LTE-A an Overview and Future Research Areas

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***Abstract*—This paper gives an overview of the Long Term Evolution (LTE) of the Universal Mobile Telecommunication System (UMTS), which is being developed by the 3rd Generation Partnership Project (3GPP). LTE constitutes the latest step towards the 4th generation (4G) of radio technologies designed to increase the capacity and speed of mobile communications. Particular attention is given to the requirements and targets of LTE, its use of multiple antenna techniques, and to the Single Carrier Frequency Division Multiple Access (SC-FDMA) modulation scheme used in the LTE uplink. Furthermore new future research areas are proposed here.**

Keywords- LTE; MIMO; OFDM; SC-FDMA; CRAN; Multihop wireless network; CR; SDR; MPLS

I. INTRODUCTION *(HEADING 1)*

Long Term Evolution is the next-generation 4G technology for both Global System for Mobile communication (GSM) and Code Division Multiple Access (CDMA) cellular carriers. Approved in 2008 with download speeds of up to 173 Mb/sec, LTE was defined by the 3G Partnership Project in the 3GPP Release 8 specification. LTE uses a different air interface and packet structure than the previous 3G systems, including GSM's UMTS: Wideband CDMA (W-CDMA) and High Speed Packet Access (HSPA), and CDMA's Evolution-Data Optimized (EV-DO). However, it is envisioned that all GSM and CDMA2000 carriers will eventually migrate to LTE to provide an interoperable cellular system worldwide. LTE is a set of enhancements to the UMTS which was introduced in 3GPP Release 8. Much of 3GPP Release 8 focuses on adopting 4G mobile communication technologies, including an all-Internet Protocol (IP) flat networking architecture. On August 18, 2009, the European Commission announced that it will invest a total of €18 million into researching the deployment of LTE and the certified 4G system LTE-Advanced (LTE-A) [1]. While it is commonly seen as a cell-phone or common carrier development, LTE is also endorsed by public safety agencies in the United States [2] as the preferred technology for the new 700 MHz public-safety radio band. Agencies in some regions have filed for waivers [3] hoping to use the 700 MHz [4] spectrum with other technologies in advance of the adoption of a nationwide standard. LTE is considerably faster than GSM's HSPA and CDMA's EV-DO but was considered a 3G technology by the ITU until late 2010. Along with the Worldwide Interoperability for Microwave Access (WiMAX) 2, the ITU previously designated LTE-A (LTE-Advanced) as the true 4G evolution. In late 2010, the ITU widened its definition to include regular LTE, WiMAX and HSPA+ as bona fide 4G technologies since they are considerably faster than existing 3G networks. LTE uses the Evolved UMTS Terrestrial Radio Access (E-UTRA) air interface, which is based on Orthogonal Frequency Division Multiple Access (OFDMA) and is a departure from the TDMA used in GSM and the CDMA used in GSM/UMTS and CDMA2000. In addition, LTE is based entirely on IP packets, and voice travels over IP (VoIP). The IP part of LTE is called "Evolved Packet System" (EPS), which was previously called "System Architecture Evolution" (SAE). Although the LTE is often marketed as 4G, first-release LTE does not fully comply with the International Mobile Telecommunications (IMT) Advanced 4G requirements. The pre-4G standard is a step toward LTE Advanced, a 4G [5] standard of radio technologies designed to increase the capacity and speed of mobile telephone networks. LTE Advanced is backwards compatible with LTE and uses the same frequency bands, while LTE is not backwards compatible with 3G systems.

II. REQUIREMENTS OF LTE

Tables I & II show the requirements of LTE's downlink and uplink, respectively. The fulfillment of peak bit rate in both downlink and uplink is fulfilled while the spectral efficiency and cell edge user throughput is 2.5 times of High Speed Packet downlink Access (HSDPA) and High Speed Packet uplink Access (HSUPA).

TABLE I. DOWNLINK

	Release-6 HSDPA	**LTE**	**LTE target**
Peak bit rate (Mbps)	14.4	144	100
Spectral efficiency (b/s/Hz)	0.75	1.84	3-4 times of HSDPA
Cell edge user throughput (b/s/Hz)	0.006	0.0184	2-3 times of HSDPA

TABLE II. UPLINK

	Release-6 HSUPA	LTE	LTE target
Peak bit rate (Mbps)	5.7	57	50
Spectral efficiency (b/s/Hz)	0.26	0.67	2-3 times of HSUPA
Cell edge user throughput (b/s/Hz)	0.006	0.015	2-3 times of HSUPA

The target of 3GPP LTE-A is to reach and surpass the ITU requirements. LTE-A should be compatible with first release LTE equipment, and should share frequency bands with first release LTE. In the feasibility study for LTE-A, 3GPP determined that LTE-A would meet the ITU-R requirements for 4G. The results of the study are published in 3GPP Technical Report (TR) 36.912 [6].

One of the important LTE-A benefits is the ability to take advantage of advanced topology networks; optimized heterogeneous networks with a mix of macros with low power nodes such as picocells, femtocells and new relay nodes. The next significant performance leap in wireless networks will come from making the most of topology, and brings the network closer to the user by adding many of these low power nodes — LTE-A further improves the capacity and coverage, and ensures user fairness. LTE-A also introduces multicarrier to be able to use ultra wide bandwidth, up to 100MHz of spectrum supporting very high data rates.

Further to the above, other LTE requirements and targets are listed below:

- Bandwidth: Scalable bandwidth of 1.25, 2.5, 5, 10, 15, and 20 MHz shall be supported.
- Interworking: Interworking with existing UTRAN/ GSM Enhanced Data rates for Global Evolution Radio Access Network (GERAN) systems and non-3GPP system shall be ensured. Interruption time for handover between Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and UTRAN/GERAN shall be less than 300ms for RT services, and less than 500ms for NRT services.
- Multimedia Broadcast Multicast Services (MBMS): MBMS shall be further enhanced and is then referred to as Evolved-MBMS (e-MBMS).
- Cost: Reduced Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) including backhaul shall be achieved. Cost effective migration from release 6 UTRA radio interface and architecture shall be possible. All the interfaces specified shall be open for multi-vendor equipment interoperability.
- Mobility: Optimized for low mobile speed (0~15km/h). Higher mobile speeds shall be supported (including high speed train)
- Spectrum allocation: Operation in paired Frequency Division Duplexing (FDD) and unpaired spectrum Time Division Duplexing (TDD) is possible.
- Co-existence: Co-existence in the same geographical area and co-location with GERAN/UTRAN shall be ensured.
- Quality of Service (QoS): End-to-end QoS shall be supported.
- Network synchronization: Time synchronization of different network sites shall not be mandated.

III. TIME LINE FOR LTE DEVELOPMENT

Current view for commercial launch around 2012 is shown in Fig, 1 where marketing and economic requirements drive commercial launch.

It seems that for some time several generations will co-exist and also the older technologies will eventually make room for superior ones to take over. The data traffic and data revenue is mainly generated in hotspots and in-building. LTE could start in hotspots, high traffic zones and enterprise / residential Femto followed by nationwide coverage at later stage.

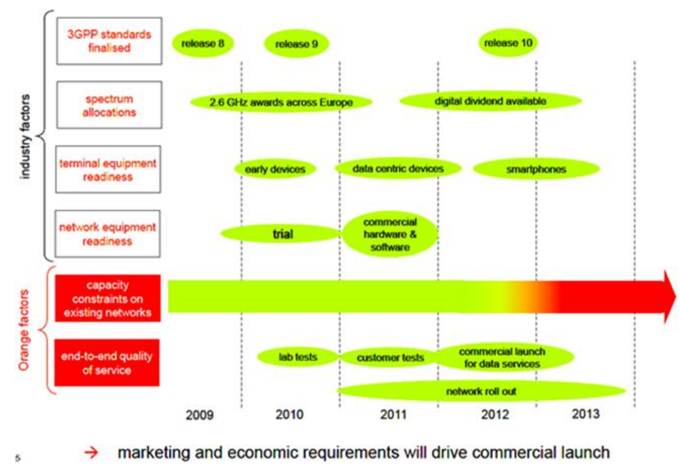

Figure 1. Marketing and economic requirements [7]

IV. MULTIPLE ACCESS TECHNOLOGY IN LTE

Downlink and uplink transmission in LTE are based on the use of multiple access technologies: specifically, orthogonal frequency division multiple access (OFDMA) for the downlink, and single-carrier frequency division multiple access (SC-FDMA) for the uplink. The downlink is considered first.

A. Downlink

OFDMA is a variant of orthogonal frequency division multiplexing (OFDM), a digital multi-carrier modulation scheme that is widely used in wireless systems but relatively new to cellular. Rather than transmitting a high-rate stream of data with a single carrier, OFDM makes use of a large number of closely spaced orthogonal subcarriers that are transmitted in parallel. Each subcarrier is modulated with a conventional modulation scheme (such as Quadrature phase-shift keying (QPSK), 16-Quadrature amplitude modulation (QAM), or 64-QAM) at a low symbol rate. The combination of hundreds or thousands of subcarriers enables data rates similar to conventional single-carrier modulation schemes in the same bandwidth. Although OFDM has been used for many years in communication systems, its use in mobile devices is more recent. The European Telecommunications Standards Institute (ETSI) first looked at OFDM for GSM back in the late 1980s; however, the processing power required to perform the many fast Fourier transform (FFT) operations at the heart of OFDM was at that time too expensive and demanding for a mobile application. In 1998, 3GPP seriously considered OFDM for UMTS, but again chose an alternative technology based on CDMA. Today the cost of digital signal processing has been greatly reduced and OFDM is now considered a commercially viable method of wireless transmission for the handset.

When compared to the CDMA technology upon which UMTS is based, OFDM offers a number of distinct advantages:

- OFDM can easily be scaled up to wide channels that are more resistant to fading.
- OFDM channel equalizers are much simpler to implement than are CDMA equalizers, as the OFDM signal is represented in the frequency domain rather than the time domain.
- OFDM can be made completely resistant to multi-path delay spread. This is possible because the long symbols used for OFDM can be separated by a guard interval known as the cyclic prefix (CP). The CP is a copy of the end of a symbol inserted at the beginning. By sampling the received signal at the optimum time, the receiver can remove the time domain interference between adjacent symbols caused by multi-path delay spread in the radio channel.
- OFDM is better suited to MIMO. The frequency domain representation of the signal enables easy pre-coding to match the signal to the frequency and phase characteristics of the multi-path radio channel.

However, OFDM does have some disadvantages. The subcarriers are closely spaced making OFDM sensitive to frequency errors and phase noise. For the same reason, OFDM is also sensitive to Doppler shift, which causes interference between the subcarriers. Pure OFDM also creates high peak-to-average signals, and that is why a modification of the technology called SC-FDMA is used in the uplink.

B. Uplink

The high peak-to-average ratio (PAR) associated with OFDM led 3GPP to look for a different transmission scheme for the LTE uplink. SC-FDMA was chosen because it combines the low PAR techniques of single-carrier transmission systems, such as GSM and CDMA, with the multi-path resistance and flexible frequency allocation of OFDMA. A brief description of SC-FDMA is as follows: data symbols in the time domain are converted to the frequency domain using a discrete Fourier transform (DFT); then in the frequency domain they are mapped to the desired location in the overall channel bandwidth before being converted back to the time domain using an inverse FFT (IFFT). Finally, the CP is inserted. Because SC-FDMA uses this technique, it is sometimes called discrete Fourier transform spread OFDM or (DFT-SOFDM).

V. Multiple Input Multiple Output

Central to LTE is the concept of multiple antenna techniques—often loosely referred to as MIMO—which take advantage of spatial diversity in the radio channel. Multiple antenna techniques are of three main types: diversity, MIMO, and beam forming. These techniques are used to improve signal robustness and to increase system capacity and single-user data rates. Each technique has its own performance benefits and costs. MIMO requires two or more transmitters and two or more receivers. For a system to be described as MIMO, it must have at least as many receivers as there are transmit-streams. The number of transmit streams should not be confused with the number of transmit antennas. The theoretical gains from MIMO are function of the number of transmit and receive antennas, the radio propagation conditions, the ability of the transmitter to adapt to the changing conditions, and the signal to noise ratio (SNR). The ideal case is one in which the paths in the radio channel are completely uncorrelated, almost as if separate, physically cabled connections with no crosstalk existed between the transmitters and receivers. Such conditions are almost impossible to achieve in free space, and with the potential for so many variables, it is neither helpful nor possible to quote MIMO gains without stating the conditions. The upper limit of MIMO gain in ideal conditions is more easily defined, and for a 2x2 system with two simultaneous data streams a doubling of capacity and data rate is possible.

VI. Future Research Areas

In this section we identify few examples of future research areas: Cloud Radio Access Network, Multihop Wireless Networks, and Resilience and reliability of LTE with MPLS.

A. Cloud Radio Access Network

From a service provider's point of view, LTE can be deployed within a wide selection of spectrum ranges, which makes it attractive in a way that it reduces the need to buy new spectrum bands for coping additional data traffic. In this context, if it is possible for additional data to be carried without increasing the spectrum licensing fees, this approach is efficient in terms of utilizing the ether and also provides financial savings. Sophisticated modulation (e.g. 128-QAM) and Turbo coding can be used to achieve this, where service providers only need to upgrade the software infrastructure of the software defined radio (SDR) for LTE. This process makes it more spectrally efficient than the other technologies.

From the network architecture point of view, recent years have shown increasing research interest in Cloud Radio Access Network (CRAN) [8-10]. Such approach changes the traditional cellular access network's architecture by taking advantage of cloud computing, SDR and advance antenna techniques. Some base station functionalities could be virtualized and pulled back to the 'cloud' where resources can be shared as a pool. Remote radio units which are decoupled from the base station can be distributed geographically to provide the required coverage.

CRAN is envisaged to have capability to reduce the RAN upgrading cost for network operators which leads to reduction on CAPEX and OPEX. It can also enhance the performance of

MIMO and Cooperative Multipoint (CoMP) by improved BS cooperation via centralized processing. The centralized and virtualized resource pool supports multi standards and allows radio resource being shared by different radio access technologies (RATs) to improve the overall spectrum efficiency and flexibility [10-12]. CRAN is also regarded as one of the key technologies supporting energy efficiency strategies.

The challenges of the CRAN architecture lie in several areas, such as high computational requirements for the base station virtualization, I/O throughput and the timing and synchronization etc. In order to maximize the benefits of CRAN, these challenges will need to be addressed.

B. Multihop Wireless Networks

The conventional infrastructure cellular networks (e.g. LTE or LTE-A) are expected to their capacity limits especially when all mobile services including voice will be migrated to packet based. The concept of decentralization multihop networks can be deployed to reduce the dependence on fixed infrastructures and increase the overall spectral efficiency and capacity. The aim of this decentralized multihop approach is to move some services of the handsets' or nodes' communications towards a distributed peer-to-peer [12-14].

The heterogeneous wireless multihop network is envisaged to have handsets as intelligent intermediate nodes that capable to self-organize and cognitive radio (CR). The CR is used in conjunction with SDR with intelligent environment-aware algorithms to improve the spectrum utilization, communication efficiency and system capacity. It can also perform wiser autonomous decision making for radio resource allocation [12,14]. This means there are possibilities to cooperate between different intelligent relays with other wireless frequency and reuse the relay slots from different wireless technologies, i.e. nodes can transmit to different mobiles at the same time using different frequency relay slots. Reusing other relay slots would significantly increase the overall system throughput.

The MIMO multihop communication technique has also become vast interest for decentralized heterogeneous wireless network in the recent years, in the case of single antennas then cooperative MIMO is used. The cooperative MIMO is particularly suitable for the mobile nodes with single antenna in the distributed clustered system where the nearby mobiles can cooperate and form virtual antenna arrays [14,15]. By combing the CR and clustering concepts, the MIMO multihop communication can certainly improve the reliability, throughput and coverage; however it is difficult to retrieve accurate information about neighboring nodes and also difficult to identify the most suitable nodes to communicate with particular nodes or cluster heads.

The decentralization multihop approaches opens new challenges in several areas, including seamless cooperation between heterogeneous nodes and base stations, CR based routing strategies, localization, clustering, interference management, synchronization and self-organizing in MIMO.

C. Resilience and reliability of LTE with MPLS

The core of LTE networks will integrate with different wireless access technologies and consolidate different radio technologies to provide higher bandwidth utilization with improved QoS and flexible use of frequency bands. However, the QoS requirements of mobile services are likely to increase in time, and the need for resilient and reliable services is hence becoming eminent.

In LTE, there are currently few active research areas where Multi-Protocol Label Switching (MPLS) is applied at the IP level to improve the performance of the shared transport channels and to reduce the operating costs and the resource availability [16-17].

Recent studies have tackled the network capacity and optimization of data-transfer speed by applying protocols such as MPLS on the IP levels and on the backhaul part of networks to enhance the network performance [18-19]. More studies are needed to look further into issues related to the LTE network resilient and reliability of infrastructure especially during increased demand, catastrophic network failures, or during natural disasters.

VII. Conclusion

In this paper an overview of the LTE and LTE-A is provided. The overview focused on the LTE requirements and targets, time line for the LTE deployment, multiple access technology in LTE, MIMO, and the proposed research areas. The paper also discusses few potential new research areas covering cloud radio access network, Multihop wireless networks, and Resilience and reliability of LTE with MPLS.

References

[1] H. Ekström, A. Furuskär, J. Karlsson, M. Meyer, S. Parkvall, J. Torsner, and M. Wahlqvist, "Technical Solutions for the 3G Long-Term Evolution," IEEE Commun. Mag., vol. 44, no. 3, March 2006, pp. 38–45

[2] 3rd Generation Partnership Project (3GPP); Technical Specification Group Radio Access Network; Physical Layer Aspects for Evolved UTRA, http://www.3gpp.org/ftp/Specs/html-info/25814.htm

[3] M. Danish Nisar, Hans Nottensteiner, and Thomas Hindelang, "On Performance Limits of DFT-Spread OFDM Systems", in Sixteenth IST Mobile Summit, July 2007 in Budapest, Hungary.

[4] B.E. Priyanto, H. Codina, S. Rene, T.B. Sorensen, P. Mogensen, "Initial Performance Evaluation of DFT-Spread OFDM Based SC-FDMA for UTRA LTE Uplink", IEEE Vehicular Technology Conference (VTC) 2007 Spring, Dublin, Ireland, Apr. 2007

[5] Hyung G. Myung, Junsung Lim, and David J. Goodman, "Single Carrier FDMA for Uplink Wireless Transmission", IEEE Vehicular Technology Magazine, vol. 1, no. 3, Sep. 2006, pp. 30–38

[6] Parkvall, Erik Dahlman, Anders Furuskär et al; Ericsson, Robert Syputa, Maravedis;"ITU global standard for IMT-Advanced; LTE Advanced – Evolving LTE" Vehicular Technology Conference, 2008. VTC 2008-Fall. IEEE 68th 21-24 Sept. 2008 Page(s):1 - 5.

[7] Arief Gunawan, "LTE Technology, Challenge, and Business", Technical Seminar, Sharjah, 18 January, 2010

[8] Huawei, "Cloud RAN – A Key Enabling Technology for NG-RAN", China Mobile Lab, April 2010

[9] H Harada, "Wireless Cloud Computing and Cognitive Wireless Cloud", The 3rd EU-Japan Symposium on the "Future Internet", Oct. 2010

[10] Y Lin, L Shao, Z Zhu, Q Wang, R K Sabhikhi, "Wireless network cloud: Architecture and system requirements", IBM Journal of Research and Development, January-February 2010

[11] H Harada, "Cognitive Wireless Cloud: A Network Concept to Handle Heterogeneous and Spectrum Sharing Type Radio Access Networks" IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Sept 2010

[12] S Liu, J Wu, “The Way Forward to the Next Generation Radio Access Network beyond IMT-Advanced: Potential Technologies and Overall Framework”, IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Sept 2010

[13] M Peng, W Wang, “Investigation of Cooperative Relay Node Selection in Heterogeneous Wireless Communication Systems”, IEEE International Conference on Communications Workshops, May 2008

[14] B Zafar, D Schulz, S Gherekhloo, M Haardt, “Ad Hoc Networking Solutions: Cooperative MIMO Multihop Networks”, IEEE Vehicular Technology Magazine, March 2011

[15] D Gündüz, M Khojastepour, A Goldsmith, and H V Poor, “Multi-Hop MIMO Relay Networks: Diversity-Multiplexing Trade-off Analysis”, IEEE Transaction on Wireless Communications, May 2010

[16] White paper: "MMBI White Paper on Use of MPLS in LTE", Broadband Forum Marketing Report MR-238, Issue 1. February 2010.

[17] A Ronai, "LTE Ready Mobile Backhaul", Cargon Networks report, 2009.

[18] White paper: "Use of MPLS in mobile backhaul networks", Broadband Forum report, 2010.

[19] NEC, "Mobile Backhaul Evolution and Convergence", E-Seminar White Paper, 2010