Evolutionary Study and Performance Analysis of Generations in Wireless Technolgy

Vikram M. Kakade,
Lecturer, Department of Electronics and Telecommunition,
P.R.M.C.E.A.M, Badnera, Amravati.

Abstract— In today's world mobile communication has become the burning topic in wireless technology and the generation is evolving according to need in mobile communication there has been explosion of diverse devices with smart capabilities. Vendors and users want better wireless networking technology to take advantage of device during this time; the technology has attracted many users and has undergone numerous changes, including internet connectivity. More industry experts had already said that every next generation in wireless technology will offer more bandwidth, security, and reliability making it more suitable for multimedia, e-commerce, video conferencing, and other advance applications. For achieving the need of this applications 1^{st} , 2^{nd} , 3^{rd} , 4^{th} Generation are developed accordingly. In this Generation's high data rate services, a new 4G system, possibly based on new radio access technology is currently envisioned. In this paper we are going to study the real and precise need behind the evolution of every generation technology and specifically 3^{rd} and 4^{th} Generation with its types and experimental work done on them.

Index Terms— 1G,2G,3G,GSM,TDMA,CDMA,WCDMA,CDMA2000,TD-CDMA,3G-UMTS,4G.

1 Introduction

The last few years have witnessed a phenomenal growth in the wireless industry, both in terms of mobile technology and its Subscribers. There has been a clear shift from fixed to mobile cellular telephony, especially since the turn of the century. By the end of 2010, there were over four times more mobile cellular subscriptions than fixed telephone lines.

Both the mobile network operators and vendors have felt the importance of efficient networks with equally efficient design. This resulted in Network Planning and optimization related services coming in to sharp focus [14, 15].With all the technological advances, and the simultaneous existence of the 2G, 2.5G and 3G networks, the impact of services on network efficiency have become even more critical. Many more designing scenarios have developed with not only 2G networks but also with the evolution of 2G to 2.5G or even to 3G networks. Along with this, inter-operability of the networks has to be considered [16].1G refers to analog cellular technologies; it became available in the 1980s. 2G denotes initial digital systems, introducing services such as short messaging and lower speed data. CDMA2000 1xRTT and GSM are the primary 2G technologies, although CDMA2000 1xRTT is sometimes called a 3G technology because it meets the 144 kbps mobile throughput requirement. EDGE, however, also meets this requirement. 2G technologies became available in the 1990s.

• Vikram M. Kakade,
Lecturer, Department of Electronics and Telecommunition,
P.R.M.C.E.A.M, Badnera, Amravati, Maharashtra, India,
E-mail:vikramkakade.160@gmail.com

3G requirements were specified by the ITU as part of the International Mobile Telephone 2000 (IMT-2000) project, for which digital networks had to provide 144 kbps of throughput at mobile speeds, 384 kbps at pedestrian speeds, and 2 Mbps in indoor environments. UMTS-HSPA and CDMA2000 EV-DO are the primary 3G Technologies, although recently WiMAX was also designated as an official 3G technology. 3G technologies began to be deployed last decade. Source: ITU World Telecommunication/ICT Indicators database. Fig. 1: Global ICT Developments, 2000-2010 [14] The ITU has recently issued requirements for IMT-Advanced, which constitutes the official definition of 4G. Requirements include operation in up-to-40 MHz radio channels and extremely high spectral efficiency. The ITU recommends operation in upto 100 MHz radio channels and peak spectral efficiency of 15bps/Hz, resulting in a theoretical throughput rate of 1.5 Gbps. Previous to the publication of the requirements, 1 Gbps was frequently cited as a 4G goal. No available technology meets these requirements yet. It will require new technologies such as LTE-Advanced (with work already underway) and IEEE 802.16m. Some have tried to label current versions of WiMAX and LTE as "4G", but this is only accurate to the extent that such designation refers to the general approach or platform that will be enhanced to meet the 4G requirements. With WiMAX and HSPA significantly outperforming 3G requirements, calling these technologies 3G clearly does not give them full credit, as they are a generation beyond current technologies in capability. But calling them 4G is not correct. Unfortunately, the generational labels do not properly capture the scope of available technologies and have resulted in some amount of market confusio[12].

2. First Generation System (Analog)

In 1980 the mobile cellular era had started, and since then Mobile communications have undergone significant changes and experienced enormous growth.First-generation mobile systems used analog transmission for speech services. In 1979, the first cellular system in the world became operational by Nippon Telephone and Telegraph (NTT) in Tokyo, Japan. Two years later, the cellular epoch reached Europe. The two most popular analogue systems were Nordic Mobile Telephones (NMT) and Total Access Communication Systems (TACS). Other than NMT and TACS, some other analog systems were also introduced in1980s across the Europe. All of these systems offered handover and roaming capabilities but the cellular networks were unable to interoperate between countries. This was one of the inevitable disadvantages of first-generation mobile networks. In the United States, the Advanced Mobile Phone System (AMPS) was launched in 1982. The system was allocated a 40-MHz bandwidth within the 800 to 900 MHz frequency rangeby the Federal Communications Commission (FCC) for AMPS.In 1988, an additional 10 MHz bandwidth, called Expanded Spectrum (ES) was allocated to AMPS. It was first deployed in Chicago, with a service area of 2100 square miles2. AMPS offered 832 channels, with a data rate of 10 kbps. Although Omni directional antennas were used in the earlier AMPS implementation, it was realized that using directional antennas would yield better cell reuse. In fact, the smallest reuse factor that would fulfill the 18db signal-to-interference ratio (SIR) using 120-degree directional antennas was found to be 7. Hence, a 7-cell reuse pattern was adopted for AMPS. Transmissions from the base stations to mobiles occur over the forward channel using frequencies between 869-894 MHz. The reverse channelis used for transmissions from mobiles to base station, using frequencies between 824-849 MHz. AMPS and TACS use the frequency modulation (FM) technique for radio transmission. Traffic is multiplexed onto an FDMA (frequency division multiple access) system [17, 18].

3. The Second Generation System (Digital)

The dominant wireless-networking technology during the past few years has been 2G technology, which is digital, circuit-based, and narrowband but suit- able for voice and limited data communications. Second-generation (2G) mobile systems were introduced in the end of 1980s. Low bit rate data services were supported as well as the traditional speech service. Compared to first-generation systems, second-generation (2G) systems use digital multiple access technology, such as TDMA (time division multiple access), GSM and CDMA (code division multiple access).

3.1 TDMA

Time-division multiple-access technology, used primarily in the US, increases bandwidth by dividing each cellular channel into three time slots (a technique known as time-division multiplexing), each of which handles a separate trans- mission. The channel then switches quickly from slot to slot, thereby handling three communications simultaneously.

3.2 GSM

Global System for Mobile Communications—the world's most popular 2G tech- nology, implemented in much of Europe and Asia—is also based on time-division multiplexing but uses wider carrier frequencies and eight, rather than three, time slots.

3.3 CDMA

Code-division multiple-access technology, developed by Qualcomm and used primarily in the US, does not divide a channel into subchannels, like TDMA. Instead, CDMA carries multiple transmissions simultaneously by filling the entire communications channel with data packets coded for various receiving devices. The packets go only to the devices for which they are coded.

4. The Third Generation System

Vendors are just beginning to activate third-generation networks for com- mercial purposes. Many sources say that 3G will be the wireless-networking technology of the future, offering data rates high enough for mobile users to work with multimedia Web content, videoconferencing, and e-commerce. 3G is fast, in part, because it uses a 5-MHz-wide carrier signal, rather than the 200- KHz-wide carrier that narrowband CDMA uses.

4.1 W-CDMA

Wideband code-division multiple access technology, an ITU standard derived from CDMA, is also known as IMT-2000 direct spread.

4.2 CDMA2000

This technology is a CDMA upgrade. CDMA2000 offers a migration path, beginning with CDMA2000 1X, which is considered by some sources to be a 2.5G technology because it offers maximum sub-3G data rates of 153.6 Kbits per second. During the next few years, users could move to 1xEV-DO (1x evo- lution, data only) and 1xEV-DV (1x evolution, data and voice), offering data rates up to 614 Kbits per second, and finally to 3x, which would provide the full 3G maximum throughput of 2.05 Mbits per second.

4.3 TD-CDMA

Timedivision CDMA developed and used primarily in China, combines time-division multiplexing and CDMA techniques**.**

4.4 ANALYSIS OF 3G

When transmitting 8 and 16 users the degradation on the received signals is more evident for the second case, since for several fiber lengths the results are worst, making transmission over 100 km impossible. The phase correction done at the receiver, for 8 users, leads to an oscillating performance behavior at short distances. The results are expressed before and after phase correction and some improvement are observed on the system performance by phase correction of the local carrier, as can be seen in Fig 2[1].

Performance analysis of the system when a different number of users are defined at the UMTS signal generator is discussed in Fig1 [1]. The results were obtainedfor 1, 8 and 16 users and the results obtained for the transmission of a single user show that until 110 km of fiber length, the transmission is possible assuring the 12% limit value for EVM.

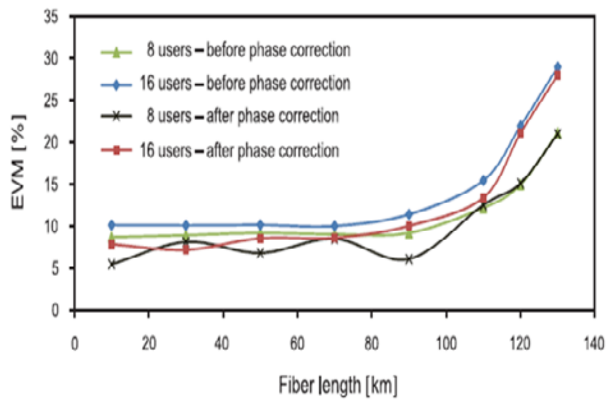

Fig. 1.Performance as function of fiber length for 8 and 16 user[1].

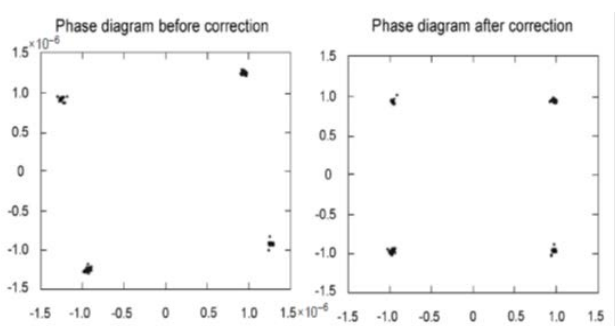

Fig. 2.UMTS Constellation obtain befor and after phase Correction[1].

5. Experimental Work On 3G-UMTS

The results obtained for the transmission of a single user show that until 110km of fiber length, the transmission is possible assuring the 12% limit value for EVM. The results are expressed before and after phase correction and some improvement are observed on the system performance by phase correction of the local carrier. When transmitting 8 and 16 users the degradation on the received signals is more evident for the second case, since for several fiber lengths the results are worst, making transmission over 100 km impossible. The phase correction done at the receiver, for 8 users, leads to an oscillating performance behavior at short distances.

To complement the simulation work on 3G-UMTS RoF links, we created an experimental scenario to conclude about the reliability of such a system.Illustratation is done Fig 3 and 4[1]. The radio frequency (RF) signals are provided through a Rohde and Schwartz vector signal generator that is used to directly modulate a laser, emitting at 1.55□m. In the WDM scenario, the RF signal is on one channel and the AM modulated one (an amplitude modulated ECL laser) 2 nm higher. The optical signal is then pre-amplified in both cases using a SOA (service oriented architecture) with an internal pump laser (1 nm below the RF channel) to control saturation, and transmitted over a standard single mode fiber. At the output, the RF signal channel is filtered, detected and applied to a vector signal analyzer to assess performance.

Considering the setup in Fig. 3, an SOA is used as a booster amplifier to amplify the optical channel together with a laser. The laser pump is used to saturate the SOA by varying its biasing current, providing the gain decrease. In this setup, it is also important to notice that before detecting and analyzing the RF signal it is needed to filter the 1550 nm DFB laser channel eliminating the pump laser and other spectral components originated by FWM.

The gain saturation of the SOA used is achieved with a laser pump at 1548.63 nm. The setup used is the one in Fig. 4 that considers the possible utilization of a control mechanism in order to maintain the SOA always at saturation. Anyway, this was not used and the SOA response without the pump laser and for different biasing currents of the pump was studied. The respective gain curves for the input power of the laser, for the different schemes, are illustrated in Fig. 5

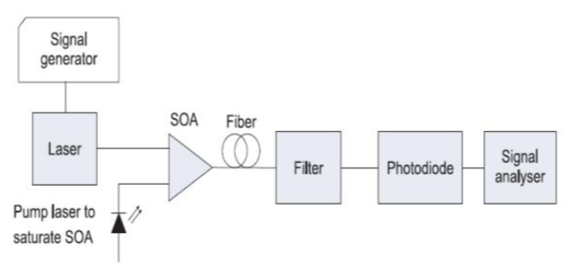

Fig. 3.Single Channel Setup[1].

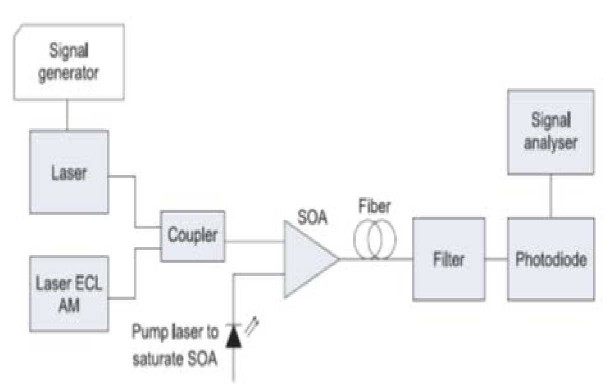

Fig. 4.WDM Setup[1].

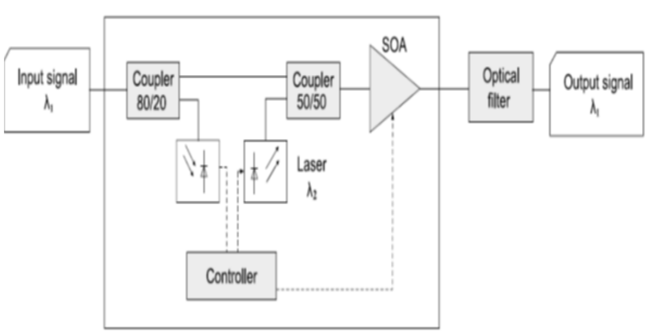

Fig. 5.The SOA Setup used[1].

For the different biasing currents, there is observed the SOA saturation behavior evidenced by its gain decrease and stabilization for the higher currents. Without the pump laser, the gain falls by 3 dB when the input signal reaches –11 dBm. For the other biasing currents the gain is mainly constant with the increase of the input signal power, showing that the amplifier is already in saturation.

In the setup used, the DFB laser biased with 20 mA or 30 mA presents an output power higher than 1 dBm, so the SOA will be saturated. Thus, when considering the pump laser, the SOA will be even more saturated, which effect can be confirmed by comparing the results for the two situations..

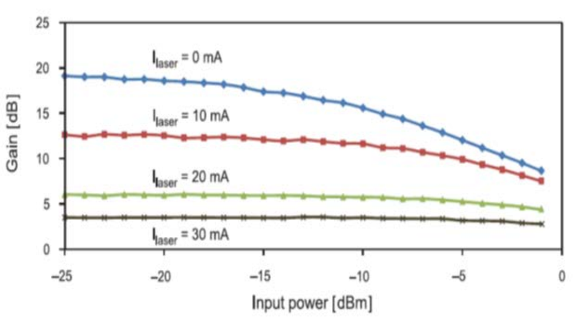

Fig. 6.SOA gain curves with the input power for Different biasing currentsof the pump laser[1].

6. Limitation To 3G

- **High costs**

Various governments in North America, Europe, and parts of Asia have auctioned off licenses to companies that want to use part of the limited 3G spectrum to provide communication. Industry observers say the desire to participate in the 3G market, whatever the cost, probably drove telecommu- nications companies to pay very high prices in the German and UK auctions. However, after the excitement from the auctions died down, financial firms began releasing sobering assessments of 3G's likely financial returns. Soon, credit ratings began falling for some companies that won 3G bids, and this endangered their ability to get loans to pay for the purchases. To recover their costs, some experts say, German and British telecommunications companies may charge consumers high fees for 3G services, which could discourage demand.

- **Qulaity of Working with data**

A problem is that 3G experiences a performance penalty that will affect ultimate user throughput. When all is said and done, predicted AT&T's Henry, "typical 3G users will get per- formance up to [only] 56 Kbits per sec- ond," the maximum speed of a PC's dial-up modem. A key to 3G's success will be how well it works with data, said Yu-Cheun Jou, vice president of technology at Qualcomm, the company that invented CDMA and a vendor of chipsets and other wireless-infrastructure technol- ogy. 3G will have to handle intensive data sets, such as those used in multi- media, because one of its principal pur- poses will be to take cellular phones beyond voice communications or simple data transfers.

- **Information content**

A key to any future wireless technol- ogy's success will be whether users can access interesting or important content with it, noted IBM's Naghshineh. In fact, said Li, "systems could suc- ceed or fail not because of the technology but because of the lack of desirable content." The issue is whether content pro- viders will be able to offer compelling material and whether users will want to bother accessing it over wireless, rather than traditional wireline, networks.

- **Lack of Application**

3G should have a killer app, but none has yet emerged, noted Mark Paxman, principal consultant in PA Consulting Group's wireless technology practice. Basic prediction done by him is that service provider and need of user demand applications.

7. Multiple Access Schemes (MIMO)

It has been demonstrated that MIMO technolo- gy has the potential to significantly improve the capacity and performance of a wireless system. Several space-time processing techniques have also been developed in recent years. Therefore, it is natural to combine two powerful technolo- gies, MIMO and OFDM, in the physical layer design. An attractive approach for the transmit diver- sity technique is space-time block code (STBC) [22] based on orthogonal design, which achieves full diversity with a simple linear maximum likelihood(ML) decoder. It utilizes orthogonal design to separate signals from different trans- mit antennas, and its decoding algorithm is very simple linear combining because of the orthogo- nality. On the other hand, spatial multiplexing techniques, such as Bell Laboratories layered space-time (BLAST) [21], that can dramatically increase the frequency efficiency have drawn considerable attention recently because they can provide high-data-rate communication without increasing transmission power and bandwidth.

In BLAST, a high-rate data signal is divided into a set of lower-rate streams, each of which is encoded, modulated, and transmitted at a different antenna. The receiver separates the different sig- nals using a spatial equalizer and an interference cancellation scheme. Furthermore, the number of antennas at a mobile terminal is often not greater than that at the base station because of limitations on hardware implementation at the terminal side in practice. It is fairly easy to apply BLAST on the uplink in MIMO systems since the number of receiver antennas a BLAST detec- tor requires is greater than or equal to the num- ber of independent transmit antennas. In the DL, combining spatial multiplexing with transmit diversity (i.e., combining BLAST with STBC) can reduce the number of receive antennas to half or less and achieve both increased data rate and more diversity gain.

8. Fourth Generation (All-IP)

The emergence of new technologies in the mobile commu nication systems and also the ever increasing growth of user demand have triggered researchers and industries to come up with a comprehensive manifestation of the up-coming fourth generation (4G) mobile communication system [11]. In contrast to 3G, the new 4G framework to be established will try to accomplish new levels of user experience and multi-service capacity by also integrating all the mobile technologies that exist (e.g. GSM - Global System for Mobile Communications, GPRS - General Packet Radio Service, IMT-2000 - International Mobile Communications, Wi-Fi - Wireless Fidelity, Bluetooth) [19]. The fundamental reason for the transition to the All-IP is to have a common platform for all the technologies that have been developed so far, and to harmonize with user expectations of the many services to be provided. The fundamental difference between the GSM/3G and All-IP is that the functionality of the RNC and BSC is now distributed to the BTS and a set of servers and gateways. This means that this network will be less expensive and data transfer will be much faster [16]. 4G will make sure about 2014-15.

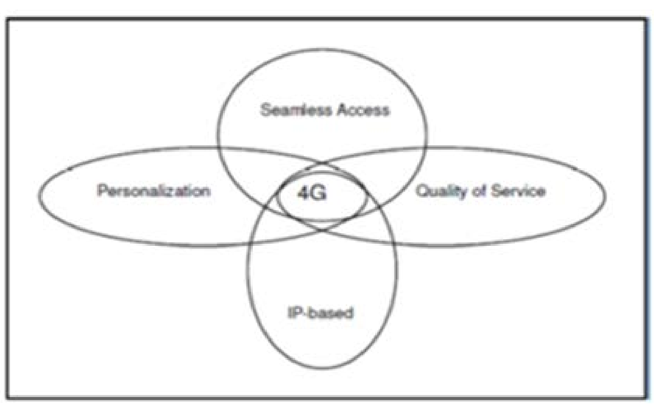

Fig. 7. The next generations of mobile system features [23].

"The user has freedom and flexibility to select any desired service with reasonable QoS and affordable price, anytime, anywhere." 4G mobile communication services started in 2010 but will become mass market in IMT-Advanced 4G standards will usher in a new era of mobile broadband communications, according to the ITU-R. IMT- Advanced provides a global platform on which to build next generations of interactive mobile services that will provide faster data access, enhanced roaming capabilities, unified messaging and broadband multimedia. According to ITU, "ICTs and broadband networks have become vital national infrastructure — similar to transport, energy and water networks — but with an impact that promises to be even more powerful and far-reaching. These key enhancements in wireless broadband can drive social and economic development, and accelerate progress towards achieving the United Nations' Millennium Development Goals, or MDGs." [20]. the current agreements on the requirements for IMT-Advanced are:

- Peak data rate of 1 Gbps for downlink (DL) and 500 Mbps for uplink (UL).
- Regarding latency, in the Control plane the transition time from Idle to Connected should be lower than 100ms. In the active state, a dormant user should take less than 10ms to get synchronized and the scheduler should reduce the User plane latency at maximum.
- Downlink peak spectral efficiency up to 15 bps/Hz and uplink peak spectral efficiency of 6.75 bps/Hz with an antenna configuration of 4 × 4 or less in DL and 2 × 4 or less in UL.
- The average user spectral efficiency in DL (with inter-site distance of 500m and pedestrian users) must be 2.2 bps/Hz/cell with MIMO 4× 2, whereas in UL the target average spectral efficiency is 1.4 bps/Hz/cell with MIMO 2 × 4.
- In the same scenario with 10 users, cell edge user spectral efficiency will be 0.06 in DL 4 × 2. In the UL, this cell edge user spectral efficiency must be 0.03 with MIMO 2 × 4.
- Mobility up to 350 km/h in IMT-Advanced.
- IMT-Advanced system will support scalable bandwidth and spectrum aggregation with transmission bandwidths more than 40MHz in DL and UL.
- Backward compatibility and inter-working with legacy systems.

8.1 Application of 4G

- **Tele-Medicine:** 4G will support remote health monitoring of patients. A user need not go to the hospital instead a user can get videoconference assistance for a doctor at anytime and anywhere.
- **Tele-geoprocessing applications:** This is a combination of GIS (Geographical Information System) and GPS (Global Positioning System) in which a user can get the location by querying.
- **Crisis management**: Natural disasters can cause break down in communication systems. In today's world it might take days or weeks to restore the system. But in 4G it is expected to restore such crisis issues in a few hours.
- **Education**: For people who are interested in lifelong education, 4G provides a good opportunity. People anywhere in the world can continue their education through online in a cost effective manner

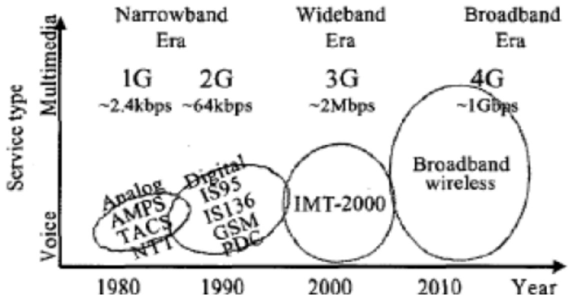

Fig. 8. : Evolution of Mobile Cellular Networks [13].

Table: 1G to 4G [23].

Generation	Requirements	Comments
1G	No official requirements. Analog technology.	Deployed in the 1980s.
2G	No official requirements. Digital Technology.	First digital systems. Deployed in the 1990s. New services such as SMS and low-rate data. Primary technologies include IS-95 CDMA and GSM.
3G	ITU's IMT-2000 required 144 kbps mobile, 384 kbps pedestrian, 2 Mbps indoors	Primary technologies include CDMA2000 1X/ EVDO and UMTS-HSPA. WiMAX now an official 3G technology.
4G	ITU's IMT-Advanced requirements include ability to operate in up to 40 MHz radio channels and with very high spectral efficiency.	No technology meets requirements today. IEEE 802.16m and LTE-Advanced being designed to meet requirements.

9. Conclusion

In wireless industry the need of users increasing day by day and ever increasing need from last few years had force researcher to come up to 4th generation in mobile communication system. Every developing generation is reducing the complexity and increasing data rate, application which is very useful for human beings. 1G the technology which was invented in 1970-80 is used analog type with CMRT and AMPS. 2G technology invented in 1990-2000 was having digital circuit switched technology. The 3rd generation mainly provides enhanced multimedia, streaming video capabilities. The last evolution in these generations is 4G which provide enhanced multimedia, streaming video capabilities with portability are increased still furthered. Speed in 4G reach up to 40Mbps.

The 4G network will encompass all systems from various networks, public to private; operator-driven broadband networks to personal areas; and ad hoc networks. The 4G systems will interoperate with 2G and 3G systems, as well as with digital (broadband) broadcasting systems. In addition, 4G systems will be fully IP-based wireless Internet which will provide access to wide range of telecommunication services, including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet based, along with a support for low to high mobility applications and wide range of data rates, in accordance with service demands in multiuser environment. This paper provides a overview from 1G to 4G with its types and performance analysis.

References

[1] CARLOS ALMEIDA*, MÁRIO LIMA, ANTÓNIO TEIXEIRA, "Performance analysis of 3G-UMTS WDM-RoF links",Optica Applicata,Vol.XL,No.4,2010.

[2] ETSI, Universal Mobile Telecommunications System (UMTS); UTRA repeater radio transmission and reception (3GPP TS 25.106 version 7.2.0 Release 7).

[3] AL-RAWESHIDY H., Radio over Fiber Technologies for Mobile Communication Networks, Artech House, 2002).

[4] S. Kaiser and K. Fazel, "A Flexible Spread-Spectrum Mul- ticarrier Multiple Access System for Multimedia Applica- tions," IEEE PIMRC, vol. 1, Sept. 1997, pp. 100–04.

[5] IST-2001-32620 MATRICE D1.3.

[6] N. Maeda et al., "Variable Spreading Factor-OFCDM with Two Dimensional Spreading that Prioritizes Time Domain Spreading for Forward Link Broadband Wire- less Access," IEEE VTC 2003-spring, vol. 1, pp. 127–32.

[7] K.Kumaravel, "Comparative Study of 3G and 4G in Mobile Technology," International Journal of Computer Science, Vol. 8, Issue 5, No. 3, September 2011.

[8] L. Zhen, Z. Wenan, S. Junde, H. Chunping, "Consideration and research issues for the future generation of mobile communication," Electrical and Computer Engineering, 2002. IEEE CCECE 2002. Canadian Conference on, Volume:3, 12- 15May,2002 , pp:1276 - 1281 vol.3.

[9] S. Chatterjee, W. A. C Fernando, M. K. Vasantha, "Adaptive modulation based MC- CDMA systems for 4G wireless consumer applications," Consumer Electronics, IEEE Transactions on , Volume: 49 , Issue:4, Nov.2003, pp:995 – 1003.

[10] J. B. Chia, "Video services over 4G wireless networks: not necessarily Streaming," Wireless Communications and Networking Conference, 2002. WCNC2002. 2002 IEEE, Volume: 1, 17-21 March 2002, pp: 18 - 22 Vol.1.

[11] Kamarularifin Abd Jalil, Mohd Hanafi Abd. Latif, Mohamad Noorman Masrek, "Looking Into The 4G Features", MASAUM Journal of Basic and Applied Sciences Vol.1, No. 2 September 2009.

[12] 3gamericas (2010). "Transition to 4G: 3GPP Broadband Evolution to IMT-Advanced", Rysavy Research/3G Americas. [Online] Available: www.rysavy.com/PR/3GA_ PR_2010_09.pdf

[13] Fumiyuki Adachi, "Wireless past and Future: Evolving Mobile Communication Systems". IEICE Trans. Findamental, Vol. E84-A, No.1, January 2001.

[14] ITU (2009). "Measuring the Information Society; The ICT Development Index", [Online] Available: http://www.itu. int/ITU-D/ict/publications/idi/2009/material/IDI2009_ w5.pdf

[15] ITU (2010). "Measuring the Information Society, 2010". [Online] Available: http://www.itu.int/ITU-D/ict/statistics/ material/graphs/2010/Global_ICT_Dev_00-10.jpg

[16] Mishra, Ajay K. “Fundamentals of Cellular Network Planning and Optimization, 2G/2.5G/3G…Evolution of 4G”, John Wiley and Sons, 2004.

[17] Toh, C. K. “Ad Hoc Mobile Wireless Networks: Protocols and Systems”, Prentice Hall, New Jersey, USA, 2002.

[18] Chen, Yue (2003). “Soft Handover Issues in Radio Resource Management for 3G WCDMA Networks”, Queen Mary, University of London, [Online] Available: www.elec.qmul. ac.uk/research/thesis/YueChen2003.pdf

[19] Pereira, Vasco & Sousa, Tiago. “Evolution of Mobile Communications: from 1G to 4G”, Department of Informatics Engineering of the University of Coimbra, Portugal 2004.

[20] ITU (2010). “ITU Paves the Way for Next-Generation 4G Mobile Broadband Technologies”. [Online] Available: http:// www.itu.int/net/pressoffice/press_releases/2010/40. aspx

[21] G. J. Foschini, “Layered Space-time Architecture for Wireless Communication,” Bell Labs Tech. J., vol. 1, Autumn 1996, pp. 41–59

[22] M. Alamouti, “A Simple Transmit Diversity Technique for Wireless Communications,” IEEE JSAC, vol. 16, Oct.1998, pp. 1451–58.

[23] Amit Kumar1; Dr. Yunfei Liu2; Dr. Jyotsna Sengupta3; Divya4, “Evolution of Mobile Wireless Communication Networks: 1G to 4G”, International Journal of Electronics and Communication Technology, Vol.1, Issue 1, December 2010.