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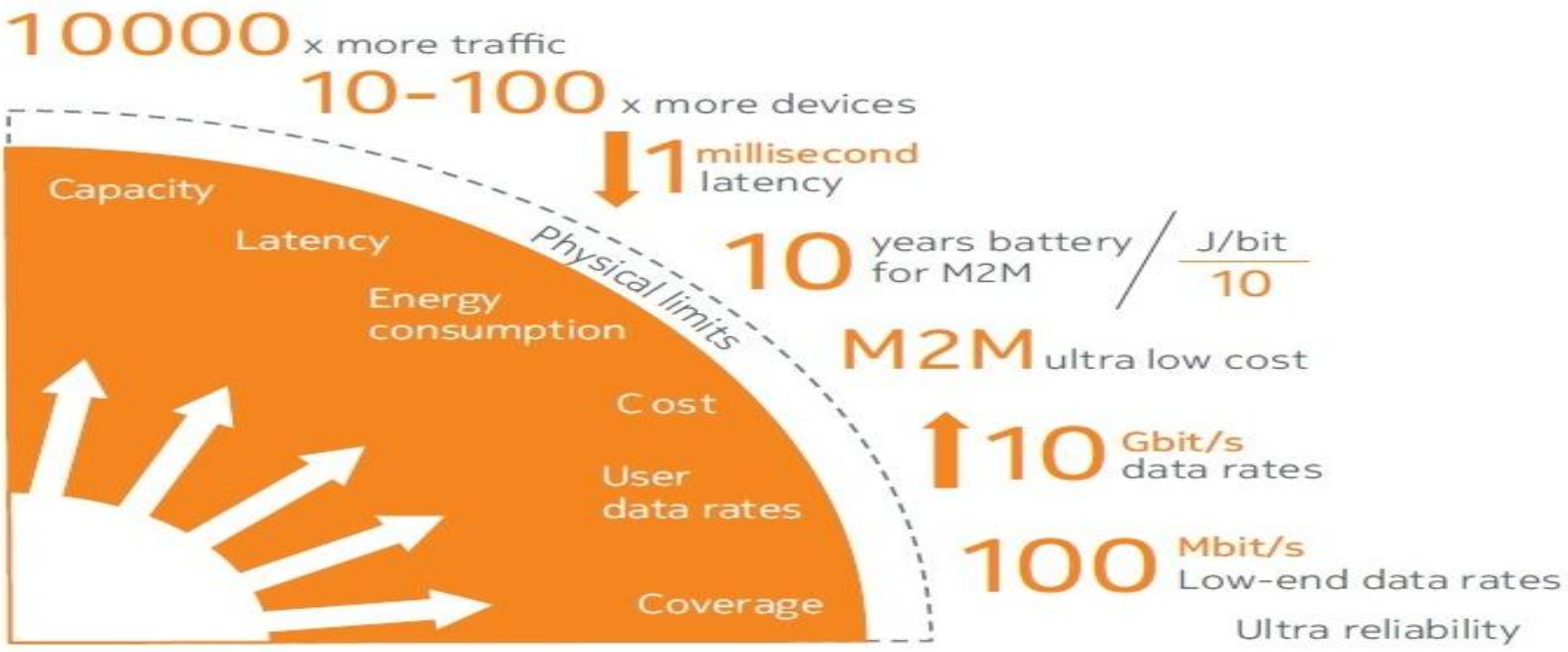
LANDSCAPE ON 5G TECHNOLOGY

A TECHNOLOGY AND SERVICE PROVIDERS PERSPECTIVE



Contents

1. Executive Summary

Fast adaptation of telecommunication technologies and services by different sects of society, and parallel development of advanced technologies at hardware and software levels are key drivers behind the success of the telecom industry,which has come a long way from the first generation cellular technology to the present day's fourth generation (4G)cellular technology. As we are moving from the world of "Internet for People" to the "Internet of Things", which aims to connect 50 billion users and devices around the world by 2020, next generation cellular technologies that can provide ultra-high bandwidth, ultra-high data rate, zero latency, high speed mobility, and high energy efficiencyare foreseen. Technology pioneers are working on 5'th generation (5G) cellular technologiesthat meet requirements of the next generation wireless devices, and this study provides an overview on the 5G platform as to how different stakeholdersare gearing up towards the next generation cellular technology. The report further tries to offer a broad level analysis/overview of their existing patent holdings and attempts to bring light to how telecom operators around the world are setting up and/or planning to set up the required infrastructure for the fifth generation wireless technology, and how Reliance Jio, among other Service Operators/Providers in India, can use their competitive strength to become a prominent stakeholdersin this domain.

2. Study Overview

As more and more devices are getting connected and reliance on network communication is increasing in an unprecedented manner, data traffic would continue to increase over time. 5'th generation wireless technology is being designed to meet the requirement of over 50 billion connected users/devices of different types (e.g. mobile phone, tablet, home appliance, probes, sensors, meters, machines, vehicles etc.) from different sectors (e.g., critical infrastructure, medicare, education, industrial automation etc) that may need to transfer 1000X data/content at ultrahigh speed (atleast 1 Gb/s or more data rates), with zero latency (less than one millisecond) while maintaining high speed mobility(max 10 millisecond switching time).There will be requirement of high density installation of wireless access points to provide connectivity to these increasing numbers of users/devices that may create highlydense crowds of connected devices or may be present anywhere in the world.

The present report presents a quick review on evolution of cellular technology and the requirement of next generation cellular technology with a focus on the Indian market.A competitive analysis of the cellular operator and technology provider with respect to Indian market has been conducted to provide an overview on competition of Reliance Jio's, and its own competitive advantages being a major player in the 4G cellular operation and infrastructure in the country.

The study further focuseson fifth generation wireless technology, and tries to analyze how different stakeholders, including government agencies, R&D institutions, standard marking organizations, OEM companies, network operators and infrastructure providers are preparing themselves for this technology. A close technology analysis has been conducted on patents filed by different stakeholders, which will contribute in realizing fifth generation cellular technology. Technology analysis has been conducted for 5G candidate technologies such as "MMwave Technology" that secures a broad bandwidth (over 1GHz) in the 30-300 GHz in band frequency, and controls a short frequency to amplify transmission capabilities, "Large Scale Multiple Antenna and MIMO" Technology that achieves high transmission speeds and energy effectiveness by installing hundreds to thousands of antennas in base stations, "CellCreation and Management Technology" that maximizes information transmission capacities by increasing densities of small cells that transmit information, "Smart and Cognitive Antennas" and other technologies than enable high bandwidth, high data rate, zero latency, zero down time, high speed mobility,and energy optimization of network devices.

Exhibit-1 below represents major companiesthat are actively involved in Research and Development of 5G technology and have filed patents that may be relevant for 5G framework. As can be seen, Qualcomm, as was also the case in 4G has taken a strong leap forward in becoming a dominant player in the market across all technology verticals relating to 5G platform, followed by companies such as ZTE and Samsung.

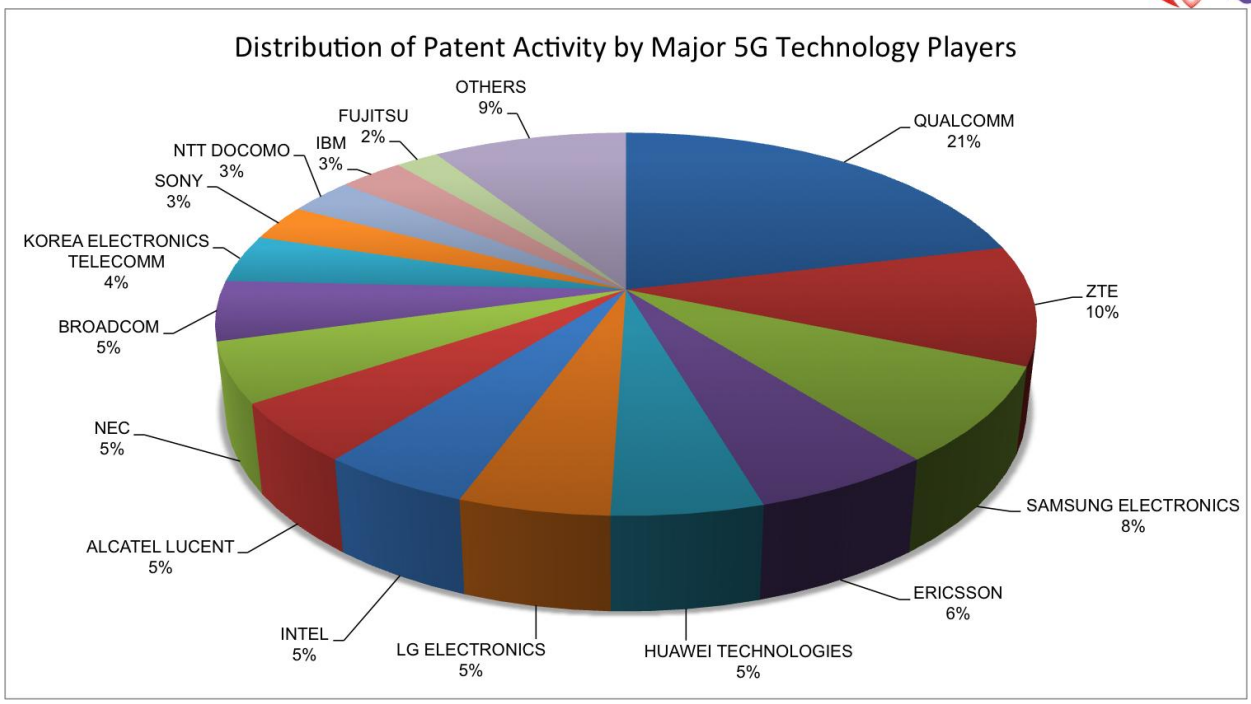


Exhibit-1

Exhibit-2 below representskey focus areas of the 5G enabling technologies:

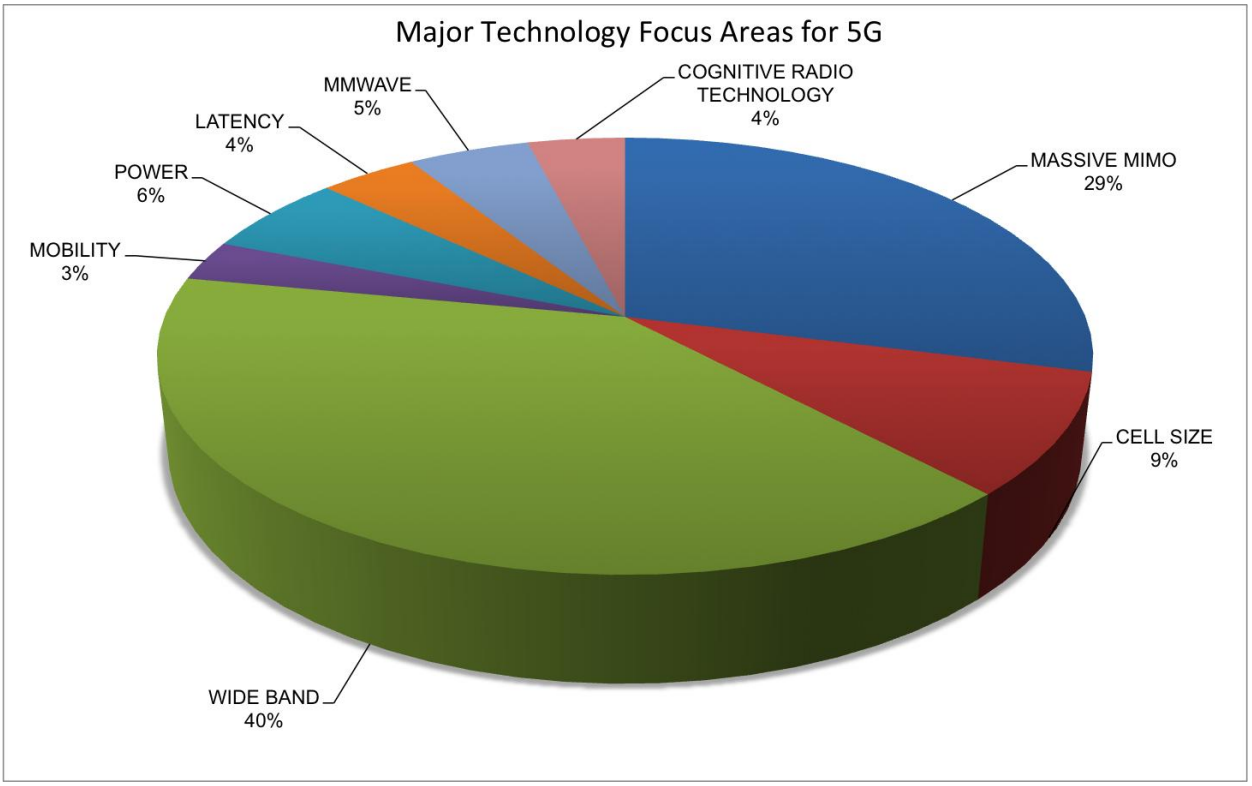
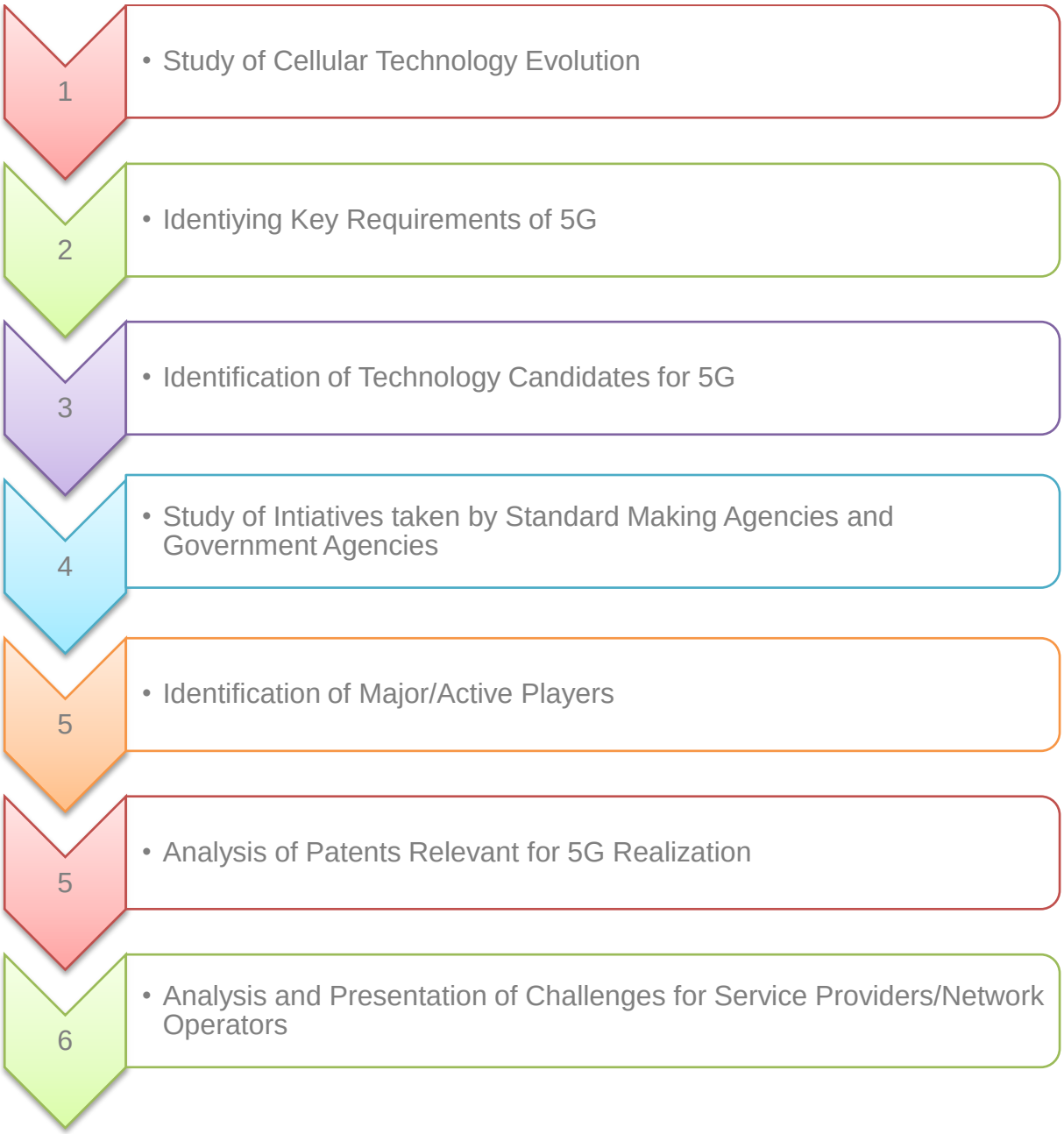


Exhibit-2

3. Research Methodology

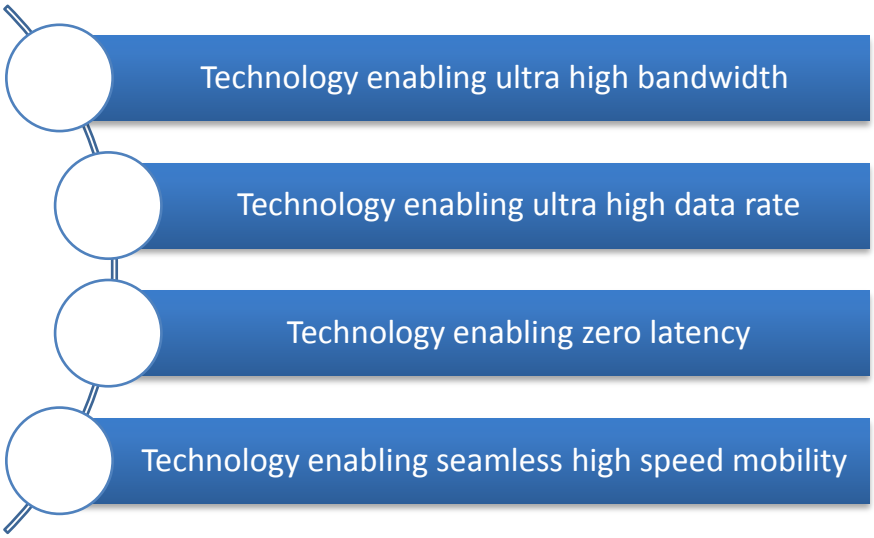
The present study has been conducted for 5G enabling technologies,and to understand the challenges/solutions of the fifth generation network that need attention of network operators. Following pointers give a very high-level research methodology that has been followed/incorporated while conducting the present study:

3.1 Step Taken



3.2 Assumption

Present study has been conducted with respect to multiple perspectives with an earnest attempt to showcase the key technology candidates for 5G. In the limited time of around one week, we have focused on identification of key technology candidates, activities of standard making agencies and Government agencies, conducting patent Searching &analysis, and have tried to bring out various perspectives of deployment challenges and technology development. The basic assumptionfor qualification of technologiesto be used in 5G includes:



3.3 Data Sources

The study was primarily carried out using Questel-Orbit, a popular database of patent applications and granted patents from 95 patent jurisdictions around the world created by Questel. Access was also made to databases such as USPTO, Patent Lens, and Thomson Innovation to validate the records and results received and also to conduct various different string searches to evaluate above-mentioned aspects of landscape analysis on 5G. Information and data published by standard making agencies and government agencies with respect to 5G have been accessed.

The database is created editorially in the sense that the key content of patent applications and granted patents such as novel feature, applications, benefits are re-abstracted from the original text of the patent document into a standard format. In addition, the architecture of the database provides for good analytical capability. The Orbit database also organizes raw patent information into families using a definition specific to the FamPat database. IIPRD however disclaims the accuracy of the data retrieved from Questel Database and errors that might be arising out of the same.

The database includes the following patent classifications for accurate and comprehensive record retrieval:

- US Patent Classification
- Cooperative Patent Classification (CPC)

- International Patent Classification (IPC)
- Japanese File Index (FI) and F Terms
- FamPat Classification (editorially applied)

The database provides comprehensive global coverage back far enough in time for accurate descriptions of the landscape. However the present study was restricted to patent applications filed in US.

3.4 Patent Applicant Naming Variations

Name of the organization to which inventors assign their invention (typically, their employer) varies considerably both within a single entity and over time. For example, IBM can patent both under the acronym and as International Business Machines. Even within these two distinctions, variations in syntax, spelling and formatting can create problems with formal accurate analysis of entity names. Furthermore, the acquisition of a company, or indeed the divestiture of subsidiaries can create issues with proper identification of patent ownership. Therefore there is a requirement for normalizing the various name variants that exist within the dataset, as well research into mergers, acquisitions and subsidiaries to provide an accurate reflection of the ownership of patent rights within the landscape.

This process is performed using various methods, including:

- Identifying and correcting minor variations in names, e.g. IBM versus I.B.M.
- Identifying likely candidates for aggregation, such as distinct entities that share inventors; performing research on name variants for definitive identification
- Aggregating known historical mergers and acquisitions

Additionally, these methods provide a good method for minimizing the number of records that are not yet associated with an organization – e.g. unassigned US patent applications.

3.5 Search String Creation

The creation of search string was performed iteratively,wherein the results output by each search string were reviewed and evaluated to inform and tailor the search to become more accurate.As each search string is created, results are sampled and reviewed for relevancy, and keywords and assignees are amended as appropriate. Furthermore, the results of each string are data mined for further key terms of interest, synonyms and alphanumeric technology classification codes of relevance, which are then incorporated in revised search strings. This process is repeated until revisions yield only minor variations in results, at which point, the search string is locked in its configuration.

4. Technology Overview

As more and more people and devices are connecting to the Internet and to "Internet of things" that aims at connecting more than 50 billion users/devices, necessity of next generation technology is foreseen by the industry. A future reality expects an exponential growth in the number of mobile users, connected homes, connected offices, smart grids, smart home appliances, next generation health care systems, smart transports, machine to machine interactions, vehicle to vehicle communications, smart sensors, smart tools and other connected devices that are expected to transfer data that is 1000 times faster/higher than the present data traffic being handled by the cellular communication.

Exhibit-3 represents a future traffic requirement that is expected to emerge after 2020.

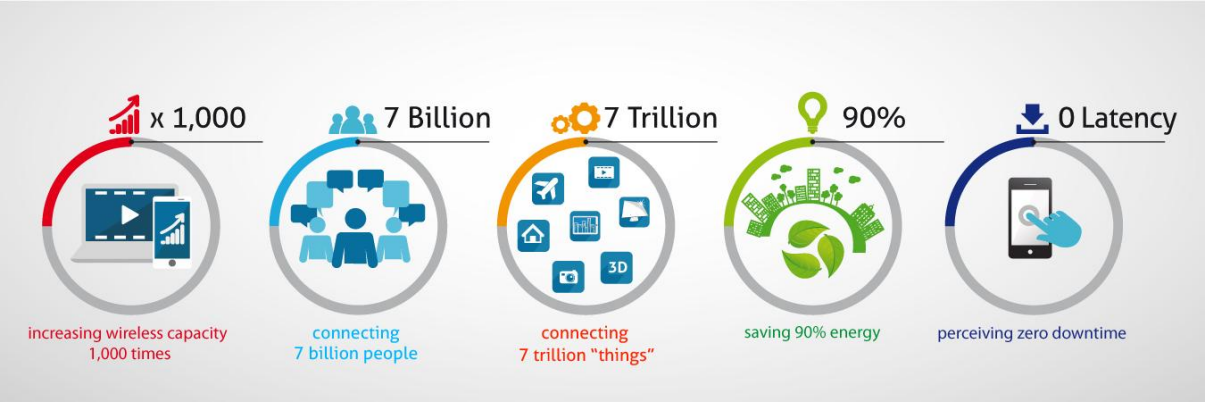


Exhibit-3

As the technology leaders around the world are trying to connect entire humanity over Internet that is expected to plug 7 billion people with over 7 trillion things through Internet, Exhibit-3 above illustrates exemplary requirements of the next generation network (5G) that should havea capacity that is 1000 times higher than the present capacity. In order to achieve such capacity, ultra-high bandwidth and ultra high data rate will be required that can transfer such a huge volume of data with zero latency during high mobility.The next generation wireless technologies and devices also need to be energy efficient so as to make sure that the increasing number of devices doesn't adversely impact the global eco-system.

Before going in detail about 5G requirements and its enabling technology, the section below presents a quick look at the evolution of wireless technologies over the years.

4.1Evolution of Wireless Technologies

Wireless technology has come a long way from analog communication systems to digital communication system,which can connect users and devices for peer-to-peer communication and Internet communication. The following key aspects of wireless technologies have evolved and have shaped generations of cellular technology: radio access, data rates, bandwidth and switching schemes. This section of the report mentions, in short, the evolution of wireless and cellular systems based on these four main key aspects, namely radio access, data rates, bandwidth, and switching schemes.

Exhibit-4 below represents a high-level graphical representation of different generations of wireless technology, their evolution time, data rate, and standards.

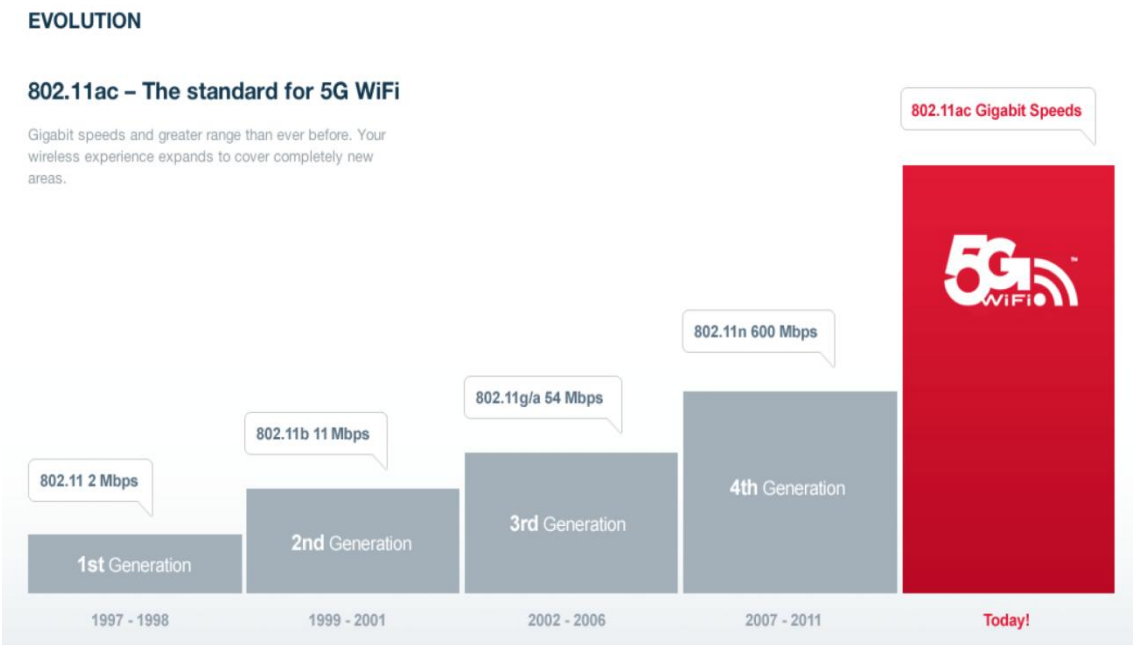


Exhibit-4

4.1.1 First Generation Systems (1G)

First generation wireless systems (1G) was an analog system that used frequency modulation technique for radio transmission using frequency division multiple access (FDMA) with channel capacity of 30 KHz and frequency band of 824-894 MHz. 1G was based on a Advance Mobile Phone Service (AMPS) technology and was pioneered for voice service in early 1980‘s.

4.1.2 Second Generation Systems (2G)

Second generation systems (2G) transitioned from analog communication system to digital communication system during late 1990’s and is still the most used wireless data communication system in different parts of the world. The second generation wireless technology was based on GSM standards, and provides data services (e.g. SMS, e-mail, web browsing etc.) in addition to regular voice service. 2G usestwo digital modulation schemes,namely time division multiple access (TDMA), and the code division multiple access (CDMA) and operates in frequency band of 850-1900 MHz. In 2G, GSM technology uses eight channels per carrier with a gross data rate of 22.8 kbps (a net rate of 13 kbps) in the full rate channel and a frame of 4.6 milliseconds (ms) duration.Few of the main benefits of 2G networks over their counterpart 1G networks include their capability to digitally encrypt phone conversations, being efficient on the spectrum by allowing far greater mobile phone penetration levels, and ability to provide data services for mobile starting with SMS text message, and multimedia services. Though 2G has its successors, it is still the most widely used wireless technology in developing countries, which would take time to build up the necessary infrastructure for 3G, much talked about 4G, and the future generation 5G.

4.1.3 Third Generation Systems (3G)

Third generation (3G) systems combine high-speed mobile access with Internet Protocol (IP)-based services that came in the global market during 2002. The technology is still under adaptation by manydeveloping countries that had some delay in infrastructuredevelopment and spectrum licensing. Countries such as India and China with massive population are still building up infrastructure to provide 3G connectivity across the nation. 3G platformis basically based on a set of standards used for mobile devices and mobile telecommunications services and networks that comply with the International Mobile Telecommunications-2000 (IMT-2000) specifications set by the International Telecommunication Union (ITU). The main features of 3G technology include wireless web-based access, multimedia services, email, and video conferencing. The 3G W-CDMA air interface standard had been designed for "always-on" packet-based wireless services that allow computers, entertainment devices, and telephones to share a common wireless network and be connected to Internet anytime, anywhere. 3G systems offer high data rates of up to 2 Mbps, over 5 MHz channel carrier width depending on mobility/velocity, and high spectrum efficiency. 3G communication works on frequency band of 1.8 - 2.5 GHz and provides data rate of up to 2 Mbps.In a broad estimation, there are almost 8,000 standard essential patents (FRAND) relating to the 483 technical specifications that form the 3GPP and 3GPP2 standards. In a high level analysis, it is observed that top 12 companies/assignees accounted in 2004 for 90% of the patents in this technology segment, which include Qualcomm, Ericsson, Nokia, Motorola, Philips, NTT DoCoMo, Siemens, Mitsubishi, Fujitsu, Hitachi, InterDigital, and Matsushita. Apart from the standard essential patents disclosed by these companies, there are numerous other patents that have not been declared by some of these companies. For instance, it has been noted that the patent portfolio of Nortel and Lucent indicates a long list of patents that may be held standard essential.

4.1.4 Fourth Generation Systems (4G)

4G wireless communicationsystems, also referred to as LTE,form part of the recent standard for wireless packet data transmission that provides faster data rate and connects people and devices to Internet. 4G standard was designed to be used for anytime anywhere access/transfer of data by users/devices to provide a comprehensive and secure IP based solution where facilities such as voice, streamed multimedia and data will be provided to users/device at much higher data rates compared to previous generations. The technology and infrastructure development to support 4G standard is still under development in several countries (In another section, we will cover 4G spectrum infrastructure and spectrum licensing with respect to India). 4G services are providedat frequency bands of 2-8 GHz, and can support data rates from 2Mbps to 1 Gbps. 4G networks is required for high speed application such as wireless broadband access, Multimedia Messaging Service (MMS), mobile TV, HDTV content transfer, Digital Video Broadcasting (DVB), video chat, and live steaming. There are several technology advancements such as MIMO, smart antennas, cognitive antennas, among others that are taking place to support better data rate, and provide mobility with good data rate. These advancements can be categorized as LTE advance technologies and will be inducted in next version 4G standards. Though the

4G standard is designed to cater the present and near future wireless network requirements, it will not be adequate to support 50 billion users/devices that are expected to connect tothe wireless internet after 2020, and hence the industry pioneers are gearing up for the next generation wireless technology.

A 4G system, in addition to the usual voice and other services of 3G, provides mobile broadband Internet access, for example to Laptops with wireless modems, to smart phones, and to other portable devices. Potential and current applications includemobile web access, IP telephony, gaming services, high-definition TV, mobile TV, video conferencing, 3Dtelevision, and cloud computing.

Table 1: Specification of 4G

Characteristics	Range
Frequency Band	2-8 GHz
Bandwidth	5-20 MHz
Data Speed/Data Rate	Upto 20 Mbps or more
Access	Multi-carrier - CDMA or OFDM(TDMA)
Fec	Concatenated Codes
Switching	Packet
Mobile Top Speeds	200 kmph

As the report is attempted to be slightly tailored for Reliance Jio, the following section provides the activity and strength of Reliance Jio with respect to their 4G focus.

Overview of Reliance Jio 4G Spectrum

Reliance needs no introduction, and in sum, is headquartered in Mumbai and is a leading organization in the domain of telecommunication. Previously known as Infotel Broadband, which is now subsidiary of Reliance Industries Ltd., the broadband service provider is the only company in India that acquired PAN India 4G spectrums in an auction held by Government of India. Infotel Broadband acquired 4G spectrum for Pan India for Rs. 12,848 crores ($2.7 billion) in 2010, and soon thereafter, Reliance Industrial bought 95%of its stake for 4800 croresand marked its entry in telecommunication domain, and became the only company who have received 4G spectrum for all the circles.

4G Spectrum Competitors

Below illustrated Table-2 represents companies thatwon the 4G spectrum in the auction held by the Govt. of India in 2010, with Reliance Jiobeing the only company acquiring PAN India.

Table 2 – 4G Spectrum Allocation in India

Company	Total Circles Won
Infotel (Reliance jio)	22
Aircel	8
Tikona	5
Bharti Airtel	4
Qualcomm	4
Augere	4

Reliance Jio Activities

After successfully acquiring Infotel and having made it's presence heard in the market, Reliance is now aggressively planning to launch 4G services with the help of its partners. As mandated by the Govt., the Company needs to launch its services in 90% of circles allocated thereto by the year 2015, wherein Reliance Jio has announced launch of 4G service in selected areas by early 2015.The company has also rolled out deals/agreements with several companies including Reliance Communication, Bharti Airtel, American Tower, Tower vision Ascend Telecome, among others for building/sharing of their infrastructure for 4G services. Through these various agreements,Reliance Jio now has access to about 1,92,500 towers across India.

Recently, Ericsson has also signed a deal with Reliance for providing 3 years operational support, which includes providing services across the country. Company has also partnered with multiple vendors such as CISCO, HP, IBM, SAP and many more to streamline its OSS and BSS operations.

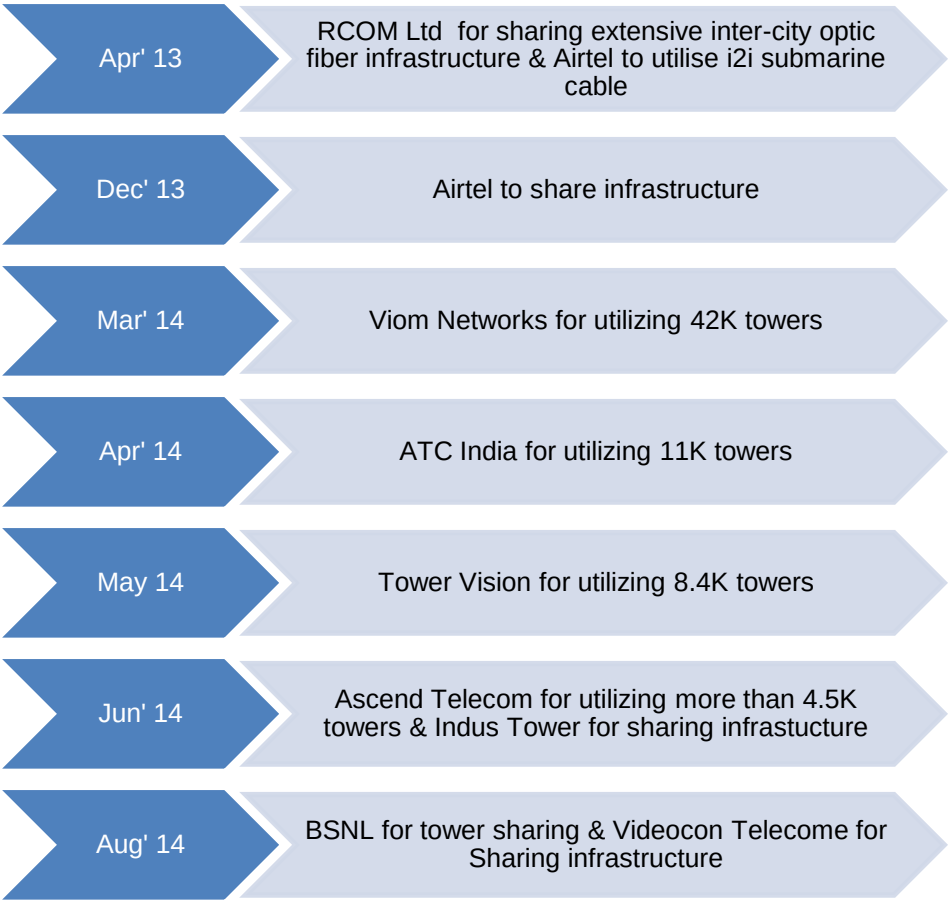


Exhibit-5:Reliance Jio's Infrastructure setup/sharing deals

4.2 Introduction of 5G

Though not specified by any standardization body, the fifth generation wireless technology can be broadly defined as a packet switched wireless system with wide area coverage and high throughput that addresses the challengesfaced by 4G/LTE and IMT technology, and can meet the requirement of over 50 billion wireless devices beyond 2020 through:

- **Ultra High Bandwidth**: 1000 times higher wireless capacity when compared with 2010 capacity
- **Ultra High Data Rate**: Provide data rate of more than 1 Gbps
- **Zero Latency**: Less than 10 milliseconds of downtime
- **High Speed Mobility**- 1 Gbps data rate in high mobility, and more than 1 Gbps data rate in low mobility with less than 10 millisecond of switching time
- **High Energy Efficiency**:Having up to 90% of energy per service provided
- **High Security**: Provide network level security and better user controlled privacy

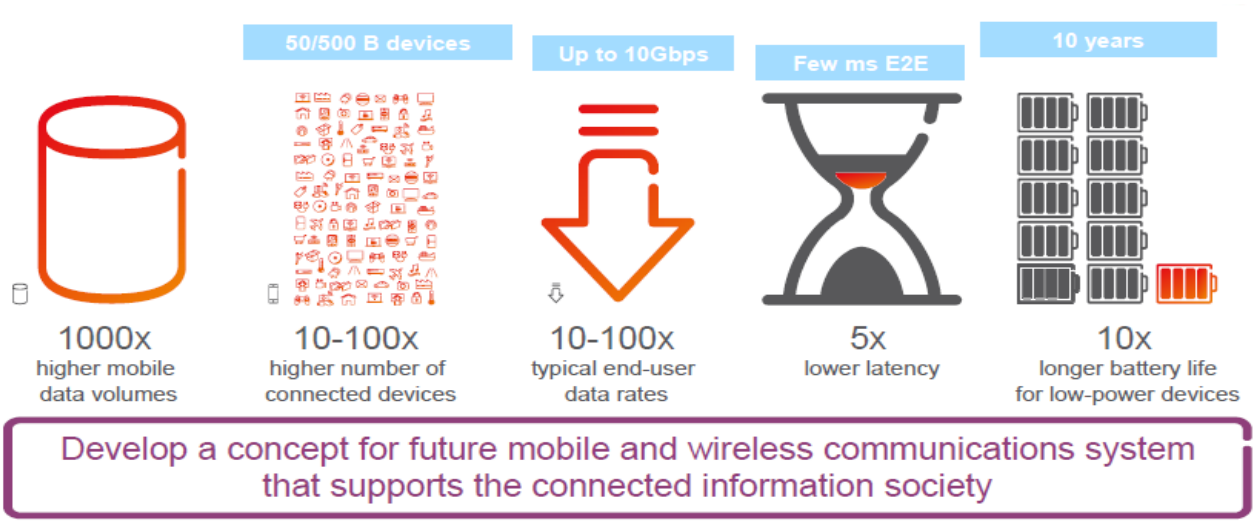
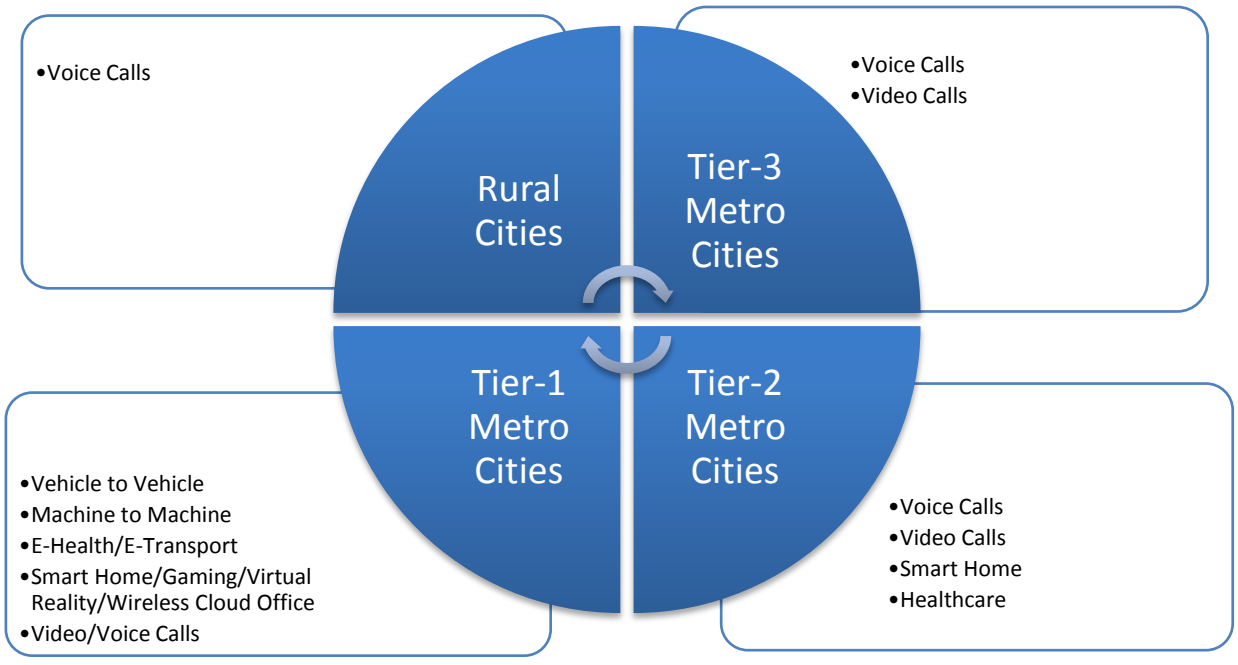


Exhibit-6

5G technologies will use CDMA, BDMA, and millimeter wireless technologies, which would enable data transfer at greater than 1Gbps at high mobility, and higher than 10 Gbps at low mobility. High security can be achieved by better cognitive radios/ software defined radios/ SDR security. Machine-type communication will be one of the bigger changes in 5G networks, with everything ranging from bike, helmets, water systems, house equipment's communicating with each other. Technology experts are also saying that 5G will not be a single spectrum or switching technique, but would instead be a network that will depend on different frequency bands andwill carry information at different speeds, and have very different propagation characteristics.Therefore, the same device may be used at a high-speed uplink band as well as at the low-speed downlink band, or vice versa. Exhibit-7 representsdifferent types of users that may have different bandwidth requirements, and therefore would be able to use different applications based on the 5G-technology platform.



4.3 Comparison of Different Generations of Wireless Technology

Before going in details of 5G enabling/candidate technologies, below Table-3provides a quick comparison of existing third generation and fourth generation wireless technologies and their capacities with those of the upcoming fifth generation wireless technologies.

Table 3: Comparison among 3G, 4G and 5G Technology

Technology/Features	3G	4G	5G
Data Bandwidth	2 Mbps	2 Mbps-1 Gbps	1 Gbps& Higher
Frequency Band	1.8-2.5 GHz	2-8 GHz	3-300 GHz
Standards	WCDMA CDMA-200 TD-SCDMA	All access convergence Including- OFMDA, MC-CDMA Network	CDMA & BDMA
Technology	Broad bandwidth CDMA IP Technology	Unified IP and Seamless combination of broadband LAN/WAN/ PAN and WLAN Wi-Max, LTE, WiFi	Unified IP and seamless combination of broadband, LAN/WAN/PAN/WLAN and technologies for 5 G new deployment (Eg: OFDM etc.), WWWW
Services	Integrated high quality audio, video and data	Dynamic information access, wearable devices, HD streaming, global roaming	Dynamic information access, wearable devices, HD streaming, upcoming all technologies, global roaming smoothly
Multiple Access	CDMA	CDMA	CDMA and BDMA
Core Network	Packet Network	All IP Network	Flatter IP Network & 5G network interfacing (5G-NI)
Definition	Digital Broadband packet data	Digital broadband, packet data, All IP	Digital Broadband, packet data , ALL IP very high throughput
Hand off	Horizontal	Horizontal & Vertical	Horizontal and Vertical
Start from	2001	2010	2015

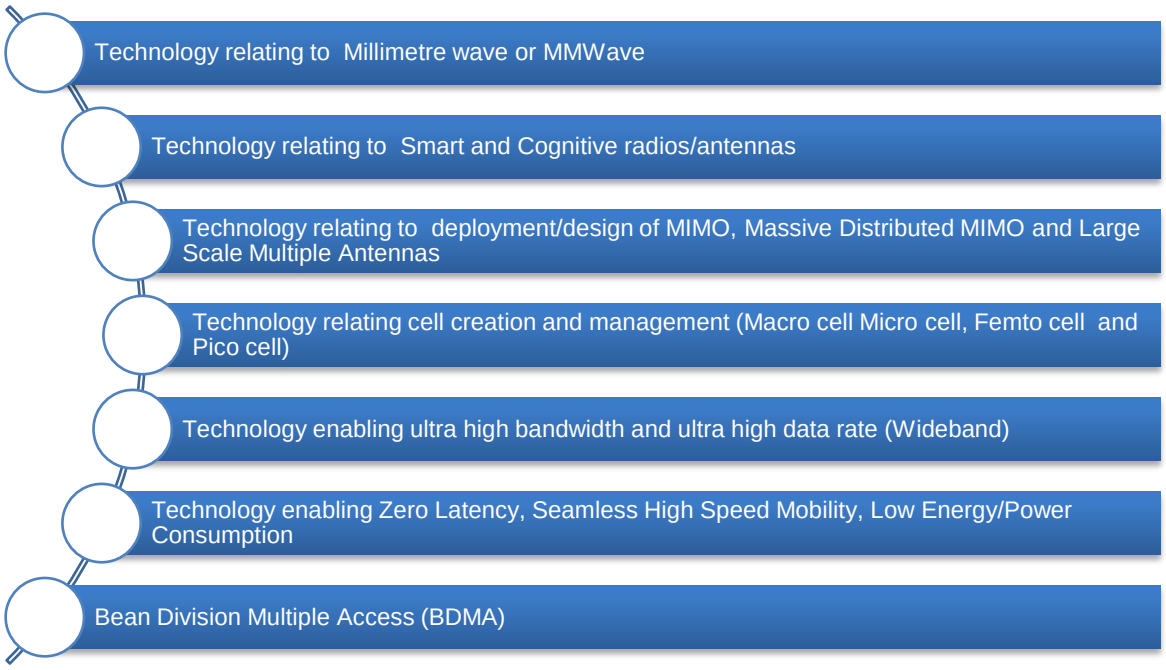
Table-4represents different releases of 3GPP for different generations of communication technologies. Release 10 and onward has been used as a standard for 4G networks, and it is expected that any Release from 13 onwards would relate to 5G technologies. Currently, study on Release 13 and 14 is on progress and it is expected that the releases would be completed in 2015.

Table-4

Rel-8 Dec-2008	Rel-9 Dec-2009	Rel-10 Dec-2010 "4G"	Rel-11 Dec-2012	Rel-12 Dec-2014
Single Carrier Upto 20 MHz	Single Carrier Upto 20 MHz	Multiple Carrier Upto 100 MHz	Multiple Carrier Multiple Bands Up to 100 MHz	Multiple Carrier Multiple Bands Up to 100 MHz
DL: 100 Mbps UP: 50 Mbps	DL: 100 Mbps UP: 50 Mbps	DL: 1 Gbps UP: 500 Mbps	DL: 1 Gbps UP: 500 Mbps	DL: 1 Gbps UP: 500 Mbps
DL: 4x4 Antennas UL: 1 Antennas	DL: 4x4 Antennas UL: 2 Antennas	DL: 8x8 Antennas UL: 4 Antennas	DL: 8x8 Antennas UL: 4 Antennas	DL: 8x8 Antennas UL: 4 Antennas
No multi-hop	Fixed Relays Supported	Fixed Relays Supported, Heterogeneous Networks	Fixed Relays Supported/Multiple BS to Mobile Transmission	Mobile Relays Supported/Device to Device Communication

4.4 Fifth Generation (5G) Candidate Technologies

The fifth generation wireless technology requires ultra high bandwidth having 1000 times higher capacity, ultra high data date, zero latency, high speed mobility and high energy optimization that can be enabled with new evolving technologies. Patent and Non-patent literatures have been surveyed and studyhas been performed to understand the 5G candidate technologies that can enable next generation wireless communication. The candidate technologies thatwill enable fifth generation wireless can be broadly classified into below categories.



4.4.1 Technology Relating to Millimetre Wave or MMWave

Usage of millimetre wave frequencies (e.g. up to 90 GHz) for wireless backhaul and/or access is a suitable and viable option that can be adopted for 5G communication. The underutilized spectrum in the millimeter-wave range frequency bands can be used to achieve tens to hundreds of times more capacity when compared with current 4G cellular networks. Millimeter Waves (mmWaves) are radio waves with wavelength in the range of 1 millimeter (mm)-10 mm and correspond to radio frequency of 30 GigaHertz (GHz)-300 GHz.

According to the definition provided by the International Telecommunications Union (ITU), these frequenciesin the range of 3 GHz-30 GHzare also referred to as Extremely High Frequency (EHF) bands. These radio waves exhibit unique propagation characteristics, wherein, for instance, when compared with lower frequency radio waves, mmWaves suffer higher propagation loss due to water vapor and oxygen absorption and have a poorer ability to penetrate objects, such as buildings, walls, foliage, and are more susceptible to other atmospheric disturbance such as deflection and diffraction due to particles (e.g., rain drops) in the air.

However,the technology has its own set of advantages, which include that fact that due to smaller wave lengths of the mmWaves, more antennas may be packed in a relatively small area, allowing for the implementation of a high-gain antenna in small form factor, which can provide densely packed communication links for more efficient spectrum reuse, and better privacy and security during communication. The mmWavesspectrum has been less utilized due to the aforementioned disadvantages,which presents a unique opportunity for a new technology to use these unutilized spectrum band for low cost. A vast amount of spectrum is available in the mmWaveband, wherein, in an instance, frequencies around 60 GHz that are typically referred to as the 60 GHz band are available as unlicensed spectrum in most countries. In the US, 7 GHz of spectrum around 60 GHz (i.e., 57 GHz-64 GHz) is allocated for unlicensed use. On Oct. 16, 2003, the Federal Communications Commission (FCC) issued a

Report and Order that allocated 12.9 GHz of spectrum for high-density fixed wireless services in the United States (i.e., 71-76 GHz, 81-86 GHz, and 92-95 GHz excluding 94.0-94.1 GHz for Federal Government use). The frequency allocation in 71-76 GHz, 81-86 GHz, and 92-95 GHz are collectively referred to as the E-band. The frequency allocation in the E-band is the largest spectrum allocation ever by the FCC as it is 50 times larger than the entire cellular spectrum. In other countries also, spectrum around 60 GHz is available for unlicensed use.

Though in past, several companies have used MmWavefor wireless communication using component electronics that can achieve a Giga bits per second (Gbps) data rate, these technologies can't be used for end user mobile communication as they are costly and complex in design and implementation. For instance, Asyrmatos Incorporated developed anmmWavecommunication system capable of 10 Gbps data transfer over distances of several kilometers. The transceiver used by Asyrmatos is based on photonics, which provides the flexibility of operating in a variety of mmWave bands such as 140 GHz (F-Band), 94 GHz (W-Band), 70/80 GHz (E-Band), and 35 GHz (Ka-Band). As another example, GigaBeam Corporation developed multigigabit wireless technologies for the 70 GHz and 80 GHz band. However, these technologies are not suitable for commercial mobile communication due to issues such as cost, complexity, power consumption, and form factor. For example, GigaBeam Corporation's WiFiber G 1.25 Gbps wireless radio requires a two-foot antenna to achieve the antenna gain required for sufficient point-to-point link quality. The component electronics used in these systems, including power amplifiers, low noise amplifiers, mixers, oscillators, synthesizers, waveguides, are too big in size and consume too much power to be applicable in mobile communication.

Recently, many engineering and business efforts have been and are being invested to utilize the mmWaves for short-range wireless communication. A few companies and industrial consortiums have developed technologies and standards to transmit data at a Gbps rate using the unlicensed 60 GHz band within a few meters (i.e., up to 10 meters).

Overview of Patent Activity

Advancement of any technology can be better reflected by indicating the patent filing activity and research focus by the industry leaders. We were able to analyze around 364 patents filed in the United States Patent Office and WIPO by top industry leaders in the field of mmWave technology. Exhibit-8 illustrates the distribution of focus areas of the analyzed set of patents, which demonstrates that most of the active players are focusing on transmission schemes, mmWave radio/antenna design, and architectures relating to mmWave capable Antenna Arrays.

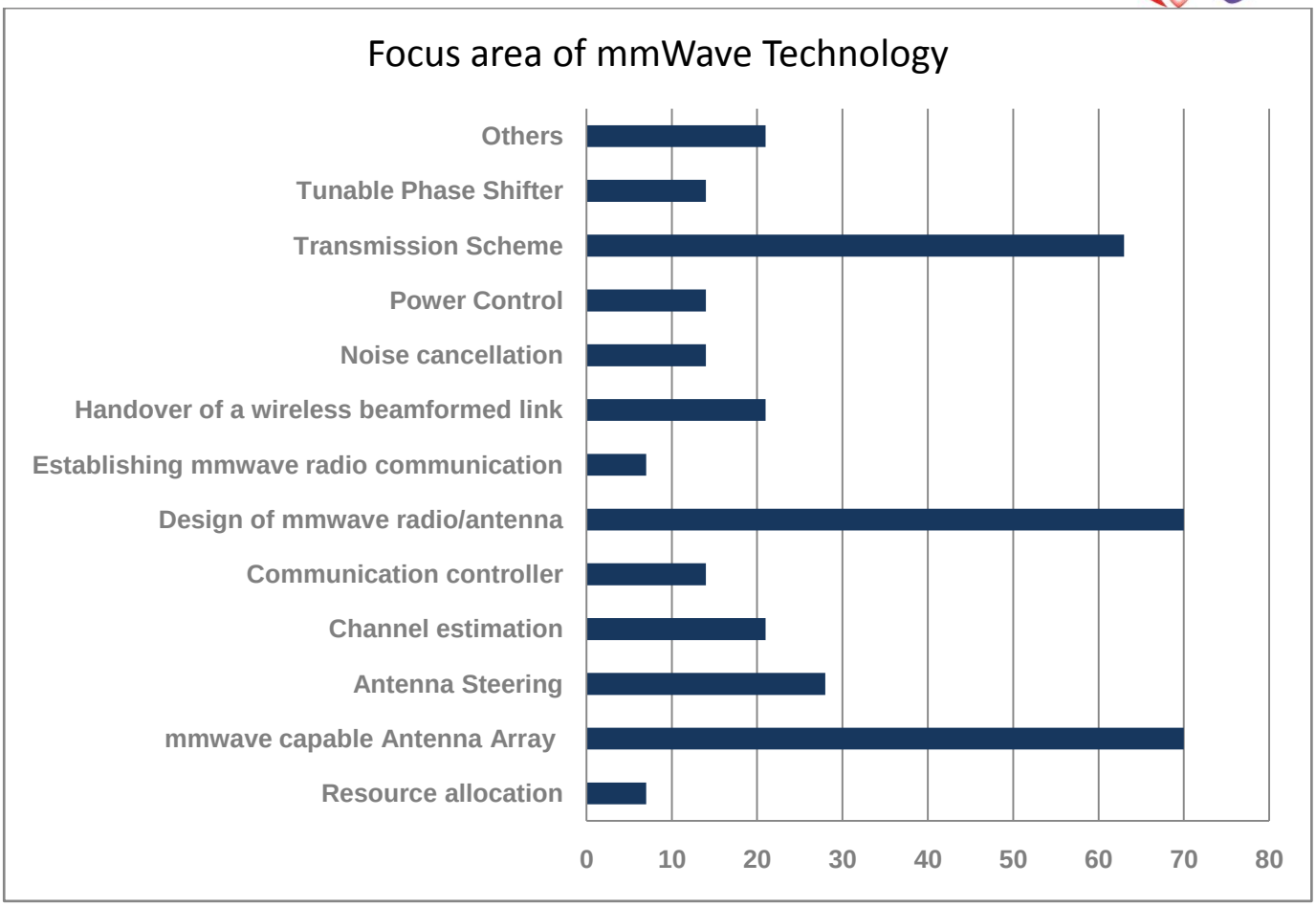


Exhibit-8

Major Players

Exhibit-9 illustrates the distribution sequence of key Applicants in the space of mmWave Technology. It has been observed that the top 10 Applicants hold around 75% of the patents relating to mmwave technology domain, wherein the key Applicants include Sony (14%), Intel (14%), Broadcom (12%), Samsung (10%), IBM (8%), Qualcomm (6%), Electronics and Telecommunication Research Institute (ETRI) (3%), Samsung (3%), Korea Electronics (2%), and Samsung Thales (2%). These patentstypically disclose use of mmWave for wireless data transfer at higher speed using the unutilized infrastructure.

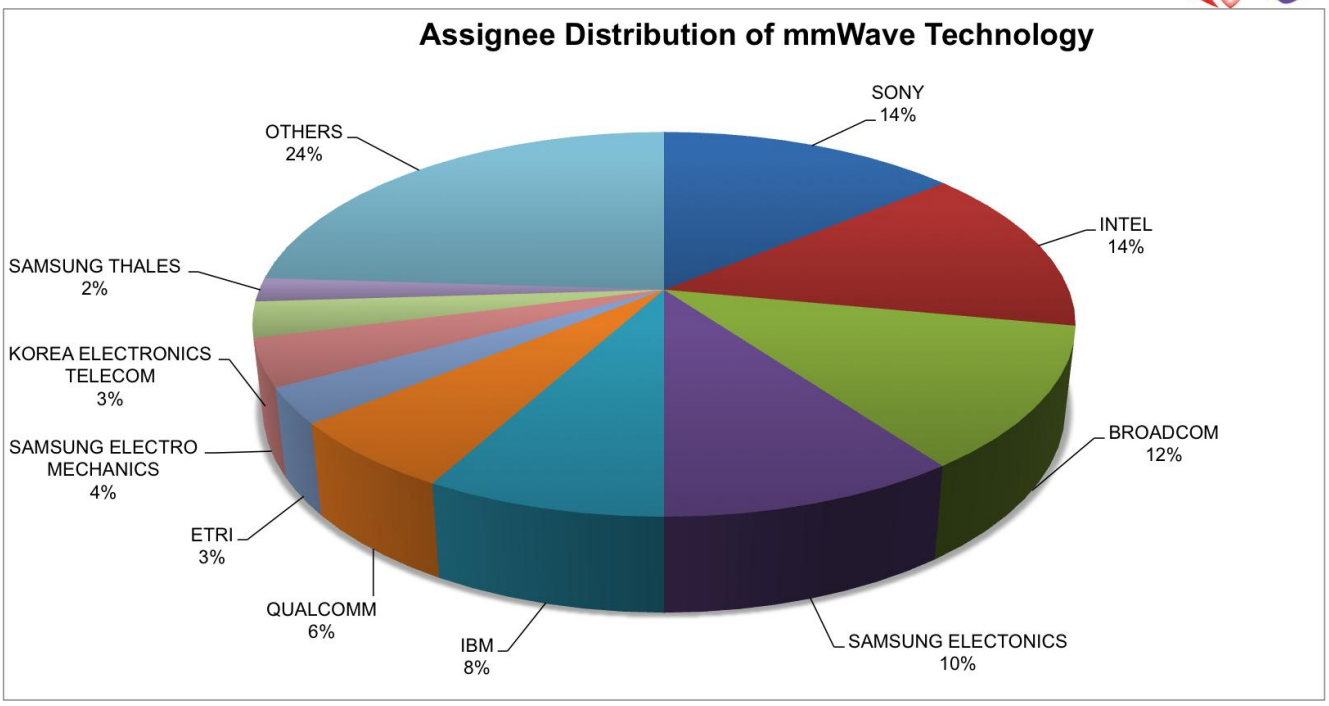


Exhibit-9

4.4.2 Technology Relating to Smart and Cognitive Radios/Antennas

Smart, Cognitive and software defined radios include radios that can be programmed and configured in real-time, and can automatically use best available channels and frequency spectrum. They can change their transmission and reception parameters dynamically in accordance with the availability of channels and can allow multiple concurrent wireless communication using different channels. These smart and cognitive radios can change their parameters such as “waveform”, “protocol”, “operating frequency” and networking parameters.

These smart and cognitive radios/antennas are self aware and continuously monitor the environment around them, and can automatically change their transmission/reception parameters accordingly. Adaptability to operate at different channels and useof the best available channels and frequencies make such radios a strong candidate technology for the next generation wireless communication.

Base stations and access terminals can be configured to have Software defined radios (SDR) that have benefits of high processing power to develop multiband, multi-standard base stations and terminals. For example,in order to increase the network capacity at a specific times (e.g. During festivals or events),an operator can reconfigure its network by adding several modems at a given base transceiver station(BTS). In the context of the expected 5G systems, SDR will become an enabler for terminal and network re-configurability through software download.

Seamless interoperability among heterogeneous networks represents the corner stone for the success of 5G systems with different evolving technologies. A novel solution that ensures interoperability between several types of wireless access network is given by developing IEEE 802.21standard, wherein the heart of the 802.21 framework is the Media Independent Handover Function (MIHF) that is responsible for communication with different terminals, networks, and remote hardware or software. The reconfigurable

interoperability offers network providers with a possibility to choose, with minimal investments, between alternative wireless access networks.

Overview of Patents Activity

We were able to analyze around 260 patents filed in the United States Patent Office and WIPO by top industry leaders in the field of smart and cognitive antennas. Exhibit-10 illustrates the distribution of focus areas of the analyzed set of patents, which demonstrates that most of the active players are focusing on interference avoidance, followed by problems relating to channel adjustment and designs for software defined radios.

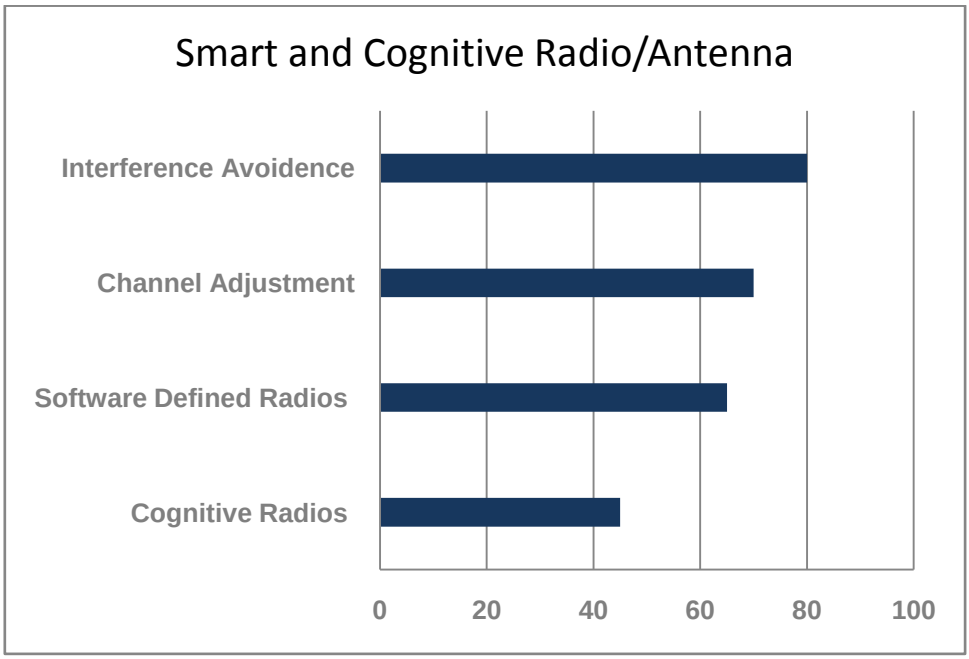


Exhibit-10

Major Players

Exhibit-11 illustrates distribution sequence of key Applicants in the space of cognitive radios, wherein it has been observed that the top 10 Applicants hold around 70% of the patents relating to smart and cognitive radios/antennas technologies, wherein the key Applicants include ZTE (16%), Qualcomm (14%), Broadcom (9%), NEC (7%), ETRI (4%), Korea Electronics (5%), Huawei Technology (4%), Ericsson (4%), Samsung (4%), and Alcatel Lucent (3%). These patents typically disclose use of design and optimization of smart and cognitive radios/antennas for wireless data transfer at higher speed using the unutilized infrastructure.

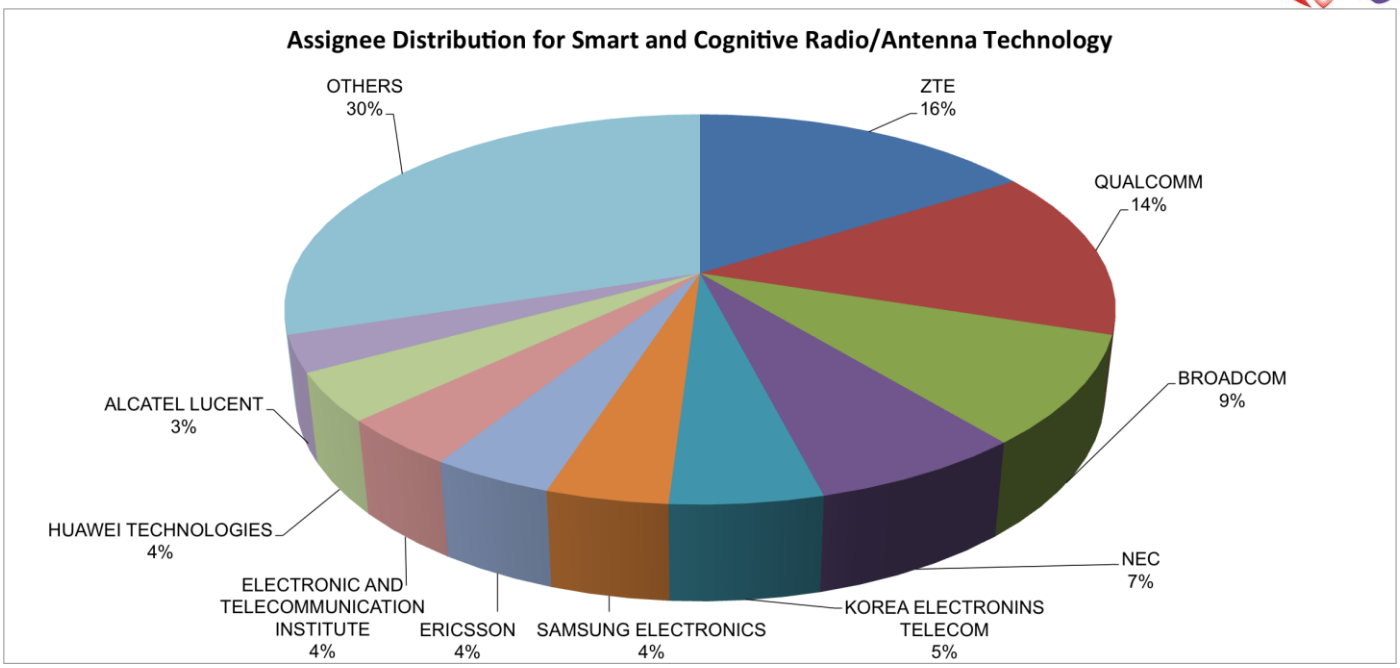


Exhibit-11

4.4.3 Technology Relating to Deployment/Design of MIMO, Massive Distributed MIMO and Large Scale Multiple Antenna

In radio communication, multiple-input and multiple-output (MIMO) technology uses a plurality of antennas at transmitter and at receiver end to improve communication quality and/or to achieve higher quality of service (QOS). MIMO technology is becoming famous for wireless radio communications and has been widely incorporated in current wireless broadband standards such as 3G, LTE and Wi-Fi etc. It is to be appreciated that, in a typical architecture, higher the number of transceiversper communication device, higher are the possible signal paths, and therefore better is the performance in terms of data rate and link reliability. With better MIMO technology, number of radios per base station can be increased and hence the cost of infrastructure development and maintenance can be reduced.

In order to further improve communication and increase data rate, a new technology referred to as "Massive MIMO" has been incorporated, which makes a clean break from current practices by use of a very large number of service antennas that are operated fully coherently and adaptively. Extra antennas help by focusing the transmission and reception of signal energy into smaller regions or spaces, which brings tremendous improvements in data throughput and energy efficiency when combined with simultaneous scheduling of a large number of user terminals. Massive MIMO was originally envisioned for time division duplex (TDD) operation, but can potentially be applied in frequency division duplex (FDD) based communications systems also.

Other benefits of massive MIMO include, but are not limited to, extensive use of inexpensive low-power components, reduced latency, simplification of media access control (MAC) layer, and robustness to interference and intentional jamming. These benefits make massive MIMO a strong potential candidate technology for fifth generation wireless communication. Massive MIMO is an exciting area of 5G wireless broadband research community. For next-generation wireless data networks, it promises significant

gains, which offers the ability to accommodate more number of active users at comparatively higher data rates and better reliability, while consuming less power. Approach taken by massive MIMO radically departs from the BTS architecture of current standards, which uses up to eight antennas in sectored topology. With hundreds of antenna elements, massive MIMO reduces the radiated power by focusing energy to targeted mobile users using pre-coding techniques. By directing the wireless energy to specific users, radiated power is reduced and, at the same time, interference to other users is decreased. This is particularly important in today's interference-limited cellular networks. If the promise of massive MIMO holds true, 5G networks of the future will be faster and accommodate more users with better reliability and increased energy efficiency.

Overview of Patents Activity

Patenting activity in the massive MIMO space has been significant in the last 2-4 years, wherein the technologies typically relate to deployment/design of massive MIMO and large-scale antenna arrays. We were able to extract and analyze around 1940 patents filed in the United States Patent Office and WIPO by top industry leaders in the field of "MIMO and Large scale antenna array". Antenna Technologies,which concentrate on delivering key requirements, sought by fifth generation of communication includelarge scale antenna, Massive MIMO, and 2D antenna arrays. Beyond 4G or 5G, mobile communication needs to be provided with frequency efficiency that is ten times higher than that of 4G systems. As the physical layer technology required to attain the frequency is ten times higher than that of 4G systems, network multi-input multi-output (MIMO), interference alignment, relay network, heterogeneous network, and large-scale antenna technologies such as massive MIMO, and 2D antenna arrays are considered to be of high impact in defining the future of high speed data technologies.

Patents filed in the space primarily deal with improvements in antenna and disclose providing of better frequency efficiency than previous models used for antennas and focus on use of inexpensive low-power components, reduced latency, simplification of MAC layer, better frequency efficiency and robustness against intentional jamming. Exhibit-12 illustrates key focus areas in the MIMO based patents analyzed as part of this study.

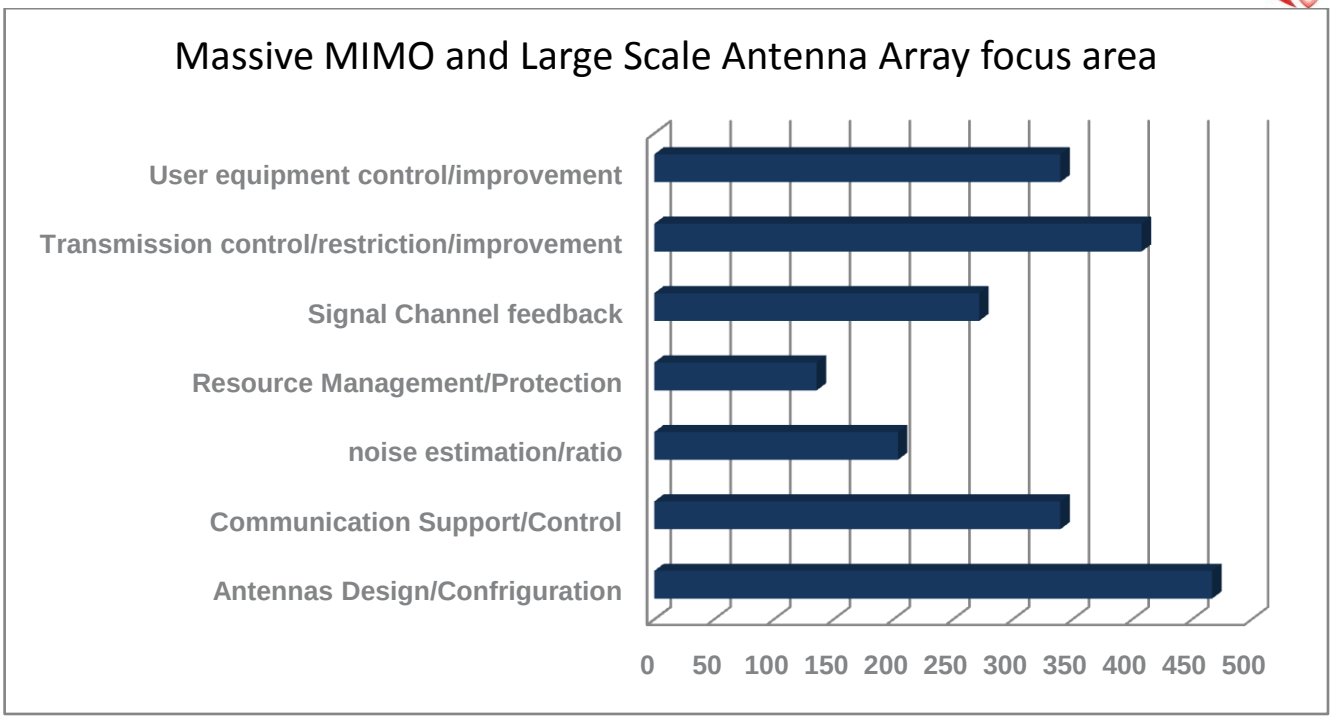


Exhibit-12

Exhibit-13 illustrates different types of antenna technologies that are being evaluated from an IP development standpoint, an analysis of which demonstrates that the key focus has been on on MIMO and configuration/structure of Antenna Arrays.

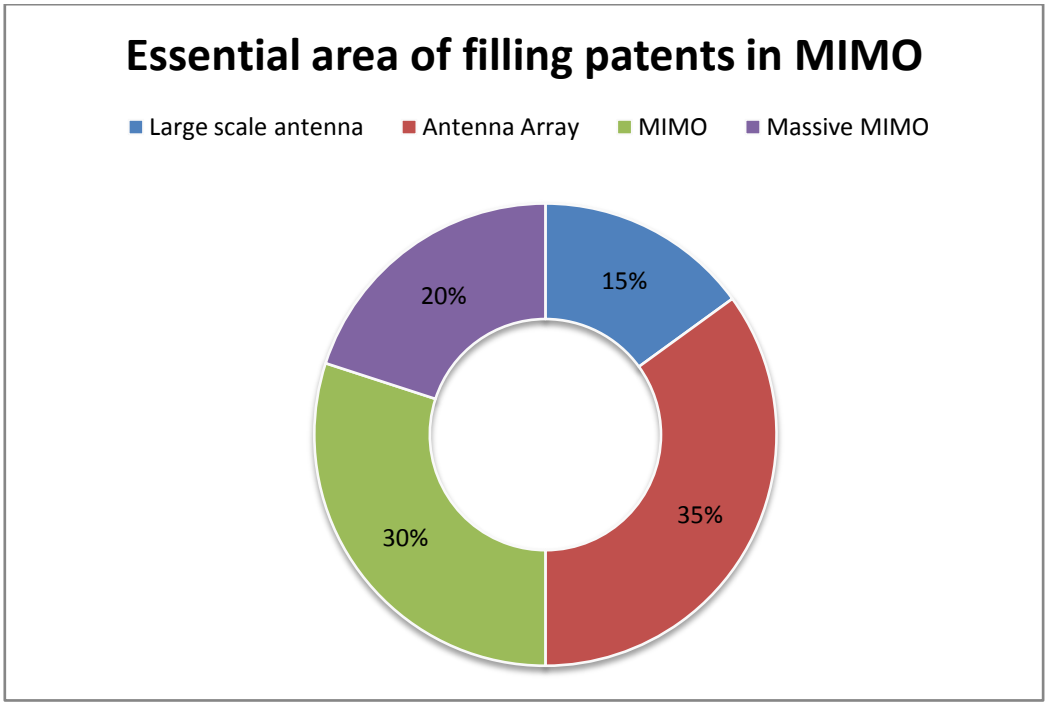


Exhibit-13

Major Players

Multiple Input Multiple Output (MIMO) technology domain is dominated by Qualcomm with a patent share of 17%, followed by Samsung electronics with 10%, Ericsson 10%, and Intel with 10%. Other telecom majors who have shown their presence in the space include LG Electronics, Broadcom, Huawei Technologies, Alcatel Lucent, NTT Docomo, and ZTE, with other Companies sharing the rest 18 percent of total patent portfolio.

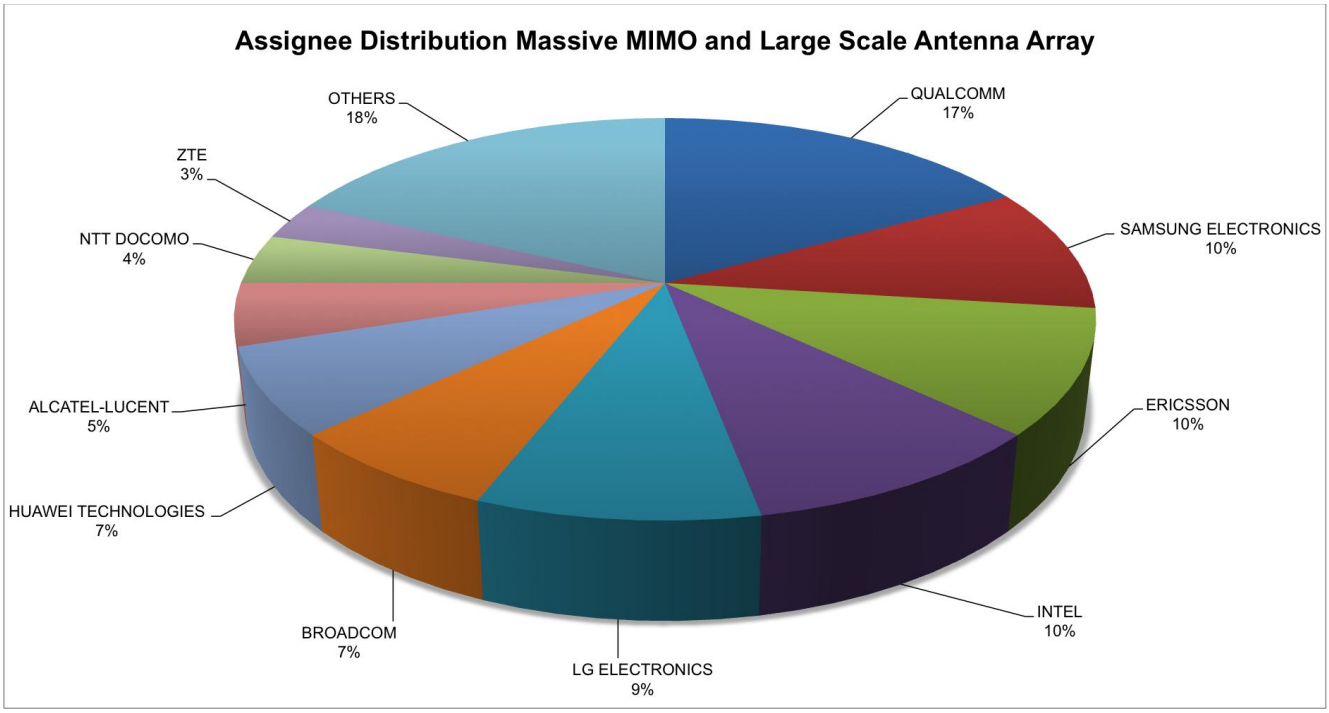


Exhibit-14

4.4.4 Technology Relating to Cell Creation and Management (Macro cell, Micro cell,Femto cell, Pico cell)

The term “cell” is most often used in reference with cellular phone technology but can also be used in context of coverage areas or geographical region that is covered by a transmission facility. A geographic region is typically split into a number of small areas or cells based on the cellular traffic offeredby that area/cell to a number of users. Transmission power levels are also decided based on the coverage area to be served by a cell. Limited availability of radio frequencies forced researchers to find a way to reuse radio frequency in order to carry more than one conversation at a time, and support ever growing number of cellular users. The solution the industry adopted was called frequency reuse, which was implemented by re-structuring the mobile telephone system architecture into the cellular concept.By making cells smaller, it is possible to increase the overall capacity of the cellular system. However, a greater number of transmitter receivers or base stations are required if the cells are to be made smaller,which increases the cost to the operator. Accordingly, in areas where there are more users, small low power base stations are installed to accommodate more number of subscribers.

Cells range in size from a few dozen meters to kilometers in diameter depending on the technology being used, power of the transmission station, and terrain topography. In cellular communication, cells are named such as Macro cell, Micro cell, Pico cell, Femto cell, Umbrella cell etc., according to the coverage area provided by a particular cell.

- **Macro cells:** Macro cells are large cells that are usually used for remote or sparsely populated areas. These may be 10 km or possibly more in diameter.
- **Micro cells:** Micro cells are those that are normally found in densely populated areas which may have a diameter of around 1 km.
- **Pico cells:** Picocells are generally used for covering very small areas such as particular areas of buildings, or possibly tunnels where coverage from a larger cell in the cellular system is not possible. Obviously for the small cells, the power levels used by the base stations are much lower and the antennas are not positioned to cover wide areas. In this way the coverage is minimized and the interference to adjacent cells is reduced.
- **Femto cells:** Femto cells or femtocells are small cellular telecommunications base stations that can be installed in residential or business environments either as single stand-alone unit or in clusters to provide improved cellular coverage especially for data transmission within a building. By using a small internal base station femto cell, cellular performance can be improved along with the possible provision of additional services.

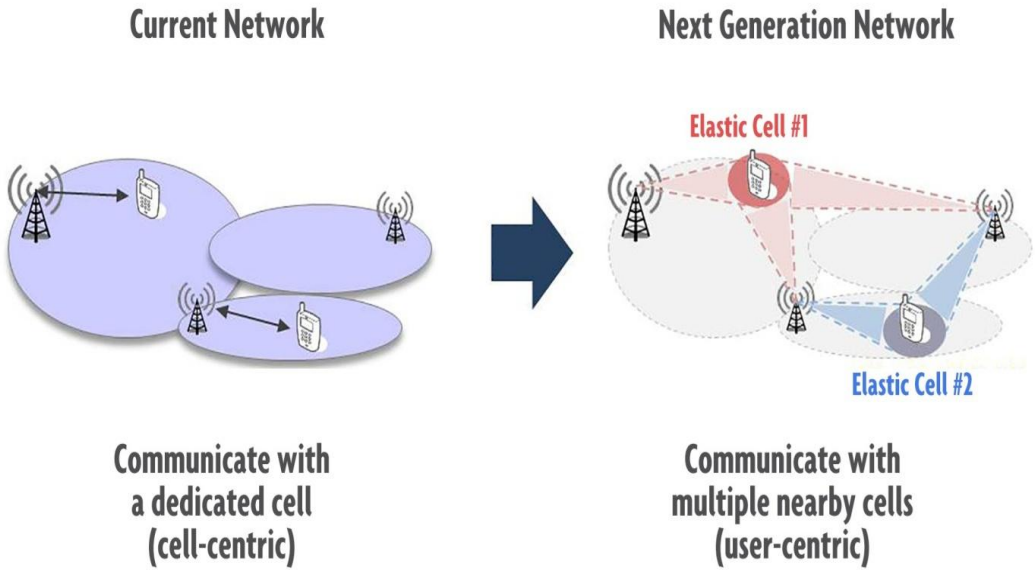


Exhibit-15

To support special requirementssuch as high speed data service for fifth generation of communication, telecom vendor “Ericsson” is working on a new kind of cell termed as “Flexible Cell” or “Elastic Cell”. The

technology has been demonstrated for the first time,and is expected to become one of the key new enablers for 5G networks. The current cellular model is based on a cell-centric architecture, where each handset communicates with only one specific cell site at a time. With elastic cell/flexible cell, multiple cell sites near the handset cooperate for every transmission, thereby creating a user-centric architecture. A serving cell receives information on nearby cells from a handset and selects a group of cells that can improve the network quality in the cell-edge for transmission while temporarily turning off the cells that cause interference.As a result, it is claimed that elastic cell technology can ensure more seamless data transmission by preventing possible quality degradation that can occur when the handset moves across cell boundaries. Ericsson has shown that data transfer rates can be improved by up to 50 per cent at the cell boundary areas compared to current LTE networks.

Overview of Patents Activity

As part of the present study, we were able to retrieve and analyze around 600 patents filed in the United States Patent Office and WIPO by top industry leaders in the field.These patent filings primarily aim to achieve requirementssuch as high-speed data communication,and are largely based on femto cell technology, which is actually concentrated signal projection in a region to support high-speed data communication. Considerable improvement is showcased by installation of small range Femto cells. However, other technologies such as micro cell also have a respectful patent filing trend followed by pico cell technologies.A few patent applications are also noticed for emerging fifth generation cell technologies such as flexible cell or elastic cell.Exhibit-16 below illustrates division of patent focus areas with respect to the different types/sizes of cells, wherein it can be observed that most of the patents focus on femto cells, followed by a rather equal focus on pico and micro cells. Exhibit-17, on the other hand, illustrates taxonomical focus areas of the Applicants of the analyzed set of patents, wherein bulk of the focus has been on configuration of cell devices and cell/signal allocation/selection.

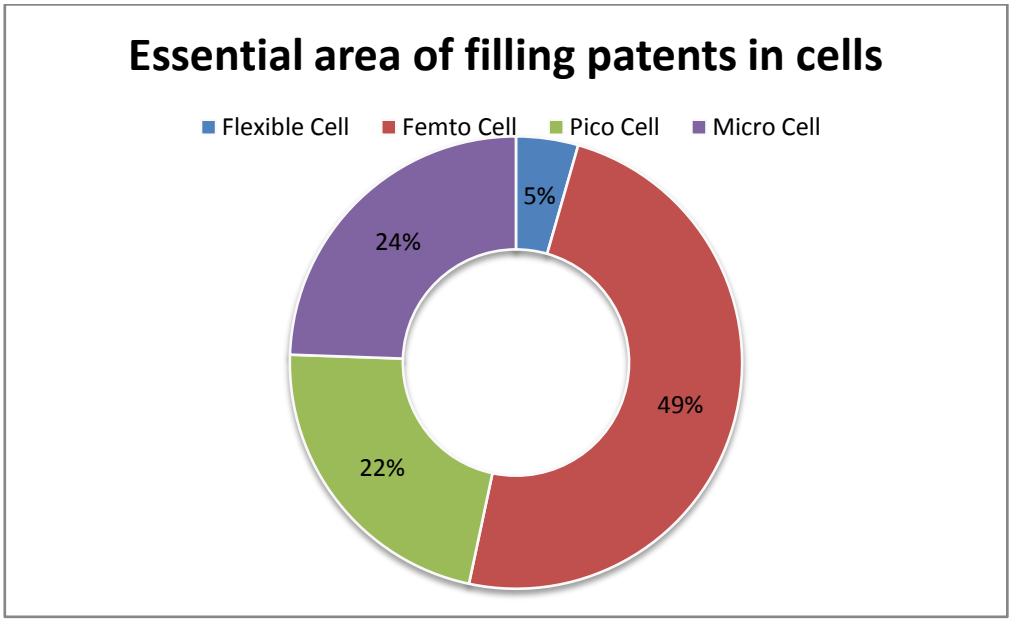


Exhibit-16

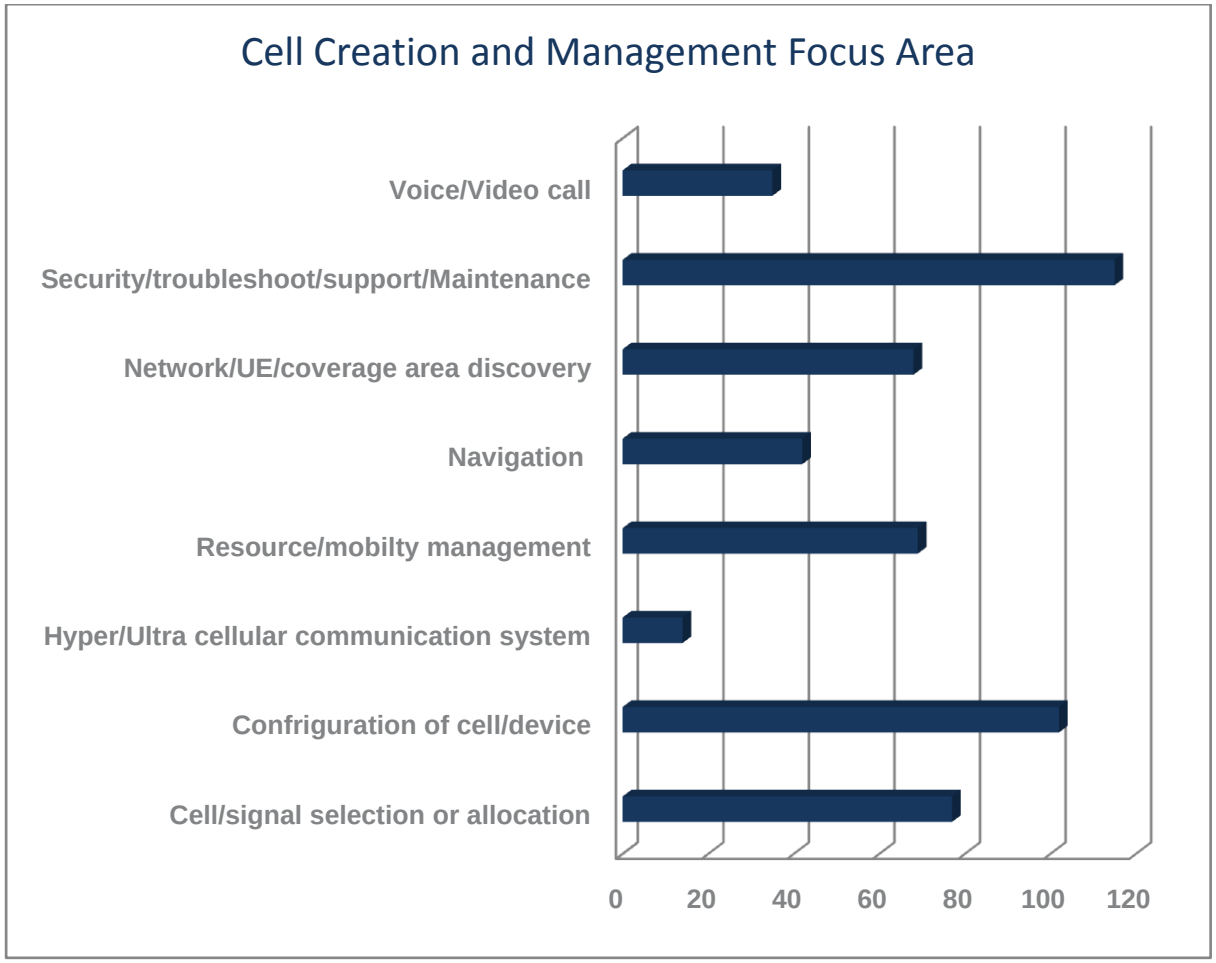


Exhibit-17

Major Players

Exhibit-18 shows representation by various technology companies in the 5G-specific cell size technology domain, wherein it can be observed that the domain is dominated by Qualcomm (24%), followed by Samsung Electronics (12%), NEC (11%), and Alcatel Lucent (8%).

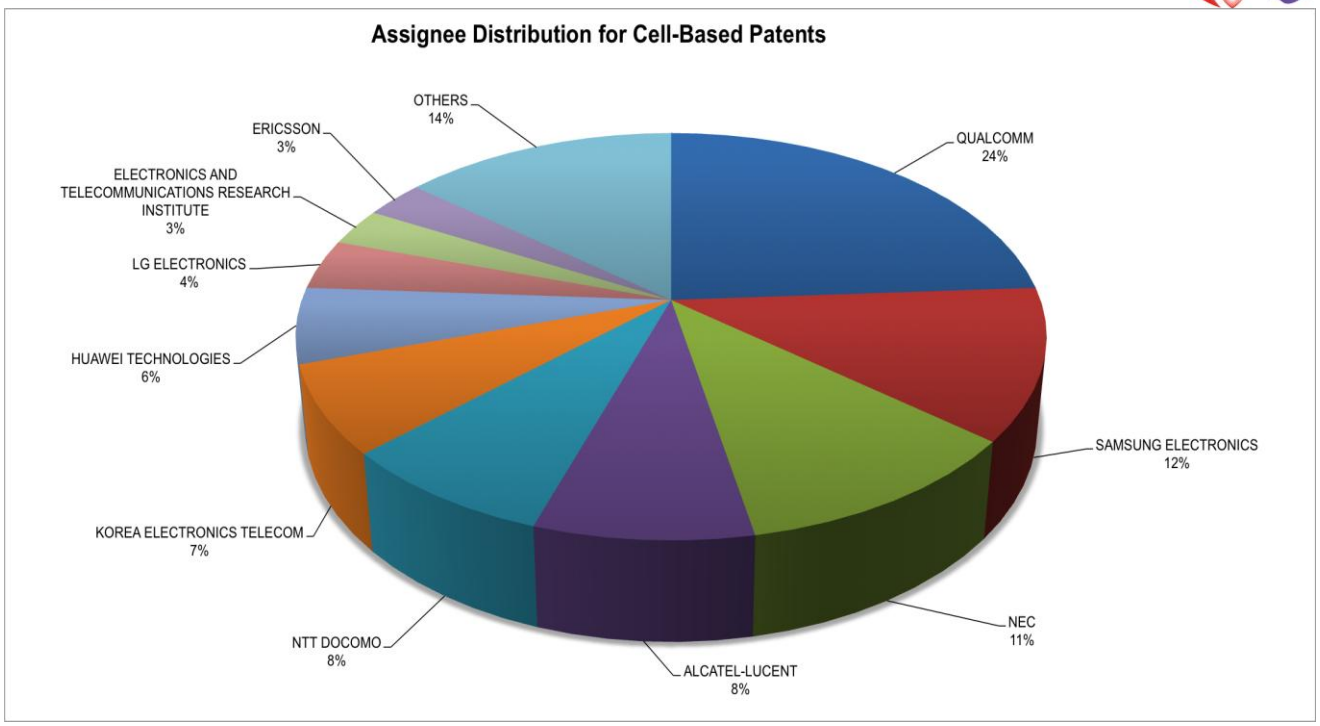


Exhibit-18

4.4.5 Technology enabling ultra high bandwidth and ultra high data rate (Wideband)

Ultra-wideband is a radio technology that is used for low energy, short-range communications, by means of a comparatively large portion of the radio spectrum. Ultra wideband is a wireless technology for transmitting greater amounts of digital data over a wide spectrum of frequency bands with low power levels and is suitable for short distance communications. Ultra wideband radio can not only carry a huge amount of data over a distance at very low power, but has the ability to carry signals through doors and other obstacles that tend to blocksmall bandwidths, higher power signals. Data transmission on Ultra Wide Band causes spreading of the radio energy over a very wide frequency band, with a very low power spectral density. The low power spectral density limits the interference potential with conventional radio systems, whereas high bandwidth can allow very high data throughput for communications devices.

Ultra wideband technology is at present defined by the Federal Communications Commission (FCC) as any wireless transmission scheme that occupies a fractional bandwidth of W/Fc >=20%, where W is transmission bandwidth and Fc is center frequency or more than 500 MHz of absolute bandwidth. In a multipath dominated environment, larger transmission bandwidths result in the ability for increasingly fine resolution of multipath arrivals, which leads to reduced fading per resolved path since the impulsive nature of the transmitted waveforms prevents significant overlap and, hence, reduces possibility of destructive combining. UWB communications are allowed at a very low average transmit power when compared with more conventional systems that effectively restricts UWB to short-ranges.

UWB is a unique and new usage of a recently legalized frequency spectrum, where UWB radios can use frequencies from 3.1 GHz to 10.6 GHz, a band more than 7GHz wide. Each radio channel can have a bandwidth of more than 500 MHz, depending on its center frequency. To allow for such a large signal

bandwidth, the FCC puts in place severe broadcast power restrictions. By doing so, UWB devices can make use of an extremely wide frequency band while not emitting enough energy to be noticed by narrower band devices nearby. This sharing of spectrum allows devices to obtain very high data throughput, but they must be within close proximity. Other advantageous features of UWB include penetration and signal power. In recent years, rise has been observed in the following two modes of ultra-wideband wireless communication: Orthogonal frequency division interoperability mode, and Pulse ultra-wideband mode.

Overview of Patents Activity

As part of the present study, we were able to retrieve and analyze around 2650 patents filed in the United States Patent Office and WIPO by top industry leaders in the field.Exhibit-19 illustrates focus areas of the patents in the domain relating to extended bandwidth or wideband technology, and it can be seen that the patents primarily focus on beam-forming solutions/architectures and MIMO based technologies, whereinbeam-forming or spatial filtering is a signal processing technique for directional signal transmission achieved by combining elements in a phased array and is aimed to improve wireless bandwidth utilization by increasing wireless network's range, which can further improve streaming, quality, and latency-sensitive transmissions. These techniques are already been used before in LTE, but their full potential remains to be unleashed, so improvements over existing solution are discussed.

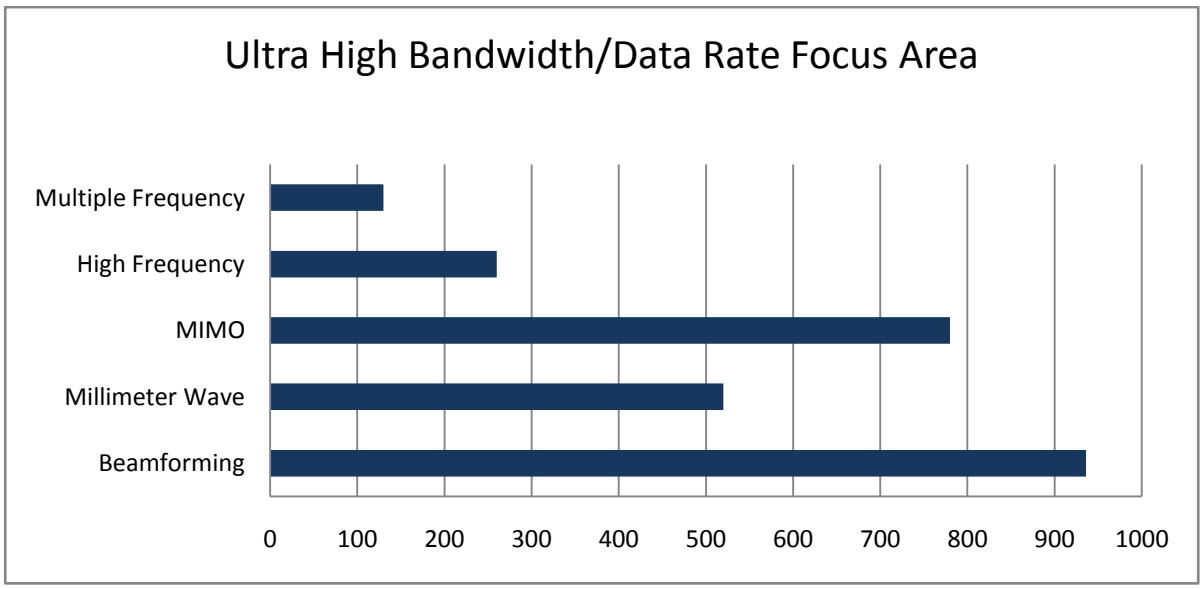


Exhibit-19

Major Players

Based on the below Exhibit-20, wideband technology domain is dominated by Qualcomm (26%), followed by ZTE (12%), SamsungElectronics (8%), Huawei Technologies (7%), and Ericsson (7%).

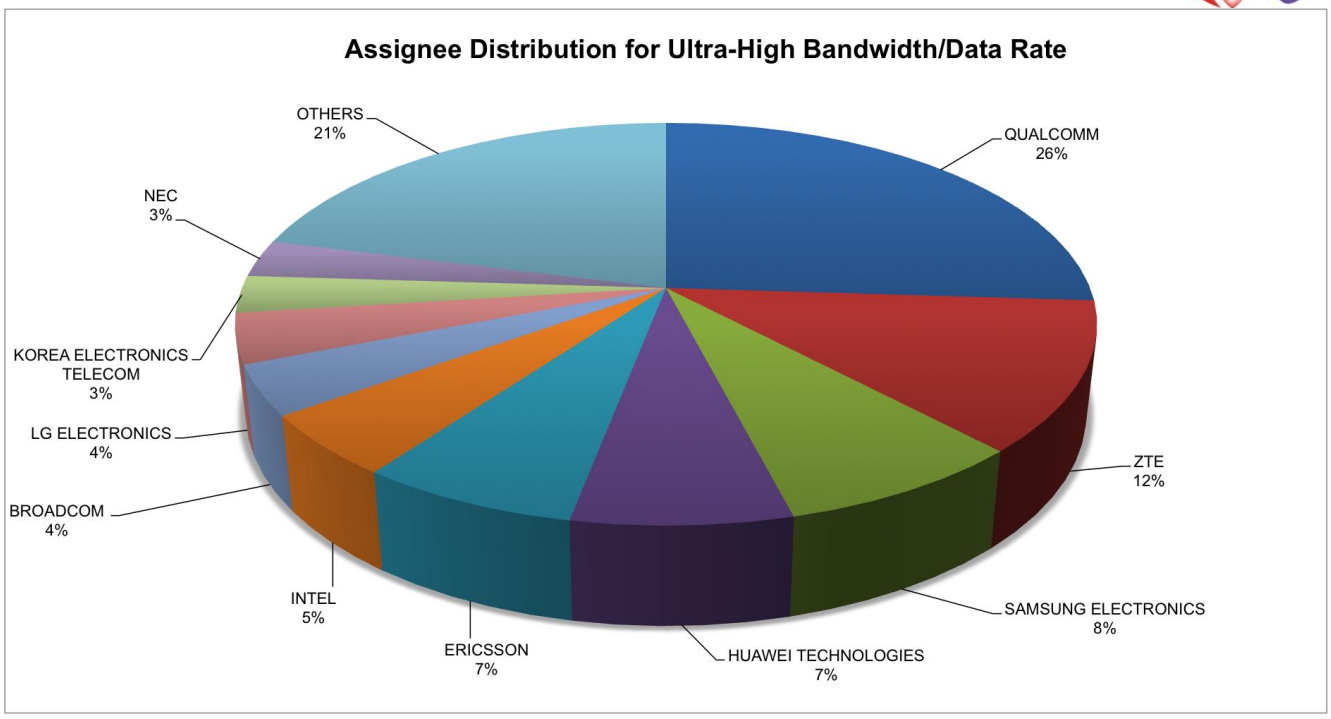


Exhibit-20

4.4.6 Technology Enabling Zero Latency

In communication network, bandwidth is just one element of what a stakeholder/user perceives as the speed of a network. Latency is another component that contributes significantly to network speed, and relates to the time taken to exchange a unit of data between 2 points in a network. For better network,design of hardware systems and protocols are geared towards minimizing time taken to move units of data between any two points on that network. The assumption about network latency is that lower the latency, better is the network. The latency assumption seems to be that data should be transmitted instantly between one point and another (that is, with no delay at all). The contributors to network latency include:

- **Propagation**: This is simply the time it takes for a packet to travel from one place and another at the speed of light.
- **Transmission**: The medium itself (whether optical fibre, wireless, or some other) introduces some delay. The size of the packet introduces delay in a round trip since a larger packet will take longer to receive and return than a short one.
- **Router and other processing**: Each gateway node takes time to examine and possibly change the header in a packet (for example, changing the hop count in the time-to-live field).
- **Other computer and storage delays**: Within networks at each end of the journey, a packet may be subject to storage and hard disk access delays at intermediate devices such as switches and bridges. (In backbone statistics, however, this kind of latency is probably not considered).

Exhibit-21below provides a quick overview of average network latency during different generation of wireless communications. Average network latency has significantly reduced with generations of cellular wireless technology. As it can be seen from the Exhibit, latency that used to be around 629 millisecond

during 2G era has reduced to 98 milliseconds in the 4G LTE eras. It is expected that latency of firth generation network will be less than 10millisecond and the technology advancement is taking place to gain near zero latency. Table-4 below illustrates an approximate impact representation of reduction in latency on the network speed.

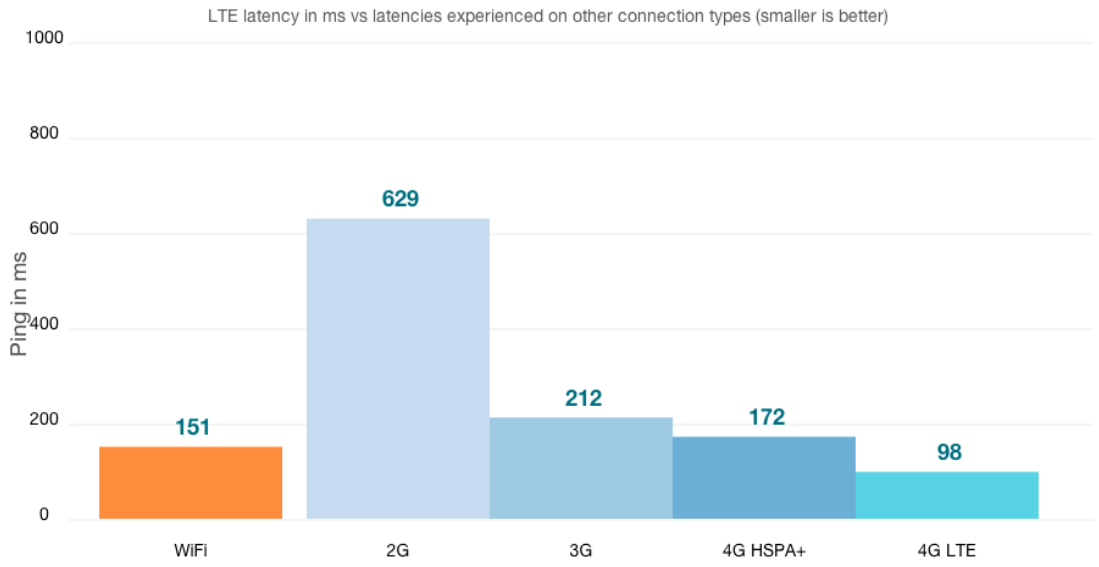


Exhibit-21

Table 4: Network Latency Comparison between Deferent Generations of Wireless Technology

Network Area	Latency	Speed (approx)
WiFi	151	1 megabytes per second
2G	629	.009 megabytes per second
3G	212	2 megabytes per second
4G HSPA+	172	21 megabytes per second
4G LTE	98	1000 megabytes per second

Latency in 5G Network

Latency is an important area of 5G wireless broadband research community, and in order to develop wireless 5G technology, further reduction in latency is required including reduction in time delays. Till date, there no defined standard for 5G that has been explicitly set out but it appears to be unanimous that 5G standard should have less than 1 millisecond (msec) of latency, wherein if the implementation of 5G is to be made practical, the network speed has to be much faster and up to 10 Gb/s and accommodate more users with better reliability and increased energy efficiency.

Overview of Patents Activity

As part of the present study, we were able to retrieve and analyze over 270 patents filed in the United States Patent Office and WIPO by top industry leaders in the field.Thoughthe specification for 5Ghas not yet been defined, a number of patent applications have been filed based on latency reduction configurations that focus on 5G specifications. For better speed of data transfer and shortening the delay of the packet, low latency protocols have been devised/incorporated. Many patents disclose improved data communication systems for network equipments. A separate unidirectional communication path is also being used by the data server to transmit information that is frequently required by the computing devices, which helps in reducing workload of the server, and, therefore, reducing latency and increases throughput of information from the system. Further, two separate transmission channels connected via a network hub or an interface card are used for routing and broadcasting data to the computers,which increases the bandwidth of the system. Also, the disclosed systems can be used with various communication networks such as Ethernet, InfiniBand, Fibre channel, Serial Attached SCSI, etc. Many of the underlying technologies of standard IEEE 802.3ab were originally developed at WideBand.

Major Players

Based on our brief analysis of the above-mentioned patents, it can be noted that the latency technology domain is dominated by Qualcomm (18%), followed by IBM (15), Intel (13%), and Huawei Technologies (9%).

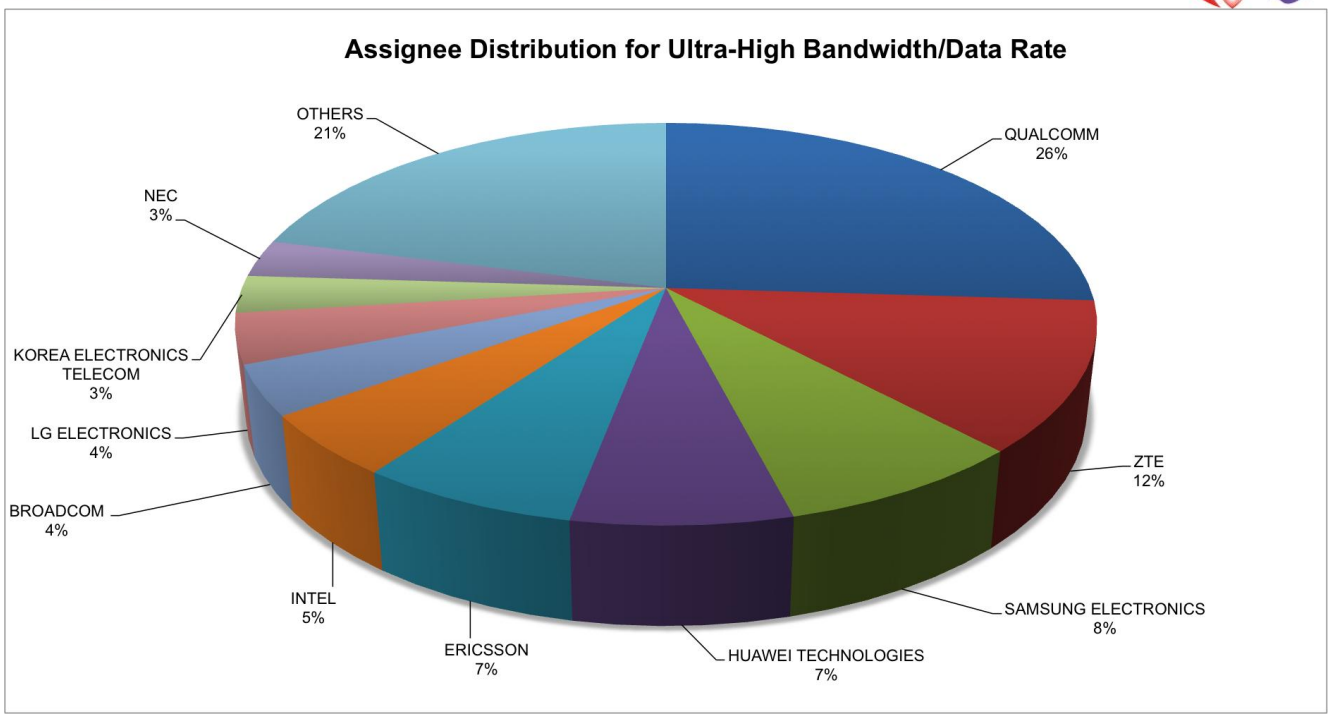


Exhibit-22

4.4.7 Technology Enabling Seamless High Speed Mobility

For high speed wireless data communication, smaller coverage cells are envisioned by technology enthusiasts and therefore seamless Mobility/Interoperability/Handover among networks represents the corner stone for the success of 5G systems with different evolving access technologies. Frequent handover with virtually hundred percent success rate is the key to achieve greater data speeds. Following are few of the key steps in faster and successful handover process to achieve seamless mobility and 5G proposed data speeds.

Fast Network Selection is one of the basic functions of interoperability process between networks. A clever selection of a suitable network by users would result in lower blocking probability, higher capacity, and enhanced QoS. These benefits can be achieved only if the user equipment (UE) enables an efficient use of network resources. As a result, UE can select the most appropriate network with an enhanced QoS with respect to the desired service requirements. Achievement of these enhancements depends on integration architecture of the two technologies, and further depends on developing efficient network selection mechanisms.

Horizontal/Intra-network and Vertical/Inter-network Handoverselection process and criteria is a very important aspect to achieve seamless and faster mobility. Once a network has been selected, the user is subject to change the initially selected network according to various conditions, thereby enhancing the importance of efficient handover criteria. Horizontal/Intra-network handover success rate can efficiently be managed by proper planning of network resources at every operator's end and can also be standardized by any of the network regulatory body. Like horizontal handover, vertical/Inter-network handover can also be regularized by co-operative management of different operators.Partnership or roaming agreements between different network operators can work wonders to gain 5G data

speeds.Operators should give the user the same benefits as if the inter-operation was handled within one network operator.Identification of subscriber should be done as if it is in a pure one system environment. Depending on the level of integration that is required between available access technologies, a variety of approaches can be taken for effective interoperability.

Overview of Patents Activity

As part of the present study, we were able to retrieve and analyze230 patents filed in the United States Patent Office and WIPO by top industry leaders in the field.Exhibit-23 typically relates to distribution of focus areas in the domain of handover, where it can be seen that the focus has been on fast handover and inter-system handover technologies.A significant number of patents also disclose using different handover techniquessuch as “Break before Make”/Hard Handover,and “Make before Break”/Soft Handover, whereinhard handover is typically incorporated for faster calls between two handover sharing neighbour cells, and wherein the handover success rate is high (triggers large number of call drops). In soft handover, on the other hand, the user equipment communicates with all neighbouring sites and links itself temporarily to the neighbour with the best radio energy level,such that if there is any error in the handover, it automatically returns to its previous frequency (home frequency) to avoid call drop or data block lose. Soft handover is therefore proposed to faster and reliable handover between one cell site to other.

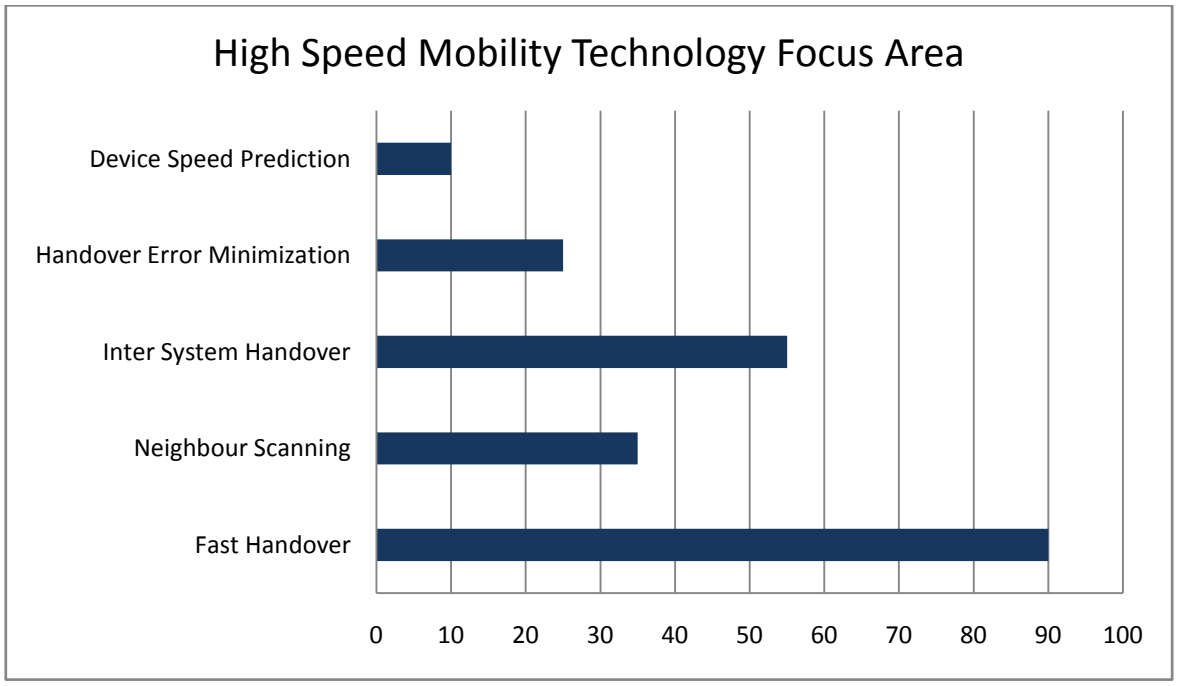


Exhibit-23

Major Players

Exhibit-24 illustrates assignee distribution of Patents in the domain of high-speed mobility, wherein Qualcomm yet again dominates with 24%, followed by Samsung Electronics (9%), ZTE (9%), Huawei (8%), and Intel (7%).

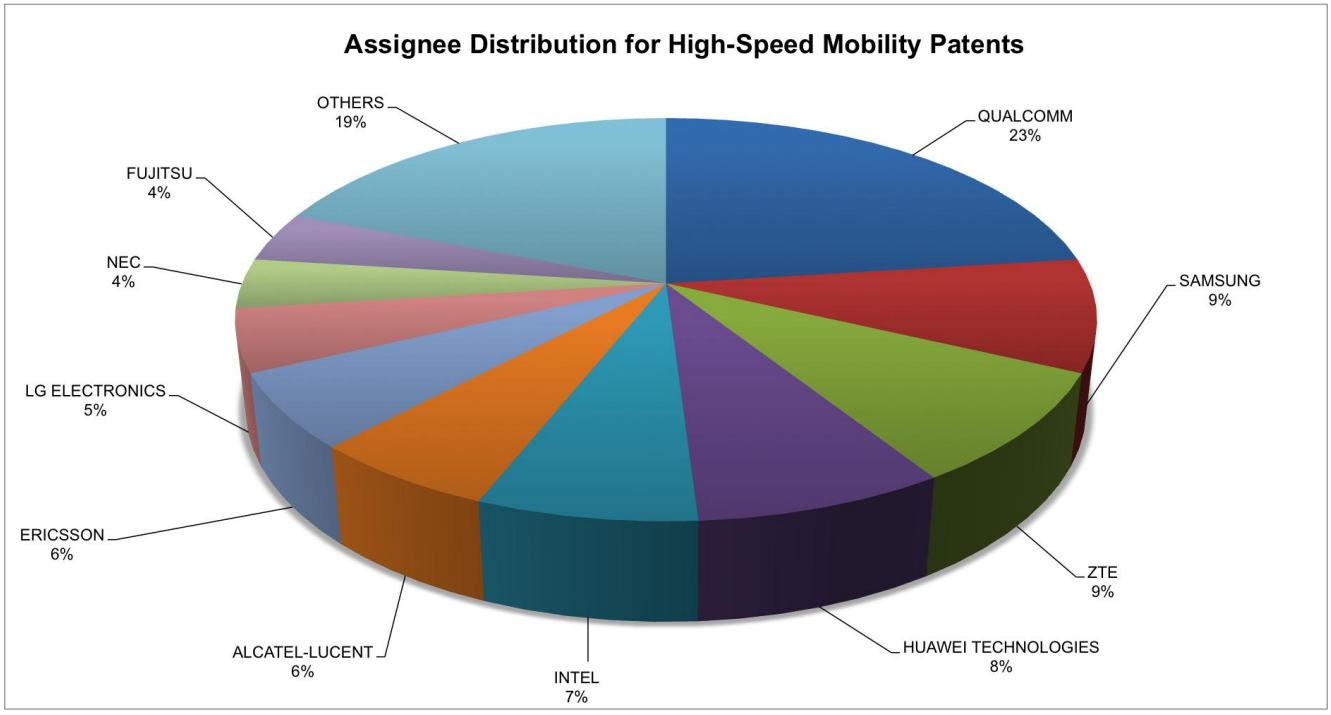


Exhibit-24

4.4.8 Technology Enabling Low Energy or Power Consumption of Network Devices

In communication networks, power consumption of network or network devices plays an important role in keeping devices alive for a period of time without affectingthe global eco-system.With the number of devicesand network equipments growing, the next generation devices and network equipments need to be energy efficient. We consider power management for networks from a perspective that has recently begun to receive attention: the conservation of energy for operating and environmental reasons. Energy consumption in network exchanges is rising as higher capacity network equipments become more power-hungry and require greater amounts of cooling. It is an initial exploration of how overall network energy consumption might be reduced without adversely affecting network performance.

As there is improvement in networking and data communication, there is a need for well improved methods and low powered devices that control power consumption of the network devices.

Power Consumption in Different Networks (2G, 3G, 4G, and Wifi)

It is obvious that LTE will be the choice of 4th generation technology in India as well as globally. In India, LTE is expected to see growth from the year 2015 with all BWA spectrum winners planning to roll out services sometime in 2015.There are some reasons behind the heavy power requirement while one is on the LTE network. First, LTE accounts for several complex algorithmsthat pack more data in the same wavelength, as a result of which the radio chip uses more power than 2G or 3G/HSPA. Secondly, some LTE phones (for e.g. from Verizon) have dual antenna for LTE and CDMA1x – to offer voice over 1x via fall

back mechanism. Thirdly, as LTE network is not made as like blanket coverage in most of the geographies, while you are off the LTE network, the phone searches for the LTE network, which will end up in faster discharge of battery.

Overview of Patents Activity

As part of the present study, we were able to capture and analyze around 360 patents filed in the United States Patent Office and WIPO by top industry leaders in the field of power management, wherein, Exhibit-25 clearly shows the growing focus on controlling power consumption such as Antennas, Applications, different modes for controlling power consumption such as sleep mode, power saving mode, halt mode etc. Other focus areas relate to optimization of power displays and signal processing.

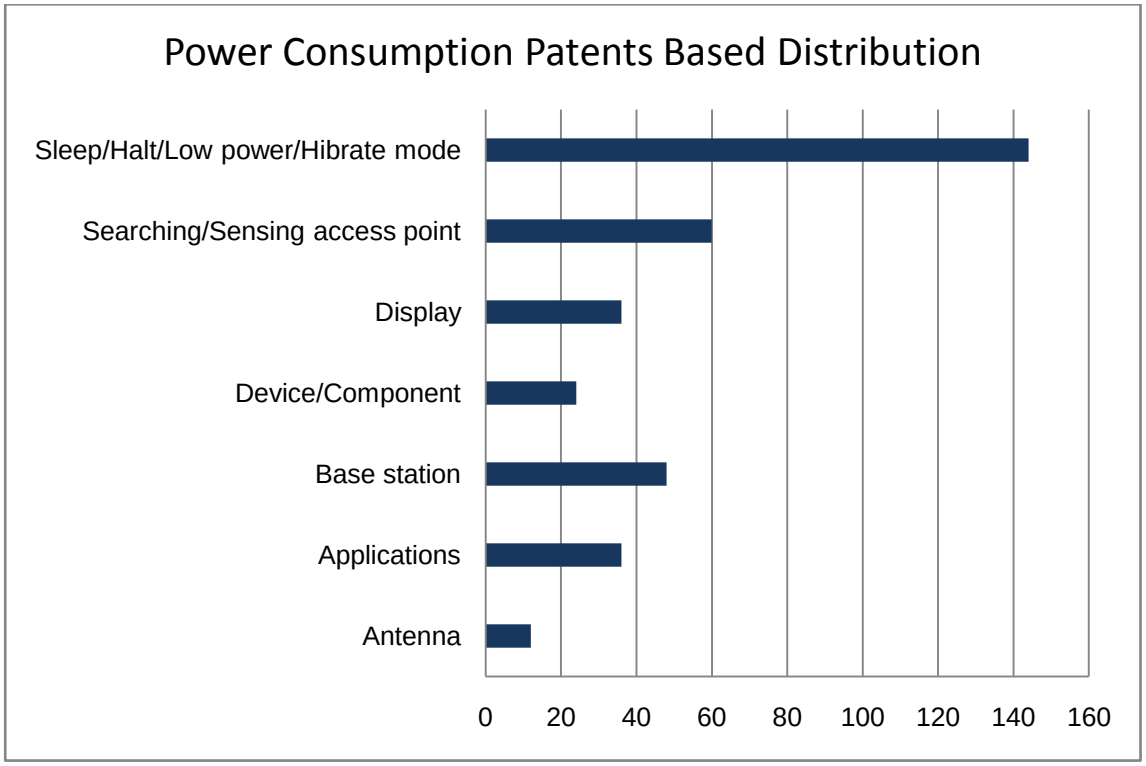


Exhibit-25

Major Players

Exhibit-26 illustrates Assignee focus on power management technologies, wherein, Qualcomm continues to dominate this part of the market as well with around 16% of the patents in the domain, followed by Samsung (8%), ZTE (7%), and LG (6%). Few other companies making it in the top assignees in this space include Toshiba and Hitachi.

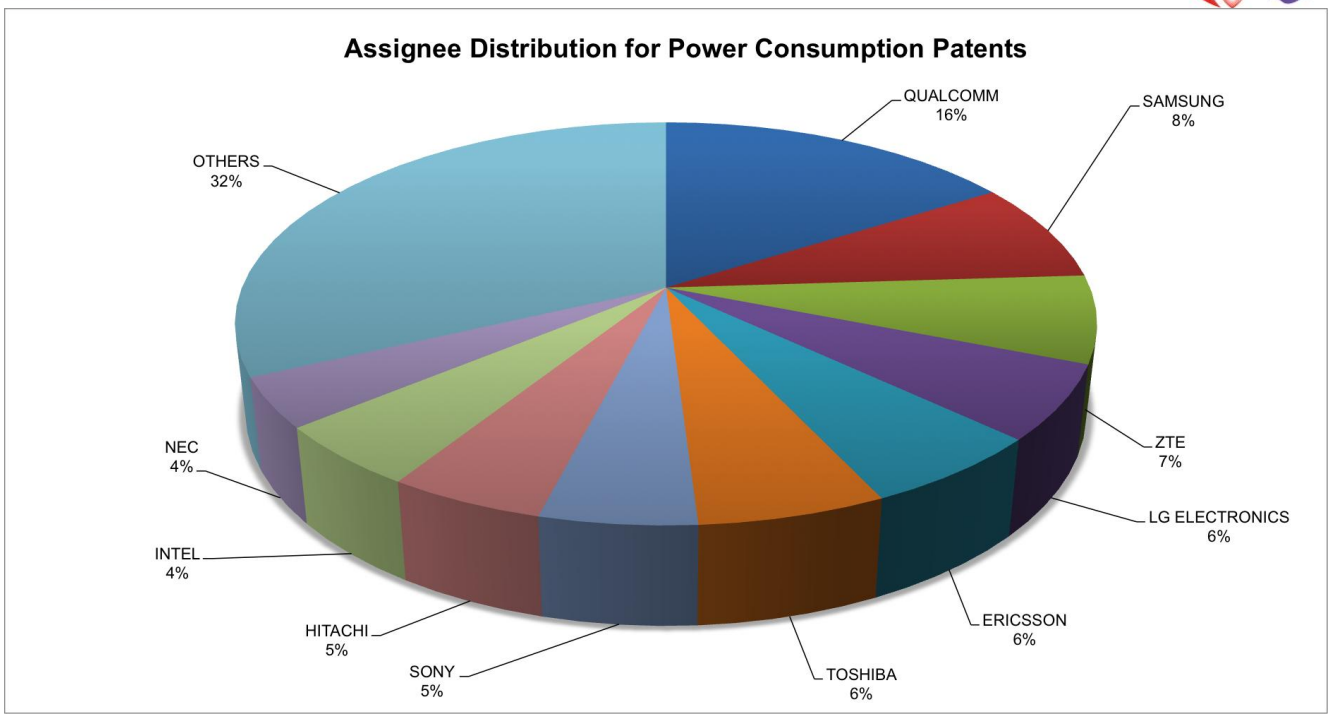


Exhibit-26

4.4.9Multiple Access Techniques

Multiple access techniques are used to allow a large number of mobile users to share the allocated frequency spectrum in the most efficient manner. As the spectrum is limited, sharing is required to increase the capacity of a cell over a geographical area by allowing available bandwidth to be used by different usersat the same time. And this must be done in a way such that the quality of service doesn't degrade within the existing users. A number of multiple access techniques such as CDMA, FDMA, TDMA, SDMA, OFDMA were previously proposed and used in various communication technologies.

Beam Division Multiple Access (BDMA) is foreseen as the possible multiple access technology for next generation communication or fifth generation of cellular communication. In BDMA, when a base station communicates with mobile stations, an orthogonal beam is allocated for every mobile station connected to that cell site. BDMA technique divides an antenna beam according to locations of the mobile stations to allow the mobile stations to give multiple accesses, thereby significantly increasing the capacity of the system. Mobile stations and a base station are in a Line of Sight (LOS) state, when they exactly know each other's positions they can transmit beams which direct to each other's position to communicate without interfering with mobile stations at cell edge. Phase array antennas are configured to use the beam forming technology and use multiple beam forming patterns simultaneously in a cell, allowing orthogonal multiple access. Mobile stations positioned at similar angle share one beam to communicate with the base station, butmobile stations positioned at different angles with respect to a base station are servedby different beams at different angles to simultaneously transmit data to multiple mobile stations.

Bands enabling broadband communication at frequencies equal to or higher than 1 GHz are limited by frequency distribution and therefore a technology using millimeter wave band equal to or higher than 30 GHz for wireless communication such as 5G is required.However, in such high frequency bands, a serious

problem of generation of signal attenuation is far evident. Propagation path loss increases as transmission frequency for wireless communication becomes higher, and accordingly, the distance of arrival becomes relatively shorter, as a result of which the service coverage is reduced. However, beam-forming of concentrating signals, transmitted from a plurality of antennas/antenna array in a particular direction adds towards a large number of antenna elements. To address the problem of using a plurality of antennas to increase the antenna gain, and to efficiently construct a beam-link, BDMA is applied.

4.4.10Cloud/Centralized Radio Access Network

In communication network, cloud radio access network (Cloud Radio Access Network, C-RAN) is a novel green radio access network architecture based on centralized processing, collaborative radio, and real-time cloud computing infrastructure. A C-RAN solution, when compared with stand-alone station solution, can provide features such as tide resource pool, inter-station tightly coupled collaboration, and centralized management, thereby improving network performance. However, a user in an edge area of a C-RAN is incapable of obtaining the same performance gain as an inter-station user of the C-RAN.Below Exhibit-27illustrates technology of C-RAN and its difference from distributed network.

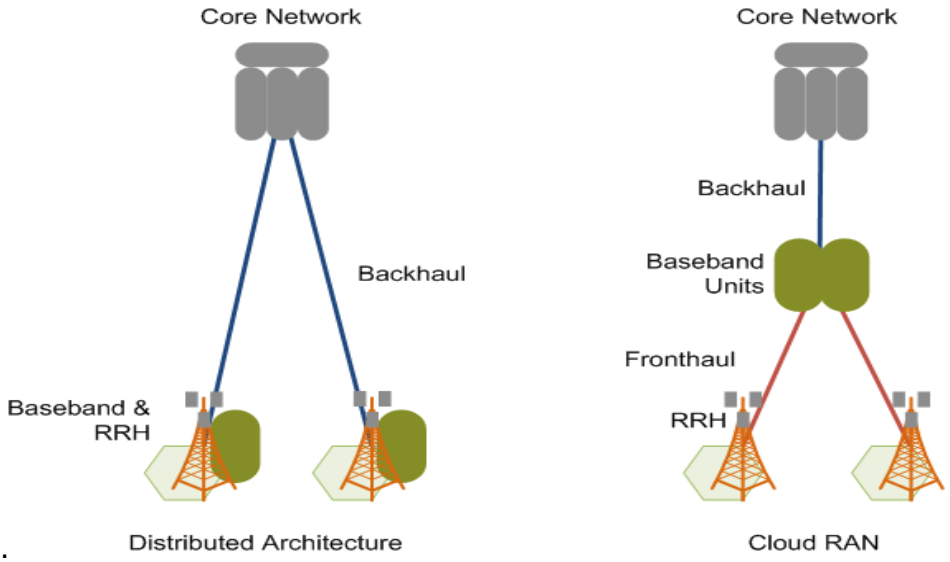


Exhibit-27

Overview of Patents Activity

Though the specification for 5Ghas not been structured as yet, quite a few patent applications have been filed on C-RAN network, which primarily relate to different methods for data exchange in C-RAN network and controlling these types of networks. Patents were filed in different categories in C-RAN such as data exchange control, method for access virtualization, encoding, and selection of channel, among other like domain areas.

5. 5G-Network Operator's Perspective

Wireless communication industry has seen an unparalleled success story resulting from synergistic innovations in wireless technology. Anywhere, anytime access of network, enabled by mobile/wireless communication,is transforming society, enhancing personal lives, and making businesses more competitive. Ever emerging technical advancement in communication industry, on one hand, has redefined ways of how human beings/machines/devices interact with each other, and at the same time has challenged network operators to think about deployment of newer technologies that will provide better speed, low latency, and high mobility.

This section of the report presents fifth generation (5G) communication technology from a network operator's perspective, their future challenges/requirements, and possible solutions. Network operators of the next generation wireless communication will be supporting different kinds of applications/services and different kinds of users/devices. An ultra high-speed and highly reliable infrastructure will be required to support applications/services such as video calling, video conferencing, virtual reality, high end gaming, HDTV, HD content streaming, 4K content sharing, sensor to sensor communication, device to device communication, machine to machine communication, connected cities, IoT, connected homes/offices, healthcare services, remote education, e-agriculture, industrial automation and control, home safety, city surveillance, smart traffics, vehicle to vehicle communication, ground to air communication (to support drone delivery and higher light weight arial services) and smart transportation.

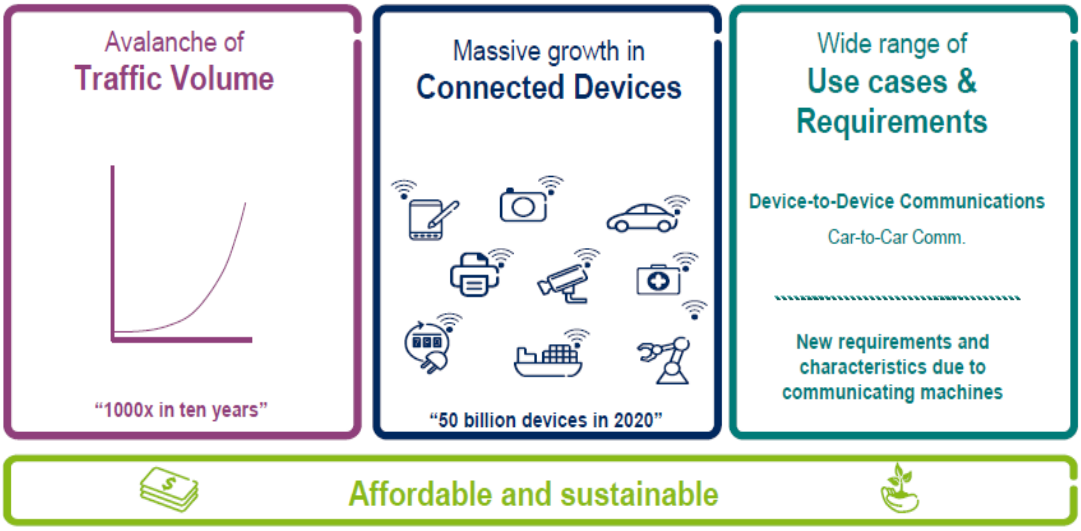


Exhibit-28 (Copyright of Ericsson)

5.1 Technology Maturity

The planning process for network upgrades and deployment/integration of next-generation technology is typically a complex, lengthy, and extremely detailed process for network operators having existing infrastructure in place. Network operators may face huge challenges in managingtheir existing infrastructure while bidding for and implementing newly available spectrum for 4G as well as 5G in the time to come. As the trend shows, in the last 30-40 years, since analog cellular networks were first deployed, new generations of technologies have come in the industry and new spectrum was made available to actually realize communication on that spectrum or technology. To have a competitive edge in the next generation network, network operators need to identify requirements, challenges, and possible solutions as early as possible. As it can be seen from technology adaptation timeline below in Exhibit-29, the next generation wireless technology arrives by the time the previous generation gains maturity.

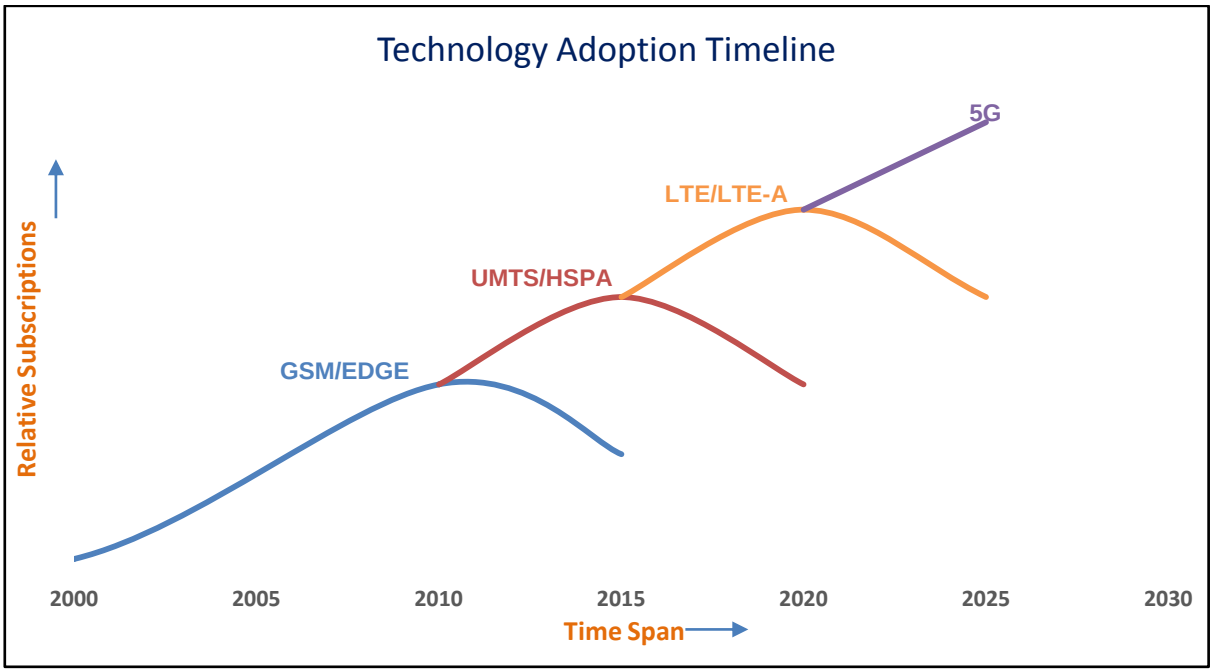


Exhibit-29

5.2 Challenges of Network Operators

In order to support a wide range of use cases and requirements where traffic volume increasesby 1000 times due to massive number of connected devices, network operators will have to use new technologies, upgrade their infrastructure, install new sites, use centralized/cloud based infrastructure, acquire new spectrum, deploy more efficient wireless technology, use cell splitting, and share infrastructure with other operators. Some of the practical challenges that these network operators may face in future are mentioned below.

Any network operator planning to be a player in the market may have to fulfil below fundamental requirements for building a fifth generation (5G) wireless network, and service the 5G users/devices.

- Capabilities for supporting massive capacity and massive connectivity

- Support for an increasing number of diverse set of services, applications, devices, and users, all with extremely diverging requirements
- Flexible and efficient use of all available non-contiguous spectrum for wildly different network deployment scenarios
- Maximizing downlink power, minimizing noise, limiting interference, minimizing signal overlap between sectors, and optimize signal to noise ratio
- Efficient usage of the spectrum to achieve optimal capacity and data throughput

Business Challengesfor 5G Platform Implementation

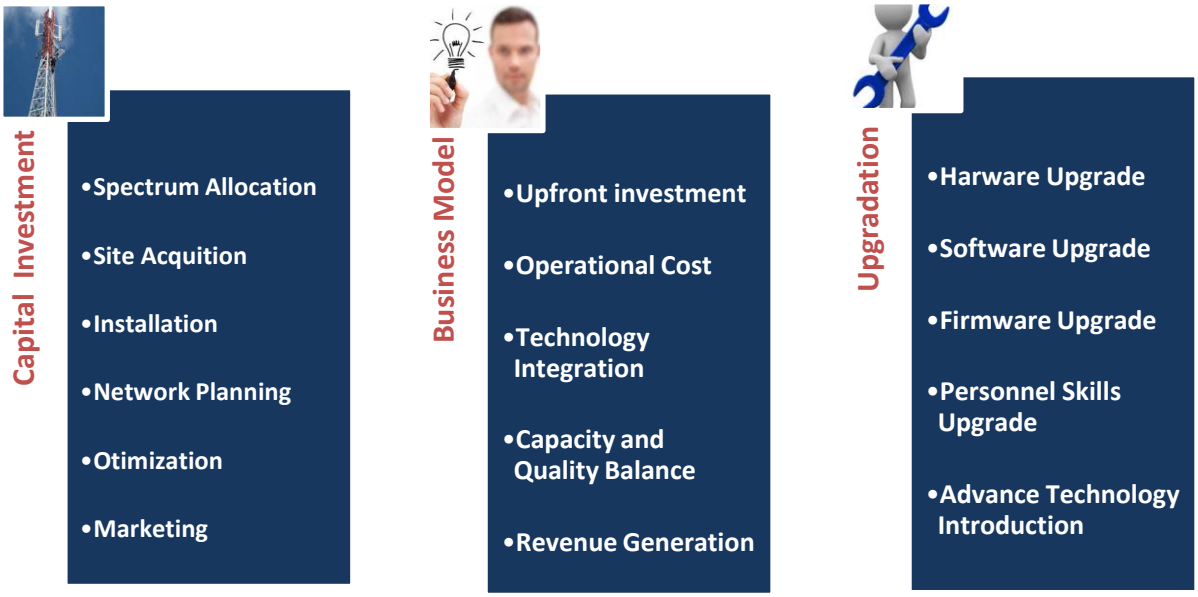


Exhibit-30

To meet even the fundamental requirements of fifth generation network, at a high level, the network operators may have to evaluate their capital investment, create new business models, and may have to upgrade their existing infrastructure, and skill sets. Huge capital investment may be required for getting new spectrum, acquire new sites, install base stations and towers, incur efforts in network planning and consultation, optimize existing networks, and market new age services and applications.

Network operators may also have to evaluate their business models and may have to consider new revenue generation architectures, other than simple traditional fixed rental basis and pay per use, especially with profit margins with new generations of wireless technology shrinking. Network operators may also have to take a close look of their upfront investment, operational costs, technology integration, balance of capacity and quality, and new way of review generation.

On technology front, as ultra-reliable communications would be one of the most important focus areas of 5G, such communications would put very stringent latency and reliability requirements on the architecture.

In order to compete for 5G services, network operators would have to focus on implementation of advanced technologies including but not limited to,mmWave, small firm factor for large scale antenna, smart and cognitive radios/antennas, and new modulation schemes.

Technology and economic challenges

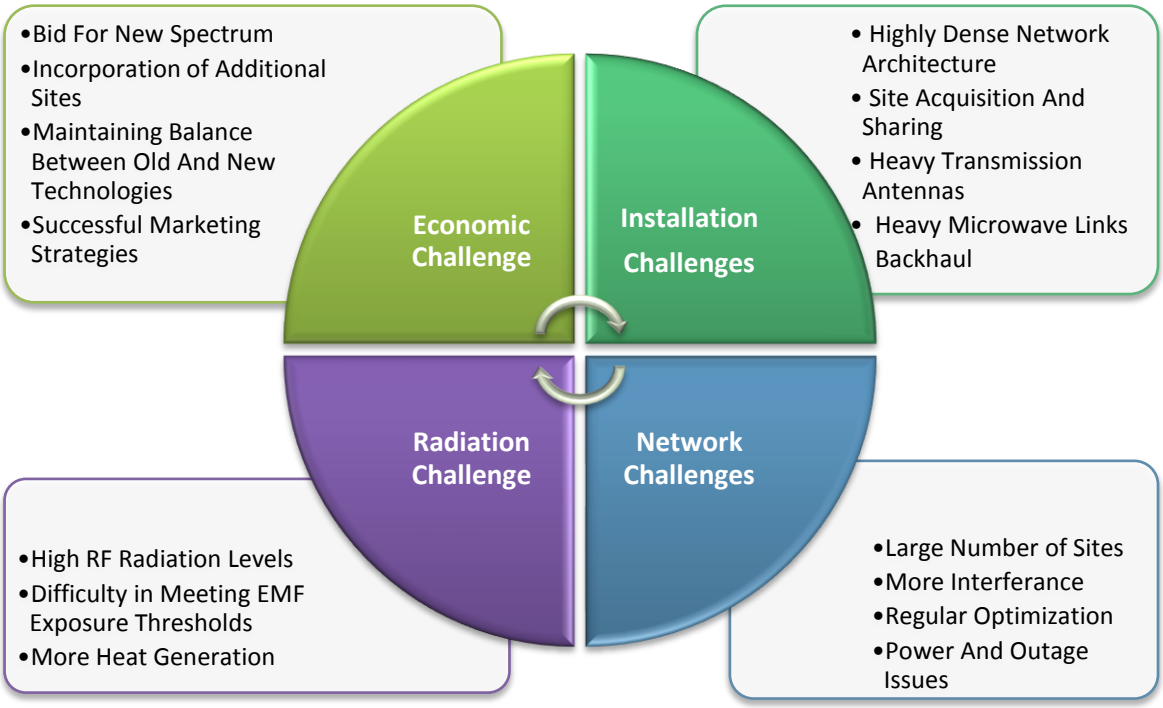


Exhibit-31

Exhibit-31 above represents an overview of network operator's business, economic and technical challenges.

5.3 Proposed Solutions

Network operators may have to choose right set of technologies, and adopt a suitable business and economic model to overcome the business, economic, and technical challenges that would be faced by a fifth generation network operator/service provider. Network operatorswould have to improve their infrastructure, adopt new technologies, and acquire new frequency bands to ensure quality of service, reliability, and security. Some of indicative high level solutions to overcome the above problems are introduced under this section of report.

5.3.1 Network Solution and Adaptation of New Technology

In order to support the above described massive requirements/demands of network beyond 2020, network operators will have to adopt new age technologies such as mmWave, smart and cognitive antennas, multi access technology, cloud/centralized radio access network, and share spectrum and other base infrastructure with other operators. An early collaboration on infrastructure development will provide an edge to operators. Although, at the hardware level, some of the existing infrastructure of 4G may be used, there will be significant changes required at the software level at base stations and at overall transmission channels, which may have to adopt new age modulation and multi access techniques. Furthermore, as the carrier frequency changes, antennas too would have to undergo configurational changes. Software level changes may be required for smart and cognitive antennas, traffic aware cells, and for adaptation of zero latency and high speed mobility. New switchingtechniques that can enable 10 millisecond of switching time for high speed mobility, next generation users/devices/applications, would also be needed for adoption. Technology that supports self-configuration/optimization of the network would be required to serve time dependent, device dependent, application/service dependent, and density dependent requirements. Operators would have to adopt more spectrum efficient technologies, wherein adoption of programmable air-interface technologies, mapping of service requirements to the best suitable combinations of frequency with radio resources may be a technology solution that can provide economy of scale.

Desired flexibility of the network will also require network management solutions in the backhaul such as the incorporation of Software Defined Networking (SDN) in order to achieve fast re-routing and congestion control, mainly in the access part. SDN concepts enable adaptation of the backhaul network to the needs of the radio access network. For example, the selection of IP break-out anchor points may depend on the current backhaul traffic situation and QoS requirements in the radio access networks. Furthermore, the smaller the cells in the radio access network, the higher the temporal and spatial traffic fluctuations. This implies that also the backhaul network may experience a higher variance of traffic. Besides, current trends suggest that Infrastructure as a Service (IaaS) can be supported by small cells in order to offer innovative proximity services and to enable a series of advantages for end customers. With this approach, energy scarce, capacity limited mobile devices can offload highly demanding computational tasks into proximal fixed units or use them for storage. This entails that novel mechanisms are needed to efficiently allocate resources, understood in a wide sense (radio/computation/storage/energy), including contextual information metrics and clustering techniques for small cells. (Courtesy: ICT-RAS)

Technology and Economic Solutions

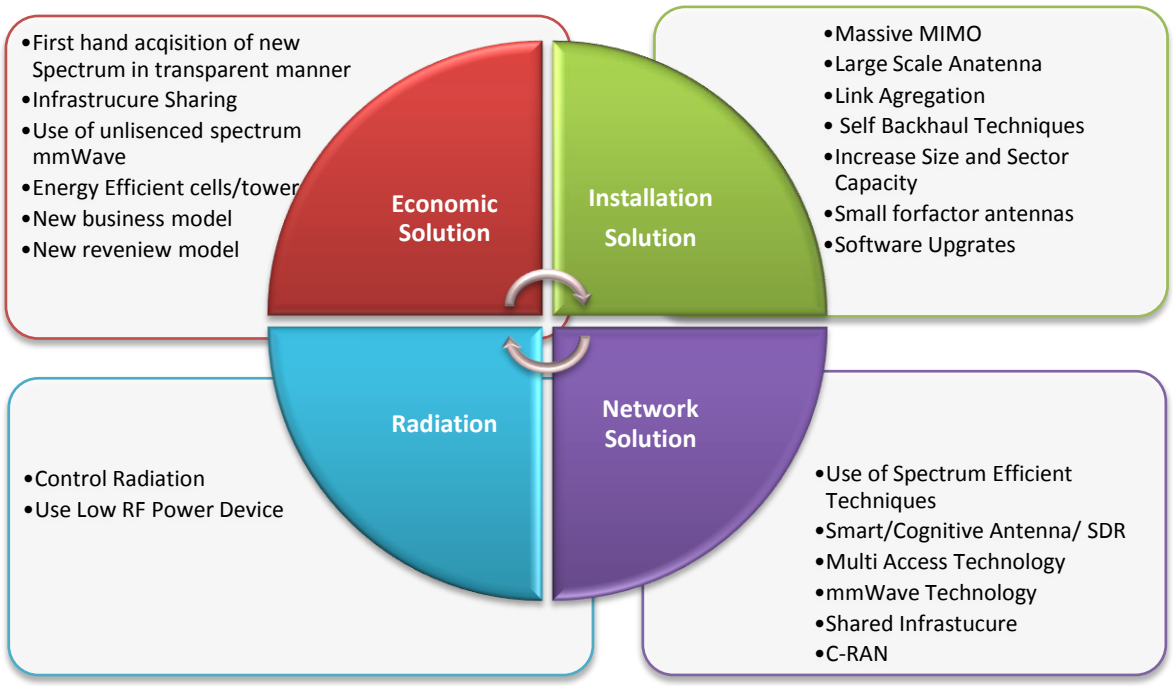


Exhibit-32

5.3.2 Installation and Infrastructure Solution

In order to support over 50 billion users/devices, significant infrastructural changeswould take place and the network operators may have to upgrade their existing sites/infrastructures to provide connectivity to highly dense users/devices. Infrastructure of 5G would also need to incorporate cost-effective automated network organization techniques such as self-configuration, automatic neighbour selection, self-organized carrier selection, and self-healing mechanisms, for managing complex heterogeneous mobile access networks as a single entity. Such techniques can also be configured to enable the network operator to specify network-oriented objectives regarding, for instance, desired service coverage, resource efficiency, and quality of experience. Massive MIMO and large scale antennas with small form factor will be the necessary solution for fifth generation network. Existing infrastructure/towers may need to be upgraded for better site and sector capacity to support high density requirement. Infrastructure of fifth generation network needs to be scalable and not restricted to single spectrum and hence should have the ability of link aggregation and adaptive spectrum uses. Core network infrastructure may have changes as the infrastructure of 2G and 3G mobile networks will not be suited for 4G/4G advanced and 5G.

Infrastructure of the future generation should not be very heavy in terms of its physical dimension as the municipal authorities may be imposing such restriction. Size of the base stations and/or the towers would need to shrink as well, and for that purpose, products such as Alcatel Lucent'sLightRadio and Ericsson's AIR antenna integrated compact solution can be used. In sensitive areas, installation of micro towers may be required, though it may elevate the cost.

In order to provide network service to anywhere anytime users/devices, network operators may use cloud based RAN and provide scalable network infrastructure. As the next generation users/devices may be present even in the remotest parts of the country where maintenance of base stations and towers are challenging, self adaptive backhaul technologies may be required. 5G will feature native support for new kinds of network deployments, including ultra-dense radio networking with self-backhauling, device-to-device communication, dynamic spectrum reframing, and radio access infrastructure sharingAir-interface and RAN systems may need to be completely redesigned to accommodate a new mobile access paradigm of massive capacity, huge numbers of connections, and ultra-fast network speeds.

5.3.3 Economic Solution

In order to overcome the economic challenges, network operators may have to take several strategic decisions such as reusing of existing spectrum, acquisition of new spectrum, sharing of spectrum, sharing of core infrastructure, and adaptation of new business and review model. While previous generations of wireless networks were characterized by fixed radio parameters and spectrum blocks, 5G will allow utilization of any spectrum and any access technology for the best delivery of services. Infrastructure and Spectrum sharing may be a very cost effective approach to serve the dynamically varying next generation network requirement.

In addition to the existing spectrum used for 2G, 3G and 4G/LTE, network operators will have to acquire new spectrum bands such, one used by mmWave technology. The government and the spectrum allocation/distribution agencies may also have to free some the reserved spectrum under different bands that can be used by different type of devices. There is growing global consensus that 500 MHz to 1GHz of spectrum needs to be made available. It has been observed with previous spectrum allocations that the first hand acquisition of the spectrum in a transparent manner can always provide an extra edge to the network operator in terms of cost of acquisition and advantage of early adoption, and being the first service provider. Network operators and government agencies need to work together for harmonisation of the spectrum and its governance rules in order to allow global circulation and enable economies-of scale for devices. For catering the requirement of next generation wireless devices, a shared infrastructure created/developed by public private partnership may be a profitable proposition for different stack holders.

5.3.4 Solution for Radiation

As the number of wireless devices and density of radio towers is increasing, radiation levels will also increase, and therefore the government and municipal authorities may impose certain restrictions on the level of radiation. The next generation wireless devices and radio stations/towers would therefore need to be optimized for low radiation, wherein network operators may use low RF power devices and technologies that are optimized for low radiation.

In addition to the above mentioned issues and potential solutions thereof, it is also important for network operators to take note the transition of hand-held devices that is taking place as to whether the growth of the smart-phone market is at the right pace to absorb and be compatible with the kind of technology platforms that 5G would demand. Spectrum allocation and implementation of 5G would therefore only make sense when the computing devices with which they are compatible are enough to sustain and make the investment of the operators viable. A different study on the projected growth of the hand-held device market is therefore required in order to assess that factor. Furthermore, with the implementation of 4G itself being in preliminary stages at the moment, 5G is really at least 5-7 years away but is undeniably on the cards.

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