e-ISSN: 2455-7013
Asian Journal of Management, Engineering & Computer Sciences (AJMECS)
Vol. 3(2), April 2018: 29-37
URL: http://www.crsdindia.com/ajmecs.html
Email: crsdindia@gmail.com

RESEARCH PAPER

A Study on Prospects of 5G Wireless Network

M.P. Mishra
School of Computer and Information Sciences,
Indira Gandhi National Open University, New Delhi, India
Email: mpmishra@ignou.ac.in

ABSTRACT

Ever since the first appearance of real mobile telephone system five decade ago, there has been a steady evolution and betterment in services and coverage of mobile networks. The performances of mobile services have improved exponentially: from basic calling services and texting to the mobile internet and smart mobile applications. The transition from one generation to the next has come up with the new technological breakthrough to support services with better Quality of Service (QoS) and Quality of Experience (QoE). With ever increasing mobile and wireless traffic, volume in next decade is expected that number of devices may touch 50 billion (connected devices) including smart phone and other Internet of Things (IoT) devices, to the cloud by 2020. All these devices need to access and share data with high speed and in cost effective manner, anywhere and anytime. As transition from one generation of mobile communication to the next generation takes place gradually and roll-out of new technology takes place in parallel to the existing technology. The 5G recommendations from International Telecommunication Union (ITU) recommendation International Mobile Telecommunications (IMT) -2020 has been made in 2015 and upcoming 5G wireless networks are expected to become functional by 2020. With development in multimedia based services and need of reliable, real-time, high-speed reliable communications the future 5G cellular system would be having interconnection of a large number of wireless services active devices all around the globe. In this paper a review of upcoming 5G wireless networks: issues, challenges and potential technological research are given.

Keywords: *5G Mobile Network Latency, MIMO, QoS, QoE, Cognitive Radio*

Received: 5th Jan. 2018, Revised: 7th March 2018, Accepted: 21st March 2018

How to cite this article:
Mishra M.P. (2018): A Study on Prospects of 5G Wireless Network. AJMECS, Vol. 3[2]: April, 2018: 29-37.

INTRODUCTION

The advancement in the mobile network technology and in IoT devices have facilitated the unprecedented growth in mobile computing applications such as smart city smart health, high quality streaming, augmented reality (AR) and virtual reality (VR). According to estimates presented in (Recommendation ITU-R M.2083-0 2015), it is expected that from 2020 to 2030, global IMT traffic will grow in the range of 10–100 times. With ever increasing number of devices it is expected to cross billions of wireless devices connected to the Internet and Cloud by 2020. Providing smooth network connectivity the required services, for such a large number is going to be a challenging task, in the years to come (Piran M. Jalil, *et al*. 2017).

With the fast growing number of smart mobile users and multimedia applications such as mobile gaming, AR, VR, video streaming etc. there will be requirements of large amount of bandwidth to offer these services with better quality. In wireless frequency bands are referred as the range of frequencies used in transmission. "If a frequency band has a broad range, it can transmit more data". A simple rule of thumb is "more the frequency, more the data rate". In mobile network radio bandwidth, normally means the "ability to pass, amplify, or somehow process a band of frequencies".

Further this paper is organized as follows; section 2, discuss about channel capacity and Popular Shannon–Hartley theorem, in section 3, a brief about 1G to 4G mobile communication is iven. Section 4, explains the IMT-2020 recommendations for upcoming 5G mobile networks, issues and challengers of 5G networks, and the probable technologies for 5G networks.Section 5 explains QoS and QoE aspects in wireless networks and communications. In section 6, some anticipated applications of 5G networks are given. Finally, in section 7, conclusions of the paper are drawn.

CHANNEL CAPACITY

The rate of transmission of information is represented using channel capacity. All wireless networks whether it is Wi-Fi, Bluetooth, WiMax or cellular communications such as 3G, LTE, or proposed 5G; operate using radio signals. Therefore all these communication methods have a maximum channel capacity, regardless of technology. The channel capacity is represented in bps/Hz. This representation is also known as spectral efficiency. Popular Shannon–Hartley theorem expresses channel capacity as (Sinha N. Bikas *et al*. 2010):

$$C=W \times log_2 2(1+\frac{S}{N})$$

Where,

C : channel capacity (in bits per second)

W : bandwidth of the channel (in Hertz)

S : average received signal power over the bandwidth (in watts)

N : average noise over the bandwidth (in watts)

If we observe the above equation, it is evident that maximum throughput of a system is increasing linearly with the bandwidth W and increasing logarithmically with the signal-to-noise ratio (SNR). Shannon's theorem shows that the channel capacity increase with increase in bandwidth. If a general look is given on signal travel, low-frequency signals can travel farther (a grater distance). On the other hand high-frequency signals do not travel as far but as they have higher bandwidth, hence can transfer more data at a time. The second important variable in Shannon's theorem is the SNR between the sender and receiver. When there is background noise of considerable amount, the signal needs to be stronger to carry useful information to the destination. In this case, to maximize channel capacity, we have to either increase the power of the signal or decrease the distance between sender and receiver (to minimize the effect of background noise) or both can be done to manage it. It is not possible to beat the Shannon Limit in transmission; but their has been an attempt to increase efficiency by using different available coding techniques such as CDMA, FDMA etc., as evident, in the case of higher data rate in 4G. Similarly in upcoming 5G networks also such breakthroughs are expected. As OFDMA work as multi-access technique and it is preferred technique compared to CDMA for operating in the high SNR regime. It has established as an efficient and effective network for 3G-4G cellular systems, and should continue with the proposed 5G networks also. It can be seen from the above equation that the higher frequency, the greater bandwidth and channel capacity. Therefore, considering the huge requirement of channel capacity for the upcoming 5G mobile systems, continuous high frequency bandwidth will be an obvious choice (Xu G. *et al*. 2017).

With the ever increasing numbers of bandwidth-hungry multimedia applications, many such applications having requirement of more bandwidth either for the uplink or for the downlink channel "Currently, Internet access is a bias towards downlink". Hence there is a need to take care, uplink and downlink bandwidth requirements as per service need. The OFDMA which uses Time Division Duplexing (TDD) techniques for allocating a varying number of channels/slots in uplink and downlink for services based on their requirement can be an option. The technology like OFDMA will continue to work at least for next 30-40 years. The multiple input multiple output (MIMO) system is one of the prominent technique which delivers exceptionally high spectral efficiency by signal management in the spatial domain with the help of provisioning equal correspondence channels. But MIMO also have channel capacity limitation which is dependent on the number of antennas and the antenna element spacing (Samimi M.K. *et al*. 2016).

1G TO 4G COMMUNICATION TECHNOLOGIES

Evolution in wireless communication has transformed working and lifestyle of the society. Similar to water and energy, now bandwidth has become essential part of human survival and growth. From the announcement of 1G in initial 1980's till now, in 2017, society has witnessed tremendous technological innovation and growth in the area of mobile communication. Initial 1G and 2G technologies used circuit switching. The 3G uses both circuit and packet switching. Currently in 4G packet switching is being used and the proposed 5G will be using packet switching technology.

The data rate in 1G was based on analog frequency modulation with FDMA with data rate up to 2.4kbps and in 2G has data rate up to 64kbps. In 2G systems, FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access) techniques were used. The 3G systems use CDDMA/CDMA 2000 with Long Term Evolution (LTE), and Worldwide Interoperability for Microwave Access (WiMAX). The 4G systems are based on OFDMA (Orthogonal FDMA). The 4G is generally a descendant of the 3G and 2G standards. 4G improves functioning of the prevailing communication networks by imparting a complete and IP centered reliable solution. In Orthogonal Frequency Division Multiplexing Access (OFDMA) networks the available frequency is divided into orthogonal subcarriers, and then grouped into subchannels. The subchannelization helps in addressing the requirement of different type of services while leveraging frequency diversity and flexibility in OFDMA. Due to its capability to work as multi-access technique, OFDMA networks have been preferred networks for 3G-4G cellular systems (Wang T. and Vandendorpe L. 2011; Al-Falahy N. and O.Y. Alani 2017; Gupta A. and Jha R.K.2015).

Practically, 4G is still being deployed, and as prevailing experience, the technological evolution and certain building blocks of 4G will certainly be used in upcoming 5G networks. Thus, coming 5G networks would be using a combination of existing access methods like LTE access, based on OFDMA with sufficient improvements or there may one or more new and improved multiple access methods like Beam Division Multiple Access (BDMA) come into existence (Gupta A. and Jha R.K. 2015; C.-X. Wang *et al*. 2017).

The ITU uses the term IMT-2000 for 3G systems and IMT-Advanced for 4G systems. For upcoming 5G systems ITU use the term IMT-2020. Collectively all these 3G, 4G and 5Gtechnologies are identified as IMT. For upcoming 5G wireless communications, desired ranges of frequency are from below 1 GHz up to approximately 100 GHz (Ancans Guntis *et al*. 2017). The emerging 5G technology is expected to be roll out in 2020 and should be completed by 2030. With emerging requirements of challenges in wireless communication services there is a shift towards 5G from 4G. As 4G is not able to effectively address the need of higher capacity, higher data rate, lower latency and reduced cost with consistent QoE provisioning, emergence of 5G is quite obvious (M. Fallgren *et al*. 2017; Jianping ZHAO *et al*. 2016).

Proposed 5G developments shall be adopting some 4G technologies such as multiple-input, multiple-output (MIMO), massive multiple-input, multiple-output (M-MIMO), beamforming, device-todevice (D2D) communications, and small cell deployment etc. Also, among one of the 5G new revolutions, the millimeter wave band will be a revolutionary technology. Reason for this anticipated development is that the overwhelming majority of existing 3G/4G systems is already operating in the microwave band (MW) below 3 GHz. This makes the MW band too scarce. Therefore upcoming 5G can address such bandwidth scarcity by using the millimeter-wave band and Artificial Intelligence (AI) techniques (Li R. *et al*. 2017; Jiang C. *et al*. 2017).

5G: IMT -2020 RECOMMENDATIONS

IMT-2020 recommendations that are the future 5G radio communication have identified some key goals including:

- Ultra-low latency of the range 1 millisecond or less
- 10-100 times faster data rates compared to 4G networks
- Massive device connectivity and highly dense network devices
- High network reliability
- High mobility management

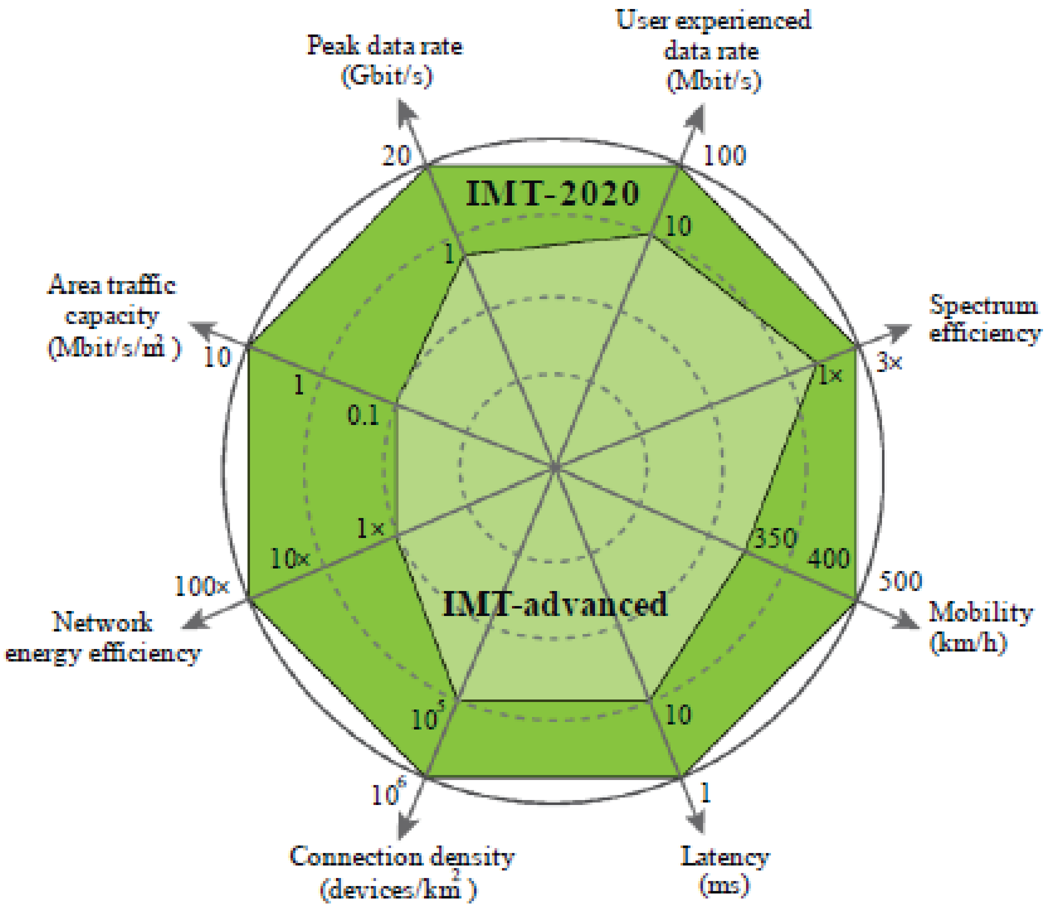

Fig. 1: IMT-Advanced to IMT-2020 ((Recommendation ITU-R M.2083-0, 2015)

So that it can meet the expectations of future communication requirements of very high data and ultra low latency. For this there will be requirements of some new multiplexing technologies new efficient spectrum allocation techniques with focus on energy saving mechanisms. Also, high speed mobility management will add more challenges for 5G development.

5G is expected to offer the high quality services. Also, it is expected that more and more Artificial Intelligent (AI) centrist applications will be surrounded by very large number of AI enabled devices connected on Cloud and will be communicating with mobile phones.

As shown in figure 1, following are the ITU established eight key performance indicators (KPI) used to specify, quantify and measure QoS and QoE characteristics of 5G systems:

- Peak data rate (Gbit/s);
- User experienced data rate (Mbit/s);

- Spectrum efficiency (bit/Hz);
- Device mobility (km/h);
- Latency (ms);
- Connection density (number of connected/accessible objects per km^2);
- Network's energy efficiency;
- Area traffic capacity ($Mbit/s/m^2$)

1. ISSUES AND CHALLENGES IN 5G COMMUNICATION:

(Source- Recommendation ITU-R M. 2083-0, 2015; Piran M. Jalil, et al. 2017; Gupta A. and Jha R.K. 2015; Hossain E. and Hasan M. 2015)

The evolving 5G cellular networks are envisioned cost effective, very high data rates, better quality-of-experience (QoE), and very low latency communication with lower energy consumption. With 5G, people's expectation is to experience instantaneous connectivity with "flash" behavior, on a click of a button, without waiting times. Very low latency and high-definition multimedia applications in areas entertainment health care, public safety, education and other sectors are anticipated. IMT-2020 will require more flexible network nodes with software defined networking (SDN) enabled configurable architecture and network function virtualization (NFV) for optimal processing of the node functionalities. There are several research challenges in rolling out the 5G networks, some of which include improvements in overall network performance with enhanced end-user QoE (Piran M. Jalil *et al*. 2017; Hossain E. and Hasan M. 2015). The 5G cellular networks would require to tailor the provisioning mechanisms for different QoS and QoE using capability of intelligent interaction including sense, mine, predict, and reason with the working conditions (Li R. *et al*. 2017; Hossain E. and Hasan M. 2015).

2. KEY ENABLING TECHNOLOGIES FOR 5G CELLULAR NETWORKS:

As 5G is expected to manage very-high-rate applications such as streaming high-definition video which may have freedom of relaxed latency and reliability requirements. On the other hand time critical applications like driverless cars or public safety applications, where lower data rate may be tolerated compare to latency and reliability. For 5G communications, technologies like- ultra-densification, mmWave, and Massive- MIMO are of importance. There are some exiting technologies as well as some new technological developments which qualify to meet the vision requirements of 5G wireless communication. Future technologies for 5G communication will be revolving around extension of some exiting technical developments and few innovative breakthroughs. Some potentially disruptive technologies for proposed 5G are listed below (Andrews J.G. *et al*. 2014; Boccardi F. *et al*. 2014; Marzetta T.L. 2010; Molisch A.F. *et al*.2017).

- Device-centric architectures
- Millimeter Wave (mmWave)
- Massive-Multiple Input Multiple Output (MIMO)
- Smarter devices
- Native support for Machine-to-Machine (M2M) communication
- NOMA (Non-Orthogonal Multiple Access)
- Network Slicing
- Beamforming
- Edge Computing
- Cognitive Radio Network
- AI and Machine Learning(ML)

MULTIPLE INPUT MULTIPLE OUTPUT (MIMO):

In MIMO technology multiple antennas are used at both the transmitter and receiver ends to improve communication performance which leverages the transmission of multiple data streams over the same frequency channel, resulting in significant increase in the data rate and improves spectral efficiency. Key features of MIMO include spatial diversity of the channel to transmission using spatial multiplexing through which multiple data streams are transmitted in parallel over the same frequency, which results in improving throughput.

MASSIVE MIMO:

Massive MIMO is an advanced antenna technology which uses a large number of antennas at both the base station (BS) as well as at end user (mobile devices) to increase the channel capacity and efficiency of wireless communication. It provides increased capacity, improved spectrum efficiency, and enhanced coverage and reliability.

NOMA (NON-ORTHOGONAL MULTIPLE ACCESSES):

NOMA is an advanced technique which permits multiple users to share the same frequency channel by distinguishing users based on power levels or other parameters. This increases capacity and improves spectrum efficiency.

SPATIAL DIVISION MULTIPLE ACCESSE (SDMA):

By leveraging massive MIMO and beamforming, SDMA allows the simultaneous use of the same frequency by different users in different spatial locations, increasing the network's capacity

NETWORK SLICING:

It allows operators to create multiple VNs within a single physical 5G system. Each network slice is customized as per specific use cases requirements (e.g., IoT, mobile broadband, emergency services) with tailored services and enhanced performance.

BEAMFORMING:

Beamforming is a technique that uses advanced antennas to direct radio waves toward specific devices rather than broadcasting them in all directions. This improves signal quality and reduces interference. This technique provided improved signal strength and reduced interference in communication. Also, this technique is energy efficient as it focusing signals where they are needed, result in reduced power consumption.

EDGE COMPUTING:

In Edge computing paradigm attempts are made to process the data closer to the user (at the network edge) instead of sending it to a centralized Cloud Server. This reduces latency and offloads traffic from the Central Network. It is suitable for IoT and Real-Time applications which needs the reduced latency.

COGNITIVE RADIO NETWORK (CRN):

CRN is a technology which enhances the spectrum utilization by opportunistically using the free spectrum of the licensed users by the unlicensed user. As upcoming 5G mobile systems will be having very large number of heterogeneous devices. Using intelligence these devices can use both the licensed frequency as well as unlicensed frequency using CR technology (Piran M. Jalil *et al*. 2017). The 5G devices would be enabled with cognitive capability using software-defined radio (SDR) (Piran M. Jalil *et al*. 2017).

AI AND MACHINE LEARNING:

5G networks optimizations leverage AI/ML for intelligent resource management, dynamic spectrum allocation and interference mitigation, optimizing network performance and user experience.

QoS AND QoE IN 5G COMMUNICATION

In wireless communication services, fair management of bandwidth and fair energy consumption are related to better QoS and QoE. There are many aspects of fairness in services relating to low latency, mobility management, cost of services etc. comes under QoS and QoE requirements (SHI H. *et al*. 2014). Quality of Service (QoS) is a core issue of consideration in any field of application. In networking and communication it refers to network performance metrics such as throughput, latency, and packet loss etc. This has direct impact on the quality of communication at a technical level. To offer better QoS is not only the responsibility of service providers but also essential for being remain in the service field with the competitors. On the other hand another very important quality measuring tool known as QoE represents the overall user satisfaction and experience, which is influenced by not only network performance and QoS but also by user expectations of service quality. It is not guaranteed that better QoS may result into better QoE. As the emerging 5G networks will be nested on heterogeneous network architecture and loaded with requirements of multimedia-rich applications and services including, internet protocol television (IPTV), virtual reality (VR), augmented reality (AR) and video conferencing. Different service may have QoS and QoE requirements. The 5G cellular systems are expected to deliver very high data rate with reliability, low latency, minimized cost to better address the QoS and QoE requirements (Piran M. Jalil *et al*. 2017; Agiwal M. *et al*. 2016).

1 QUALITY OF SERVICE (QoS):

Many researchers have considered different QoS parameters including quality of transmission, performance, flexibility, latency, fairness**,** spectrum utilization and communication complexity in their study (Piran M. Jalil *et al*. 2017; Malla A. *et al*. 2003). Objective of better QoS is keep network performance better and satisfy the user. QoS parameters are considered by service provider to for smooth transaction of services. In wireless communication QoS established measurement parameters includes response time, throughput, rate of data transfer, blocking and dropping calls, delay in access, delay in transmission, jitters and rate of packet loss etc (Huang Lei *et al*. 2004). Also, QoS requirements depend on the type of services. For example multimedia services with varying bandwidth requirement and its less time-critical nature may be having different QoS requirement compare to simple voice applications which are time-critical and less tolerant to delay.

2. QUALITY OF EXPERIENCE (QoE):

QoE is rated to the subjective observation of the user about the availing services. User experience relating to application performance relate to QoE. For example, user's experience with the quality of delivered video transmission, low latency in online gaming applications represent QoE. In upcoming 5G cellular network, stringent QoE requirements are anticipate due to ultra low latency, high mobility management and high reliability requirements in communication. Therefore, it is going to be very challenging to meet the desired level of QoE (Piran M. Jalil *et al*. 2017; Menkovski V. *et al*. 2010; Huang Lei *et al*. 2004). There is always a trade-off between user excrescence and service provider's objective to utilize the resources effectively. As users of wireless communication are more interested in getting higher bandwidth, reliability in services, security and low cost of spectrum uses. Simultaneously, the service providers interestes lies in a less complex system, low infrastructure and management cost, scalability, security, fault tolerance etc. (Piran M. Jalil *et al*. 2017; Menkovski V. *et al*. 2010). Table 1 present different aspect of QoS and QoE in 5G systems.

Table 1: QoS vs. QoE in 5G Wireless Systems

Key Feature	QoS	QoE
Focus Area	Network performance	User satisfaction
Service Metrics	Bandwidth, latency, packet loss, jitter, error rates	User feedback, video/audio quality, application performance
Network & User Perspective	Network-centric, focused on traffic management	User-centric, focused on service delivery experience
Basic Service Concerns	Ensuring network reliability and performance	Ensuring user satisfaction and perception of quality
Channel Allocation	Allocating spectrum to meet specific network demands (e.g., bandwidth, latency)	Allocating spectrum fairly to maximize user satisfaction

SOME 5G SERVICES

5G Technology stands proposes high data rate, low latency and mobility management. The users with their 5G technology enabled phone may get broadband internet access on their Laptop. Expectation from IMT-2020 indicates that expected user experience from 5G shall be matching, as far as possible to the fixed networks services (Menkovski V. *et al*. 2010; Yu Heejung *et al*. 2017). This expected QoS and QoE in 5G services opens door for many future 5G mobile services. Some of these services are-

Use of immersive 5G Services such as Virtual Reality (AR) and Augmented Reality (VR) which are future real-time services of transmission with low-cost head-mounted display (HMD). Another service category is massive contents streaming where continuous transmission of multimedia content takes place in video broadcasting, movies, and personal media. The 5G technologies are expected to be able to stream 4-K and 8-K ultra-high-definition (UHD) contents. Future intelligent services such as user-centric computing and IoT devices communication would form heterogeneous and complex network communication. In future, large number of wearable devices would be connected to Cloud, and smart home devices connected to 5G networks would often communicate with each other as well as with smart city services and exchange large volume of information.

In the area of robotics very high-growth of information exchange is expected in both the industrial and the consumer sectors. 5G will provide networking communication functions for these industries to move into the next phase of evolution in this Industry. There are many more services including unmanned vehicles (UAVs) communication, smart disaster monitoring with the help of real-time data inputs and information sharing. In the area of military services and public safety applications, 5G communication technologies will be very helpful with its high data rate, reliable and very low latency communications. With 5G role out, 3D holograms with high quality are also expected to be delivered.

CONCLUSION

Development in ICT enabled services sector has been unprecedented due to massive innovation and development in communication technologies. In mobile wireless communications transition from one generation to the next has come up with the new technological breakthrough with better QoS and QoE. Recent advancement in the cellular communication technology and in IoT devices opening door for many mobile computing applications such as smart city, smart health, high quality streaming, AR and VR. The upcoming 5G mobile network would be capable of ultra-low latency, faster data rates compared to 4G networks. Also, it is expected that 5G will have massive device connectivity, high network reliability and equipped with high mobility management. There are several potential technologies like- mmWave, Massive-MIMO and CRN suitable to meet 5G recommendations. As future direction in 5G research and development, leverage of AI/ML techniques will be helpful in intelligent resource management, dynamic spectrum allocation, and network optimization.

REFERENCES

1. (Recommendation ITU-R M. 2083-0, 2015): IMT Vision– Framework and overall objectives of the future development of IMT for 2020 and beyond.

2. Agiwal M. *et al*. (2016): Next Generation 5G Wireless Networks: A Comprehensive Survey. *IEEE Communications Surveys & Tutorials*, 18(3): 1617-1655.

3. Al-Falahy N. and O.Y. Alani (2017): Technologies for 5G Networks: Challenges and Opportunities. IT Professional, 19(1): 12-20.

4. Ancans Guntis *et al*. (2017): Spectrum Considerations for 5G Mobile Communication Systems. Procedia Computer Science, 104: 509-516.

5. Andrews J. G. *et al*. (2014): What Will 5G Be? *IEEE Journal on Selected Areas in Communications*, 32(6): 1065-1082.

6. Boccardi F. *et al*. (2014): Five disruptive technology directions for 5G. *IEEE Communications Magazine*, 52(2): 74-80.

7. Fallgren M. *et al*. (2017): Scenarios, Requirements and KPIs for 5G Mobile and Wireless System. document ICT-317669-METIS/D1.1

8. Gupta A. and Jha R.K. (2015): A Survey of 5G Network: Architecture and Emerging Technologies. *IEEE Access*, 3:1206-1232.

9. Hossain E. and Hasan M. (2015): 5G cellular: key enabling technologies and research challenges. *IEEE Instrumentation & Measurement Magazine*, 18(3): 11-21.

10. Huang Lei *et al*. (2004): Adaptive resource allocation for multimedia QoS management in wireless networks. *IEEE Tran. on Vehicular Technology*,53(2): 547-558.

11. Jiang C. *et al*. (2017): Machine Learning Paradigms for Next-Generation Wireless Networks. IEEE Wireless Communications, 24(2): 98-105.

12. Jianping ZHAO *et al*. (2016): Technical challenges for high-frequency wireless communication. Information Networks, 1(2).

13. Li R. *et al*. (2017): Intelligent 5G: When Cellular Networks Meet Artificial Intelligence. IEEE Wireless ommunications 24(5): 175–183.

14. Malla A. *et al*. (2003): A fair resource allocation protocol for multimedia wireless networks. *IEEE Tran. on Parallel and Distributed Systems*, 14(1): 63-71.

15. Marzetta T.L. (2010): Noncooperative cellular wireless with unlimited numbers of base station antennas. IEEE Trans. on Wireless Communications, 9(1): 3590-3600.

16. Menkovski V. *et al*. (2010): Quality of experience models for multimedia streaming. International Journal of Mobile Computing and Multimedia Communications (IJMCMC), 2(4): 1-20.

17. Molisch A.F. *et al*. (2017): Hybrid Beamforming for Massive MIMO: A Survey. *IEEE Communications Magazine*, 55(9): 134-141.

18. Piran M. Jalil *et al*. (2017): QoE-Driven Channel Allocation and Handoff Management for Seamless Multimedia in Cognitive 5G Cellular Networks. *IEEE Transactions on Vehicular Technology*, 66(7): 6569-6585.

19. Samimi M.K. *et al*. (2016): MIMO channel modeling and capacity analysis for 5G millimeter-wave wireless systems. *10th European Conference on Antennas and Propagation (EuCAP):* 1-5.

20. SHI H. *et al*. (2014): Fairness in Wireless Networks: Issues, Measures and Challenges. *IEEE Communications Surveys & Tutorials*, 16(1): 5-24.

21. Sinha N. Bikas *et al*. (2010): Performance Enhancement of MIMO-OFDMTechnology for High Data Rate. Wireless Networks International Journal of Computer Science and Application.

22. Wang C.X. *et al*. (2017): Cellular architecture and key technologies for 5G wireless communication networks. IEEE Communication Magazine, 52(2): 122–130.

23. Wang T. and Vandendorpe L. (2011): terative Resource Allocation for Maximizing Weighted Sum Min-Rate in Downlink Cellular OFDMA Systems. *I*EEE Transactions on Signal Processing, 59(1): 223-234.

24. Xu G. *et al*. (2017): Full Dimension MIMO (FD-MIMO): Demonstrating Commercial Feasibility. IEEE Journal on Selected Areas in Communications, 35(8): 1876-1886.

25. Yu Heejung *et al*. (2017): What is 5G? Emerging 5G Mobile Services and Network Requirements. Sustanability, MDPI, 9: 1848.