IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 9, Issue 3, Ver. I (May - Jun. 2014), PP 88-94
www.iosrjournals.org

Comparative studies on 3G,4G and 5G wireless technology

Olumuyiwa Oludare FAGBOHUN
Department of Electrical & Electronic Engineering, Faculty of Engineering, Ekiti State University, Ado-Ekiti, Ekiti-State Nigeria.

Abstract: *The fifth generation wireless 5G development initiative is based upon 4G, which at present is struggling to meet its performance goals. The comparison between 3G and 4G wireless communication systems in relation to its architecture, speed, frequency band, switching design basis and forward error correction is studied, and were discovered that their performances are still unable to solve the unending problems of poor coverage, bad interconnectivity, poor quality of service and flexibility. An ideal 5G model to accommodate the challenges and shortfalls of 3G and 4G deployments is discussed as well as the significant system improvements on the earlier wireless technologies. The radio channel propagation characteristics for 4G and 5G systems is discussed. Major advantages of 5G network in providing myriads of services to end users personalization, terminal and network heterogeneity, intelligence networking and network convergence among other benefits are highlighted.The significance of the study is evaluated for a fast and effective connection and communication of devices like mobile phones and computers, including the capability of supporting and allowing a highly flexible network connectivity.*

Keywords: *Data rates, Interfacing, Mobile communications, Packet switching mode, Remote servers, Wireless networks*

I. Introduction

Wireless communications is one of the most active areas of technology development of our time. This development is being driven primarily by the transformation of what has been largely a medium for supporting voice telephony into a medium for supporting other services, such as the transmission of video, images, text, and data. Thus, similar to the developments in wire line capacity in the 1990s, the demand for new wireless capacity started growing at a very rapid pace. Although there are, of course, still a great many technical problems to be solved in wire line communications, demands for additional wire line capacity can be fulfilled largely with the addition of new private infrastructure, such as additional optical fibre, routers, switches, and so on. There has been considerable research effort in recent years aimed at developing new wireless capacity through the deployment of greater intelligence in wireless networks. A key aspect of this movement has been the development of novel signal transmission techniques and advanced receiver signal processing methods that allow for significant increases in wireless capacity without attendant increases in bandwidth or power requirements [1,2].The wireless network refers to any type of network that is not connected by cables of any kind. It is a method by which homes, telecommunications networks and enterprise (business) installations avoid the costly process of introducing cables into buildings, or as a connection between various equipment locations.Many years after the advent of wireless technology, the problem and hindrances of effective communication is still present. Many people around the world are now using the wireless communication and this has led to the congestion of network, low connectivity speed and low bandwidth. Without wireless networks, internet browsing, the usage of cellular phones which are part of everyday wireless networking that allows easy personal communications is impossible. Wireless networking is also applicable in inter-continental network systems and the use of radio satellites to communicate across the world. This technology allows for an alternative to installing physical network mediums such as, coaxial and fiber-optic cables, which are expensive. Wireless networking helps save the cost of installation of cable mediums, save time from physical installation, and also creates mobility for devices connected to a network [3].

Mobile and wireless networks have made tremendous growth in the last fifteen years. Nowadays many mobile phones are equipped with a WLAN adapter. In the nearest future many mobile phones will have WiMAX adapter, besides their 4G, 3G, WLAN, and Bluetooth adapters. Using IP for both 2.5G and 3G Public Land Mobile Networks (PLMN) on one side and WLAN on the other, raised research on their integration. Regarding the 4G, its focus is towards seamless integration of cellular networks such as GSM and 3G. Multimode user terminals are seen in 4G, but different security mechanisms and different QoS support in different wireless technologies remains a challenge [1,2]. However, integration among different wireless networks (e.g. PLMN and WLAN) is functioning in practice even today, with different wireless networks from a single terminal being used exclusively; that is, there is no combining of different wireless access technologies for a same session (e.g. FTP download). The proposed Open Wireless Architecture (OWA) in 5G is targeted to

provide open baseband processing modules with open interface parameters to support different architectures existing as well as future wireless communication standards. The OWA is targeted to MAC/PHY layers of future (5G) mobile terminals [3,4] . This referenced work provides a ground for definition of a concept beyond 4G mobile networks, as in the 5G mobile networks. In the proposed concept the mobile user is on the top of all. The 5G terminals have software defined radios and modulation scheme as well as new error-control schemes[3,5]. The development is seen towards the user terminals as a focus of the 5G mobile networks. The terminals have access to different wireless technologies at the same time and the terminal able to combine different flows from different technologies[4,6,7]. Each network responsible for handling user-mobility, while the terminal make the final choice among different wireless/mobile access network providers for a given service.

The fifth generation communication system is envisioned as the real wireless network, capable of supporting wireless World Wide Web (www) applications in 2010 to 2015 time frame. There are two views of 5G systems: evolutionary and revolutionary. In the evolutionary view the 5G (or beyond 4G) systems will be capable of supporting the www allowing a highly flexible network such as a Dynamic Adhoc Wireless Network (*DAWN*). In this view, advanced technologies including intelligent antenna and flexible modulation are keys to optimize the adhoc wireless networks. In revolutionary view, 5G systems would be an intelligent technology capable of interconnecting the entire world without limits [3,4,8]. An example application could be a robot with in-built wireless communication with artificial intelligence.

II. Method and Materials

A study of 3G and 4G wireless network was conducted with the use of referenced networking materials, and the 5G as a future preferred network was studied, to develop a comparative discussions among the 3 networks.

2.1 Wireless Network Studies

2.1.1 *The third generation 3G wireless Network*

3G wireless technology represents the convergence of various 2G wireless telecommunications systems into a single global system that includes both terrestrial and satellite components. One of the most important aspects of 3G wireless technologies is its ability to unify existing cellular standards, such as CDMA, GSM, and TDMA under one umbrella. The following three air interface modes accomplish this result: wideband CDMA, CDMA2000 and the Universal Wireless Communication (UWC-136) interface. Wideband CDMA (W-CDMA) is compatible with the current 2G GSM networks prevalent in Europe and parts of Asia. W-CDMA requires bandwidth of between 5 MHz and 10 MHz, making it a suitable platform for higher capacity applications[9,10]. It can be overlaid onto existing GSM, TDMA (IS-36) and IS95 networks. Subscribers are likely to access 3G wireless services initially via dual band terminal devices. WCDMA networks are used for high-capacity applications and 2G digital wireless systems are used for voice calls.

The second radio interface is CDMA2000 which is backward compatible with the second generation CDMA IS-95 standard predominantly used in US. The third radio interface, Universal Wireless Communications – UWC-136, also called IS-136HS, was proposed by the TIA and designed to comply with ANSI-136, the North American TDMA standard. 3G wireless networks consist of a Radio Access Network (RAN) and a core network. The core network consists of a packet-switched domain, which includes 3G SGSNs and GGSNs, which provides the same functionality that they provide in a GPRS system, and a circuit-switched domain, which includes 3G MSC for switching of voice calls. Charging for services and access is done through the Charging Gateway Function (CGF), which is also part of the core network. RAN functionality is independent from the core network functionality. The access network provides a core network technology independent access for mobile terminals to different types of core networks and network services [8,10]. Either core network domain can access any appropriate RAN service; e.g. it should be possible to access a "speech" radio access bearer from the packet switched domain. The Radio Access Network consists of new network elements, known as Node B and Radio Network Controllers (RNCs). Node B is comparable to the Base Transceiver Station in 2G wireless networks. RNC replaces the Base Station Controller.

2.1.2 *The fourth generation 4G wireless Network*

The fourth generation (4G) is a conceptual framework and a discussion point to address future needs of a high speed wireless network that can transmit multimedia and data and interface with wire-line backbone network perfectly just raised in 2002.The main distinguishing factors between 3G and 4G are the data rates, services, transmission ways, access technology to the Internet, the compatibility to interface with wire-line backbone network, quality of service and security. 4G can support at least 100 Mbps peak rates in full-mobility wide area coverage and 1Gbps in low-mobility local area coverage [3,5]. The speeds of 3G can be up to 2Mbps, which is much slower than the speeds of 4G [11,12].

2.1.3 *The fifth generation 5G wireless Network*

The 5G terminals will have software defined radios and modulation schemes as well as new error-control schemes that can be downloaded from the Internet. The development is seen towards the user terminals as a focus of the 5G mobile networks. The terminals will have access to different wireless technologies at the same time and the terminal will be able to combine different flows from different technologies. In 5G, each network will be responsible for handling user-mobility [13], while the terminal will make the final choice among different wireless/mobile access network providers for a given service. Such choice will be based on open intelligent middleware in the mobile phone.

2.1.4 *The 5G Nanocore*

The 5G Nanocore is a convergence of the below mentioned technologies. These technologies have their own impact on exiting wireless network which makes them in to 5G. They areNanotechnology, Cloud Computing, All IP Platform.Nanotechnology is the application of nano-science to control process on nanometer scale i.e. between 0.1 and 100nm. The field is also known as molecular nanotechnology (MNT). MNT deals with control of the structure of matter based on atom-by-atom and molecule by molecule engineering [6,9].
Nanotechnology has shown its impact on both mobile as well as the core network. Apart from this, it has its own impact on sensor as well as security. This is considered as a most significant in telecommunication.Cloud computing is a technology that uses the internet and central remote server to maintain data and applications. In 5G network, this central remote server will be our content provider. Cloud computing allows consumers and business to use applications without installation and access their personal files at any computer with internet access. The same concept is going to be used in Nanocore where the user tries to access his private account from a global content provider through Nanocore in form of cloud. The development of cloud computing provides operators with tremendous opportunities. Since cloud computing relies on the networks, it shows the significance of networks and promotes network development.It also requires secure and reliable service providers, capabilities that operators have deep expertise in. Operators can enter the cloud computing market and create new value-added services and experiences by integrating industry content and applications in the digital supermarket model. This could make users to obtain much more real-time application to utilize his 5G network efficiently [14].

2.1.5*Features of 5G Technology*

5G technology offer high resolution for cell phone users and bi-directional large bandwidth. The advanced billing interfaces of 5G technology makes it more attractive and effective. 5G technology also provides subscriber supervision tools for fast action. The high quality services of 5G technology based on Policy to avoid error. 5G technology is providing large broadcasting of data in Gigabit which will support almost 65,000 connections. The traffic statistics by 5G technology makes it more accurate. Through remote management offered by 5G technology a user can get better and fast solution. The uploading and downloading speed of 5G technology touching the peak.

2.1.6 5G System Architecture

The system model that proposes the design of network architecture for 5G wireless systems, which is all-IP based model for wireless and mobile networks interoperability is as shown in Fig.1. The system consists of a user terminal and a number of independent, autonomous radio access technologies. Within each of the terminals, each of the radio access technologies is seen as the IP link to the outside internet world. However, there will be different radio interface for each Radio Access Technology (RAT) in the terminal.For example, if we want to have access to four different RATs, we need to have four different access specific interfaces in the terminal, and to have all of them active at the same time, with aim to have this architecture to be functional [1,4,6].Application connections are realized between clients and servers in the Internet via sockets. Internet sockets are endpoints for data communication flows. Each socket of the web is a unified and unique combination of local IP address and appropriate local transport communications port, target IP address and target appropriate communication port, and type of transport protocol. Considering that, the establishment of communication from end to end between the client and server using the Internet protocol is necessary to raise the appropriate Internet socket uniquely determined by the application of the client and the server. This means that in case of interoperability between heterogeneous networks and for the vertical handover between the respective radio technologies, the local IP address and destination IP address will be fixed and unchanged. Fixing of these two parameters will ensure handover transparency to the Internet connection end-to-end, when there is a mobile user at least on one end of such connection. In order to preserve the proper layout of the packets and to reduce or prevent packets losses, routing to the target destination and vice versa will be uniquely using the same path [8,11,14].

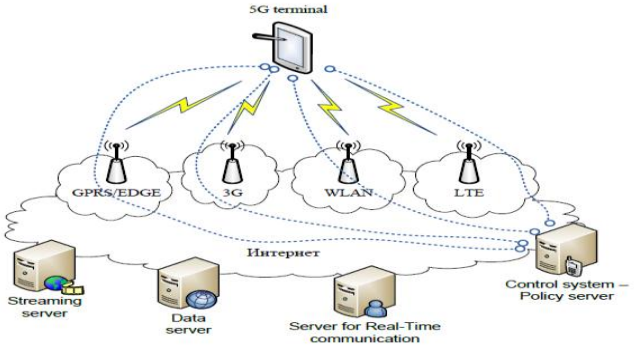

Figure 1. Functional Architecture for 5G Systems [1,4].

Each radio access technology that is available to the user in achieving connectivity with the relevant radio access is presented with appropriate IP interface. Each IP interface in the terminal is characterized by its IP address and net mask and parameters associated with the routing of IP packets across the network. In regular inter-system handover the change of access technology (i.e., vertical handover) would mean changing the local IP address. Then, change of any of the parameters of the socket means closing the socket and opening a new one. This means, ending the connection and starting a new one. This approach is not-flexible, and it is based on today's Internet communication. To enable the functions of the applied transparency and control or direct routing of packets through the most appropriate radio access technology, in the proposed architecture, a control system is introduced in the functional architecture of the networks, which works in complete coordination with the user terminal and provides a network abstraction functions and routing of packets based on defined policies. At the same time this control system is an essential element through which it can determine the quality of service for each transmission technology. It is on the Internet side of the proposed architecture, and as such represents an ideal system to test the qualitative characteristics of the access technologies, as well as to obtain a realistic picture regarding the quality that can be expected from applications of the user towards a given server in Internet (or peer).

III. Comparative studies on 3G and 4G Networks

3.1. *Comparisms between 3G and 4G network*

The biggest difference between the two is in the existence of compliant technologies. There are a bunch of technologies that fall under 3G, including WCDMA, EV-DO, and HSPA among others. Although a lot of mobile phone companies are quick to dub their technologies as 4G, such as LTE, WiMax, and UMB, none of these are actually compliant to the specifications set forth by the 4G standard. These technologies are often referred to as Pre-4G or 3.9G.4G speeds are meant to exceed that of 3G. Current 3G speeds are topped out at 14Mbps downlink and 5.8Mbps uplink. To be able to qualify as a 4G technology, speeds of up to 100Mbps must be reached for a moving user and 1Gbps for a stationary user. So far, these speeds are only reachable with wired LANs [14,15].

Another key change in 4G is the abandonment of circuit switching. 3G technologies use a hybrid of circuit switching and packet switching. Circuit switching is a very old technology that has been used in telephone systems for a very long time. The downside to this technology is that it ties up the resource for as long as the connection is kept up. Packet switching is a technology that is very prevalent in computer networks but has since appeared in mobile phones as well. With packet switching, resources are only used when there is information to be sent across. The efficiency of packet switching allows the mobile phone company to squeeze more conversations into the same bandwidth. 4G technologies would no longer utilize circuit switching even for voice calls and video calls. All information that is passed around would be packet switched to enhance efficiency.

3.2. *Comparative quotient between 5G and 4G*

4G and 5G wireless access technologies offers Ethernet speed on mobile devices to experience the triply play services as explained above. LTE and WiMAX are two different technologies to achieve 4G defined speeds. New standard proposals or releases beyond 4G are submitted to standard bodies like 3GPP, WiMAX Forum or ITU-R. Ideal 5G model will accommodate the challenges and accommodate the short falls of the 4G Technology and 4G deployment experiences.

Table 1:Comparism between 3G and 4G.

Major requirement driving architecture	3G (Including 2.5G, Sub3G)	4G
	Predominantly voice driven; data was always add on	Converged data and voice over IP
Network Architecture	Wide area cell-based	Hybrid: Integration of wireless LAN (WiFi, Bluetooth) and wide area
Speeds	384 Kbps to 2 Mbps	20 to 100 Mbps in mobile mode
Frequency Band	Dependent on country or continent (1800-2400 MHz)	Higher frequency bands (2-8 GHz)
Bandwidth	5-20 MHz	100 MHz (or more)
Switching Design Basis	Circuit and Packet	All digital with packetized voice
Access Technologies	W-CDMA, 1xRTT, Edge	OFDM and MC-CDMA (Multi Carrier CDMA)
Forward Error Correction	Convolutional rate 1/2, 1/3	Concatenated coding scheme
Component Design	Optimized antenna design, multi-band adapters	Smarter Antennas, software multiband and wideband radios
IP	A number of air link protocols, including IP 5.0	All IP (IPv6)

To understand the necessities and uses of 5G could be raised once the 4G rollout is completed and experienced. Thus typical 5G concept would be raised in somewhere around 2013-2015. Expected speed will be multiple of Gigabit Ethernet [10,12]. This technology would be mainly used in back hauling telecom networks rather than end user access. 4G offers theoretically closer to Gigabit Ethernet whereas users expect multiple Gigabit speed from 5G.

IV. Advantages of 5G communication systems as a future preferred network

5G aims at providing myriad of services to the end users at high speed. The applications developed to avail these services are highly user friendly minimizing the interaction between the application and the user. For example, integration of speech recognition technology in the user interfaces would ease the use of the applications for every layman.

4.1. ***User personalization*****:** High data transfer rates and ubiquitous coverage of 5G networks would provide users access to large repository of data and services. Users would have flexibility to filter these data and services as per his preferences by configuring the operational mode of their devices, so that he can preselect the service features he wants to use. For an example, user in a mall interested in buying clothes should receive alerts about various discount offers on clothes rather than about the other accessories.

4.2. ***Terminal and Network heterogeneity*****:** Terminal heterogeneity refers to the different types of terminals in terms of the size, weight, display features, power consumption, etc. Network heterogeneity means the different types of access networks like WiMAX, Wi-Fi (Wireless Fidelity), UMTS (Universal Mobile Telecommunications System) and so forth which differ in their coverage area, data rate, latency and data loss rate.

Each of these terminals and services cater to different user requirements. In 5G, all these terminals and networks will provide common services independent of their capabilities. This is also called as service personalization.

4.3. ***High Performance:***Low transfer rates of 4G restrict the user's ability to take advantage of the rich multimedia contents across the wireless networks. 5G is expected to provide wireless download speeds of above 1Gbps in local area network (LAN) and 500 Mbps in wide area network (WAN), about 260 times greater than the 3G wireless networks.

4.4. Interoperability: Multiple standards of 4G restrict the user's mobility and interoperation across different networks. 5G targets at providing a unified global standard which will facilitate global mobility and service portability. In other words, end user can subscribe to different services from different service providers using the same mobile device.

Table 2: General table of comparism of 1G to 5G technologies [5,8].

Technology/Features	**1G**	**2G/2.5G**	**3G**	**4G**	**5G**
Start/ Development	1970/ 1984	1980/ 1999	1990/ 2002	2000/ 2010	2010/ 2015
Data Bandwidth	2 kbps	14.4-64kpbs	2 Mbps	2000 Mbps to1 Gbps for low mobility	1 Gbps and higher
Standards	AMPS	2G:TDMA, CDMS, GSM 2.5:GPRS, EDGE, 1xRTT	WCDMA, CDMA-2000	Single unified standard	Single Unified standard
Technology	Analog Cellular technology	Digital cellular technology	Broad bandwidth CDMA, IP technology	Unified IP and seamless combination of broadband, LAN/WAN/PAN and WLAN	Unified IP and Seamless combination of broadband, LAN/WAN/PAN /WLAN and wwww
Service	Mobile Telephony (voice)	2G: Digital voice, Short Messaging 2.5G: Higher capacity Packetized data	Integrated Higher Quality audio, video and data	Dynamic Information Access, Wearable devices	Dynamic Information Access, wearable device with IA capabilities
Multiplexing	FDMA	TDMA, CDMA	CDMA	CDMA	CDMA
Switching	Circuit	2G: Circuit 2.5G: Circuit for access network & air interface; packet for core network and data	Packet except circuit for air interface	All packet	All packet
Core Network	PSTN	PSTN	Packet network	Internet	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal and vertical	Horizontal and vertical

4.5.*Intelligent Networking:* 4G is based primarily on cell or base station WAN design. 5G aims at building hybrid networks utilizing both the Wireless LAN concept and WAN design. Thus, the world would have base stations everywhere providing ubiquitous network coverage to users at high speed. For example, a user walking on road is browsing internet using GPRS (General Packet Radio Service-WAN design). The moment he enters a mall with Wi-Fi (LAN design), seamless hand-over from GPRS to Wi-Fi would take place without the user's knowledge.

4.6. ***Network Convergence:*** Network convergence is the efficient coexistence of multimedia, voice and data communication within a single network. Currently the telecommunication environment is divided into wireless and fixed line communication. To avail these different kinds of services, the end user require different devices such as cellular phones, fixed line phones, laptops and PDA's. Once the fixed mobile convergence is in place in 5G, the distinction between these services will disappear. The current 4G technology is not able to capture the market share as done by the fixed line services partly because of its low bit rates of 384kbps and because of the high costs associated with these services. But with the emergence of 5G aiming at global integrated IP based network, the wireless sector will be able to match the fixed line sectors in terms of both costs and speed. 5G will lead to convergence in terms of both devices and services.

4.7. ***Lower power consumption:*** Battery technology has not been able to keep pace with the growing telecom industry. 3G devices required one battery while 4G required two batteries. Battery drain is a persistent problem of wireless devices. 5G aims at breaking this directly proportional rule. Shorter communication links is one of the few solutions proposed to cater to this requirement.

V. Threats of 5G implementation

The following threats are expected from the application implementation of 5G network as a future system;

i). Since all the network operators and service providers would share a common core network infrastructure, compromise of a single operator will lead to the collapse of the entire network infrastructure, if not carefully guide against.

ii). Third-parties can masquerade as legitimate users resulting in theft of service and billing frauds can easily arise.

iii). Since 5G is a secure IP based solution it will be vulnerable to all the security threats as the current Internet world.

iv). On the lines of email-spam, the Spam over Internet telephony (SPIT), the new spam over VoIP may become serious and become serious threats.

v). Spooling attacks can lead to misdirected communication and internet banking related frauds.
vi). Eavesdropping and interception of private communications.
vii). Phishing attacks, stealing bank account details and other secured information, are more likely.

VI. Government support for actualization of 5G deployment in Nigeria

The government through the Nigeria communications commission (NCC) should sanction any wireless service provider that fails to pay attention to quality of service. The government should also provide enabling environment for investors in the communication industry i.e. Provision of necessary social amenities e.g. Regular power supply should be adequately provided to reduce cost of running communication investments, likewise the burden of double tax should be resolved. Also, NCC should issue more telecommunication license to qualified bidders to increase competition among service providers. The government should make use of the Nigerian Sovereign Wealth Investment Authority Bill which is statutorily charged inter alia with the mandate to enhance the development of Nigerian infrastructure by establishing the Nigerian Infrastructure Fund. The Nigerian Infrastructure Fund is part of the Nigerian Sovereign Wealth Investment Fund and is primarily set up to support the development of basic, essential and critical infrastructures in Nigeria (such as mobile telecommunication networks) in order to stimulate the growth and diversification of the Nigerian economy and create jobs for Nigerians. Hence, Part of the Infrastructures Fund should be applied to funding projects expanding mobile networks by building additional base stations only in geographic areas where QoS parameters such as coverage, service accessibility and service retain ability are perceived by mobile telecommunications users to be low.

VII. Conclusion

During the course of examining the performance of the previous wireless communication systems in this study, it was discovered that they are still unable to solve the unending problems of communications such as poor coverage, bad interconnectivity, poor quality of service and flexibility. The advent of 5G will revolutionize the field of communication domain, bringing wireless experience to a completely new level. It will provide wealth of features and services making the world a smaller place to live. The mobile terminals of the 5G have more processing power and more memory on board. It is expected that the initial Internet philosophy of keeping the network simple as possible, and giving more functionalities to the end nodes, will become a reality in the fifth generation wireless system (5G). This technology helps to promote stronger links between people working in different fields creating future concepts of mobile communication, internet service, cloud computing and nanotechnology.

References

[1] G. Abdullah, L. Xichun, Lina Yang, Omar Zakaria, and NorBadrulAnuar, Multi-Bandwidth Data Path Design for 5GWireless Mobile Internets, 6(2), ISSN: 1790-0832. 2009
[2] F.G. Bria, 4th Generation Wireless Infrastructures: Scenarios and Research Challenges, IEEE Personal Communications, 8(1), 2010
[3] T. Janevski,5G Mobile Phone Concept, Consumer Communications and Networking Conference, 6th IEEE [1-4244-2308-2], 2009
[4] W. W. Lu, An Open Baseband Processing Architecture for Future Mobile Terminals Design, IEEE Wireless Communications,2008
[5] H. Honkasalo, WCDMA and WLAN for 3G and Beyond,IEEE Wireless Communications, 9(2), 2002, 14 – 18.
[6] M. Zeng, A. Annamalai, V.K. Bhargava,Recent Advances in Cellular Wireless Communications,IEEE Communications Magazine, 37(9), 1999, 128-138.
[7] J. Ibrahim, 4G Features," Bechtel Telecommunications Technical Journal, 1(1), 2002, 11-14.
[8] R. Berezdivin, R. Breinig, and R. Topp, Next Generation Wireless Communications Concepts and Technologies,IEEE Communications Magazine, 40(3), 2002, 108-116.
[9] R. Berezdivin., and W.W. Lu,Technologies on Fourth Generation Mobile Communications, IEEE Wireless Communications, 9(2), 2002, 8-71
[10] T.S. Rappaport, A. Annamalai, R.M. Buehrer, and W.H. Tranter, Wireless Communications: Past Events and a Future Perspective," IEEE Communications Magazine, 50th Anniversary Issue. 2002
[11] T.B. Zahariadis,and D. Kazakos,Evolution toward 4G Mobile Communication Systems, IEEE Wireless Communications, 10(4), 2003
[12] Daniel Minoli, Nanotechnology Applications to Telecommunications and Networking, Nanotechnologies for Future Mobile Devices,Tapaniryha- nen Nokia Research Center, Cambridge. 2010
[13] T.B. Zahariadis,Migration towards 4G wireless communications," IEEE Wireless Communications, 11(3), 2009, 6-7.
[14] B. F. Gessler, O. Queseth, R. Stridth, M. Unbehaun, J.Wu, J.Zendler, "4th Generation Wireless Infrastructures: Scenarios and Research Challenges", IEEE Personal Communications, 8(2), 2010. Web Sites
[15] Global Systems for Mobile Communication (GSM) Association.
[16] International Telecommunications Union (ITU), http://www.itu.orgvisited 21-11-2012
[17] CDMA Development Group, http://www.cdg.orgvisited 10-01-2013
[18] Institute of Electrical and Electronics Engineers (IEEE), http://www.ieee.org visited 28-01-2013
[19] International Standards Organization (ISO), http://www.iso.org visited 28-01-2013
[20] Wikipedia. visited 18-02-2013