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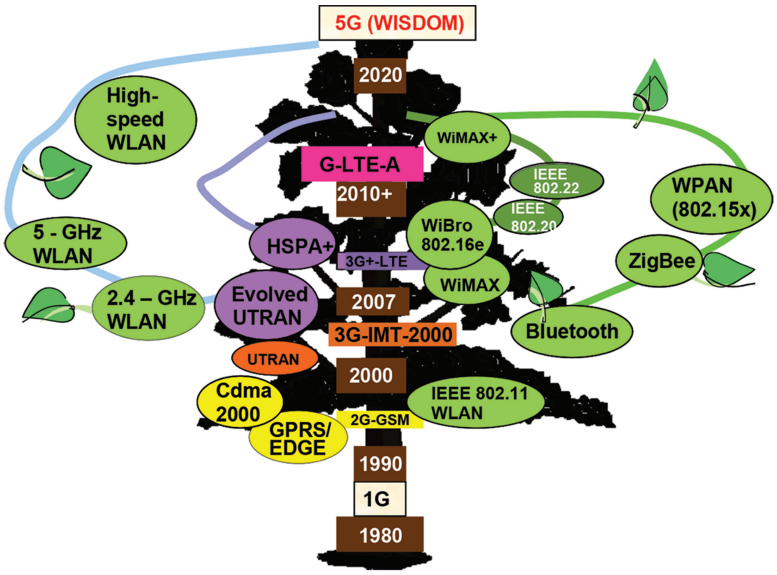
Introduction

In the last decade world has witnessed a tremendous growth in the wireless technologies. The result is an enormous growth in the evolution of various wireless communication devices like smart phones, laptops, tablets. Due to the enormous growth in the number of these devices for various applications, there is also the requirement for the development of various wireless solutions that are cost effective and reliable. The focus on the mobile wireless communications is dominant as it is the main means of communication in the world.

Based on the type of services and data transfer speeds, mobile wireless technologies have been classified according to their generations. They are shown in the form a tree in the Figure 1.1 for easy understanding and are explained below.

1.1 Mobile Wireless Technology Generations

The first generation mobile systems (1G) were analogue. The first cellular system was put into operation in 1978 by Nippon Telephone and Telegraph (NTT) in Tokyo, Japan. Some of the most popular analogue cellular systems were Nordic Mobile Telephones (NMT) and Total Access Communication Systems (TACS), Advanced Mobile Phone System (AMPS). AMPS and TACS use frequency modulation technique for the radio transmission. The inevitable disadvantage of this generation of mobile systems is that, even though these systems rendered handover and roaming capabilities the cellular networks were not able to interoperate among countries. Multiplexed traffic is carried over a Frequency Division Multiple Access (FDMA) system [2]. The second generation mobile systems (2G) are based on the standard Global System for Mobile Communications (GSM). GSM appeared first in 1991 and they are digital cellular systems. Digital communications enable advanced source coding techniques to be implemented thus allowing the spectrum to



5G-WISDOM: Wireless Innovative System for Dynamically Operating Mega Communications *4G-LTE-A*:Long Term Evolution Advanced *HSPA*: High Speed Packet Access *3G+LTE*:Long Term Evolution *3G-IMT-2000*: International Mobile Telecommunications *EDGE*: Enhanced Data Rate for GSM Evolution *2G-GSM*:Global System for Mobile Communications 1G – NMT: Nordic Mobile Telephones TACS: Total Access Control System AMPS: Advanced Mobile Phone Systems

Figure 1.1 Tree of Standards [1].

be used much more efficiently. This also reduces the bandwidth required for voice and video [2, 3].

The main disadvantage with GSM is that it could handle a maximum data rate of 9.6 kbps which is too slow for the Internet related services. The 2G was subsequently superseded by 2.5G and 2.7G.

2.5G systems are evolved based on the General Packet Radio Service (GPRS) standard. These systems support Wireless Application Protocol, Multimedia Message Service, Short Message Service, mobile games, and search and directory mobile services.

2.75G systems are evolved based on standard Enhanced Data rate for GSM Evolution (EDGE) and this technology is an extended version of GSM. Data transfer rate is high compared to GPRS.

The third generation mobile systems (3G) systems were designed to provide a very high speed Internet access (about 384 kbps in burst mode). Some of the important services that these systems support are wide area

wireless voice telephony, video calls, broadband wireless data and additional services like mobile television, Global Positioning System (GPS), other real time audio, video broadcast services. The three important technologies that paved the way to the development of 3G systems are given in reference [3]:

Universal Mobile Telecommunication System (UMTS) was developed that used Frequency Division Duplex (FDD) for forward and backward channels. With the help of wideband Code Division Multiple Access 5MHz channel spacing, high data rates of up to 2 Mbps can be achieved.

Time Division Synchronous CDMA (TD-SCDMA) used 1.6 MHz channel spacing.

The fourth generation mobile system (4G) offered very high speeds of up to 100 Mbps. The important feature of 4G systems are the high quality video and audio streaming over end to end Internet Protocol. The two important standards in 4G technologies are Worldwide Interoperability for microwave Access (WiMax) and Long Term Evolution (LTE). 4G is the current technology used all over the important places of the world. But there are many countries where the 4G services are not yet accessible because of the spectrum related issues [4, 5].

1.2 5G – From History to the Present and Future

The concept of realizing next generation communication systems in the form of 5th Generation communication network based on Wireless System for Dynamic Operating Mega Communications (WISDOM) followed by other leading initiatives at research facilities in industry and academia is as shown in Table 1.1. The operational concept of WISDOM has been discussed in detail in the following subsection and the various specific details related with its operation, and operational challenges that WISDOM – 5G would require to overcome have been elaborated in Chapter 2.

It has been long since the rollout of 4G based services by the cellular companies. Advent and possible utilization of 5G based services in future is already picking up. 5G based services are expected to commence from 2020. High data rate is expected to usher a new digital age ubiquitous communication for the masses that is unimaginable to be fulfilled by today's communication networks. 5G mobile wireless communications are expected to incorporate a large number of advanced technologies in order to increase the bandwidth further; Quality of Service (QoS), improve usability and security, decrease delays and cost of service. Some of the interesting services that users

Table 1.1 Significant 5G Initiatives till date.

Year	5G Initiative	Entity	Country
2008 February	WISDOM: Wireless Innovative System for Dynamic Operating Mega Communications [1]	Keynote Speech: **First International IEEE Conference on Cognitive Radio and Advanced Spectrum Management** Center for TeleInFrastruktur, Aalborg University	Denmark
2008 November	5G through WISDOM [7]	Center for TeleInFrastruktur, Aalborg University	Denmark
2008 November	5G systems based on Beam Division Multiple Access [7]	South Korea IT R&D department	South Korea
2012 May	First 5G System [7]	Samsung Electronics	South Korea
2012 October	5G Research Center [7]	University of Surrey	United Kingdom
2013 November	Research on 5G systems [7]	Huawei Technologies Co. Ltd	China

can experience are wearable or flexible mobile devices, Ultra High Display video streaming, smart navigation, mobile cloud, real time interactive games. Spectrum remains a key challenge for 5G, high frequency bands are to be explored to achieve those higher data rates than any other currently emerging technology. Some sources specify that when 5G arrives, it will have to handle billions of devices and myriad traffic types. It will offer improved reception and less network congestion, allowing for better connectivity and smoother roaming functionality [1].

1.3 WISDOM (Wireless Innovative System for Dynamically Operating Mega Communications)

WISDOM is an important and novel concept that defines 5G. The main reason for its description in this chapter is that it is an evolution towards a new communication connectivity era, which will offer the frequencies up to Tera Hertz and data rate up to Tera bps.

The fastest communication and ubiquitous connectivity is the foremost priority of the present era with the need of quick data transfer, distant

business correspondence by sharing data and use of single IP for worldwide connectivity using hand held mobile.

To make it happen, the 5G network is assumed as the perfection level in mobile technology, which provides real life mobility. In this regard WISDOM is expected to advance the state-of-the-art in the architecture of next generation of wireless networks and cognitive technologies for higher data rates up to 1 Tera bps.

The relation between WISDOM and 5G can be expressed like this:

$$4\text{G} + \text{WISDOM} \triangleq 5\text{G}\,[1]$$

The 4G and WISDOM concept will lead the wireless communication towards the realization of true 5G systems.

The main motivation for the development of the WISDOM concept for 5G is the needs of the society 2020 and beyond. These days, there is an exponential increase in wireless access bandwidth that is commercially available to the end user.

This will continue to increase in future wireless networks, taken by the rising needs of the mass market in the fields of bandwidth demanding applications such as entertainment, multimedia, Intelligent Transport Systems (ITS), telemedicine, emergency and safety/security applications [1].

Also the futuristic applications like 3D Internet, virtual and augmented reality that combines data for all senses, audio, visual, haptic, digital scent (e.g., tele-haptic applications, like planet or deep sea exploration), networked virtual reality (e.g., video streaming in social networks – users stream their own reality), and tele-presence (e.g., immersive environments with applications in both the commercial and military fields) can push the demand for real-time symmetric wireless connectivity to an individual with a data rate of 300 Mbps [1].

WISDOM aims for up to 1 Tbit/s (1 Tera bps = 10^{12} bits/s) wireless link rates in short-distance burst-mode or for up to 1 Tbit/s of system aggregated traffic with sustainable symmetric link rates of larger than 300 Mbps to mobile terminals at high speed [1, 3, 6, 7]. The communication at 1 Tbit/s is expected to be achieved utilizing millimetre waves (around 30 GHz and above), this has been discussed further in Chapter 4.

Existing wireless technologies like 3G+ cellular, WiMax IEEE 802.16e, Wi-Fi, Wi-Media as well as the corresponding emerging next generation networks (LTE/LTE-advanced, IEEE 802.16m, IEEE 802.11n, etc.) in the Wireless Wide Area Network (WWAN), Wireless Local Area Network

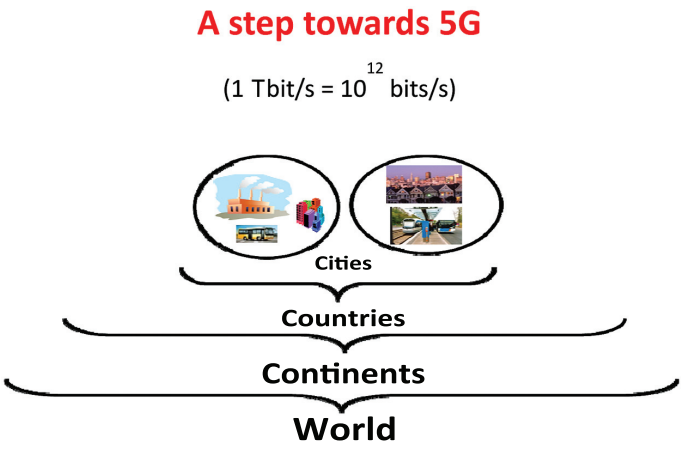


Figure 1.2 Global Connectivity through WISDOM [1].

(WLAN) and Wireless Personal Area Network (WPAN) scales are not expected to meet such demanding needs for data rates.

WISDOM is a way towards 5G with a coverage extending from a city region to a country, continents and the world as shown in the Figure 1.2 forming a Global Information Multimedia Communication Village (GIMCV). Considering a user to shift between geographical locations swiftly and rely on different access networks, WISDOM based 5G network would be capable of dynamically aligning the communication network to support drastic changes in the overall network topology and therefore referred as dynamically operating mega communications based system.
In brief the key features of WISDOM are [6, 7]:

a) combines established, competitive cellular standards with a promising frequency spectrum and novel enabling technologies;
b) reduced coverage, electricity and operational expenditure (OPEX) costs;
c) offers scalable and flexible technology options.

1.4 Global Information Multimedia Communication Village (GIMCV)

The different applications of the WISDOM network includes, home and office network, medical and health care, IT services, entertainment-movies high-speed data transfer, educational systems, rescue vehicular communications,

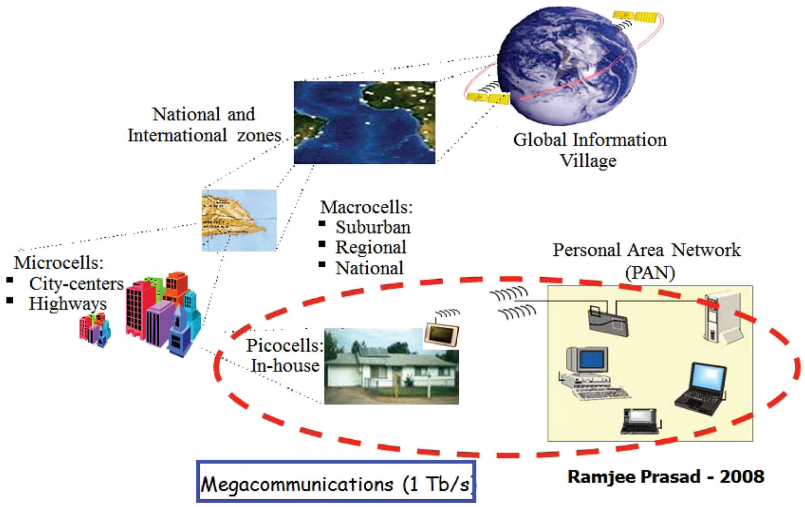


Figure 1.3 Global Information Multimedia Communication Village [1].

meteorology, security, aviation, global communication, smart town, virtual reality, intelligent transportation systems, and so forth.

All these diverse applications of WISDOM are the operating functionality and basis for the Global Information Multimedia Communication Village (GIMCV) as shown in the Figure 1.3.

The Global Information Multimedia Communication Village consists of national and international zones which are divided into macro cells (Suburban, Regional and National network). Macro cells comprise many micro cells (city – centres/highway networks), it further contains small pico-cells (in-house – network) where there are many small personal area networks. It gives scope for WISDOM application which varies from a person in home to globe from where they belong. It is the way of groupings of the devices in close vicinity of user [3].

The new 5G network is expected to improve the services and applications offered by GIMCV. WISDOM is a dynamic entity for human centric systems offering GIMCV.

1.5 Requirements of 5G

Based on the operational requirements of WISDOM based 5G to support a data rate of 1 Tbit/s there are certain things necessitated in the conventional networks. The requirement of the network is categorized into

pico, micro and macro cells. It would be necessary for the mobile terminal to be recognized with a single ID so as to allow seamless network connectivity irrespective of the access network. The envisioned high data rate applications would necessitate that possible authentication and access validation to the mobile device are granted in miniscule time period, i.e., latency as low as 1 ms [8]. This would also necessitate minimization of possible shadowing effect and path loss due to be absolutely minimized. Utilization of distributed antenna systems (DAS) and multi-input and multi-output (MIMO) antennas would be unavoidable. The current MIMO systems would be insufficient and the requirement would be for massive MIMOs [9]. Similarly, the capability of mobile devices to communicate directly, bypassing the conventional network infrastructure, i.e., base station, would be necessary.

As stated earlier the high data rate operations would necessitate measures that can minimize latency to the absolute minimum. The capacity of mobile devices to initiate and establish cellular connections among themselves would be highly beneficial, commonly referred as device-to-device communication (D2D). Utility of D2D in WISDOM 5G communications has been elaborated extensively in Chapter 3. The current cellular operation spectrum bands are excessively crowded. The high data rate and existing spectrum situation would necessitate utilization of frequency bands that are conventionally not utilized for cellular radio communications. Frequency bands, higher than referred as mm bands mm-waves are capable of supporting the high data rated along with use of visible light communication (VLC), are two frequency bands that can suffice the operational requirements. Details about mm bands for WISDOM based 5G communication have been elaborated in Chapter 4. Apart from the using these frequency bands the core network would require to rely on cognitive radio technology for ensuring reliable high data services especially for supporting it on mobile devices that are mobile and change geographic locations swiftly. The relevant concepts for effective spectrum utilization in economic aspects of spectrum trading and sharing have been also elaborated in Chapter 4. The capacity of ubiquitous communication as envisioned to be provided in WISDOM 5G based communications would require specific measures in respect of security and privacy. Various aspects relating with security and privacy challenges and appropriate strategy to address them have been discussed in Chapter 5. Possible technologies such as Human Bond Communication and COmmunications-NAvigation-SENsing-SErvices that would be significant

for fulfilling communication needs of society in 2020 in relation to 5G have been elaborated in Chapter 6.

1.6 Standardization of WISDOM

The major areas where the standardization of WISDOM shown in the Figure 1.4 is required are [3]:

- *Multimedia Communications* where it needs to focus on the areas of Machine-to-Machine (M2M) and Peer-to-Peer (P2P) with global identifications for home networking and smart cities and Techno-social Systems.
- *Cognitive Communications* where WISDOM based personalized cognitive communication includes all the educational, office, community, emergency, commercial and intelligent transportation systems.
- *Personalized Medicine* includes bioinformatics, multi-sensor networks, body sensors, and data protection and ethical guidelines.
- *Network without borders* basically comprises the wide range communications for the future Internet or the next generation networks. The main focus is on the Physical layer security, management and resource optimization, identity management, cooperative communications and Internet of things.
- *Embedded Optimal Resource and Computing* It has Energy harvesting techniques and models, time and power conscious hardware

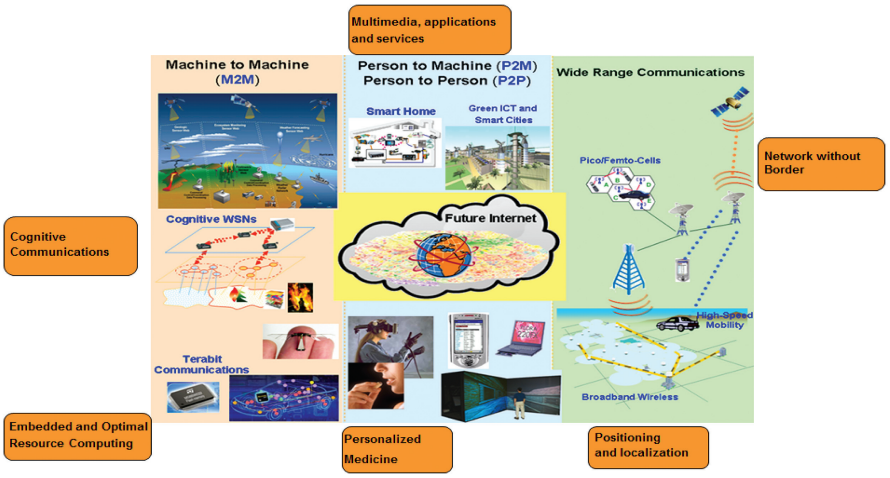


Figure 1.4 Standardization of WISDOM [1].

(HW)/software (SW) code sign methodologies, terminal energy trade-offs and energy aware reconfigurable and heterogeneous Architectures.
- *Positioning and Localization* includes the navigation systems, ubiquitous and cooperative localization, geo tagging, navigation ID systems and Robotics.

1.6.1 Global ICT Standardisation Forum for India

Global ICT Stadardisation Forum for India (GISFI, http://www.gisfi.org/) is playing a pivotal role in formalizing standards for 5G based on WISDOM that ensure the overall operational objective of uninterrupted Tera bps data rate to the end user and support human centric computing [13]. GISFI is addressing the aforesaid objective through its working groups that are looking into sub-aspects pertaining to it. There are seven working groups at GISI, which are as follows:

- Security and Privacy
- Future Radio Networks and 5G
- Internet of Things (IoT)
- Cloud and Service Oriented Network
- Green ICT

In addition to the working groups there are two additional groups:

- Special Interest Group
- Spectrum Group

GISFI has produced several documents covering the various aspects of standardization related to 5G through the working groups and they have been submitted to the government bodies such as International Telecommunication Union-T (ITU-T, Standardisation), Department of Telecom India (DoT) and Telecom Regulatory Authority of India (TRAI). Provided inputs to Telecommunication Engineering Center (TEC), DoT on "Implementations of directions issued by DOT on TRAI recommendations on 'Approach toward Green Telecommunications'" and emergency telecom services to TRAI amongst many others.

1.7 Vision of 5G

The overall vision of 5G can be summarized into the following broad also shown in Figure 1.5 [6].

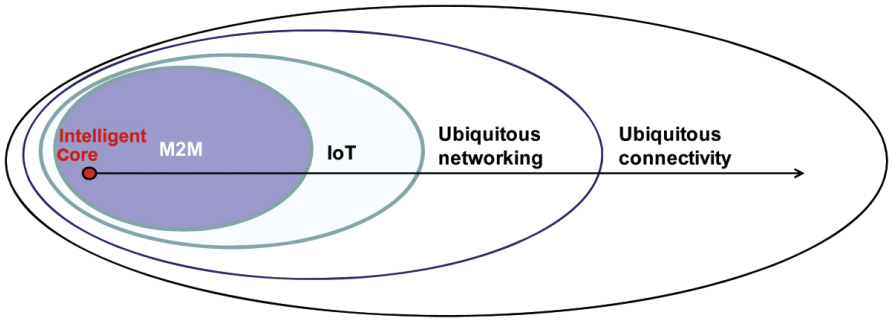


Figure 1.5 Plethora of technologies to deliver 5G services and applications [6], [13].

1.7.1 Enabling the 5G Intelligent Core

M2M and IoT are the two major criteria for realizing the intelligent core, which in turn is the key for enabling seamless ubiquitous networking and connectivity in a 5G context.

M2M and IoT are the key enabling technologies for a pervasive and always-connected 5G mobile services. Research challenges to fully deployable intelligent core are related but not limited to handling the big data collected through M2M and IoT communications (e.g., heterogeneous gateways, energy efficiency, decentralization of routing, naming and addressing), and to security, privacy and trust.

1.7.2 Enabling Ubiquitous Connectivity

This feature has two aspects. On one hand, technical challenges relate to sufficient coverage range even in a scenario of very high mobility and data rates, and on the other, to moving application from device-to-device without any content interruption.

Use of millimetre wave links novel multiple antenna concepts, virtualization, small cell deployments, and novel spectrum usage methods are some of the key research enabling areas for ubiquitous connectivity [1].

1.7.3 Enabling Ubiquitous Networking

This means that regardless of how many access networks are integrated for connectivity purposes, the quality of the delivered service must be retained end-to-end. In the aspect of increased importance of the cloud computing concept for supporting the big data originating from the intelligent 5G core,

end-to-end ubiquitous networking will require interoperable decentralized service-oriented mechanisms with support of real-time interactions.

1.8 Summary

The evolution of mobile wireless communications from 1G to 4G has brought revolution in the communication among the people of the world. It is expected that 5G brings another revolution by offering very high data speeds. It incorporates many sophisticated technologies and uses important concepts like WISDOM for the better performance than their predecessors. This generation is expected to be rolled out by 2020.

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