An Evolution to Next Generation Heterogeneous Cellular Networks

Mahmood Adnan*, **Shadi M. S. Hilles, Wael M. S. Yafooz**
Faculty of Computer and Information Technology
Al-Madinah International University, Shah Alam, Selangor, 40100, Malaysia

ABSTRACT

The convergence of internet and wireless mobile communication accompanied by a massive growth in the number of cellular subscribers has led mobility management to emerge as a significant and challenging domain for wireless mobile communication over the internet. Over the recent past, wireless communication market has witnessed a considerable amount of intensification, both in terms of mobile technology and subscribers, which has led network operators and vendors to fully apprehend the importance of efficacious networks along with equally intelligent design processes. Wireless communication has undoubtedly become ubiquitous; it has almost revolutionized every single aspect of our daily lives. The unprecedented increase in number of cellular phones, mobile handheld devices, personal digital assistants, and mobile subscribers has demanded an upgradation of cellular communication technologies in several generations to cater demand for the modern data services, multimedia services, and voice communications. Therefore, to commend state-of-the-art technologies and in order to extensively contribute to their enhancement in near future, it is always interesting to have a quick glance at history of such technologies so as to sketch certain smaller steps that have led to their present development. This manuscript outlines and traces key developments and trends in this ever-growing domain of wireless communications.

Keywords:
4G Technology, Next Generation Cellular Networks, Heterogeneous Networking.

1. Introduction

Over the recent past, the wireless communication market has witnessed a significant amount of intensification, both in terms of mobile technology and subscribers, which has led network operators and vendors to fully apprehend the importance of efficacious networks along with an equally intelligent design processes. Wireless communication has today become ubiquitous; it has almost revolutionized every single aspect of our daily lives [1-3, 5]. A sheer increase in the number of cellular phones, mobile handheld devices, personal digital assistants, and network subscribers has in turn demanded the upgradation of cellular communication technologies through several generations in order to cater a demand for modern data services, multimedia services, and voice communications. Table 1 illustrates the key features of each of these generations by comparing the service type, key standards, frequency bands, data rates, access technology, and core network.

2. Evolution of Wireless Communication Systems

The First Generation (1G) wireless communication technology started in early 1980s, when certain mobile standards such as Advanced Mobile Phone System (AMPS) was deployed throughout in most parts of United States, Australia, South America, and China; Extended Total / Total Access Communication System (ETACS / TACS) in parts of Europe [6]; Nordic Mobile Telephone (NMT) system in Nordic countries; and Nippon Telephone and Telegraph (NTT) system in Japan. These systems broadcasted speech signals / transmissions using frequencies around 900MHz and analogue modulation [7].

The Second Generation (2G) digital cellular systems followed the 1G analog cellular systems, with number of considerable advancements as early as 1990s [4]. 2G systems employed the digital multiple access technology, and were classified into Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) based technology. Typical 2G standards included Global System for Mobile Communications (GSM) – *a pan European Digital Cellular*, Personal Digital Cellular (PDC) in Japan, North American Interim Standard (IS-54) later upgraded to IS-136 ~ all three based on TDMA technology; and IS-95 in North America and parts of Asia employing the CDMA technology. The most widely used 2G network, i.e., GSM, broadcasts data at around 9.6 kbps and is used in 900MHz and 1800 MHz band except for North America (i.e., 1900 MHz) [4].

The Second and a Half Generation (2.5G) wireless systems were driven as a result of ever-increasing demands caused due to the growth in a number of mobile subscribers and data services which could not be catered by the 2G circuit-switched domain possessing a low data rate [8]. Thus, the 2G wireless networks were augmented to 2.5G with introduction of new nodes in the core network that can support packet data service. 2.5G standards include

Manuscript received April 5, 2017
Manuscript revised April 20, 2017

General Packet Radio Service (GPRS) providing a throughput rate of 53.6 kbps so as to provide subscribers with access speeds similar to a dial-up modem; and Enhanced Data Rates for GSM Evolution (EGDE / EGPRS) with data transmission rate of up to 384 kbps. EDGE / EGPRS is also regarded as 2.75G.

Standardization work for the Third Generation (3G) wireless networks initiated in late 1990s [9]; wherein, fundamental perspective was to provide subscribers with a high-rate voice and data service along with network security and reliability (3G cellular network data rates for users in the high-speed vehicles on vast areas is 144 kbps, 384 kbps for the pedestrians slowly traversing in small areas, and 2,048 kbps for indoor offices / stationary users) [10]. The aim of the 3G networks is to support an IP-based data, voice, and multimedia services with integration to internet to provide useful internet applications to mobile users [9-12]. Similarly, improved interoperability to handle the mobility across various radio technologies amongst the different network providers is also a critical task for 3G services. The International Telecommunication Union (ITU) has devised a set of globally harmonized standards for 3G cellular services, referred to as International Mobile Telecommunications-2000 (IMT-2000) in order to support a ubiquitous wireless communication across the world. The IMT-2000 is further classified into two standards, i.e. Universal Mobile Telecommunication System (UMTS, also referred to as Third Generation Partnership Project – 3GPP) and CDMA 2000 (referred to as Third Generation Partnership Project Two – 3GPP2).

In contrast to the preceding generations, the 3G technology assisted network operators and service providers to offer users with a greater bandwidth, reliability, and security; thus making it more suitable for certain advanced applications such as mobile e-commerce (i.e., m-commerce), video-conferencing, video-on-demand, location-sensitive services (mobile programs to search for bars or restaurants), and customized personal information services, etc. However, its major drawbacks lies in its associated high costs for both the network operators and end-users due to a continuous upgradation of the cellular infrastructure and soaring spectrum-license costs [1, 13]. Fig. 1 depicts the evolution of wireless communication systems along with their salient characteristics in terms of mobility and data rates.

Table 1: Salient Features of Different Generations of Wireless Communication Technologies

GENERATIONS / SALIENT FEATURES	1G	2G	2.5G	3G	4G
SERVICE TYPE	Analog Voice Telephony (Less Secure)	Digital Voice, SMS (More Secure)	Data Service (Relatively Slow Internet)	Broadband Data, Some Multimedia (Audio & Video Clips)	Complete IP - Based, High Stream Multimedia
KEY STANDARDS	AMPS, ETACS, TACS, NMT	GSM, PDC, I-Mode	GPRS, EDGE / EGPRS, HSCSD	IMT-2000 (UMTS - 3GPP, CDMA 2000 - 3GPP2)	LTE Advanced, WiMAX Release 2
FREQUENCY BANDS (HZ)	400M 800M 900M	800M 900M 1800M 1900M		2G	800M 2.6G
DATA RATE (BPS)	2.4K - 30K	9.6K - 14.4K	53.6K - 384K	2M	100M (LTE Advanced theoretically up to 1Gbps)
MAIN ACCESS TECHNOLOGY	FDMA	TDMA, CDMA		CDMA	OFDM
CORE NETWORK	PSTN	PSTN	PSTN, Packet Network	Packet Network	Internet

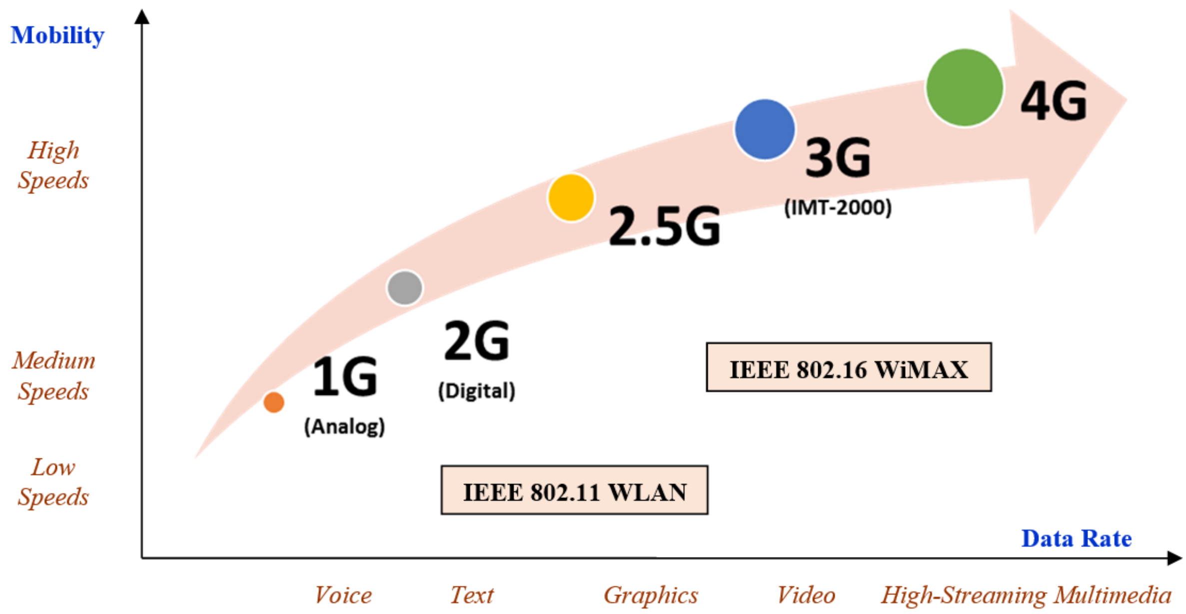

Fig. 1: Evolution of Wireless Communication Systems

3. Motivation for Beyond 3G Wireless Networks

The Beyond Third Generation (B3G) wireless communication systems intends to offer the end-users with the appropriate global information access competences and personalized wireless communication services [14]. Their architecture aims to integrate an assortment of heterogeneous wireless networks over an Internet Protocol (IP) backbone. The recently sanctioned / ratified IEEE 802.21 Media Independent Handover standard intends to support seamless roaming amongst the various wireless access technologies, comprising of GSM, UMTS, WLAN, WiMAX, and Bluetooth, etc. through the different handover techniques. Several leading world's operators have already started deploying this approach. In January 2009, 4G network CLEAR was launched via the collaboration of Clearwire and Intel in Portland, Oregon, USA. Similarly, other major carriers such as AT&T are in the process of converting their existing networks into 4G by using a successor of UMTS – 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) standards [8].

4. The 4G Wireless Networks

The convergence of internet and wireless mobile communication accompanied by the massive growth in number of cellular subscribers has led mobility management to eventually emerge as a significant and challenging domain for wireless mobile communication over the internet. Mobility management enables serving networks to locate a roaming terminal for call delivery (i.e., *location management*) and ensures seamless connection as MT enters into new service area (i.e., *handover management*).

Several network operators and academic researchers have varying views pertaining to 4G network. These include the following prophetic viewpoints:

In Asia, Japanese predominant cellular operator NTT DoCoMo envisaged 4G by establishing the notion of MAGIC – Mobile Multimedia; Anytime / Anywhere / Anyone; Global Mobility Support; Integrated Wireless Solution; and Customized Personal Service that particularly deliberates on public systems and regards 4G as an extension of 3G cellular service. This is also referred to as a Linear 4G Vision, which implies a future 4G network possessing only a cellular infrastructure with extremely high data rates of up to 100 Mbps [18]. In particular, this is the present actual tendency in South Korea and China [19]. Nevertheless, if 4G is treated as the successor of earlier generations, it couldn't be only confined to cellular systems.

European Commission (EC) offered a Concurrent 4G Vision – ensuring seamless service among(st) a multitude of wireless systems and an optimum delivery via most appropriate available network [9]. Nonetheless, it had not provided any underlying methodology for justifying such a broad version of this definition [10, 20].

Technical perspectives of 4G have been envisaged in [21], wherein, a 4G feature framework has been proposed based on kernel concept of integration. Two key features, diversity (both internal and external) and the adaptability of three targets (i.e., terminals, applications, and network) has been deliberated in depth.

A clear pragmatic vision of the 4G was provided by [18] in terms of a user-centric methodology / system that regards users as a cornerstone in design of 4G and identifies their functional needs and expectations in their daily lives with regards to the products and services (i.e., based on the societal customs, habits, norms, subjective preferences, motivations, etc.). This results in mapping a fundamental user scenario that extrapolate and interrelate the key features of 4G expressed in terms of system design, services, and devices [1, 16].

The ITU's Radiocommunication Sector (ITU-R) is still in the process of establishing a globally accepted and agreed definition of the 4G in consultation with its diverse stakeholder groups. Several 'Working Party Sessions' have already been convened, as to what should be encompassed in the nucleus of a 4G System (or the International Mobile Telecommunication Advanced – IMT Advanced as defined by ITU) so that technologies in the near future could earn the right to be categorized into this group [22]. By the mid of 2008, ITU has explicitly specified the said 4G requirements, which mainly includes [23-28]:

- *4G Systems would be an All Internet Protocol Based Packet Switched Network providing seamless communication / mobility anywhere and anytime;*
- *4G Systems will provide peak data rates at the lower transmission costs. The peak bit rates would be approximately 100 Mbps for high mobility (i.e., mobile access) and 1 Gbps for low mobility (i.e., local wireless access or hot-spots);*
- *4G Systems will provide seamless mobility / smooth handovers across a multitude of diverse heterogeneous wireless networks in an Always Best Connected (ABC) paradigm;*
- *4G Systems will be utilizing scalable channel bandwidth of 5-20 MHz, with an option of maximum up to 40 MHz;*
- *4G Systems will be capable of offering / supporting high quality-of-service (QoS) for the next generation multimedia support; and*
- *4G Systems will dynamically share and intelligently utilize the available network resources as to support more simultaneous users per cell.*

At present, there are only two families of standards that fit in the bill, i.e., LTE Advanced and WiMAX Release 2. Though High Speed Packet Access (HSPA) and Evolved High Speed Packet Access (HSPA+) are marketed by various network operators as 4G services in various parts of the world, but they are not considered 4G in the true sense [29-32].

5. Conclusion and Future Directions

We are living in a swiftly changing world, wherein, mobile communication technology has evolved from being fairly expensive and for a few selected indiviuals to eventually in a ubiquitous system available at *'anytime and anywhere to anyone'* via several mediums including, but not limited to, emails, instant messages, voice, and video, etc. Users now intend to share the crucial life experiences, news, and ideas on debatable issues with their peers through various social networking modes by employing their intelligent handheld cellular devices. Furthermore, the paradigm of *Embedded Internet* has also expanded its reach from human beings to smart machines; and thus the wireless industry now aims to retain billions of smart machines seamlessly connected to a global network, eventually realizing the vision of *Internet of Everything*.

This manuscript is a significant and most updated effort in order to trace down key trends and fundamental wireless communication technologies that have powered the rapid growth of wireless industry over the past several decades. While 4G technology has not yet been realized in its true sense – several telecom operators worldwide have already started taking steps in a relentless pace and debating over the launch of Fifth Generation (5G) and Sixth Generation (6G) technologies by the end of year 2020.

In short, the wireless tribe is undoubtedly ravenous when it comes to a'*Generation Game*'.

References

[1] X. Yan (2010). *Optimization of Vertical Handover Decision Processes for Fourth Generation Heterogeneous Wireless Networks.* Ph.D. Dissertation, Monash University, Australia.

[2] M. Kassar, B. Kervella, and G. Pujolle (2008). *An Overview of Vertical Handover Decision Strategies in Heterogeneous Wireless Networks.* Computer Communications, 31(10), pp. 2607-2620.

[3] K. Taniuchi, Y. Ohba, V. Fajardo, S. Das, M. T. C. Yuu-Heng, A. Dutta, D. Baker, M. Yajnik, and D. Famolari (2009). *IEEE 802.21: Media Independent Handover: Features, Applicability, and Realization.* IEEE Communications Magazine, 47(1), pp. 112-120.

[4] T. L. Singal (2010). *Wireless Communications.* New Delhi, India: Tata McGraw Hill Education Private Limited.

[5] I. S. Mishra (2013). *Wireless Communications & Networks: 3G and Beyond*. 2nd Edition, India: McGraw Hill Education Private Limited.

[6] W. R. Young (1979). *Advanced Mobile Phone Service: Introduction, Background, and Objectives.* Bell System Technical Journal, 58(1), pp. 1-14.

[7] K. Tacikawa (Eds.) (2002). *W-CDMA Mobile Communications System.* Chichester, West Sussex, England: John Wiley & Sons Ltd.

[8] A. R. Mishra (2004). *Fundamentals of Cellular Network Planning and Optimisation: 2G / 2.5G / 3G ... Evolution to 4G.* Chichester, West Sussex, England: John Wiley & Sons Ltd.

[9] T. Mshvidobadze (2012). *Evolution Mobile Wireless Communication and LTE Networks.* In: Proceedings of Sixth International Conference on Application of Information and Communication Technologies, pp. 1-7, Tbilisi, Georgia.

[10] J. M. Pereira (2000). *Fourth Generation, Now, It is Personal.* In: Proceedings of IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications, 2, pp. 1009-1016, London, United Kingdom.

[11] D. N. Knisely, Q. Li, and N. Ramesh (2002). *CDMA2000: A Third-Generation Radio Transmission Technology*. Bell Labs Technical Journal, 3(3), pp. 63-78.

[12] W. Webb (2001). *The Future of Wireless Communications.* Norwood, Massachusetts, United States: Artech House Inc.

[13] L. Garber (2002). *Will 3G Really Be the Next Big Wireless Technology*. Computer, IEEE Computer Society, 35, pp. 26-32.

[14] E. S. Navarro, V. W. S. Wong, and Y. Lin (2007). *A Vertical Handoff Decision Algorithm for Heterogeneous Wireless Networks.* In: Proceedings of IEEE Wireless Communications and Networking Conference, pp. 3199-3204, Kowloon, Hong Kong.

[15] A. Hasswa, N. Nasser, and H. Hassanein (2007). *A Seamless Context-Aware Architecture for Fourth Generation Wireless Networks*. Wireless Personal Communications, 43(3), pp. 1035-1049.

[16] X. Yan, Y. A. Şekercioğlu, and S. Narayanan (2010). *A Survey of Vertical Handover Decision Algorithms in Fourth Generation Heterogeneous Wireless Networks*. Computer Networks, 54(11), pp. 1848-1863.

[17] R. Hussain, S. A. Malik, S. Abrar, R. A. Riaz, and S. A. Khan (2012). *Minimizing Unnecessary Handovers in a Heterogeneous Network Environment. PRZEGLĄD ELEKTROTECHNICZNY (Electrical Review)*, Vol. 88, No. 6, pp. 300-303.

[18] S. Frattasi, H. Fathi, F. H. P. Fitzek, R. Prasad, and M. D. Katz (2006). *Defining 4G Technology from the Users Perspective.* IEEE Network, 20(1), pp. 35-41.

[19] F. Bauer *et al.* (2003). *Synthesis Report on Worldwide Research on 4G Systems.* Del. D7.1 1ST MATRICE *[retrieved online on Feb. 22, 2017 from http://istmatrice.org]*.

[20] J. Schwarz Da Silva (2000). *Beyond IMT-2000.* CEC DG-INFSO, Brussels, Belgium.

[21] J. Z. Sun, J. Sauvola, and D. Howie (2001). *Features in Future: 4G Visions from a Technical Perspective.* IEEE Global Telecommunications Conference, 6, pp. 3533-3537, San Antonio, Texas, United States.

[22] 3G Americas (2008). *Defining 4G: Understanding the ITU Process for the Next Generation of Wireless Technology. [http://tacs.eu/Analyses/Wireless%20Networks/Defining4G 2008.pdf]*.

[23] K. D. Wong (2011). *Fundamental of Wireless Communication Engineering Technologies.* New Jersey, United States: John Wiley & Sons.

[24] M. Ilyas and S. Ahson (Eds.) (2005). *Handbook of Wireless Local Area Networks - Applications, Technology, Security, and Standards.* Florida, United States: CRC Press, Taylor & Francis Group.

[25] E. Gustafsson and A. Jonsson (2003). *Always Best Connected.* Wireless Communications (IEEE Communications Society), 10(1), pp. 49-55.

[26] E. Piri and K. Pentikousis (2009). *Towards a GNU / LINUX IEEE 802.21 Implementation.* In: Proceedings of IEEE International Conference on Communications, pp. 1-5, Dresden, Germany.

[27] J. Stein (2006). *Survey of IEEE 802.21 Media Independent Handover Services [retrieved online on Feb. 22, 2017 from http://www.cse.wustl.edu/~jain/cse57406/ftp/handover.pdf]*.

[28] A. Agarwal, P. J. Pramod, and D. K. Jain (2011). *Implementation of IEEE 802.21 Based Media Independent Handover Services.* In: Proceedings of Asia Pacific Advanced Network, 32, pp. 71-78.

[29] U. D. Dalal and Y. P. Kosta (Eds.) (2009). *WIMAX New Developments.* Croatia: InTech Publishers.

[30] A. de la Oliva, I. Soto, A. Banchs, J. Lessmann, C. Niephaus, and T. Melia (2011). *IEEE 802.21: Media Independence Beyond Handover.* Computer Standards and Interfaces, 33(6), pp. 556-564.

[31] G. Lampropoulos, A. K. Salkintzis, and N. Passas (2008). *Media - Independent Handover for Seamless Service Provision in Heterogeneous Networks.* Communications Magazine (IEEE Communications Society), 46(1), pp. 64-71.

[32] R. Hussain, S. A. Malik, S. Abrar, R. A. Riaz, H. Ahmed, and S. A. Khan (2013). *Vertical Handover Necessity Estimation Based on a New Dwell Time Prediction Model for Minimizing Unnecessary Handovers to a WLAN Cell.* Wireless Personal Communications, 71(2), pp. 1217-1230.