

The Journey of 5G Mobile Communication Networks

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Abstract

It is expected by 2020 5G cellular technologies will be rolled out, and it is expected to provide higher data rate, reduces end-to-end delay, ultra-low energy consumption and interconnects to other existing and emerging technology (autonomous systems).

Different working groups have proposed different template that will suite 5G cellular network, but these can only be achieved by harmonizing all these standards, policies and regulations to achieve this goal. This paper will be focusing on how existing mobile cellular technologies can be fused into the proposed 5G cellular technology and highlight key challenges that will be experienced from planning phase to full deployment phase.

Keywords: Second generation, Third Generation, Fourth generation, Fifth Generation, Point-to-Point, Software Defined Radio

Introduction

The need to explore new frontier of radio spectrum globally is a hot topic in order to cope with the exponential increase of data usage. It is expected that by year 2020 the numbers of connected devices will be 50 Billion and the volume of data traffic per year will be between (300- 420) Exabyte's amounting to (25-50) % increase (Ancans, Bobrovs, Ancans, Kalibatiene, et al., 2017)(Cisco, 2012)(Osseiran et al., 2014). The current consumer trends are shifting from voice oriented traffic to data driven traffic with the emergence of smarter phones to satisfy services like video gaming, multimedia streaming, video conferencing ,VoIP(Voice over Internet Protocol), making technology advancement to move at an extremely fast pace.

Therefore data-centric users have taking the bull-horn to push technology to provide for their needs which includes faster data rate to download or upload and gaming experiences, extremely low latency for their real time applications, reliability connection for critical services , low energy consumption devices and low cost smart devices. It is expected, that by 2021, Middle East and Africa CARG (Compound Annual Growth Rate) would have increase by 65% indicating that these regions will be the fastest growing mobile data traffic user (Cisco, 2012). Expected growth explained in(Cisco, 2012) shows that 4G (fourth Generation) won't be able to cater for such services which triggered researchers and the industry at large to envisage on creating another generation of network called NGN(Next Generation Network) or 5G (fifth Generation) Network(Ancans, Bobrovs, Ancans, Kalibatiene, et al., 2017).

Therefore this paper will be focusing on key challenges facing deployment of 5G cellular networks, and how diverse development by researchers can be integrated to meet 5G requirements.

The rest of this paper is organized as follows. Section II discuss the background study while section III discusses the challenges facing the reliability of 5G networks and section IV discusses the challenges, proposed solutions and conclusions.

Evolution of Mobile Cellular Technologies from 1G to 5G

Mobile cellular communications have been in existence for over 30 years. The mobile industry started with the first wireless technology called First Generation (1G) which was first of it's kind to implement the cellular concept (Panwar, Sharma, & Kumar, 2016) (Bhalla & Bhalla, 2010). During this time there were no concrete standardization countries like USA was using AMPS (Advanced Mobile Phone System), Russia and other eastern European countries were using NMT (Nordic Mobile Telephone), United Kingdom were using TAC (Total Access Communication System) to mention a few. Issues such as handover management, interference, coverage, poor capacity, QoS (Quality of Service) and standardization did not allow this technology to spread (Panwar et al., 2016) (Bhalla & Bhalla, 2010) see Table 1.

Second Generation (2G) cellular network was developed to answer issues encountered in 1G. ETSI (European Telecommunication Standards Institute) developed what is now known as GSM (originally called Group Special Mobile but translated as Global System for Mobile Communication) which was first deployed in Finland in 1991 (Panwar et al., 2016) (Bhalla & Bhalla, 2010) [6]. GSM used a combination of FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access) as its multiple access technique and transmitted signal using digital signal in a circuit switched system see *Figure 1*. While the Americans were busy developing CDMA which was using spread spectrum based technology which showed a more promising advantage, there were three lines of development of the 2G system in the United States of America. The first, introduced in 1991, was the IS-54 (North America TDMA Digital Cellular), with a new version supporting additional services (IS-136) introduced in 1996. Meanwhile, IS-95 (CDMA One) was deployed in 1993 (Chen, 2003).

Later technologies like GPRS (General Packet Radio Service), EDGE (Enhanced Data rates in GSM Environment), and HSCSD (High Speed Circuit Switched Data) were developed to enhance services provided by GSM (see *Table 1* and *Figure 1*). Limitations encountered by 2G were few but includes, better mobility management that is soft handover, higher data rate, interoperability between 2G cellular networks, roaming and poor standardization.

Third Generations (3G) was developed to solve limitations in 2G and proffer better services. IMT-2000 (International Mobile Telecommunications) was created to unify all standards and work together to build 3G cellular network. ITU (International Telecommunications Union) created WCDMA (Wideband Code Division Multiple Access) while ETSI in Europe created UMTS (Universal Mobile Telecommunications Services). 3G networks was developed to provide a unified standardization, backward compatibility with GSM, multimedia services, roaming, higher data rate as compared to 2G, vehicular user experience, better network coverage, softer handover, high speed packet data rate and larger capacity (Bhalla & Bhalla, 2010) [6] (Chen, 2003) (Prasad, R., Mohr, W., Konhauser, 2000) see *Table 1* and *Figure 1*.

Later, IMT-2000 then divided the standardization into two groups: 3GPP (3G partnership project) for WCDMA standard which will be backward compatible with GSM, GPRS systems and 3GPP2 (3G Partnership Project for CDMA 2000 standard) which will provide a backward

compatibility of older CDMA technologies such as IS-95 (Prasad, R., Mohr, W., Konhauser, 2000).

With the advent of Internet Protocol (IP) standard acceptability in telecommunication industry, the need for mobile technology to adopt this standard was pertinent, after all packet switched technology has been able to provide a significant revolutionary change in mobile internet usage. Fourth Generation (4G) was developed to meet IMT-Advanced specifications (Ancans, Bobrovs, Ancans, & Kalibatiene, 2017), which were IP based packet switched network, backward compatibility with existing cellular technologies and wireless standards, spectral efficient, seamless connectivity and global roaming, data rate up from 100Mbps to 1Gbps, higher QoS, support broadband services (Panwar et al., 2016) (Bhalla & Bhalla, 2010)(Wang et al., 2014)(Intelligence, 2014) see *Table 1* for details and *Figure 1* for system architecture. LTE-A (Long Term Evolution Advance) system is a 3GPP LTE Release 10 (Cao, Ma, Li, Zhang, & Luo, 2014)(Ergen, 2009)(Paradisi, Figueiredo, Yacoub, & Tronco, 2016) which is an IP-based network, compatible with other existing network, focusing more on reducing the network architecture for 4G cellular network as shown in *Figure 1*. LTE-A provides better security, higher data rate, better spectral efficiency, interconnectivity to HetNet (Heterogeneous Networks), support data-centric users, flexible radio planning as compared to other existing technologies. Other features for LTE-A cellular system are Carrier Aggregation, Multiple Input Multiple Output, and Coordinated Multi Point (CoMP) operation(Cao et al., 2014)(Nakamura, 2009). 4G mobile technology had limitations which were end-to-end (E2E) delay for real-time services, handoff delay, security, poor battery life, coverage and connection cost (Ancans, Bobrovs, Ancans, Kalibatiene, et al., 2017)(Martin & Amin, n.d.) (Intelligence, 2014)(Mitra & Agrawal, 2016).

Fifth Generation (5G) is the next generation network in focus to solve many of the limitations being encountered in 4G. 5G Mobile Technology which is expected to be rolled out by 2020 is attracting researchers, academics, industries, and government at large (Osseiran et al., 2014) (Ancans, Bobrovs, Ancans, & Kalibatiene, 2017) [(Intelligence, 2014) (Mitra & Agrawal, 2016) (Massaro, 2017)(Hossain & Hasan, 2015). It's being expected that by 2020 the total number of connected device should be over 50 billion (Ancans, Bobrovs, Ancans, Kalibatiene, et al., 2017) (Mitra & Agrawal, 2016). It can be shown from figure 2, the world data traffic growth as at 2016 was 67% (Cisco, 2012) while figure 3 indicates world internet usage as at 2017 was 66.3% ("World Internet Users Statistics and 2018 World Population Stats," n.d.). With this exponential increase of data usage different groups which will be mentioned later has been working tirelessly to meet the demand.

5G by IMT-2020 is expected to have the following characteristics(Osseiran et al., 2014)(Panwar et al., 2016)(Intelligence, 2014) (Ancans, Bobrovs, Ancans, & Kalibatiene, 2017) (Mitra & Agrawal, 2016)(Paradisi et al., 2016) (Ericsson, 2016)(Mohammed, Huq, Mumtaz, Rodriguez, & Telecommunicaç, 2017)(Akyildiz, Nie, Lin, & Chandrasekaran, 2016) as shown in Figure 4:

- i. Below 1ms E2E latency
- ii. Support other technologies such as P2P (Point-to-Point) communications, Internet of Things (IoT), SDR (Software Defined Radio)
- iii. Larger bandwidth
- iv. Higher data rate (1-10) Gbps
- v. Backward compatibility with existing mobile technologies

- vi. Very low energy consumption
- vii. High reliability to support critical services such as Fire Service, Police, Military, Ambulance Services
- viii. Larger coverage area
- ix. Better mobility management i.e. seamless handoff amongst existing wireless technologies

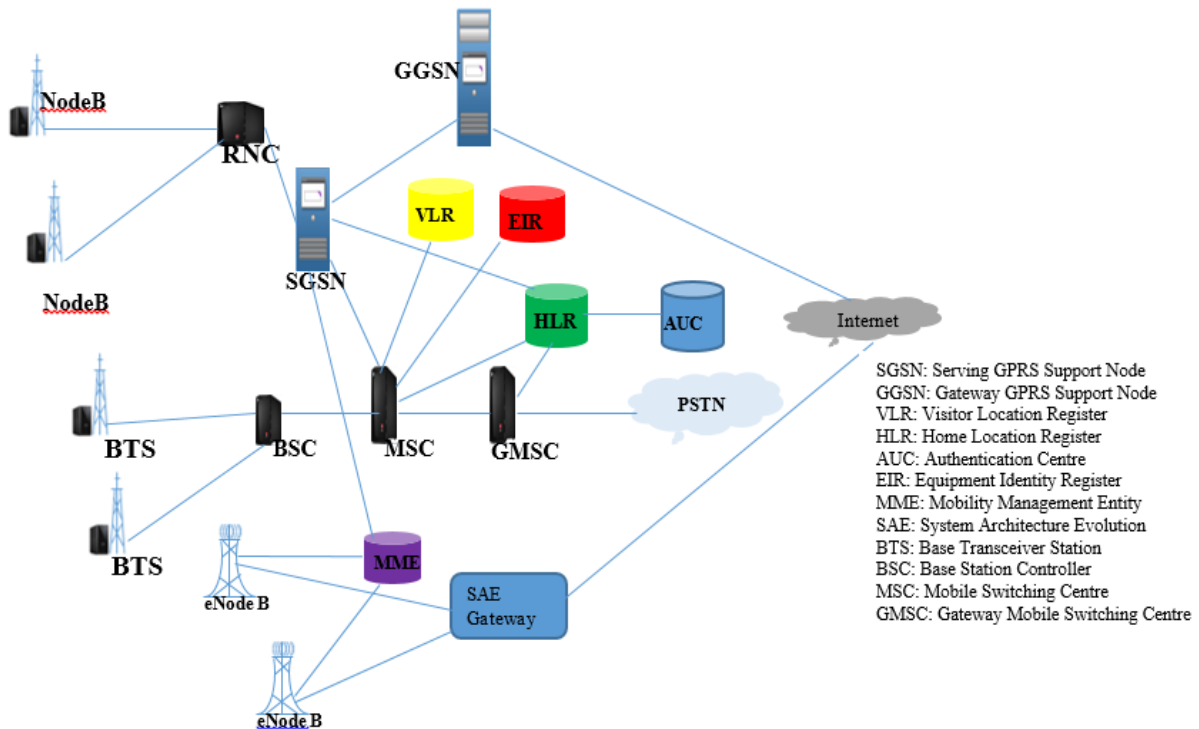


Figure 1: 2G/3G/4G System Architecture

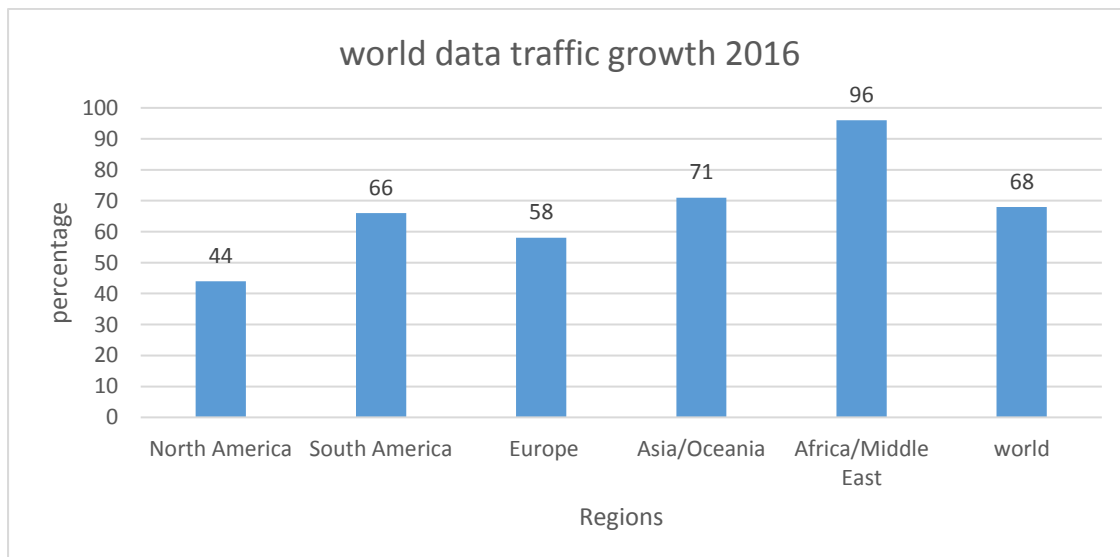


Figure 2 : 2016 world data traffic growth (“World Internet Users Statistics and 2018 World Population Stats,” n.d.)

Table 1 : Summarized mobile cellular generations

Generation	1G	2G			3G	4G
Year Deployed	1980's	1991			2001	2012
Data rate	2.4Kbps	9.6 Kbps	115 Kbps	(80-100)Kbps	384Kbps(Outdoor) – 2Mbps(Indoor)	Up to 50Mbps
Services provided	Voice only	Voice, SMS,	Voice, SMS, MMS, WAP	Voice, SMS, MMS, WAP	Voice, data and multimedia service	Voice, data and multimedia, Mobile broadband service
Modulation technique	Binary FSK	GMSK	GMSK	QPSK	DPSK & BPSK	OFDM/MIMO
Multiple access techniques	FDMA	FDMA and TDMA	TDMA	TDMA(1S-136)CDMA	DS-CDMA	Uplink: SC-FDMA Downlink: OFDMA
Bandwidth	40MHz	25MHz	varies	varies	5MHz	20MHz or 40MHz
Transmission mode	Analog	Digital signal	Digital signal	Digital signal	Digital signal	Digital Signal, IP Based
System Architecture Components	MTS, O, Land Station	BTS, BSC, MSC, AUC, EIR, GMSC, HLR, VLR	SGSN, GGSN	BTS, BSC, MSC, AUC, EIR, VLR, GMSC, HLR	NodeB, RNC	eNodeB, MME, SAE gateway, SGW, PCRF, HSS
Technologies	AMPS, NTT, TACS	GSM	GPRS, EDGE, HSCSD	IS-54, IS-136, IS-95	WCDMA, UMTS, CDMA 2000(1xRTT, EVDO), HSDPA, HSUPA, LTE	WiMAX, LTE-A

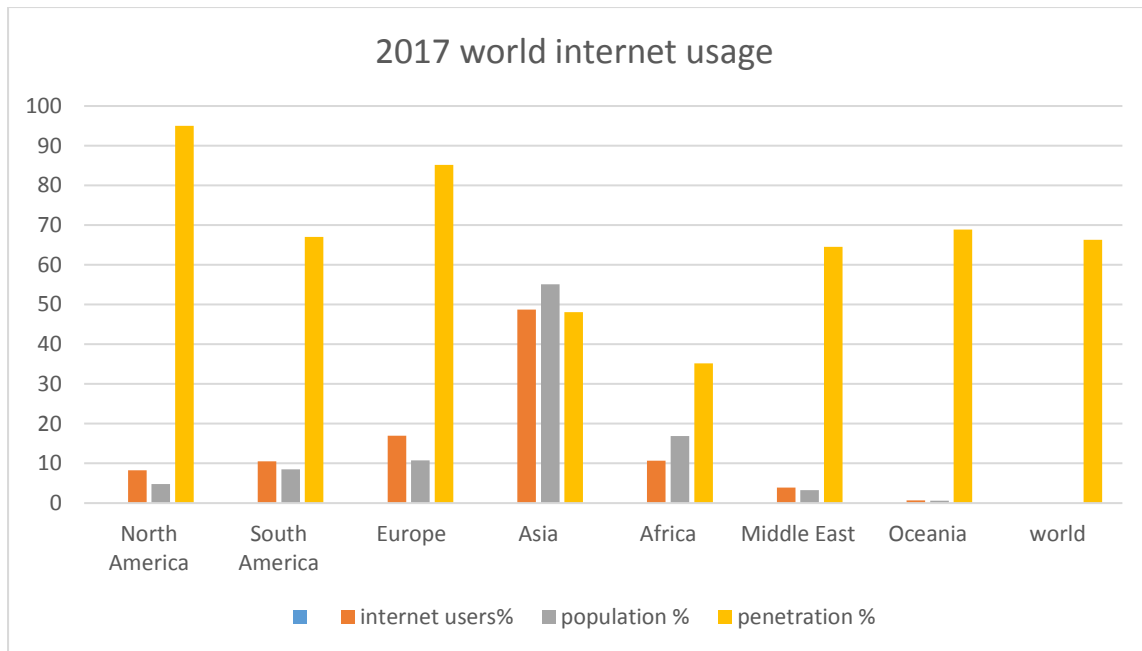


Figure 3: 2017 world internet usage as per population

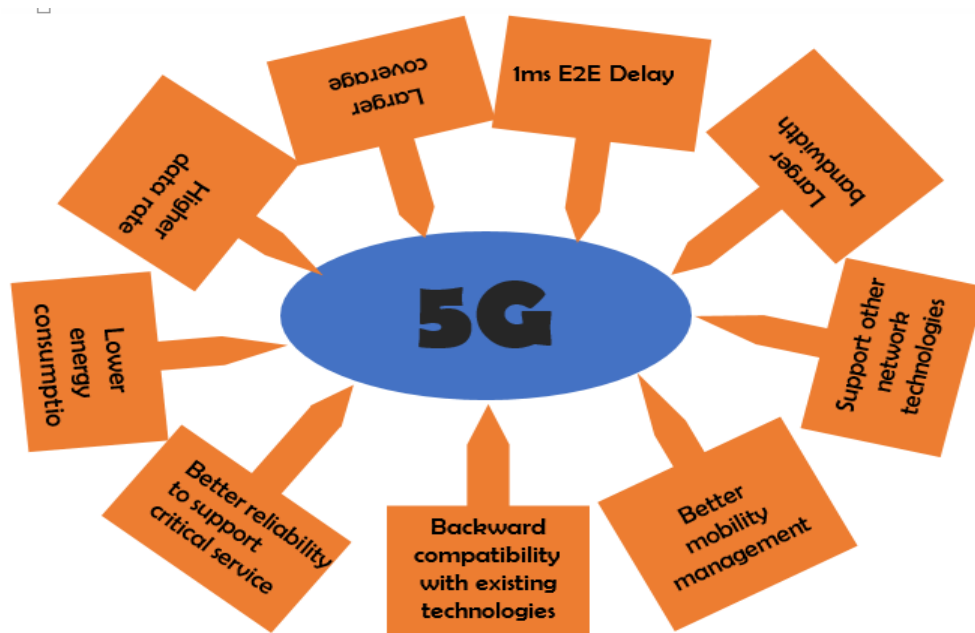


Figure 4: 5G mobile Technology characteristics

5G Mobile Networks

This section, will focus on current research group's activity and their achievements, system architecture, key challenges, possible solutions.

Current Research Groups activities

Various research groups such as. METIS (Mobile and Wireless communication enablers for the twenty-twenty Information Society), 5GNow (5th Generation Non-Orthogonal Waveforms for Asynchronous Signalling), EM-PhAtiC (Enhanced Multicarrier Technology for Professional Ad-Hoc and Cell-Based Communications), NEWCOM (Network of

Excellence in Wireless Communications), 5GPPP (5G Infrastructure Public Private Partnership), ETRI (Electronics and Telecommunications Research Institute), 5GIC (5G Innovation Center) (Ergen, 2009), NYU WIRELESS are currently working on different aspects of 5G cellular network (see Table 2 for further details):

Table 2: 5G research group activities

	Research Group	Research activities
1	METIS	METIS published in 2015, final report, which consists of system architecture, channel models, technology component. METIS consist of telecommunication companies, such as NSN, Ericsson, T-Mobile, Docomo, and Orange, and academic institutions, such as the Royal Institute of Technology in Stockholm (KTH), Poznan University of Technology, Kaiserslautern University of Technology, Polytechnic University of Valencia, and University of Oulu, as its partners(Osseiran et al., 2014) (Mitra & Agrawal, 2016). They proposes 5G KPI's (Key Performance Indicator) such as traffic volume per subscriber, traffic volume per area, average user data rate during busy hours, and actual user data rates. There simulation achieved E2E latency under 1ms, simulated environment were carried out at outdoor, indoor, shopping mall and stadiums. Currently METIS is working on METIS II standardization, and overall 5G RAN architecture design(Osseiran et al., 2014) (Mitra & Agrawal, 2016).
2	5GNow	They are researching on achieving a frame structure, ultra-low latency and ultra-high reliability (Mitra & Agrawal, 2016). Currently they developed a signalling system called Gabor signalling which uses a combination of time and frequency shift of a short term Fourier Transform (STFT) (Mitra & Agrawal, 2016)
3	EM-PhAtiC	EM-PhAtiC are exploring how to improve MIMO transmission, equalization, developing high flexibility filter-bank and multi-hop or relay based communication (Mitra & Agrawal, 2016). They researched on different schemes for MIMO transceiver for FBMC under Frequency selective channel (Mitra & Agrawal, 2016).
4	NEWCOM	They are working on how they could form a bridge between 4G and 5G spectrum, multi-hop coding, mobile broadcasting, Cloud-RAN, localization with distributed antenna .Currently working on multi-hop coding, mobile broadcasting, signal processing for 5G, channel efficiency(Ergen, 2009)
5	5GPPP	5GPPP is a joint partnership between European Commission and European ICT (Information Communication Technology) industries (Mitra & Agrawal, 2016) (5GPPP Architecture Working Group, 2017) .Their aim is meet up with 5G criteria. They are currently working on more than 16 project air

		interface, system architecture, KPI's, management, RAN to mention a few(Mitra & Agrawal, 2016) (5GPPP Architecture Working Group, 2017) . June 2017, a white paper was release to end the first phase of their research which includes identifying design recommendations for 5G development and standardization (5GPPP Architecture Working Group, 2017).
6	ETRI	ETRI is a Korean based global ICT research institute, which created a sub-group called 5G Giga Service Research Laboratory dedicated for 5G mobile communication technologies see (Mitra & Agrawal, 2016)(“Introduction of Research Laboratory 5G Giga Communication Research Laboratory Organization Welcome to ETRI,” n.d.).Their key research interest is into mmWave (Millimeter Wave) communication and convergence technologies. They are researching on D2D communication, reliability and mobile hotspot network (MHN) protocol stack (Mitra & Agrawal, 2016)(“Introduction of Research Laboratory 5G Giga Communication Research Laboratory Organization Welcome to ETRI,” n.d.)
7	5GIC	Achieved 1Tbps speed for P2P communication, currently working on how to achieve the basic characteristics of 5G cellular networks
8	NYU Wireless	NYU Wireless is an academic research group in collaboration with some technical partners in working on Next Generation Network (NGN) Technologies (Mitra & Agrawal, 2016)(Theodore S Rappaport, Sun, & Shafi, 2017)(T. S. Rappaport, 2014). They have extensively conducted experiments on mmWave propagation models and path loss at different millimetre frequency bands in New York and Austin (Mitra & Agrawal, 2016).

Key Challenges and Possible Solutions

In this section, the focus will be highlighting key challenges facing 5G mobile technology deployment and possible solutions.

A. Spectrum Usage

Many literatures have highlighted that though the spectrum is scarce but truly under-utilized (Faruk et al., 2016). From resolution 238, World Radio Conference (WRC-2015) report shows that 11 mmWave frequencies bands (24.25–27.5GHz; 31.8 GHz–33.4 GHz; 37 – 40.5GHz; 42.5GHz -43.5GHz;45.5GHz – 47GHz; 47 GHz- 47.2GHz; 47.2 GHz – 50.2 GHz; 50.4GHz – 52.6GHz; 66 GHz- 76 GHz; 81 GHz– 86 GHz) were highlighted as possible spectrum to be used(Mohammed et al., 2017)(Akyildiz et al., 2016)(Ancans, Bobrovs, Ancans, & Kalibatiene, 2017) while some researchers concluded that the existing spectrum bands below 6GHz can still be used for deployment of 5G (Ancans, Bobrovs, Ancans, & Kalibatiene, 2017)(Intelligence, 2014) (Theodore S Rappaport et al., 2017). It is worthwhile to note that mmWave band spans between 24 GHz -300 GHz.

Rappaport et al and METIS to mention a few have extensively worked on mmWave band spanning from propagation model to path loss model (Mitra & Agrawal, 2016)(Panwar et al.,

2016). It is expected that by 2019 a concise propagation model will be available for deployment (Ancans, Bobrovs, Ancans, & Kalibatiene, 2017).

B. Radio Access Technology and Channel Modelling

Air Interface

New air interface will be required to be developed in order to meet 5G criteria and also coexist with other existing air interface being deployed (Ancans, Bobrovs, Ancans, Kalibatiene, et al., 2017)(Osseiran et al., 2014). 5GPP group proposed that different air interface and RAT (Radio Access Technology) should be reconciled at the MAC layer putting in mind that flexibility is key (5GPPP Architecture Working Group, 2017). FANTASTIC 5G considered a frequency – time resource allocation using a multi-service air interface (Mohammed et al., 2017).

Frame Structure and Multiple Access Techniques

Immerse research work is being conducted in this area. 5GNOW which is an EU based research group considered a unified frame structures using both NOMA (Non-Orthogonal Multiple Access) and OFDM for both uplink and downlink. 5GNOW, METIS, 5GPP t are currently working a wide range of waveforms which could be jointly considered and they are Filter Bank Based Multicarrier (FBMC), Universal Filtered Multicarrier (UFMC), Zero-tail Discrete Fourier Transform spread OFDM, NOMA, Generalized Frequency Division Multiplexing (GFDM) for more details see (Mohammed et al., 2017)(5GPPP Architecture Working Group, 2017).

Designing a realistic channel modelling

METIS proposed a WINNER II/+ channel model originally designed for below 6GHz band, . It extended its work using 3-D parameters, small scale considering (AOA, AOD propagation delay and power) and large scale like r.m.s delay spread. WINNER II/+ model is a 3D model with geometric polarization. GSCM doesn't full compliments continuous motion (non-stationary). Not suitable for P2P communications (Medbo et al., 2014).

COST 2100 Model which is similar to WINNERII model, modelled for scattered scenarios, it support spherical wave modelling but does take mobility into consideration not applicable to P2P, there is no fixed model for a particular scenarios for more details see (Verdone & Zanella, 2012)(Medbo et al., 2014).

Rappaport and other researchers at NYU conducted an extensive channel measurement for different mmWave frequencies at NY and Austin details can be found in (Theodore S Rappaport et al., 2017)(T. S. Rappaport, 2014).

Effective, realistic and extensive propagation model at different mmWave frequency bands and below 6GHz band for outdoor, indoor, dense, less dense, stationary and vehicular environment needs to be harmonised. Bearing in mind, that propagation model is environment dependent, the need to model different scenarios for a longer period using different modelling techniques should be key to development of propagation models.

C. Network Architecture (RAN and Core Network) and Network convergence

One of the key characteristics of 5G is lower ultra-low energy consumption of UE, RAN and CN. RAN technology to be used will be a combination of physical and virtual infrastructure (Huawei, 2014)(5GPPP Architecture Working Group, 2017). Cloud RAN has been proposed to be the embedded into 5G to cater for service like cloud computing, software define network (SDN), network function virtualization (NFV), HETNET (Heterogeneous Networks). Network overhead is expected to be reduced at the BS (base station) consisting of low powered radio heads and antenna, also a centralized BBU (Base Band Unit) will be required. BBU will function as an intermediary between RRH and the CN, act as a transportation system for traffic flow (Mohammed et al., 2017)(Ancans, Bobrovs, Ancans, Kalibatiene, et al., 2017).

C-RAN will be in charge of Mobility management, congestion control, handoff management, security, QoS management, Resource management and reliability management for critical services(Mohammed et al., 2017)(5GPPP Architecture Working Group, 2017) . Deployment of C-RAN is going to be one of the most challenging aspect for 5G architecture in nearest future. It is expected that other newer technologies such as D2D, V2V,V2I,,P2P,M2M communication devices and IoT will be able to connect to this network(Intelligence, 2014)(Ancans, Bobrovs, Ancans, Kalibatiene, et al., 2017) . The use of very large antenna arrays or Massive MIMO for future base stations also should be explored (Wang et al., 2014).

D. Mobility and Interference Management

A new approach is being considered consisting of UE autonomous mobility, softer handover and mobility concept for URLLC() (5GPPP Architecture Working Group, 2017). It is expected that mobility management in intra-RAT, inter-RAT and multi-connectivity to different technologies will be seamless and less complex to achieve low energy consumption, higher data rate and ultra-low E2E delay(Intelligence, 2014) (5GPPP Architecture Working Group, 2017). Handoff between different RAT will require UE to select most suitable RAT without compromising QoS.

It is expected that managing interference between mobile technologies with other network technologies will require a new dynamic approach. This approach has to sense the spectrum and compute if the SINR (Signal-to-Interference Ratio) using CR (Cognitive Radio) technique to manage interference.

E. Privacy and Security

In 3G and 4G, certain security concerns were not addressed such as softwarization, virtualization, trust models which will be the core values of 5G systems(5GPPP Architecture Working Group, 2017). Consideration of attacks such as eavesdropping, man-in the middle attack, denial of service, impersonation, malicious attack on transfer of data needs to be addressed. Applying security control on all layers at 5G model is required, embedding softwarization and virtualization to the proposed security model to mitigate known and unforeseen attack(5GPPP Architecture Working Group, 2017).

In order to achieve ultra-low latency, present authentication mechanism used is unsuitable. Therefore, there is need to develop a fast, reliable, low complexity and efficient E2E authentication mechanism to achieve below 1ms, also authentication mode should be enhance right from the UE (User Equipment) to the core network.

Conclusion

In this paper, we discussed in summary existing mobile technologies evolution and their limitations, reasons why 5G is required to meet future data traffic demands and highlight key challenges facing the deployment of 5G. In spite of various group working on 5G Cellular system, before year 2020, regulation, policies and standardization would have been agreed upon

However, it is expected that by World Radio Congress 2019 (WRC-2019), remarkable milestone would have been achieved.

Reference

- 5GPPP Architecture Working Group. (2017). *view on 5G architecture. white paper*. Retrieved from <https://5g-ppp.eu/wp-content/uploads/2018/01/5G-PPP-5G-Architecture-White-Paper-Jan-2018-v2.0.pdf>
- Akyildiz, I. F., Nie, S., Lin, S., & Chandrasekaran, M. (2016). 5G roadmap : 10 key enabling technologies. *Computer Networks*, 106, 17–48.

<https://doi.org/10.1016/j.comnet.2016.06.010>

- Ancans, G., Bobrovs, V., Ancans, A., & Kalibatiene, D. (2017). Spectrum Considerations for 5G Mobile Communication Systems. *Procedia - Procedia Computer Science*, 104(December 2016), 509–516. <https://doi.org/10.1016/j.procs.2017.01.166>
- Ancans, G., Bobrovs, V., Ancans, A., Kalibatiene, D., Osseiran, A., Boccardi, F., ... Guizani, M. (2017). Ten 5G Challenges for Engineers to Overcome. *Procedia - Procedia Computer Science*, 104(August), 1–11. <https://doi.org/10.1016/j.dcan.2017.09.010>
- Bhalla, M. R., & Bhalla, A. V. (2010). Generations of mobile wireless technology: a survey. *International Journal of Computer Applications*, 5(4), 7. <https://doi.org/10.5120/905-1282>
- Cao, J., Ma, M., Li, I. H., Zhang, Y., & Luo, Z. (2014). A Survey on Security Aspects for LTE and LTE-A Networks. *IEEE Communication Surveys and Tutorials*, 16(1), 283–302.
- Chen, Y. (2003). Soft Handover Issues in Radio Resource Management for 3G WCDMA Networks. 书, (September).
- Cisco. (2012). Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2011–2016 [Visual Networking Index (VNI)]. Cisco, 2016–2021. <https://doi.org/10.1109/SURV.2008.080403>
- Ergen, M. (2009). *Mobile Broadband including WiMAX and LTE*. Berkeley, CA, USA: Springer Science+Business Media. <https://doi.org/10.1007/978-0-387-68192-4>
- Ericsson. (2016). 5G Radio Access. *White Paper*, (April), 10. [https://doi.org/Uen 284 23-3204 Rev C | April 2016](https://doi.org/Uen%20284%203204%20Rev%20C)
- Faruk, N., Bello, O. W., Sowande, O. A., Onidare, S. O., Muhammad, M. Y., & Ayeni, A. A. (2016). Large scale spectrum survey in rural and urban environments within the 50 MHz-6 GHz bands. *Journal of the International Measurement Confederation, Elsevier*, 91(May), 228–238. <https://doi.org/10.1016/j.measurement.2016.05.046>
- Hossain, E., & Hasan, M. (2015). 5G Cellular : Key Enabling Technologies and Research Challenges. *IEEE Instrumentation & Measurement Magazine*, 18(3), 11–21.
- Huawei. (2014). 5G : A Technology Vision. *Huawei, White Paer*, 1–16.
- Intelligence, G. S. M. A. (2014). Understanding 5G : Perspectives on future technological advancements in mobile. *White Paper*, (December), 1–26.
- Introduction of Research Laboratory | 5G Giga Communication Research Laboratory | Organization | Welcome to ETRI. (n.d.). Retrieved March 27, 2018, from https://www.etri.re.kr/eng/sub6/sub6_0101.etri?departCode=6
- Martin, J., & Amin, R. (n.d.). Limitations of 4G Wireless Systems.
- Massaro, M. (2017). Next generation of radio spectrum management : Licensed shared access for 5G. *Telecommunications Policy*, 41(5–6), 422–433.
- Medbo, J., Börner, K., Haneda, K., Hovinen, V., Imai, T., Järvelainen, J., ... Kusume, K. (2014). Channel Modelling for the Fifth Generation Mobile Communications. In

Antennas and Propagation (EuCAP), 2014 8th European Conference (pp. 219–223).

- Mitra, R. N., & Agrawal, D. P. (2016). 5G mobile technology : A survey ☆. *ICT Express*, 1(3), 132–137. <https://doi.org/10.1016/j.icte.2016.01.003>
- Mohammed, K., Huq, S., Mumtaz, S., Rodriguez, J., & Telecommunicaç, I. De. (2017). A survey of 5G technologies : Regulatory , standardization and industrial perspectives, (August), 1–11. <https://doi.org/10.1016/j.dcan.2017.09.010>
- Nakamura, T. (2009). Proposal for candidate radio interface technologies for IMT-advanced based on LTE Release 10 and Beyond (LTE-advanced). In *ITU-R WP 5D 3rd Workshop on IMT-Advanced* (pp. 1–63). Retrieved from http://webstaff.kmutt.ac.th/~suwat.pat/material/2009_10_3gpp_IMT.pdf
- Osseiran, A., Boccardi, F., Braun, V., Kusume, K., Marsch, P., Maternia, M., ... Uusitalo, M. A. (2014). Scenarios for 5G Mobile and Wireless Communications : The Vision of the METIS Project, (May), 26–35.
- Panwar, N., Sharma, S., & Kumar, A. (2016). A survey on 5G : The next generation of mobile communication. *Physical Communication*, 18, 64–84. <https://doi.org/10.1016/j.phycom.2015.10.006>
- Paradisi, A., Figueiredo, F. L., Yacoub, M. D., & Tronco, T. R. (2016). *Long Term Evolution: 4G and Beyond*. (A. Paradisi, F. L. Figueiredo, M. D. Yacoub, & T. R. Tronco, Eds.). Switzerland: Springer Science+Business Media. <https://doi.org/10.1007/978-3-319-23823-4>
- Prasad, R., Mohr, W., Konhauser, W. (2000). *Third Generation Mobile Communication Systems* (First). Boston, United State of America: Artech House.
- Rappaport, T. S. (2014). Millimeter Wave Cellular Communications: Channel Models Capacity Limits Challenges and Opportunities. In *Invited Talk, IEEE Comm. Theory Workshop*.
- Rappaport, T. S., Sun, S., & Shafi, M. (2017). Investigation and Comparison of 3GPP and NYUSIM Channel Models for 5G Wireless Communications. In *IEEE 86th Vehicular Technology Conference (VTC Fall)* (pp. 6–11). Toronto, Canada.
- Verdone, R., & Zanella, A. (2012). *Pervasive mobile and ambient wireless communications: COST action 2100*. Retrieved from [https://books.google.com/books?hl=en&lr=&id=VVAmcZxn9akC&oi=fnd&pg=PR3&dq=R.+Verdone+and+A.+Zanella+\(Editors\),+“Pervasive+Mobile+and+Ambient+Wireless+Communications:+COST+Action+2100,”+Springer,+2012.&ots=Fx6pBRvgtH&sig=gt0sGdgK8IYdNpXelQ4ctn8a0FU](https://books.google.com/books?hl=en&lr=&id=VVAmcZxn9akC&oi=fnd&pg=PR3&dq=R.+Verdone+and+A.+Zanella+(Editors),+“Pervasive+Mobile+and+Ambient+Wireless+Communications:+COST+Action+2100,”+Springer,+2012.&ots=Fx6pBRvgtH&sig=gt0sGdgK8IYdNpXelQ4ctn8a0FU)
- Wang, C.-X., Haider, F., Gao, X., You, X.-H., Yang, Y., Yuan, D., ... Hepsaydir, E. (2014). Cellular architecture and key technologies for 5G wireless communication networks. *IEEE Communications Magazine*, 52(2), 122–130. <https://doi.org/10.1109/MCOM.2014.6736752>
- World Internet Users Statistics and 2018 World Population Stats. (n.d.). Retrieved March 26, 2018, from <https://www.internetworldstats.com/stats.htm>