Toward LTE Commercial Launch and Future Plan for LTE Enhancements (LTE-Advanced)

(*Invited*)

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Abstract*— As a promising radio access technology for next generation mobile communication systems, LTE (Long-Term Evolution) is being standardized by the 3rd Generation Partnership Project (3GPP) international standardization organization. LTE Release 8 has many advantages to the other systems, e.g., the peak throughput is 300Mbps in Downlink (DL) and 75Mbps in Uplink (UL), 2-3 time higher spectrum efficiency than Rel. 6 HSPA (High Speed Packet Access), very low latency around 5msec in RAN (Radio Access Network) and 100msec for connection setup time. With Release 8, the first version for LTE specification, being completed in March 2009, the LTE standard is now being developed towards commercialization in various countries in the world. This paper addresses the plan for LTE commercial launch in NTT DOCOMO and future plan for LTE Rel. 9 and LTE-Advanced (LTE Rel. 10 and beyond).

Keywords-component: LTE, Deployment scenario, LTE-Advanced

I. Introduction

The international deployment of the W-CDMA (Wideband Code Division Multiple Access) / UMTS (Universal Mobile Telecommunications System) system is progressing steadily, and more than 180 mobile network operators throughout the European region, North America, and Asia are providing 3rd generation (3G) services using W-CDMA at the end of 2009. The maximum transmission data rate (throughput) specified in 3GPP Rel. 6 via High Speed Downlink Packet Access (HSDPA) in the downlink (DL) is 14 Mbit/s and that via High Speed Uplink Packet Access (HSUPA) in the uplink (UL) is 5.7 Mbit/s. The use of HSDPA and HSUPA can improve not only the transmission data rate but also the spectrum efficiency thereby reducing the transmission cost per bit. At the same time, the trends toward greater data traffic and high-capacity content are making further reduction in bit cost a more critical issue. To provide a long-term development of 3G services, NTT DOCOMO proposed the “Super 3G” concept in 2004 [1]. Super 3G is a standard that expands upon the 3GPP specification, i.e., HSDPA/HSUPA extension technologies of the W-CDMA system, and it is called Long-Term Evolution (LTE) within the 3rd Generation Partnership Project (3GPP). First release of 3GPP LTE specifications (i.e. Release 8) was frozen in March 2009 [2].

Thus, the commercial introduction of LTE is now being planned in various countries around the world [3]. In fact, commercial services of LTE single mode have begun in Northern Europe at the end of 2009, and at NTT DOCOMO, commercial LTE dual mode services with W-CDMA/HSPA (High Speed Packet Access) are scheduled to be launched at the end of 2010. This paper addresses the deployment scenario for the LTE Release 8 (hereafter LTE Rel. 8) and the migration scenario toward LTE-Advanced. The rest of the paper is organized as follows. Section II briefly introduces the features and technical aspects of LTE Rel. 8. Section III describes the world trend for LTE Rel. 8 commercialization. Section IV investigates the plan for commercial launch and deployment scenario in NTT DOCOMO. Section V introduces LTE Rel. 9 features and section VI describes briefly technical features and future plan for LTE – Advanced, followed by the conclusion in Section VII.

II. LTE Rel.8 Features

A. System Requirements

Table I summarizes the system requirements for the LTE Rel. 8 [4]. The LTE Rel. 8 supports scalable multiple transmission bandwidths including 1.4, 3, 5, 10, 15, and 20 MHz. One of the most distinctive features is the support for only the packet-switching (PS) mode. Hence, all traffic flows including real-time service with a rigid delay requirement such as voice services are provided in the PS domain in a unified manner. The target peak data rate is 100 Mbps in the DL and 50 Mbps in the UL, respectively. The target values for the average or cell-edge user throughput and spectrum efficiency are specified as relative improvements from those of HSDPA or HSUPA in the DL and UL, respectively. Here, the average cell spectral efficiency corresponds to capacity, and the cell-edge user throughput is defined as the 5% value in the cumulative distribution function (CDF) of the user throughput. Both average and cell-edge user throughput are very important requirements from the viewpoint of practical system performance in cellular environments. In particular, improvement in the cell-edge user throughput is requested to mitigate the unfair achievable performance between the vicinity of the cell site and cell edge. The other important requirement is to reduce the latency. Here, the two types of latency are defined. One is the control plane latency, i.e. connection setup latency, the other one is the user plane latency i.e. transfer delay in RAN. After extensive discussions in the 3GPP meetings, it was verified that the requirements and targets for the LTE Rel. 8 were achieved by the specified radio interface using the relevant techniques [5].

In addition to performance requirement in lower layer, the requirements for deployments such as co-existence of current 3G and 2nd generation (2G) system, and inter-working with 2G/3G system are also captured in [4].

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TABLE I. MAJOR REQUIREMENTS

Bandwidth		Support of scalable bandwidth (1.4, 3, 5, 10, 15, 20MHz)	
Peak date rate		DL	100Mbps
		UL	50Mbps
Spectrum efficiency (vs. Rel. 6 HSPA)		DL	3-4 times
		UL	2-3 times
User throughput (vs. Rel. 6 HSPA)		DL	3-4 times (average) 2-3 times (cell edge)
		UL	2-3 times (average) 2-3 times (cell edge)
Latency	Transfer delay in RAN	5msec (one-way)	
	Connection setup delay	100msec	

B. *Multi-Access Techniquess*

1) *DL Multiple Access*

In the LTE Rel. 8 DL, orthogonal frequency division multiple access (OFDMA) was adopted because of its inherent robustness against multipath interference (MPI), and its affinity to different transmission bandwidth arrangements. In the DL using OFDMA, intra-cell orthogonal multiplexing among physical channels is achieved in the time and frequency domains by utilizing localized or distributed transmission as shown in Fig. 1. Data traffic is carried via the physical downlink shared channel (PDSCH) by localized transmission using frequency domain channel-dependent scheduling based on the reported channel quality indicator (CQI) measurement, which is employed to improve the user throughput and cell throughput. Real-time traffic including Voice over IP (VoIP) can be carried by distributed transmission employing semi-persistent scheduling (SPS) [6]. Moreover, downlink control channels carrying Layer 1 (L1)/Layer 2 (L2) control signals are multiplexed over the entire system bandwidth employing distributed transmission over the duration of one-to-three OFDM symbols at the beginning of each subframe duration.

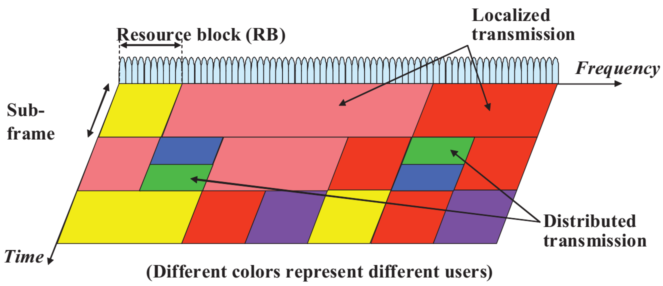

Fig. 1: DL multiple access based on OFDMA

2) *Uplink Multiple Access*

In the LTE Rel. 8 UL, single-carrier (SC)-frequency division multiples access (FDMA) was adopted. This is because higher priority is given to achieving wider area coverage than achieving higher performance by utilizing the robustness against MPI in a multicarrier approach. Moreover, discrete Fourier transform (DFT)-Spread OFDM is adopted to generate SC-FDMA signals to provide high commonality with radio parameters and signal processing of DL OFDMA as shown in Fig. 2. In the LTE Rel. 8 UL, intra-cell orthogonal multiplexing is achieved in the time and frequency domains as well. Only localized FDMA transmission is used for the physical uplink shared channel (PUSCH), which carries user traffic and/or control data. Distributed FDMA transmission using a comb-shaped spectrum is employed to multiplex sounding reference signals (SRS) for CQI measurement at a base station (eNB). Orthogonal CDMA is used for SRSs, physical random access channel (PRACH), and physical uplink control channel (PUCCH). In this case, cyclic-shifted sequences generated from the original constant amplitude and zero auto-correlation (CAZAC) sequence are used, which provide orthogonality among multiple cyclic-shifted versions of the original sequence. In addition to cyclic-shift based multiplexing, block spread based multiplexing is used to accommodate a large number of PUCCHs within one sub-frame duration.

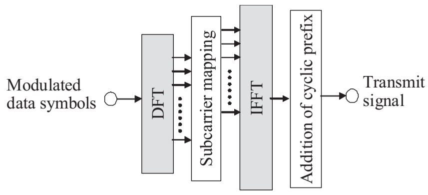

Fig. 2: Transmission scheme for DFT-Spread OFDMA

III. WORLD TRENDS FOR LTE REL. 8 COMMERCIALIZATION

Next Generation Mobile Networks (NGMN) is an organization that provides the views of mobile communications operators and promotes standardization to study the requirements of mobile communications beyond 2010. As of August 2010, 18 operators and 37 vendors are participating in the NGMN. NGMN evaluated the several technologies beyond the current 3G system and announced that "*3GPP LTE/SAE(System Architecture evolution) is the first technology which broadly meets its recommendations and is approved by its Board.*"

The LTE/SAE Trial Initiative (LSTI) organization, which aims at achieving early deployment of LTE commercial services, is testing LTE performance using verification test equipment and conducting tests for early stabilization of interoperability between multiple vendors amongst other activities. The goal here was to complete commercial system development around 2009 – 2010. As of August 2010, 12 operators and 28 vendors are participating in the LSTI. LSTI demonstrated the LTE performances by multiple field trials and confirmed LTE/SAE capabilities against 3GPP and NGMN requirements [7].

Figure 3 shows NTT DOCOMO's development schedule. Development of LTE began on the completion of Study Item (SI), which studied the feasibility of the basic ideas in June 2006, and indoor experiments began using trial equipment in July 2007. After the completion of SI, 3GPP work was shifted to the Work Item (WI) which specified the detail procedure, signaling, and performance. Outdoor experiments then began in February 2008 to perform tests toward practical deployment including the verification of important functions like handover and further optimization of the system. The objective is to complete commercial system development in 2009. This schedule is consistent with LSTI targets.

In February 2010, GSM association (GSMA), which represents the interests of the worldwide mobile communications industry and unites, i.e., nearly 800 of the world's mobile operators, as well as more than 200 companies in the broader mobile ecosystem, announced that "*More than 74 mobile operators from around the world have committed to plans, trials or deployments for LTE, with many more commitments expected to be announced over the coming year. The world's first commercial LTE network was launched at the end of 2009 in Sweden by TeliaSonera, with NTT DOCOMO in Japan on track to join China Telecom and Verizon Wireless in deploying commercial LTE services by the end of 2010. LTE is expected to experience substantial growth over the next three years with research firm Infonetics predicting the number of global LTE connections to exceed 72 million by 2013*" [3].

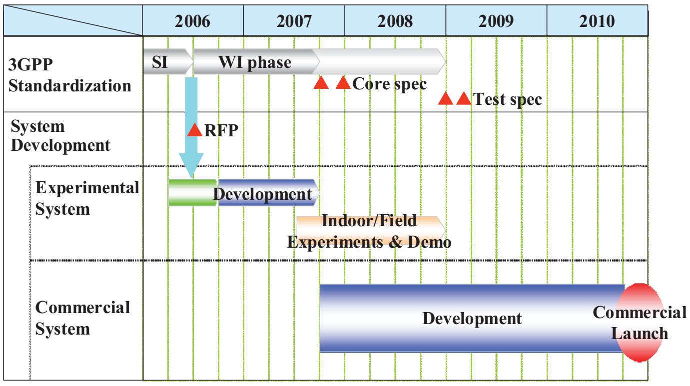

Fig. 3: Time plan for LTE deployment in NTT DOCOMO

IV. DEPLOYMENT SCENARIOS

A. Area Deployment Scenario

Figure 4 shows an example for area deployment scenario. At the initial stage of LTE, similar to the 3G NW deployment scenarios in Europe, LTE area is overlaid with 3G coverage. All the user terminals (UEs: User Equipments) support both LTE and 3G (W-CDMA/HSPA). In case of out-of-service area for LTE, the UE connects to the 3G NW. Thus, it is not necessary to expand rapidly the LTE coverage. With expanding the LTE NW, operator would upgrade their NW to the latest Release such as LTE Rel.9 or later. Operators can deploy the area according to the customer's demands. Since LTE focuses only on PS domain, data type services are first supported and Circuit Switching (CS) services such as voice will be supported according to the wide-spread of the LTE UEs. The deployment scenario for voice service is described in Section IV C.

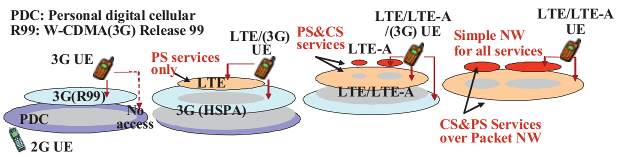

Fig. 4: An example of area deployment scenario

B. Frequency Deployment Scenario

At the initial LTE launch, 2GHz spectrum band will be used because of the global spectrum band and utilization of the existing NW facilities such antenna, amplifier, RF filter. NTT DOCOMO has already installed the common RF equipments between 3G and LTE from 2009 to reduce the NW deployment cost [8]. Figure 5 shows the configuration of common RF equipment. The digital baseband signals of 3G and LTE are multiplexed and transferred to RRE (Remote Radio Equipment) via optical fiber.

LTE spectrum can be increased gradually in the future according to the wide spread of LTE UEs and new spectrum band allocation. In 2009, new spectrum, 1.5GHz, for LTE has been allocated from Ministry of Internal Affairs and Communications (MIC) in Japan. NTT DOCOMO is planning to launch LTE using this new spectrum from 2012.

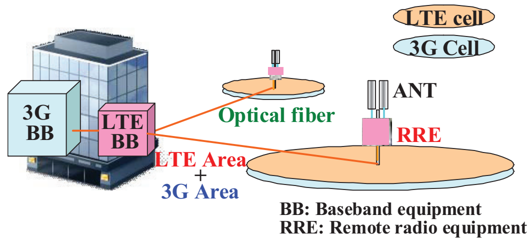

Fig. 5: Common RF equipments between LTE and 3G

C. Deployment Plan for Voice Service

LTE can provide all services using IP without existing CS domain functions. Accordingly, services like voice calls and the short message services (SMS) that have traditionally been provided over the CS domain will be replaced, in principle, by VoIP, for example. This will eventually require the deployment of the IP Multimedia Subsystem (IMS) as a service control platform. However, at the beginning of LTE deployment, it may take some time before IMS and VoIP services can be provided due to the size of the target coverage area, the time required for facility planning, etc. As a consequence, a scenario in which services are provided in step-by-step approach has been discussed at 3GPP.

Figure 6 shows an example of voice service deployment scenario. Since IMS is not provided on LTE and the UE would not be able to originate or terminate any voice call at the initial LTE launch, voice service will be supported by CS fall back (CSFB) [9]. In CSFB, the UE first connects to the LTE NW in the PS domain, i.e. setup PS bearer. Then, handover (or release with redirection) from LTE NW to the 3G (W-CDMA/HSPA) NW is conducted. In the 3G NW, voice bearer (CS bearer) is added to support voice call. After UEs support IMS voice and the LTE area is expanded, IMS Voice over LTE (VoLTE) will be supported in the LTE NW. This deployment scenario is also recommended by GSMA.

The capacity evaluation for voice call is also investigated in [5]. By applying SPS to save cost of the signaling overhead, the voice capacity in LTE is 3 times higher than that of 3G system [5].

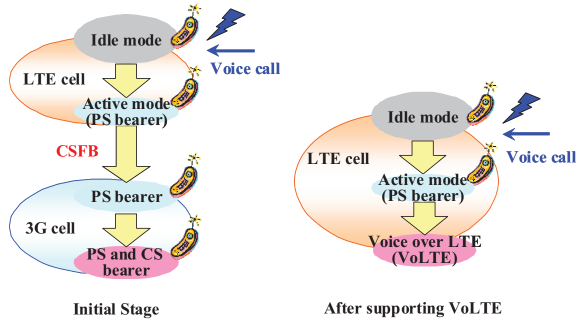

Fig. 6: Migration scenario for voice call

V. LTE REL.9 FEATURES

Although the LTE system is far superior to the existing systems in many aspects including throughput, delay, and spectrum efficiency, the 3GPP worked on further enhancements of LTE towards Rel. 9 and completed in June of 2010. LTE Rel. 9 enhances some of the features introduced in Rel. 8. In this section, the main features for LTE Rel.9 are briefly described.

A. Closed Subscriber Group (CSG) Control

CSG is a mechanism to limit cell access rights to only users belonging to the CSG [6]. An example of a potential application is for a femto-cell base station installed in a home (HeNB: Home eNodeB), allowing only family members to access. Through this function, the UE stores a list of allowed CSG IDs, and accessibility is determined based on whether the CSG ID being broadcast in the cell is included in this list or not. Non-allowed CSG cells are not considered as cell selection candidates for camping by the UE in the idle mode.

B. Self-Organizing Networks (SON)

SON is the mechanism to automatically organize or optimize the system parameters [10]. Several SON functions, particularly focused on the parts that are useful for the initial NW deployment, have been standardized. The main features of Rel.9 SON include mobility load balancing, mobility robustness optimization and random access optimization [11].

C. Location services (LCS)

Location Service (LCS) in Rel. 9 supports the following three positioning methods [12]:

1) Assisted-Global Navigation Satellite System

This positioning method utilizes Global Navigation Satellite Systems (GNSS) (e.g. Global Positioning System (GPS) satellite) information both received by the UE and obtained through the network to calculate final UE position.

2) Observed Time Difference of Arrival (OTDOA)

This positioning method utilizes the time differences in arrival times of a DL positioning reference signal received from multiple eNBs. This information allows the computation of the UE position by determining the intersection of several hyperbolas created from the time difference information [12][13].

3) Enhanced-Cell ID (E-CID)

In this positioning method, in addition to the serving eNB and the broadcast cell ID which defined in LTE Rel.8, the information such as propagation delay calculated from the difference in timing of signal transmission and reception and the Angle of Arrival (AoA), is utilized to estimate the UE position [12],[13].

D. Multimedia Broadcast/Multicast Services (MBMS).

MBMS is a bearer service for broadcast/multicast transmission of data, to transmit the same information to all interested terminals in an area over a common bearer. One of the main features is to support the MBMS Single Frequency Network (MBSFN) transmission. By applying the MBSFN transmission, a 3GPP study concluded that a spectral efficiency of 3 bps/Hz or greater can be achieved while providing 95% coverage with a packet error rate of 1% [5].

VI. LTE – ADVANCED (LTE REL.10 AND BEYOND)

The 3GPP is also working on the standardization of LTE-Advanced, which is the development radio interface for LTE. LTE-Advanced maintains full backward compatibility with LTE Rel. 8/9, while achieving higher system performance than LTE and satisfying the minimum requirements for IMT-Advanced, which is in the process of being standardized by the International Telecommunication Union Radiocommunications Sector (ITU-R).

The requirements for LTE-Advanced are given in [14]. The following general requirements for LTE-Advanced were agreed upon. First, LTE-Advanced will be an evolution of LTE Rel. 8. Hence, distinctive performance gains from LTE Rel. 8 are requested. Moreover, LTE-Advanced will satisfy all the relevant requirements for LTE Rel. 8 [4]. Second, full backward compatibility with LTE Rel. 8 is requested in LTE-Advanced. Thus, an LTE-Advanced UE must be able to access to LTE Rel. 8 networks, and LTE-Advanced networks must be able to support LTE Rel. 8 UEs. Third, LTE-Advanced shall meet or exceed the IMT-Advanced requirements within the ITU-R time plan.

Another important requirement for LTE-Advanced is to reduce the cost in the radio access network, so the use of radio relay transmission for the backhaul is being introduced as a low-cost means to expand coverage in environments where wired transmission is particularly expensive [9],[21],[22].

To satisfy the requirements for LTE-Advanced, improvements to the radio interface technologies were studied, with LTE Rel. 8 as a baseline. LTE Rel. 8 supports bandwidths up to 20 MHz, while support for peak data rates of up to 1 Gbit/s in the DL and 500 Mbit/s in the UL is a goal of LTE-Advanced, so wider bandwidths are needed. On the other hand, LTE-Advanced must also maintain backward compatibility with LTE Rel. 8. Accordingly, wider bandwidths are supported by combining multiple frequency blocks of bandwidth supported by LTE Rel. 8, called Component Carrier (CC). This technique is called Carrier Aggregation (CA) [15 - 18].

With LTE Rel. 8, multiple-input multiple-output (MIMO) multiplexing up to four layers is supported in the DL, but MIMO multiplexing is not supported in the UL. However, LTE-Advanced supports single-user MIMO multiplexing with up to eight layers in the DL and four layers in the UL in order to satisfy the peak spectral efficiency requirements of 30 bit/s/Hz in the DL and 15 bit/s/Hz on the UL [18]. Multi-user MIMO has also been improved in order to increase the system capacity. Introduction of Coordinated Multi-Point transmission / reception (CoMP), which coordinates communication among multiple cells, is also studied in order to improve the throughput performance of cell edge users particularly [18-20].

A. Migration Scenario

Figure 7 shows the migration scenario toward LTE-Advanced. The horizontal axis explains the performance which includes capacity, throughput, latency and cost, etc. As described above, LTE (Rel. 8) area will be overlaid firstly with 3G area and expanded gradually according to the customer's demand. Since LTE-Advanced is based on the LTE Rel. 8 and supported with full backward compatibility with LTE Rel. 8, LTE-Advanced UE can be shared with LTE of previous release in the same frequency and area. Thus, the migration from LTE toward LTE-Advanced is very smooth, e.g. support of CA with new frequency to improve the capacity and throughput. In other words, LTE operators can easily upgrade to the LTE-Advanced according to the market demands and new frequency allocation.

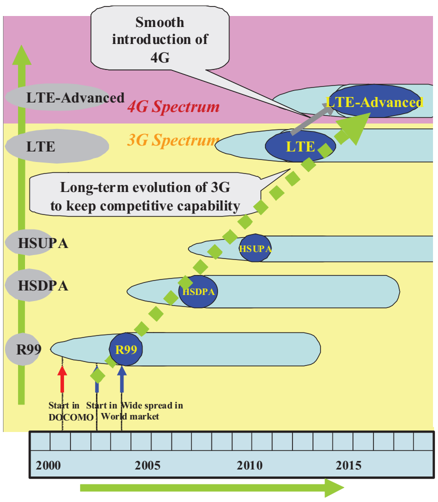

Fig. 7: Migration scenario toward LTE-Advanced

VII. Conclusion

This paper addressed the LTE features, activities for LTE commercial launch in the world, and deployment scenario for the LTE commercial launch at NTT DOCOMO. The commercial launch for LTE single mode has already been launched in Northern Europe and a huge number of operators from around the world have committed to plans, trials or deployments of LTE, with more commitments expected to be announced over the coming years. NTT DOCOMO will launch the LTE commercial service at the end of 2010 as one of the leading LTE operators.

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