Potential technologies to 5G network : challenges and opportunities

Al-Falahy, NFA and Alani, OYK

http://dx.doi.org/10.1109/MITP.2017.9

Potential Technologies to 5G Network: Challenges and Opportunities

Naser Al-Falahy and Omar Y. Alani
School of Computing, Science & Engineering,
University of Salford, Manchester, United Kingdom
N.F.A.AL-Falahy@edu.salford.ac.uk , O.Y.K.Alani@salford.ac.uk

Abstract— **Recently, there has been a substantial growth in mobile data traffic due to the widespread of data hungry devices such as smart handsets and laptops. This has encouraged researchers and system designers to develop a further efficient network design. The objective of this paper is to overview the technologies that can support multi Gbps for future Fifth Generation (5G) network. This paper presents many challenges, problems and questions that arise in research and design stage. It concluded that the anticipated high traffic demands and low latency requirements stemmed from the Internet of Things (IoT) and Machine to Machine Communications (M2M) can only be met with radical changes to the network paradigm such as harnessing millimetre-wave band in dense deployment of smallcells. Future wireless system will include all types of smart features and applications that make 5G the most intelligent and dominant wireless technology.**

I. Introduction

Wireless broadband traffic growth has introduced major impact on future mobile network architectures, and hence, it requires more demands. These demands include: (i) High traffic volume (massive capacity): increases on the order of several magnitudes. The future requirement is a 1000x increase in data traffic for 2020 and beyond. (ii) Increased indoor and smallcells/hotspot traffic: will be the majority of mobile traffic volume. Today, about 70 per cent of mobile traffic happens indoors; in the future, indoor data traffic as well as hotspot area may exceed this figure. (iii) Higher numbers of connected devices (massive connectivity): stemmed from Internet of Things (IoT) due to massive machine-to-machine (M2M) communications and applications, as all devices that benefit from internet connectivity will become connected. (iv) Energy consumption: 5G need to be a green network to reduce carbon footprint [1].

Mobile communication has transformed from only voice service into a complex inter-connected environment with multi services, built on a system that support multitude of applications and provide high speed access to massive number of subscribers and machines [2].

In this paper, we have overviewed the potential technologies that could define 5G standard in the few upcoming years. We have present many challenges and made some comments on important questions that are a point of interest to researchers in this field.

II. What will 5G be? Evolution or Revolution?

As per the future emerging technologies and the change that will shape the network, 5G will be determined whether it is mere evolution to the existent network or revolutionary network. Here, massive Multi input Multi Output (m-MIMO), beamforming, Device-to-Device (D2D) communication, smallcells deployment and other technologies are already been adopted in 4G in recent releases and it need for improvement only to be adopted by 5G. In such case, network is evolved from 4G and all current mobile devices will be supported. However, using the millimetre wave band (mm-wave) will impose many revolutionary technologies due to its different propagation characteristics and hardware constraint. Therefore, there will be a significant change on network node and architecture level, and this change will be extended to mobile devices; current devices will need to be changed or upgraded to support 5G revolution as the mm-wave signal is incompatible with the frequency of these devices [3]. However, this change will come on the account of higher data speed, more reliable network, and more application.

Therefore, the answer will highly depends on the change that will shape 5G [4], this change could be:

- Minor change at the base station or network architecture levels (Network Evolutions).
- Major change at base station level (Component Changes), e.g. new transmission waveform.
- Major change at the network level (Architectural Changes) e.g. introducing new type of base stations, applications, and functions.
- Major change in base station and network levels (Radical Changes) e.g. adopting mm-wave.

III. POTENTIAL TECHNOLOGY AS PART OF 5G

Wireless research activity has already begun to study many technologies for consideration as part of future wireless system. High speed data and low latency demand will be the theme of future 5G environment. Five key research areas will have the largest impact on progressing 5G: dense smallcells deployment, massive-MIMO, D2D, M2M, and mm-wave communications, as shown in fig.1. In addition to that, new waveform, advance Coordinated Multi Point (CoMP), carrier aggregation, multiple radio access technology m-RAT, efficient coding techniques, network virtualisation and the emergence of cloud radio access network c-RAN [4][5]. In this paper, the aforementioned technologies has been classified into four categories according to their impact on 5G network performance, these are: capacity and speed, latency, spectral efficiency, and massive connectivity and IoT.

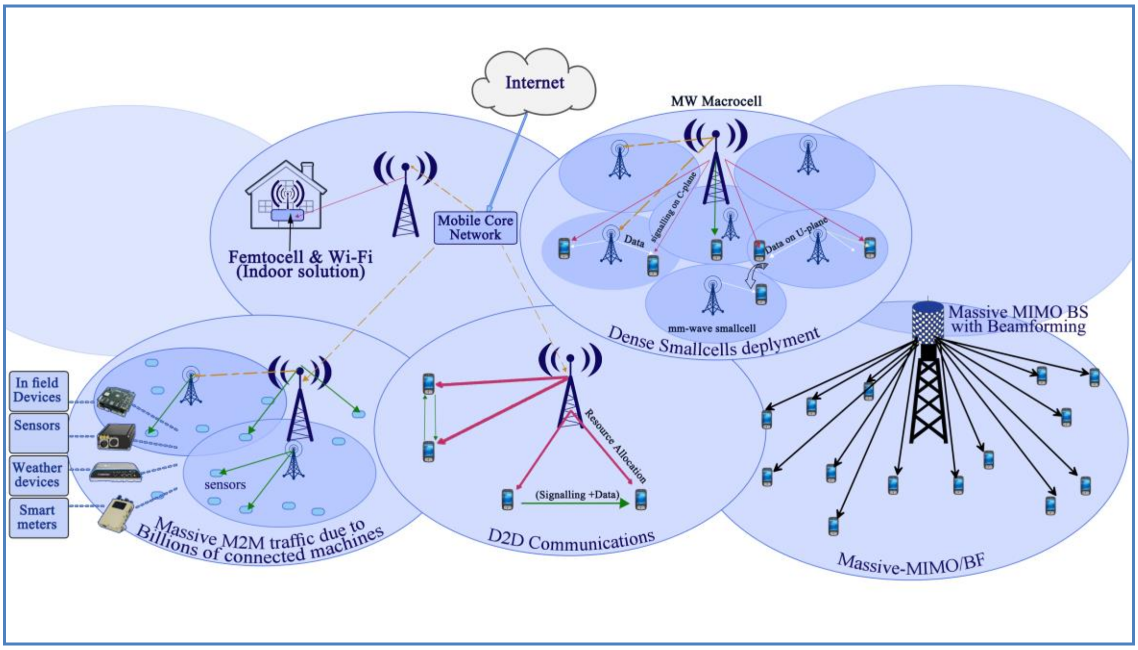

Fig.1 5G multi-tier network Architecture, composed of macrocells (<3GHz band), smallcells (mm-wave), femtocells and Wi-Fi (mm-wave), massive MIMO with beamforming, D2D, and M2M. Solid arrows indicate wireless (fronthaul) links, whereas the dashed arrows indicate backhaul links.

A. NETWORK CAPACITY & DATA SPEED IMPROVEMENT

1. DENSE DEPLOYMENT OF SMALLCELLS

Dense deployment of smallcells is necessary to off-load macro cells and to improve the signal power. It can be employed indoor or outdoor and offer a simple cost effective solution to network capacity to tackle the massive growth in mobile traffic. Smallcells need to be deployed with limited cell radius to help reuse the spectrum (increase spectral efficiency) as well as increase network capacity (as network resources will increase). One of the problems here is the significant increase in the handoff rate as the mobile station need to move from/to many hotspots, which can lead to increase in handover failure and call drops.

i. POSSIBLE CHALLENGES

a. Inter-cell-Interference:

Dense deployment of smallcells will increase interference from nearby cells. In addition to that, the uncontrolled deployment of smallcells could lead to uncontrolled cell shape; where the network operators have little control on the location of the smallcell.

b. Handoff rate:

As user moves from one smallcell coverage area into another coverage area continuously, this will create too much and unnecessary handovers. This problem is a point of concern as the deployment of smallcells become denser.

ii. HOW WILL 5G ADDRESS THE HIGH HANDOFF RATE?

To minimise the handoff rate in future 5G HetNet, control/user plane (C/U plane) splitting may be used in this regard. The basic idea of C/U plane splitting is to enable mobile terminals to receive system information, issue access requests to a base station and getting assigned radio resources for high-rate data transmission at a different base station. Signalling and data services can be provided by specialized base stations or implemented as separated and independent services into the same physical equipment. In the case of HetNets a possible approach is to have the macro basestation providing the signalling service for the whole area in licenced low frequency band (legacy <3GHz), and the mm-wave small cells (Phantom cells) specialized in data resources for high-rate transmission with a light control overhead and appropriate air interface. Therefore, the control signalling due to high handovers between smallcells and macrocells, or among small cells, can further be reduced [6].

2. MILLIMETRE-WAVE FREQUENCY BAND

Since the overwhelming majority of communication systems are already operating in the microwave band (MW) below 3GHz, due to its favourable propagation characteristics. This makes MW band too scarce. Therefore, 5G system is anticipated to use mm-wave bands, particularly (20-90) GHz, due to the availability of wide chunk of unused bandwidth. This step is revolutionary because mm-wave has very different propagation condition, atmospheric absorption and hardware constraint. Such challenges, however, could be compensated using beamforming and larger antenna array. It is widely accepted that mm-wave need to be used with very limited cell radius <100 m, to minimize high pathloss at this band. Fortunately, this action fit well with the trend of dense deployment of smallcells [7][8].

i. POSSIBLE CHALLENGES

a. HIGH PATH LOSS:

One of the challenges in mm-wave band 5G system is the high pathloss compared to microwave bands below 3 GHz. Generally, the pathloss is given by [9]:

$$L_{FS} = 32.4 + 20 \log_{10} f + 20 \log_{10} R \tag{1}$$

where L_{FS} is the free space pathloss in dB, f is the carrier frequency in GHz, and is R the distance between the transmitter and receiver in metre.

Therefore, there will be around 23 and 31 dB of extra path losses when moving the operating frequency from 2 GHz to 28 GHz and 70 GHz respectively. Therefore, mm-wave is used with highly directional antennas in Line-of-Site (LOS) transmission, as its non LOS (reflected) signal is very weak. Furthermore, shrinking the cell coverage area will further reduce the pathloss by reducing the required signal path. Therefore, the losses (see table 1) for 28 GHz and 73 GHz are minimised by 10dB compared to the 2GHz for distances up to 100m.

Table.1. *Relative pathloss for specific frequencies and distances, according to equation (1)*

f(GHz)	1km PL(dB)	100m PL(dB)
2.0	98.46237	78.46237
28.0	121.3849	101.3849
73.0	129.7082	109.7082

b. HIGH ATMOSPHERIC ATTENUATION:

Signal attenuation at high frequency band is a serious issue as it limits signal propagation. Millimetre wave energy is absorbed by oxygen and water vapour. The oxygen molecule absorbs electromagnetic energy at around 60 GHz; therefore, the free-licensed band 57–64 GHz has high oxygen absorption with attenuation about 15dB/km. Furthermore, water vapour (H2O) absorbs electromagnetic energy at 164–200 GHz with even higher attenuation [4][8].

c. HIGH PENETRATION LOSS

Millimetre-wave signals penetrate solid materials with very high losses (if penetrate), which make it too sensitive to blockage such as buildings [10]. High levels of attenuation could limit the use of mm-wave communication from outdoor cells to only outdoor receivers. Therefore, the indoor coverage can be provided by indoor mm-wave smallcells or Wi-Fi solutions.

ii. HOW WILL 5G ADDRESS THE BANDWIDTH SCARCITY?

When higher network capacity and connectivity is required, additional spectrum is required as a result. Moreover, mobile network has improved Quality of Service (QoS) by utilizing additional spectrum (higher frequency and wider bandwidth). Therefore, it is expected that 5G will also utilize higher spectrum, such as utilizing mm-wave band due to the very wide available bandwidth [2].

Additional spectrum for 5G network is vital to satisfy 5G demands. Extra spectrum above 6 GHz will become available in next WRC’15 [11]; however, this addition will fulfil only part of 5G need. And substantial amount of spectrum can be made available if mm-wave band is utilised to fulfil all the requirements of 5G.

As per the Federal Communications Commission (FCC), many bands within mm-wave band seem promising and can be a candidate for future 5G mobile system, including, local multipoint distribution service (LMDS) band from 28 to 30 GHz, the license-free band at 60 GHz, as well as 12.9 GHz located at 71–76 GHz, 81–86 GHz, and 92–95 GHz from the E-band (see fig.2) [4][8].

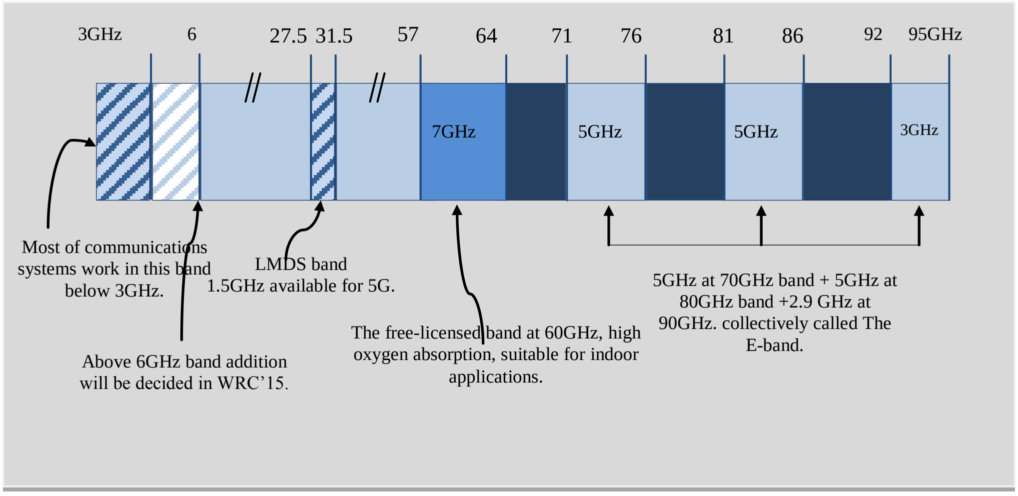

Fig.2 Millimetre-wave band as a candidate spectrum to 5G

3. Massive MIMO/ Beamforming

The idea of massive MIMO is the principle when a network is equipped with a very large number of antennas at the base stations, which can accommodate many co-channel users at a time. Beamforming (BF) is the concentration of power in certain direction with very limited beam width but with very large gain.

Beamforming and m-MIMO are key enabling technologies of 5G system. Massive MIMO can significantly improve signal strength, which could result in much higher cell throughput and better cell-edge performance than traditional 4G systems [12].

i. Possible Challenges

a. Pilot Contamination:

Massive MIMO suffers from pilot contamination [4] from other nearby cells as the number of antennas increase. Researcher's activities are required to optimise pilot orthogonality without consuming network resources.

b. Channel Estimation:

Due to the "massive" number of antennas used, accurate channel estimation is challenging issue even with Time Division Duplexing (TDD) due to huge cost and complexity. A more sophisticated algorithm is necessary to enable accurate channel estimating in Frequency Division Duplexing (FDD) and reduce signalling overhead.

c. Very Large Physical Architecture:

The physical size [13] of m-MIMO is a point of concern, as it require very large scale architecture. Therefore, it will face a conflict from public and property owners regarding a potential health issues. And the larger size of towers will create extra technical challenges which will cause a further confrontation.

However, a successful marriage that could address the physical size issue is by pairing the massive-MIMO with the millimetre-wave band [14]. Therefore, a realistic array size will become possible that facilitate m-MIMO installation.

B. Latency Reduction

D2D Communication

If two devices are in a close proximity, their communications can be handled by D2D without consuming network resources. D2D has the ability to handle local traffic efficiently. It is very important option for applications that require low latency. D2D is already studied as a 4G technology (release 12) in the Third Generation Partnership Project (3GPP), and their adoption is driven by its importance in safety and disaster applications and low latency applications [4].

i. Possible Challenges

In this area, the challenges are efficient proximity detection, network integration, and native support in future 5G networks.

ii. How Latency is foreseen by 5G?

Latency is the time that the signal undertakes to complete a full single transaction. Besides the achievement of high data rates, latency reductions become vital to enable energy savings and long battery life time. Current 4G latency is about 15 ms based on the 1ms sub-frame. This latency is considered perfect as it fulfils the current applications; however, 5G will introduce technologies such as tactile internet, two-way real time gaming, cloud-based applications, and augmented reality. These applications, however, cannot fulfilled by the current latency, see fig.3. Therefore, 5G should support lower latency of 1ms, which will have major impact on design choices at all layers [5].

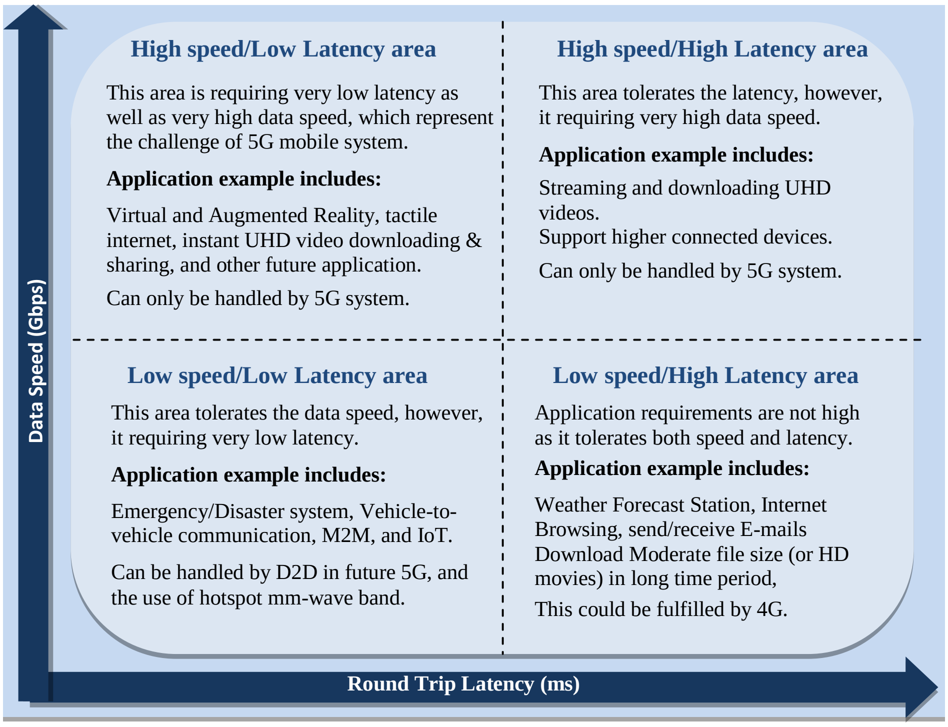

Fig.3 Data speed vs. Latency

C. SPECTRAL EFFICIENCY IMPROVEMENT

NEW TRANSMISSION TECHNIQUE

OFDM is a powerful and inherent way to address the problem of Inter-symbol-Interference (ISI). Instead of sending the information on a single carrier, OFDM use multi carrier to transmit simultaneous sub-frame after dividing the main stream, and modulating each sub-frame on a different sub-carrier frequency, which help combat multipath and ISI.

i. POSSIBLE CHALLENGES

5G waveforms should cope with a set of requirements, such as high spectral efficiency, low latency and limited cost and complexity. 5G system will have several strategies, such as, dense smallcells deployment and mm-wave band, which directly influenced by the modulation format used at the physical layer [15].

ii. DOES OFDM BE THE DOMINANT THEME IN 5G?

OFDM is not exempt of drawbacks, and its adoption in 5G is not taken for granted. The main disadvantage in OFDM is its high peak-to-average-power ratio (PAPR), which decrease power amplifier efficiency. Also, cyclic-prefix (CP) insertion decreases the spectral efficiency.

New schemes such as non-orthogonal multiple access (NOMA), filter bank multicarrier (FBMC) where signal on each subcarrier is shaped by a well-designed filter to suppress signal sidelobes and limit its band, and sparse coded multiple access (SCMA) can further be utilized to improve spectral efficiency. NOMA with successive interference cancelling (SIC) receivers has improved throughput in macrocells compared to orthogonal multiple access schemes by up to 30% [6].

D. MASSIVE CONNECTIVITY & IOT

MACHINE-TO-MACHINE COMMUNICATIONS

In the long term, it is expected that [12] all devices that benefit from network connectivity eventually will become connected, and the number of connected devices will exceed the number of human devices. With the increased availability of mobile broadband, connectivity has become a realistic issue for M2M.

i. POSSIBLE CHALLENGES

Due to the massive traffic growth expected from machine-type-communication as a result of billions of connected devices in future, this will cause the network to be congested. Therefore, a several order of magnitude increase in network connectivity and capacity is required, which can be met with network densification, dense smallcells deployment and massive MIMO.

Moving data access to the cloud will also have the chance to appear in 5G, so that the network can be accessed from anywhere. Network Function Virtualization (NFV) can make functions with hardware compatibility issues to run on cloud computing infrastructure. Therefore, there will be a higher reuse of network infrastructure than the current network. In addition, coordinated multi-point (CoMP) can turn interference into useful signals [5][12]. Table 2 illustrates some challenges that can be tackled with specific technologies in 5G system.

Table 2, *How 5G will tackle network challenges*

Feature	Descriptions	Technology
Extreme Data rate (Gb/s)	The peak data rate will be (10 to 20) times 4G speed.	• Millimetre wave band • Massive MIMO
no. of connected devices (# device/m^2)	All devices that benefit from wireless connectivity should become connected in 5G e.g. (sensors, machines, weather & medical sensors).	• IoT stemmed from Massive M2M Communication • D2D Communication • Wider bandwidth (mm-wave) • Dense smallcells
Spectral Efficiency (b/s/Hz)	5G will further improve spectral efficiency.	• New waveform (FBMC, NOMA) • Massive MIMO • Coordinated Multi Points
End-to-End Latency (milliseconds)	5G will support much lower latency than 4G.	• D2D Communication • Dense smallcell deployment • Smart data caching
Data processing Speed (Mb/s/m^2)	5G will be able to process data 100 times faster than 4G in an area.	• mm-wave band • Dense smallcell • NFV • D2D Communication
Energy Efficiency (millijoule/bit)	5G will be able to transfer data with much less power, to reduce carbon footprint.	• Massive MIMO in conjunction with mm-wave band. • mm-wave multi-hop relay station
Mobility (m/s)	Faster user speed will be supported by 5G.	• Advanced HetNets

IV. WHAT TECHNOLOGIES WILL BE MIGRATED TO 5G

In 5G, coverage holes are expected as a result of the high path loss at millimetre wave band. Therefore, 4G system is required to cover the overall area at the early stage of 5G deployment. 5G is required to use the primary microwave band in addition to the complementary mm-wave band. This spectrum must be migrated to 5G otherwise poor coverage will be expected. In addition, among the new features foreseen by 5G, D2D transfers may have a prominent role. The adoption of D2D transfers is driven by: safety and disaster system, application requiring low latency, and network traffic offloading. M2M is the engine for future IoT, CoMP technology and carrier aggregation will also be transferred for better spectral efficiency and QoS. Beamforming and m-MIMO is key enabling technologies to mm-wave band, therefore, their transfer will be taken for granted.

V. ON THE WAY TOWARD 5G

The trend in future mobile networks (5G) has shown a different pattern, as the main objective has changed from enabling users to connect wirelessly to the internet into enabling massive number of users and devices to be seamlessly connected in a smart cities (internet of things) in the 2020 and beyond [11].

In 2015 World Radiocommunication Conference (WRC'15), the main objective will be focused on adding extra spectrum for mobile communication above 6 GHz. However, the massive growth in global mobile traffic cannot be fulfilled by this addition. 5G will need access and extend its operation to mm-wave band to enable multi Gbps data rates.

The ITU-R Working Party (WP) 5D [11] will define the technical performance requirements for next generation system and develop an evaluation process between 2016 and 2017. According to ITU timeframe, the standardization and proposals will be studied in 2018. From 2018 till 2020, an evaluation will be held by external groups, and the definition of new radio interfaces will be included in IMT-2020, similar to what happened for IMT-2000 and IMT-Advanced. Table 3 show the difference between 5G and old mobile network generations.

Table 3, *Basic comparison among mobile system generations.*

Feature \ Generation	1G	2G	3G	4G	5G
Deployment	1980	1990	2001	2010	2020 or beyond [11]
Frequency Band	800 MHz	900 MHz	2100 MHz	2600 MHz	3-90 GHz [16]
speed	2 kbps	64 kbps	2 Mbps	1 Gbps	Higher than 1 Gbps
Technology	Analogue Cellular	Digital Cellular	CDMA, UMTS	LTE-A, Wi-Fi	Multi RAT, Wi-Fi, Wi-Gig [17]
Services	Voice	Digital Voice, SMS, packet (GPRS), low rate data	Higher quality audio & video calls, mobile broadband	High data rate, wearable devices	Very high data rate [14] to fulfil extreme user demands, D2D, M2M, IoT
Multiplexing	FDMA	TDMA	CDMA	OFDMA	OFDM, FBMC, NOMA [15]
Handover	No	Horizontal	Horizontal	Horizontal/Vertical	Horizontal/Vertical
Switching	Circuit	Circuit / Packet	Packet	All packet	All packet [18]
Core Network	PSTN	PSTN	Packet Network	Internet	Internet

VI. Current Development to 5G Realisation

Since current mobile phones operate in frequency between 0.8 to 2.5-GHz, they are capable of download speeds of only 230 Mbps. Therefore, a new mobile device operating in the millimetre wave band is essential to cope with higher speed data transmission required from 5G. Fujitsu has developed mm-wave prototype receiver small enough to be incorporated into a mobile phone [3]. This receiver has achieved 20 Gbps download speeds. Fujitsu will begin field-testing in 2016, and will launch it in 2020. Furthermore, IEEE has developed IEEE802.11ad standard [19], which operate at the 60 GHz and support a speed of 7 Gbps within short distance.

Samsung has announced that the company achieved 7.5 Gbps, the fastest ever 5G data transmission rate in a stationary environment [20]. They have achieved a stable connection at 1.2 Gbps in a mobile environment from a vehicle at speed of 100 km/h at 28GHz. In addition, Nokia has used the 73 GHz carrier with 2 GHz bandwidth to achieve a speed of 10 Gbps with latency around 1 ms [21]. The ITU set a timeframe for 5G system and their (IMT-2020) Group reviewed many research proposals and will soon set the first 5G network design [14].

VII. Conclusion

As the demand on high speed and low latency applications is increasing dramatically, the 5G system should have the technology and flexibility to meet these requirements and support multi fold increase in network capacity and connectivity.

The extremely high data throughput and very low latency required from 5G cannot be satisfied by only evolution or modification to the existing 4G network. Therefore, researchers have to focus on technologies that would have major impact on system performance. This would come through introducing radical changes in base stations (component) level and network (core, backhaul) level. The most prominent technologies and aspects that currently have this ability are: millimetre-wave band, dense deployment of smallcells, D2D, M2M, and massive-MIMO with beamforming.

REFERENCES

[1] S. Chen and J. Zhao, "The requirements, challenges, and technologies for 5G of terrestrial mobile telecommunication," *IEEE Commun. Mag.*, vol. 52, no. 5, pp. 36–43, May 2014.
[2] Ericsson, "5G : what is it ?," *White Pap.*, pp. 1–10, 2014.
[3] J. Boyd, "Fujitsu Makes a Terahertz Receiver Small Enough for a Smartphone," *IEEE Spectrum*, 2015. [Online]. Available: www.spectrum.ieee.org/tech-talk/telecom/wireless. [Accessed: 05-Nov-2015].
[4] F. Boccardi and P. P. Robert W. Heath Jr., Angel Lozano, Thomas L. Marzetta, "Five Disruptive Technology Directions for 5G," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 74–80, 2014.
[5] J. G. Andrews, S. Buzzi, W. Choi, S. V Hanly, A. Lozano, A. C. K. Soong, and J. C. Zhang, "What Will 5G Be ?," *IEEE J. Sel. AREAS Commun.*, vol. 32, no. 6, pp. 1065–1082, 2014.
[6] P. K. Agyapong, M. Iwamura, D. Staehle, W. Kiess, and A. Benjebbour, "Design Considerations for a 5G Network Architecture," *IEEE Commun. Mag.*, vol. 52, no. 11, pp. 65–75, 2014.
[7] S. G. Larew, T. A. Thomas, M. Cudak, and A. Ghosh, "Air Interface Design and Ray Tracing Study for 5G Millimeter Wave Communications," in *IEEE Globecom Workshops*, 2013, pp. 117–122.
[8] F. Khan and Z. Pi, "An Introduction to Millimeter-Wave Mobile Broadband Systems," *IEEE Commun. Mag.*, vol. 59, no. 6, pp. 101–107, 2011.
[9] F. Khan, Z. Pi, and S. Rajagopal, "Millimeter-wave mobile broadband with large scale spatial processing for 5G mobile communication," in *50th Annual Allerton Conference on Communication, Control, and Computing (Allerton)*, 2012, pp. 1517–1523.
[10] T. Bai and R. W. Heath, "Coverage analysis for millimeter wave cellular networks with blockage effects," in *IEEE Global Conference on Signal and Information Processing, Global SIP Proceedings*, 2013, pp. 727–730.
[11] "ITU towards IMT for 2020 and beyond." [Online]. Available: www.itu.int/en. [Accessed: 08-May-2015].
[12] International Telecommunications Union, "Future technology trends of terrestrial IMT systems," *Rep. ITU-R M.2320-0*, 2014.
[13] C. Lin, C. Rowell, S. Han, Z. Xu, G. Li, and Z. Pan, "Toward Green and Soft : A 5G Perspective," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 66–73, 2014.
[14] L. J. Young, "Telecom Experts Plot a Path to 5G," *IEEE Spectrum*, 2015. [Online]. Available: www.spectrum.ieee.org/telecom/wireless. [Accessed: 05-Nov-2015].
[15] P. Banelli, S. Buzzi, G. Colavolpe, A. Modenini, F. Rusek, and A. Ugolini, "Modulation Formats and Waveforms for 5G Networks: Who Will Be the Heir of OFDM?," *IEEE Signal Process. Mag.*, vol. 31, no. 11, pp. 80–93, 2014.
[16] F. Khan and Z. Pi, "mmWave Mobile Broadband (MMB): Unleashing the 3-300GHz Spectrum," in *34th IEEE Sarnoff Symposium*, 2011, pp. 1–6.
[17] K. Zheng, Long Zhao, J. Mei, M. Dohler, W. Xiang, Y. Peng, and Kan, "10 Gb/s HetSNets with Millimeter-Wave Communications : Access and Networking – Challenges and Protocols," *IEEE Commun. Mag.*, vol. 53, no. 1, pp. 222–231, 2015.
[18] R. S. Sapakal and S. S. Kadam, "5G Mobile Technology," *Int. J. Adv. Res. Comput. Eng. Technol.*, vol. 2, no. 2, pp. 568–571, 2013.
[19] T. Nitsche, C. Cordeiro, A. B. Flores, E. W. Knightly, E. Perahia, and J. C. Widmer, "IEEE 802.11ad : Directional 60 GHz Communication for Multi-Gigabit-per-Second Wi-Fi," *IEEE Commun. Mag.*, vol. 52, no. 12, pp. 132–141, 2014.
[20] J. Gozalvez, "Samsung Electronics Sets 5G Speed Record at 7.5 Gb/s," *IEEE Veh. Technol. Mag.*, vol. 10, no. March, pp. 12–16, 2015.
[21] Nokia Solutions and Networks, "Looking ahead to 5G," *White Pap.*, pp. 1–16, 2013.

Naser Al-Falahy received his BSc and MSc degree in electronic and communications from Al-Nahrain University-Baghdad in 2001 & 2005 respectively. He Joined Motorola® as an optimisation engineer for mobile networks from 2005 till 2010. Currently, he is pursuing a PhD degree from the University of Salford-UK. His research interests include Mobile communications, radio network planning & optimisation, and millimetre wave communications. Contact him at naser_falahi@yahoo.com.

Omar Y. Alani received his PhD degree in Telecommunication Engineering from De Montfort University, UK in 2005. He is currently the programme leader of Computer Networks at the School of Computing, Science & Engineering in the University of Salford, UK. His research interests include wireless multimedia communications, Radio resource management and location/mobility management in next generation mobile communication systems, diversity and smart antennas techniques as well as Ad hoc and sensors networks. He is a member of IET and an editor in the International Journal of Mobile Communication. Contact him at o.y.k.alani@salford.ac.uk.