increase telco revenues to Rs 2.5 to 3 lakh crore. From gross revenue of Rs 2.65 lakh crore in 2016-17, the industry saw this go down to Rs 2.24 lakh crore in 2018-19 – a decrease of Rs 41,000 crore.[92] So, an increase in ARPU will only take the telecom industry, at best to its 2014-15 level. Telcos have to invest in upgrading to

> 5G infrastructure. This requires a minimum of $3 billion to cover parts of the country. The government intervention, in the form of relief through financial incentives is a must. It's disheartening to read that the Committee of Secretaries created for this purpose has been disbanded. Neither has the Digital Commission reduced the base price of 5G spectrum.

This presents a grim scenario of the government abdicating its role in the development of the telecom sector, which is the backbone of digital economy, and the services sector – IT, Banking, digital payments, e-commerce, e-governance, shared economy, and so on. A digital economy of a trillion dollars, for the growth of GDP to $5 trillion, by 2024, is possible only if the telecom industry is healthy and vibrant. The sector presently employs over 2.8 million people directly, and 7 million indirectly. The Government must intervene with policies conducive to the stability, sustainability and growth of the telecom industry.

4.4 SOME IMMEDIATE STEPS

5G will be key to Digital India becoming a trillion-dollar digital economy, and a significant part of five trillion-dollar economy in 5 years. All the telecom companies use equipment manufactured by Nokia, Ericsson, Huawei, Samsung and Siemens, like any other country in the world, except that Huawei from China has attracted major attention. 5G trials have to begin. India has to test both the western and Chinese equipment for security, especially back doors. It is time that the indigenous technology developed by start-ups be inducted for large scale trials by telecom companies. India has time to do so since it is projected that even by 2024, only 6% smartphones will be 5G. Data consumption per smartphone per month in India is presently 9.8GB; it will double by 2024 as subscriptions reach 1.1 billion, out of which 82% will be LTE (compared to 38% in 2018). Ericsson estimates that users are willing to pay 66% premium for 5G TV, VR Cloud Gaming, 5G in-car entertainment and virtual Tactile Shopping. Thus, 4G will be in use for another decade; it will continue to improve, reaching data transfer 2Gbps. So, India still has time to put its act together. We need to remember that in India the present 4G data transfer speeds average 6 Mbps, compared to 45 Mbps globally. So, we have a long way to go.

Hence, in 5G trials we must include Indian start-ups. It is time that telecom companies be asked to test and try the 4G and 5G chip sets of start-ups in field trials, under the aegis of the regulator. This alone will give them a chance to prove their technology in competition with Nokia, Ericsson, Siemens, Samsung and Huawei. We have some time, though not enough, to help them rollout and compete. As noted above, governments in the west and in China have models to help develop technology through funding, buying the same and deploying it in key projects in military and civil sectors. Without this effort, India will remain a laggard in indigenous technology development, and dependent on imported technology. In the absence of government's ability to evaluate and test technology, the start-ups are at disadvantage with respect to foreign players who come with proven and certified technology. Start-ups cannot be put at disadvantage for government's inability to test and certify technology. Some of the above policy approaches should be implemented immediately.

It is useful to heed IHT Markit advice on policy challenges. The 5G economy will introduce a new level of complexity to policymaking and regulation as new business models replace existing ones. Some of the areas that present policy and regulatory challenges for a 5G-economy include cyber security, privacy, spectrum licensing, public infrastructure, healthcare, transportation, education, training and development. The regulators have to accept ubiquity of 5G devices as a given in the economy and help create regimes for stunt continued innovation. The policy frameworks must be predictable so that start-ups, telcos and companies can take risks, make investments and continue to innovate. Our regulators should be aware of the challenges; they should introduce light touch regulations, with lot of flexibility to help the industry and nation move forward in building the 5G infrastructure and adopting use cases that create value.

CONCLUSION

5G is not just a game changer; it is likely to emerge as a GPT. Potential global sales activity across multiple industry sectors enabled by 5G could reach USD$12.3 trillion in 2035. This represents about 4.6% of all global real output in 2035. Global 5G value chain will add $3.8 trillion, with 22 million jobs by 2035.

5G mobile will move from being a consumer device to an industrial productivity and efficiency tool, with billions of IoT devices connected seamlessly for transformative applications in all sectors of economies and governance models. Smart cities, hospitals, manufacturing, agriculture, and transport deploying IoT will get transformed with ultra-fast data throughputs, and near zero latency will unleash the potential of AI and ML in all these sectors. AR and VR will usher in new ways of providing education, gaming, and 360 degree viewing of live stadia in real-time. Driverless cars, robotic surgery, real-time health care, and manufacturing will transform society.

According to GSMA, by 2025, 5G will account for 15 per cent of global mobile connections, reaching 1.4 billion. China and Europe will account for 30 percent, while the US will half of the total connections. 4G will continue to grow – it will be 60 percent of the total mobile subscriber base, up from 43 percent in 2018. During the same period, the IoT connections will triple to 25 billion, while the global revenue will quadruple to $1.1 trillion. With the addition of a billion new unique mobile subscribers since 2013, a total of 5.1 billion by the end of 2018, representing about two thirds of the global population, were connected. With projection of over 700 million new subscribers to be added over the next seven years (about a quarter of these coming from India alone), this will stand at 5.8 billion.

The operators worldwide are currently investing around $160 billion per year (capex) on expanding and upgrading their networks. The mobile ecosystem supported almost 32 million jobs in 2018 (directly and indirectly) and contributed to the funding of the public sector, with more than $500 billion raised through general taxation. GSMA reported that another 16 major markets worldwide will switch on commercial 5G networks in 2019, following on from the first 5G launches in South Korea and the US in 2018. GSMA believes that 5G will usher an era of Intelligent Connectivity, which along with IoT, big data and AI, will drive economic growth over the next few years. More than a billion new people will connect to the Mobile Internet, spurring adoption of mobile-based tools and solutions in areas such as agriculture, education and healthcare, utilities, professional and financial services, which will improve livelihoods of people around the world.

India is not among the top seven economies that are spending on R&D and rollout of 5G infrastructure, building use cases, new business models as first movers. With a large population, it's a ready market for technology and use cases that may be brought from these seven nations – US, China, UK, South Korea, Japan, Germany, France. With SDN and NFV forming the backbone, the core, of 5G networks, India, with its software prowess, has a chance to make a mark in building parts of 5G. It can design some of the chipsets too as demonstrated by a few start-ups. It may not get into semiconductor fabricators, since it's a very capital intensive and risky area. But it can, instead, forge long-term relationships with TSMC in Taiwan, and with Japanese fabricators, to get its designed chips manufactured there.

The telcos should be encouraged to work closely with Indian start-ups who are developing chips, and evaluate them in field trials. They should also use the skills of software industry to develop specific modules for SDN and NFV, including for securing the infrastructure. The key lies in deploying them, and in appropriately configuring them for specific use cases. The government and industry associations should play a lead role in helping build bridges through incentives, to encourage investments. Talking of suppliers of technology, cyber security, and supply chain risks, we have noted that 5G standards offer more security than all the previous generations of cellular networks. While the RAN and core network are more secure, user authentication is done in more secure way, it is the applications which are outside the network that have to be secured by the respective OTT providers, that require attention as is the case now. IoT devices, which are on the open Internet have to be secured. They cannot be left with factory defined passwords, which are open to known attacks. With billions of IoT on the 5G, the attack surface is bigger. It's not the underlying 5G network that is to be blamed for this, but the devices themselves. Application and service providers offering vertical solutions have to own up, and not blame 5G more than 4G networks.

Supply chain trust issues have to be handled within a framework such as the one proposed by EWI in its paper on Technology Nationalism. But the fear of Chinese companies reporting to its government in times of crises, under its cyber security law, cannot be ruled out. The nature of Chinese government, with opaque judicial process does not inspire confidence in democratic nations, including India. So, our decision of going beyond testing of Huawei in 5G, has to be based on national interest. It is a geopolitical challenge that is being addressed differently by various countries like the US, France, Germany, and the UK. That the existing 4G networks using Huawei technology cannot use the infrastructure for moving to 5G, is not correct. Nokia has confirmed it has a solution to build 5G using the existing 4G infrastructure of any other vendor. But as a nation, at the very least, India must have the capability to test the equipment for back doors. Testing laboratories are urgently required. We are caught in catch22 situation. No labs, no standards, no testing capability. Some vendors are willing to get their products tested, but no labs to do that. Government has not notified any standards.

Finally, to ease the financial squeeze that the Indian telcos are facing, the government should re-examine the definition of AGRs for taxation matters. Giving a moratorium on spectrum payments for two years is a welcome step. But as noted earlier, the government should give free 5G airwaves for two years to help telcos experiment with, and rollout networks for use cases in our own environment. China has already done that. Let’s remember that 5G is a key infrastructure for the next decade. India is already way behind.

APPENDIX 1: CELLULAR ARCHITECTURE - TECHNOLOGY BASICS: 1G TO 3G

CELLULAR AND WIRELESS COMMUNICATIONS

Communications using radio waves began with successful transmission of Morse code signals over 3.2 KMs by Marconi in 1895. Since then, engineers and scientists have been working on ever more efficient ways, to communicate audio and video data, over longer distances, at high speeds, using radio frequency (RF) waves. However, all this is a recent phenomenon; telephone for voice communication being the only device over physical lines – the wire – till the turn of the century. The quest for a device which didn't require a wired connection, but would transmit voice using radio waves, was realised by Motorola during 1970s, in the form of a handheld device capable of two-way communication wirelessly. Designed for use in a car, the first prototype was tested in 1974. After initial deployment in Japan by Nippon Telephone and Telegraph company (NTT) in Tokyo during 1979, it became popular in the US, Finland, UK and Europe in the 1980s. Today, this is referred to as the first-generation mobile phone, or 1G – First generation mobile communication system. Each operator used a different technology. 2G led to standardization based on Global System for Mobile (GSM) communication.

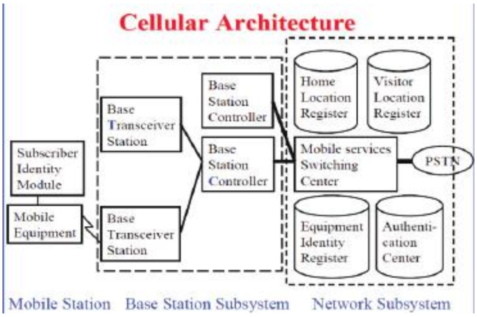
Its key components are: mobile station; Base Station Subsystem (BSS) comprising Base Station Controller (BSC) and base station transceivers; and network subsystem comprising mobile services switching centre (MSSC/MSC) connected to a gateway switching centre that links it to public switched telephone network (PSTN); with communication protocols providing ways to manage radio resources, connectivity etc; and radio interfaces – the encoding methods to access radio networks by mobile instruments in efficient way to maximise number of simultaneous multiple users. These are briefly described below.

Mobile Station (MS) – user's handset has two parts: Mobile Equipment (ME) + Subscriber Identification Module (SIM). It communicates across air interface with base station transceiver in same cell as the mobile unit. ME has Radio equipment, User interface, Processing capability and memory required for various tasks (Call signaling, Encryption, SMS), Equipment IMEI number (essentially a radio transceiver, and a digital signal processor) plus Subscriber Identity Module (SIM). SIM contains a microcontroller and storage for authentication, encryption and accounting information with 4-digit PIN controlled by the user, International Mobile Subscriber Identity (IMSI number of 15 digits), Subscriber's own information (telephone directory), Third party applications (banking etc.).

Base Station Subsystem (BSS): Base Station Controller (BSC) + one or more Base Transceiver Stations (BTS). Transcoding Rate and Adaptation Unit (TRAU) is a part of BSS – responsible for performing coding between the MS and the backbone network.

Network Subsystem: The backbone of a GSM network is a telephone network with additional cellular network capabilities: Mobile Services Switching Centre (MSSC), and Gateway Mobile Switching Centre (GSMC) which links the system to PSTN and other operators.

Mobile Services Switching Centre: it connects to PSTN; contains HLR (Home Location Register), VLR (Visitor Location Register), EIR (Equipment Identity Register), AuC (Authentication Centre). It is at the core to switch calls between BSCs; provides mobile registration, location, and authentication. The HLR database stores information about each subscriber that belongs to it. VLR database maintains information about subscribers currently physically in the region. The AuC is used for authentication activities; it holds encryption keys of all SIM cards. EIR database keeps track of the type of equipment that exists at the mobile station. Each handset is uniquely identified by International Mobile Equipment Identification (IMEI) Number.



Functions Provided by Protocols: Protocols above the link layer of the GSM signalling protocol architecture provide specific functions: Radio resource management: controls setup, termination and handoffs of radio channels; Mobility management: location and security (MTSO); Connection management: connects end users; Mobile application part (MAP): between HLR, VLR; BTS management: management base system.

Radio Interfaces: These are encoding methods to allow multiple mobile users to share the same spectrum. Efficient usage of the frequency band has been made possible by the signal encoding methods – also known as air interfaces or RAN interfaces. Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA) define access to networks. More efficient encoding methods have been developed to increase use of spectrum and data transfer speeds. These radio access network (RAN) interfaces include: UMTS, HSPA, EVDO, Orthogonal Frequency Division Multiplexing (OFDM), Multiple Input Multiple Output (MIMO), WiMax, LTE etc The generations are marked by a break in encoding methods, or "air interfaces," that make it incompatible with the previous generation. 2G used TDMA, FDMA, CDMA, GPRS, and EDGE, while 3G made use of UMTS, HSPA, EVDO. 4G key technologies that have made these possible are MIMO (Multiple Input Multiple Output) and OFDM (Orthogonal Frequency Division Multiplexing), and WiMax, LTE. 5G networks use OFDM encoding, similar to the encoding used by 4G LTE, but the air interface is designed for much lower latency and greater flexibility than LTE.

4G made wireless video-streaming a reality, and through its constant connection to GPS satellites enabled the rise of companies like Uber; speeds of 100-200 Mbps; attempts to scale upto a few Gbps. 5G on the other hand promises to be different than previous mobile upgrades; greater speed (to move more data), lower latency (to be more responsive), and the ability to connect a lot more devices at once (for sensors and smart devices). Data will move 100 times; it will handle far more data, with far lower lag times. It is about machine-to-machine communications, with billions of IoT devices connected - everything from washing machines to self-driving cars to entire “smart cities”. It is in order to understand the differences in the cellular generations. So, a bit more details.

1G: ANALOGUE MOBILE COMMUNICATION

It used multiple cell sites, with ability to transfer calls from one site to the next as the user travelled between cells during a conversation. It was Bell Labs which developed modern commercial cellular technology in 1984, which employed multiple, centrally controlled base stations (cell sites), each providing service to a small area (a cell). The cell sites would be set up such that cells partially overlapped. In a cellular system, a signal between a base station (cell site) and a terminal (phone) needs to be strong enough to reach between the two, so the same channel can be used simultaneously for separate conversations in different cells. As the system expanded, the ability to reduce transmission power allowed new cells to be added, resulting in more, smaller cells and thus more capacity.

1G system used analogue signals in the frequency range 800 - 900 MHz; Bandwidth: 10 MHz; Technology: Analogue switching; Modulation: Frequency Modulation (FM); Mode of service: voice only; Access technique: Frequency Division Multiple Access (FDMA). The drawbacks included: poor voice quality due to interference; poor battery life; large sized mobile phones; lack of security in calls since decoding was possible by anyone using an FM demodulator; number of users and cell coverage were limited. Roaming was not possible because operators were using their own standards.

2G: DIGITAL NETWORKS – CIRCUIT-SWITCHED

The second generation (2G) mobile phone systems, used a standard - the Global Systems for Mobile (GSM) communication; so roaming was possible. 2G cellular phone systems used digital transmission instead of analogue, though it was still circuit switching. It introduced advanced and fast phone-to-network signalling, in what is known as Radio Access Network (RAN). Digital coding improved the voice clarity and reduced noise in the line. Digital encryption provided secrecy and safety to the data and voice calls. 2G technology requires strong digital signals, but consumed less battery power, which led to smaller phones with longer lasting batteries. Starting with Finland in 1991, 2G spread all over the world.

It also introduced texting – Short Message System (SMS) – a new variant to communication. SMS text messaging became the communication method of preference for the youth. Picture messages, and multimedia messages (MMS) could also be exchanged. Today, it continues to be used, along with many other forms of messaging like WhatsApp, Telegram, and messengers provided by many other Applications (Apps) as a preferred mode of communication, to placing voice calls.

Data transfer rates became a measure of the speed of 2G, and of subsequent generations. Initially, 2G data transfer rate was only around 9.6kbps (kilobits per second), but the GSM standard could support up to 64kbps – adequate for SMS and email services. However, within 2G new technologies were developed, and telecom operators invested in new infrastructure such as mobile cell towers, which helped pushed data transfer rates to 500 kbps. Code Division Multiple Access (CDMA) system developed by Qualcomm, and implemented in the mid-1990s, saw more features than GSM in terms of spectral efficiency, number of users and data rate.

Quest for higher data rates led to development of General Packet Radio Service (GPRS), and Enhanced Data GSM Evolution (EDGE) for GSM networks. GPRS was capable of data rate up to 171kbps, while EDGE pushed the limit up to 473.6kbps. Both the technologies were introduced and successfully deployed in what came to be known as 2.5G and 2.75G. Yet another popular technology was CDMA2000; it supported maximum data rate upto 384kbps for CDMA networks.

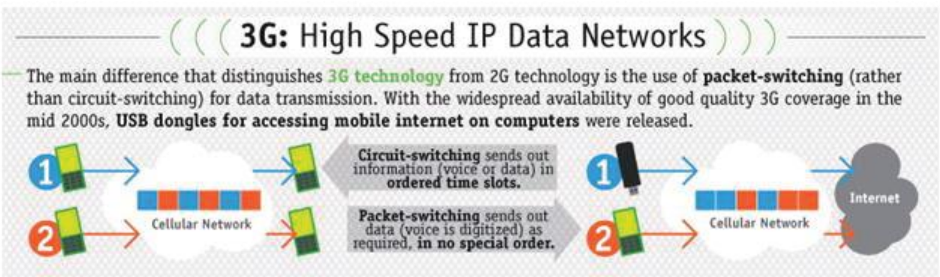
2.5G using GPRS technology is a cellular wireless technology developed in between its predecessor, 2G, and its successor, 3G. GPRS could provide data rates from 56 kbps up to 115 kbps. It can be used for services such as Wireless Application Protocol (WAP) access, MMS, and for Internet communication services such as email and World Wide Web access.

2.75 – EDGE technology is an extended version of GSM. It allows the clear and fast transmission of data and information up to 384kbps speed. The 2G era from 1980s to 2003, saw advancements such as GSM, GPRS, EDGE, and CDMA within the spectrum itself.

3G: DIGITAL PACKET-SWITCHED NETWORK – HIGH SPEED

Demand for data services, such as access to the Internet, was growing with popularity of mobile phones in the daily lives of people. It was clear that 2G circuit-switched digital, even with upgrades to 2.75G had to undergo major technological change. 3G was a truly digital, IP-based network that used packet switching rather than circuit switching for data transmission. 3G was launched by NTT DoCoMo in 2001 and aimed to standardize the network protocol used by vendors. This meant that users could access data from any location in the world as the ‘data packets’ that drive web connectivity were standardized. This made international roaming services possible. Universal Mobile Terrestrial / Telecommunication Systems (UMTS) was standardized by the International Telecommunication Union (ITU), which was carried out by Third Generation Partnership Project (3GPP). UMTS is an upgrade from GSM via GPRS or EDGE. Data rates of UMTS are: 144 kbps for rural, 384 kbps for urban outdoor, and 2048 kbps for indoor and low range outdoor. It led to new services like video calling, video conferencing, video streaming of TV content, and voice over IP (such as Skype) on mobile phones, supporting Virtual Home Environment (VHE). Blackberry with its powerful features, launched in 2002 was a result of 3G connectivity. Soon, smart phones with apps to handle multimedia chat, email, video calling, games, social media and healthcare became the rage.

3G speed was four times that of 2G. But 3G continued to evolve to achieve much higher speeds. High-Speed Downlink Packet Access (HSDPA) was developed as an enhanced 3G mobile telephony communications protocol in the High-Speed Packet Access (HSPA) family. It became known as 3.5G, since it enabled UMTS to have higher data transfer speeds and capacity. HSDPA deployments supported downlink speeds of up to 14Mbps. Further speed increases became available with HSPA+, up to 42 and 84Mbps downlink.

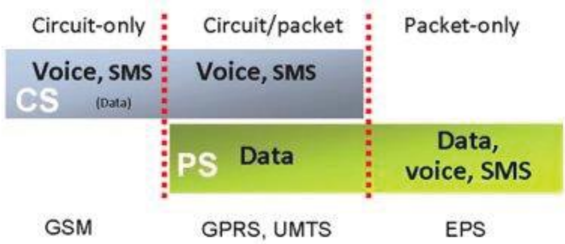


Source: [cellphones.org]

3G UMTS Frequency band: 1900 – 2200 MHz

3GPP standards for RAN interfaces: W-CDMA, EDGE, TD-SCDMA; CDMA2000-1xRTT; CDMA2000-1xEV, DV,EO; CDMA2000-3xRTT

2G and 3G network architectures process and switch voice and data through two separate sub-domains: circuit-switched for voice and packet-switched for data. Evolved Packet Core (EPC) unifies voice and data on an Internet Protocol (IP) service architecture and voice is treated as just another IP application. EPC is a framework for providing converged voice and data on a 4G Long-Term Evolution (LTE) network ; it allows operators to deploy and operate one packet network for 2G, 3G, WLAN, WiMAX, LTE and fixed access (Ethernet, DSL, cable and fibre).

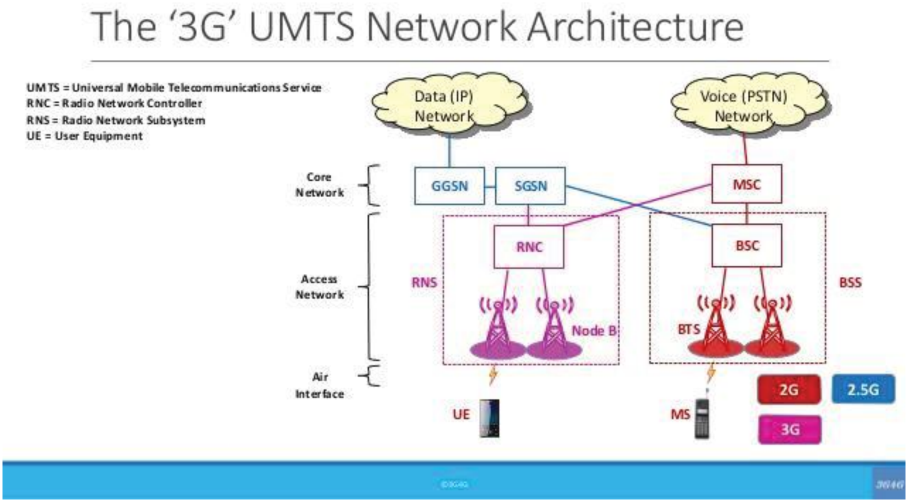


[Image Source: 3gpp.org]

UMTS Network Architecture consists of three domains:

- Core Network (CN): provides switching, routing and transit for user traffic
- UMTS Terrestrial Radio Access Network (UTRAN): provides the air interface access method for user equipment.
- User Equipment (UE): terminals work as air interface counterpart for base stations. The various identities are: IMSI, TMSI, P-TMSI, TLLI, MSISDN, IMEI, IMEISV

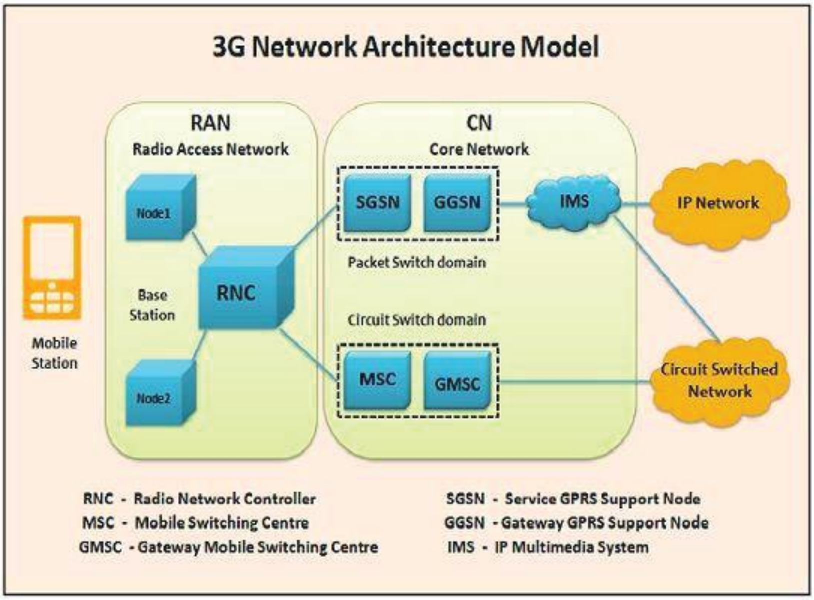
UTRAN: Radio access is over wide band CDMA technology selected for UTRAN air interface (WCDMA, TD-SCDMA). Base stations referred to as Node-B and control equipment for Node-B is called as Radio Network Controller (RNC). Functions of Node-B are to provide air Interface Tx/Rx, modulation/demodulation; while functions of RNC are radio resource control, channel allocation, power control settings, handover control, ciphering, segmentation and reassembly.



[source: slideshare.net]

3.5G HSPA: High Speed Packet Access (HSPA) - amalgamation of two mobile telephony protocols, High Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA), that extends and improves the performance of existing WCDMA protocols.

3.5G introduced many new features to enhance the UMTS technology. These include: Adaptive Modulation and Coding; Fast Scheduling; Backward compatibility with 3G; and Enhanced Air Interface. Speeds of 200kbps to tens of Mbps; even 5-30 Mbps was realised by the end of 3G.



[Source: ITU Adaptation]

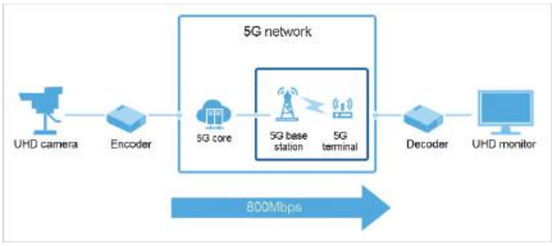
4G and 5G are in the main text of this paper. Suffice to note that 4G is a full IP-based digital network.

[International Journal of Computer Applications (0975 – 8887), Volume 5– No.4, August 2010Generations of Mobile Wireless Technology: A Survey][93]

APPENDIX 2: SOFTBANK AND HUAWEI 5G USE CASES - DEMONSTRATION DETAILS

REAL-TIME UHD VIDEO TRANSMISSION

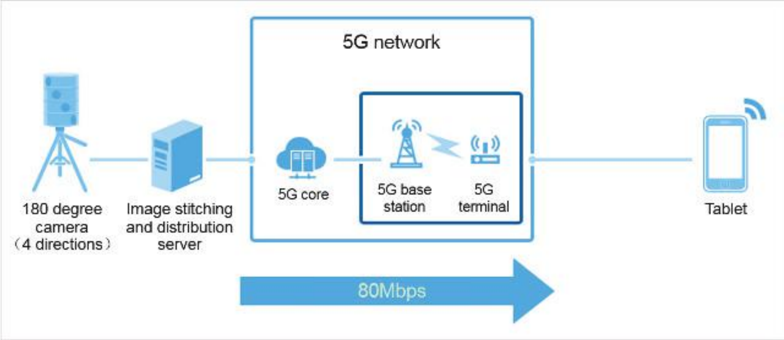
A UHD camera was installed inside the demonstration room to capture outdoor scenery. The data from this camera was then compressed in real-time using an encoder and transmitted through the ultra-high throughput 5G network to a UHD monitor via a decoder, where the original data was recovered. In this demonstration, the scenery of the Odaiba Tokyo Bay area was successfully displayed on the UHD monitor using the ultra-high throughput provided by the 5G network. This technology can be applied to various industries, including tele-health or tele-education.



[Source: Vanillaplus.com]

IMMERSIVE VIDEO

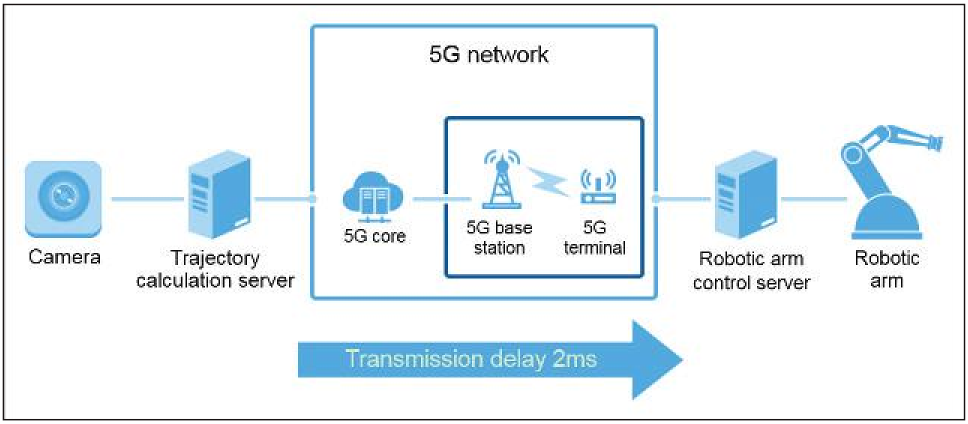
Scenery was captured by a 180-degree camera equipped with four lenses pointing four different directions installed in the demonstration room, and captured scenery was distributed to smartphones and tablets over the 5G network. Four separate cameras were set up to capture the scenery in different directions, and the video images captured by these cameras were stitched together to generate a 180-degree panoramic video image that enabled multiple simultaneous camera views. Then the video image was compressed and distributed to smartphones or tablets in real-time over the 5G network, which gives users a truly realistic user experience. Coupled with a 5G network, this technology can be applied to virtual reality (VR) or augmented reality (AR).



[Source: Vanillaplus.com]

REMOTE CONTROL OF ROBOTIC ARM WITH ULTRA-LOW LATENCY

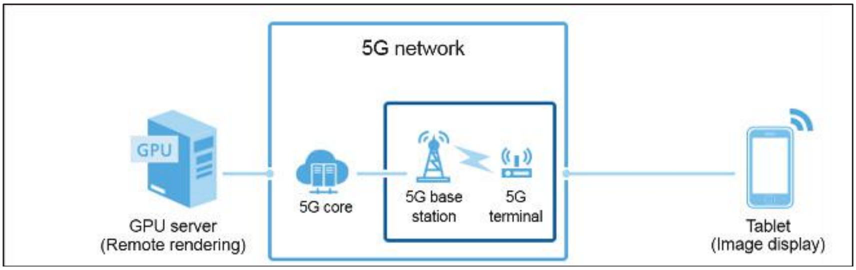
A robotic arm played an air hockey game against a human in this demonstration. A camera installed on top of the air hockey table detected the puck's position to calculate its trajectory. The calculated result was then forwarded to the robotic arm control server to control the robotic arm. In this demonstration, the robotic arm was able to strike back the puck shot by the human player on various trajectories. This technology can be applied to factory automation, for example.



[Source: Vanillaplus.com]

REMOTE RENDERING BY GPU SERVER

Rendering is a technology used to generate videos or images using computers with GPUs (Graphic Processor Unit). This technology is used for generating HD videos in computer games or for CAD (Computer Aided Design). The rendering consumes a large amount of computing resources. Therefore, HD computer games or HD CADs were not executable on tablets or smartphones on their own. However, edge computing technology provided by the 5G network allows us to enjoy HD computer games or HD CADs on tablets or smartphones. A GPU server located near a 5G base station performed rendering and the image generated by the GPU server was sent to the tablet over the ultra-high throughput and ultra-low latency 5G network. This technology can be applied to check the CAD data at a construction site with a tablet or to enjoy a HD game application on a smartphone.



[Source: Vanillaplus.com]

*" Immersive video" and “remote control of a robotic arm with ultra-low latency" were jointly integrated and configured for demonstration by SoftBank and Huawei. "UHD real-time video transmission" and "Remote rendering with GPU servers" were integrated and configured for demonstration by SoftBank.

APPENDIX 3: EXCERPTS FROM IHT MARKIT REPORT ON THE 5G IMPACT ON ECONOMY

Economic contribution: The 5G economy will be characterized by strengthening of the infrastructure and technology base in the next few years, followed by large scale global deployment of the 5G use cases. It is clear that the early deployments are likely in eMBB applications, MIoT (mMTC) and MCS (URLLC) applications will gain traction in the medium-to-long term as 5G drives mobile deeper into industrial applications.

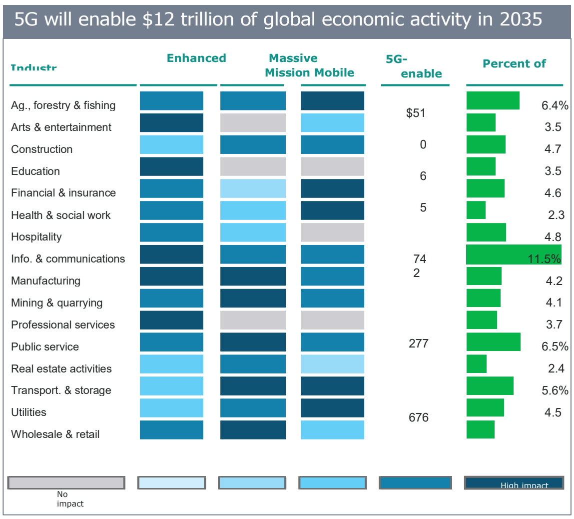
To understand the extent and timing of the economic impact of 5G deployments, IHS Markit analyzed 16 major industry sectors, from the UN ISIC global industry classification system, which provide standardized reporting of economic indicators regardless of the country.

To understand the global economic impact of the 5G Economy, IHS Markit, in partnership with the Berkeley Research Group and the Global Business group at the Haas Business School at the University of California at Berkeley developed an economic model of the potential global sales activity across multiple industry sectors. It estimated that Global output is a $12.3 trillion global opportunity.

5G deployments will positively affect virtually every industry sector. Adoption and integration across many industry sectors will solidify the role of 5G in transforming mobile technology into a GPT. However, their respective economic and regulatory structures will affect the timing and creation of the new business models that 5G will enable. It is because of this reason that IHS Markit focuses on the longer-term horizon and the choice of 2035 as the analysis year. IHS Markit estimates the potential global sales activity across multiple industry sectors enabled by 5G could reach $12.3 trillion in 2035. This represents about 4.6% of all global real output in 2035.

Manufacturing will see the largest share of 5G-enabled economic activity in 2035—almost $3.4 trillion or 28% of the $12.3 trillion in sales enablement. At first, this may appear high, until one considers that implementing any of the 5G use cases will stimulate, at a minimum, complementary spending on equipment, all of which are produced by the manufacturing sector. For example, drones will enable sales within the transportation sector. However, this will require the transportation sector to buy additional drones from the manufacturing sector. Medical use cases will require complementary spending on 5G-ready equipment from the manufacturing sector. The same line of reasoning applies to the information and communications sector, which will see the second largest share of 5G-enabled economic activity, at more than $1.4 trillion. Implementing any of the 5G use cases will require spending on communication services.

IHS Markit presents the following Table that gives sector-wise contribution to economy.



[Source: IHS Markit]

While 5G could enable about 4.6% of global real output in 2035, the enablement percentage by industry will vary from a high of 11.5% in the information and communications sector to a low of 2.3% in the hospitality sector. The sheer size of the manufacturing sector, which will account for nearly 30% of global real output in 2035, along with the fact that much of the 5G-enabled manufacturing sales will be secondary (i.e., equipment sales in support of use case) will lead to a percentage (4.2%) that is slightly below the overall average. More notable is the fact that 5G could enable 6.5% of public service (government) and 6.4% of agricultural output in 2035, supported by smart city and smart agriculture deployments, respectively.

To put these findings in a broader context, one must also consider how many industries will be truly affected by each use case. For example, the availability of autonomous vehicles and drones will do more than stimulate sales of driverless cars and Unmanned Aerial Vehicles (UAVs) to consumers. They will also be deployed in agricultural and mining applications ranging from surveillance of remote natural resources to autonomous transport of ores to self-driving tractors. They will be widely used in the transportation sector for driverless transport and delivery of commercial and consumer goods. Municipalities will integrate autonomous vehicles into their transit systems while using drones for monitoring functions. In manufacturing, autonomous vehicles will also be used in intra-plant stocking and retrieval systems. Finally, autonomous vehicles will also positively affect the insurance industry as vehicle accident rates decrease. 5G value chain in 2035: $3.5 trillion in output and 22 million jobs.

Achieving the output enablement potential of 5G will require on-going investments by firms in the 5G value chain to continually improve and strengthen the foundational technology base. The 5G value chain will encompass a broad spectrum of technology firms, including but not limited to: Network operators, Providers of core technologies and components, OEM device manufacturers, Infrastructure equipment manufacturers, and Content and application developers. The United States and China are expected to dominate 5G R&D and Capex, investing a total of $1.2 trillion and $1.1 trillion, respectively, over the 16-Year time horizon of this study. IHS Markit estimates that the United States will account for about 28% of global 5G investment, followed by China at 24%. Spending beyond the seven core countries will make up about 23% of the global 5G investments.

The IHS Markit modelled the economic activity of the 5G value chain for seven countries that are expected to be at the forefront of 5G development: the United States, China, Japan, Germany, South Korea, the United Kingdom, and France. From 2020 to 2035, IHS Markit anticipates the collective investment in R&D and Capex by firms that are part of the 5G value chain within these countries will average over $200 billion annually. In the early years, foundational R&D and network infrastructure deployments will dominate 5G investment activities.

Subsequently, IHS Markit expects the overall investment in R&D and Capex to slowly taper. During this period, the focus of the investments will shift from primarily infrastructure towards development of applications and services that exploit the unique capabilities of 5G. The sustained investment cycle is another indicator that 5G is a “long game” that will see investment priorities shift as infrastructure is deployed, new business models come online, the underlying technology base is continually strengthened, and replacement cycles for many of the use cases are lengthened.

- Ultimately, the investments in R&D and Capex will help bring the 5G use cases online, thereby enabling sales across virtually all industry sectors while also driving sales throughout the 5G value chain and its associated supply networks. IHS Markit estimates that, by 2035, the 5G value chain alone will drive $3.5 trillion of economic output and support 22 million jobs. Given the relative size of the population and the investments made, 5G will support the highest number of jobs in China. The investments made by these seven countries, will impact the rest of the world. Many developing and emerging economies are already leapfrogging older technology and becoming more mobile oriented, and 5G will have significant economic impact on these mobile-enabled economies. Economic activity stimulated in the rest of the world is slightly higher than those for the United States (the biggest investor in 5G).
- Global 5G value chain output and employment in 2035
- China: Gross output: $984B; Employment: 9.5M
- United States: Gross output: $719B; Employment: 3.4M
- Japan: Gross output: $492B; Employment: 2.1M
- Germany: Gross output: $202B; Employment: 1.2M
- South Korea: Gross output: $120B; Employment: 963K
- France: Gross output: $85B; Employment: 396K
- United Kingdom: Gross output: $76B; Employment: 605K
- Rest of the world: Gross output: $800B; Employment: 3.6M
- Global total in 2035: Gross output: $3.5T; Employment: 22M

The IHS Markit models reveal that 5G technology would contribute very large and sustainable economic benefits across all sectors of the global economy. Like previous generations of mobile technologies, 5G will have a profound effect on how people live, work, and interact, but 5G will transcend the communications field and help fundamentally alter how a vast and diverse group of industries operate. It views 5G as a catalyst that will thrust mobile technology into the realm of GPTs. By 2035, mobile applications will experience pervasive adoption across multiple industries, initiating transformative changes that will redefine work processes and spur innovations that rewrite the rules of competitive economic advantage. These innovations will have extraordinary effects on human and machine productivity and ultimately may help elevate living standards for people around the world.

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