Super 3G | High-speed, Large-capacity Wireless Transmission | Low Delay

Technology Reports

Special Articles on Technology Supporting Large-capacity and High-efficiency Communication in the Flat-rate Era

Super 3G for Further Reduction of Bit Cost

Super 3G (also known as LTE) is a standard that expands upon the HSDPA/HSUPA extension technologies of the W-CDMA system to provide elemental technologies for further reduction of bit cost toward a flat-rate system. This article introduces global trends toward the standardization and commercialization of Super 3G and demonstrates its effectiveness through experiments using trial equipment.

Radio Access Network Development Department

Sadayuki Abeta
Minami Ishii
Atsushi Harada
Yoshiaki Ofuji
Naoto Okubo

1. Introduction

The commercial deployment of the W-CDMA system is progressing steadily not only in Europe but in North America and Asia as well, and at present, more than 180 mobile network operators have commenced Third-Generation (3G) services using W-CDMA. Today, the maximum downlink transmission data rate provided by NTT DOCOMO in its packet services via High Speed Downlink Packet Access (HSDPA)[*1] is 7.2 Mbit/s, but the technical specifications of HSDPA and High Speed Uplink Packet Access (HSUPA)[*2] support maximum transmission data rates between a base station and mobile terminals of 14 Mbit/s in the downlink and 5.7 Mbit/s in the uplink. These technologies can improve not only data transmission rate but also spectrum efficiency thereby reducing cost per bit. At the same time, data traffic and content capacity are increasing rapidly while the demand for lower rates or a flat rate is rising. The further reduction of bit cost has become a major issue in dealing with these developments.

To provide for long-term development of 3G, NTT DOCOMO proposed the "Super 3G" concept in 2004. Super 3G is a standard that expands upon the HSDPA/HSUPA extension technologies of the W-CDMA system. It is called Long Term Evolution (LTE)[*3] within the 3rd Generation Partnership Project (3GPP). Super 3G (LTE) aims to achieve the following three main features by adopting various new technologies.

- Higher throughput (namely, a maximum of 300 Mbit/s in the downlink and 75 Mbit/s in the uplink)
- Shorter delays (namely, connection delays under 100 ms and one-way transmission delays within the Radio Access Network (RAN) under 5 ms)
- Significantly improved spectrum efficiency

In addition to reducing cost per bit by improving spectrum efficiency, Super 3G (LTE) can achieve low delays and faster speeds enabling the provision of services with strict delay requirements and the transmission of large-capacity files.

*1 **HSDPA**: A high speed downlink packet transmission technology based on W-CDMA and standardized by 3GPP. It optimizes the modulation method and coding rate according to reception conditions at the mobile terminal.

*2 **HSUPA**: A high speed uplink packet transmission technology based on W-CDMA and standardized by 3GPP. It optimizes the coding rate, spread factor, and transmission power according to reception conditions at the base station.

*3 **LTE**: An evolutional standard of the Third-Generation mobile communication system specified at 3GPP; LTE is synonymous with Super 3G proposed by NTT DOCOMO.

This article describes Super 3G (LTE) standardization trends and the state of its development focusing on the results of experiments using trial transmission equipment.

2. Super 3G (LTE) Trends

2.1 Super 3G Objectives and Scope

It is thought that the introduction of HSDPA is one way of enabling 3G mobile communication systems that use W-CDMA technology to satisfy market needs and to maintain competitiveness with other systems over a number of years. However, to deal effectively with multimedia and ubiquitous traffic that is expected to grow in the years to come, there will be a need for long-term technology evolution including Fourth-Generation (4G). A number of proposals have been studied as a long-term migration scenario to 4G, and it has been decided that the most optimal one is to begin by extending 3G and then constructing 4G on that extension (**Figure 1**). Against this background, NTT DOCOMO put forward the Super 3G concept as a migration scheme for the mobile system [1].

In addition to facilitating a smooth migration to 4G, Super 3G aims to maintain the long-term competitiveness of the W-CDMA system by expanding 3G (**Figure 2**) [2].

Super 3G will be required to provide short delays in addition to a dramatic jump in data rates and improved spectrum efficiency. Achieving short delays means that the time required for call setup (connection delay) and the time involved in data transfer during a call (transmission delay) will be reduced enabling high-speed data transmission by a protocol like TCP/IP.

At ITU-R, where the future outlook of mobile communications is discussed, approval was given in 2003 for Recommendation M.1645 titled "Framework

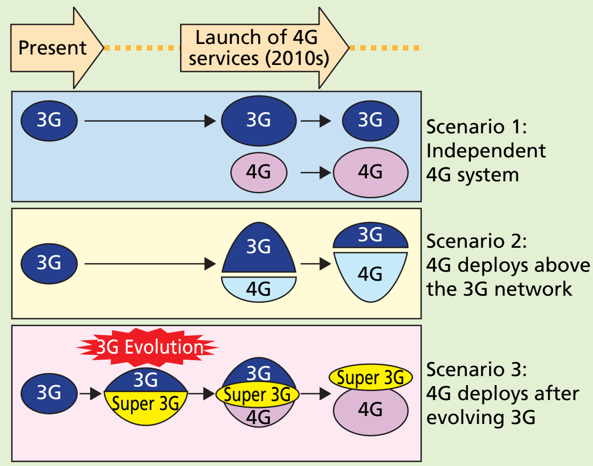

Figure 1 4G deployment scenarios

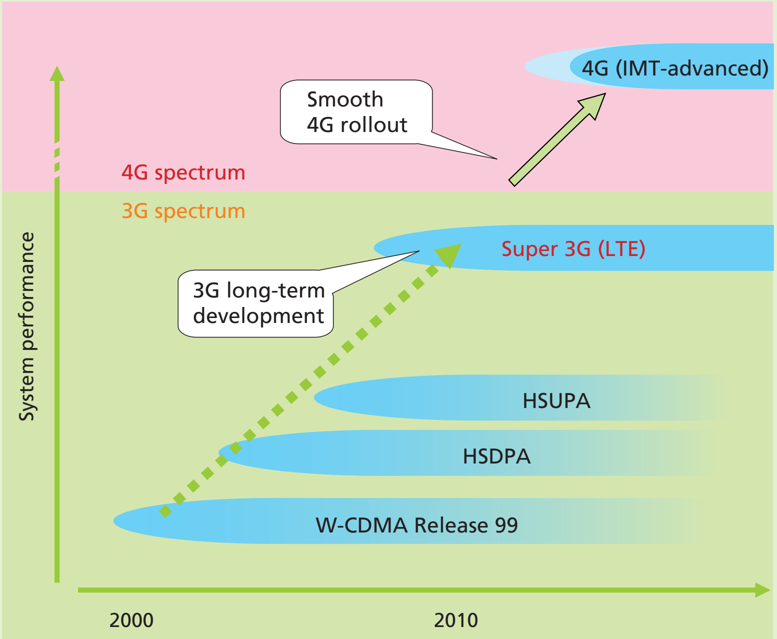

Figure 2 Super 3G concept

and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000." This recommendation includes a graph depicting the relationship between mobility and data rate (**Figure 3**). In the figure, IMT-2000 corresponds to 3G, while the new capabilities of Systems beyond IMT-2000 correspond to 4G in what is now called IMT-Advanced at ITU-R. Here, Super 3G (LTE) is an extension of IMT-2000 and is consequently included within the framework of IMT-2000.

For 4G (IMT-Advanced), new spectrum is expected to be allocated to increase bandwidth and achieve even higher data rates, but Super 3G (LTE) will be using spectrum that includes additional bands allocated for IMT-2000.

Super 3G is therefore a system that will be using the 3G spectrum, but Super 3G is studied taking into account the capability of using 5 MHz (as used by W-CDMA) and higher bandwidths for more flexible operations. It is also assumed that the amount of facility investment and operational expenses for deploying Super 3G will be moderate and appropriate, and to this end, the target must be for simple and inexpensive system construction that removes the complexity of system architecture surrounding the radio network and mobile terminals.

2.2 Standardization Trends

Reflecting the urgent need to study the development of the 3G long term evolution system, a workshop titled "3G RAN LTE" was held in November 2004 by the TSG RAN technical body in 3GPP. The Super 3G concept was proposed by NTT DOCOMO at this workshop, and after obtaining support from 26 companies, LTE studies within 3GPP was proposed and agreed upon. **Figure 4** shows the standardization schedule at 3GPP. A technical report (TR25.913) [3] related to requirements was approved in June 2005, while a technical report (TR25.912) [4] issued on completion of basic studies including feasibility considerations was approved in June 2006. The preparation of detailed technical specifications then commenced followed by the approval of main specifications in the period

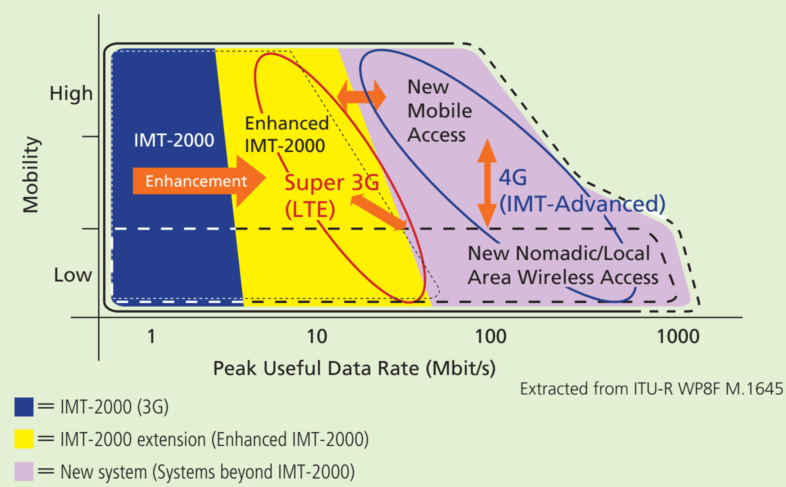

Figure 3 Relationship between Super 3G and Recommendation M.1645

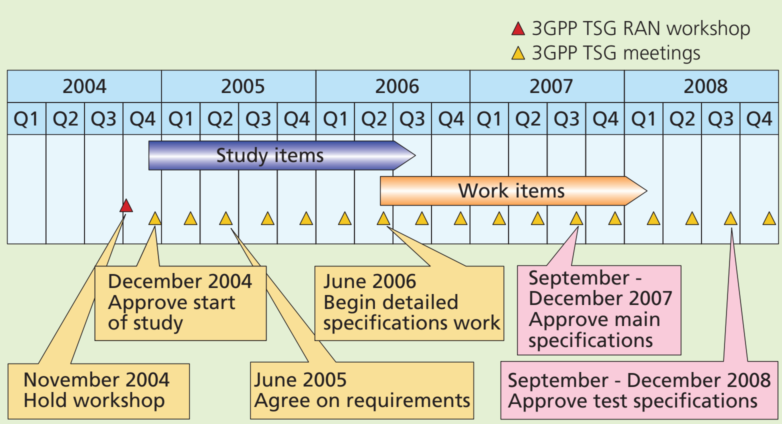

Figure 4 Standardization schedule

from September to December 2007. From here on, the plan is to complete detailed specifications and to prepare specifications toward the completion of test specifications scheduled for the end of 2008.

2.3 Global Trends and Development Schedule

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 May 2008, 18 operators and 28 vendors are participating in NGMN. Super 3G (LTE) is one of the technologies targeted for study here and the most promising. In addition, the LTE/SAE Trial Initiative (LSTI) organization, which aims to achieve early deployment of Super 3G (LTE) commercial services, is testing Super 3G (LTE) performance using verification test equipment and conducting tests for early stabilization of interoperability between multiple vendors amongst other activities. The goal here is to complete commercial system development around 2009 - 2010. **Figure 5** shows NTT DOCOMO's development schedule. Development of Super 3G began on the completion of basic studies in June 2006 and indoor experiments began using trial equipment in July 2007. Field trials 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.

3. Overview of Super 3G (LTE) Radio System

Table 1 shows the basic specifications of Super 3G trial equipment [5]-[7]. These specifications agree with LTE specifications in 3GPP standardization activities. The downlink uses Orthogonal Frequency Division Multiple Access (OFDMA) providing high resistance to multipath interference and flexible support for a wide range of frequency bandwidths by changing the number of subcarriers. The uplink, meanwhile, uses Single Carrier - Frequency Division Multiple Access (SC-FDMA)[*4] that can achieve low power consumption by decreasing the Peak-to-Average Power Ratio (PAPR)[*5] of User Equipment (UE) and reduce interference from other users by maintaining orthogonality in the frequency domain. The following outlines these radio access systems.

3.1 OFDMA Downlink Radio Access

Orthogonal Frequency Division Multiplexing (OFDM) achieves signal transmission robust to multipath interference (interference from delayed waves) through the parallel transmission of a high-data-rate wideband signal using multiple low-symbol-rate multi-carrier signals. The OFDM scheme uses subcarrier signals with narrow bandwidths, which enables flexible support of a wide range of signal bandwidths by changing the number of subcarriers. It incorporates a guard interval called a Cyclic Prefix (CP) at the head of each symbol to eliminate symbol interference caused by the delayed wave of the previous symbol and inter-subcarrier interference caused by the destruction

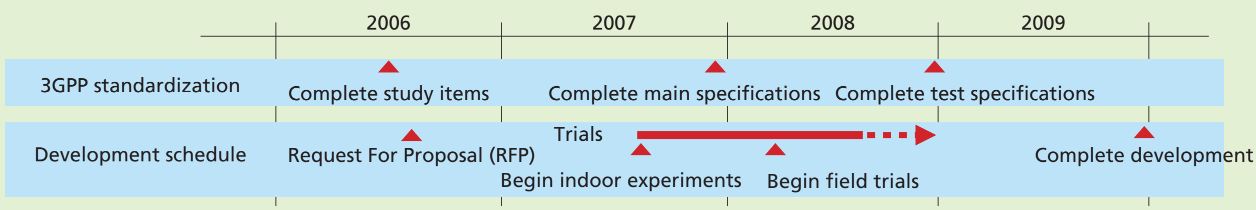

Figure 5 Development schedule

*4 **SC-FDMA**: A method that allows multiple user access by allocating consecutive frequency bandwidths for each user within the same frequency band.

*5 **PAPR**: An index indicating the level of transmission power at peak times as the ratio of maximum to average transmission power of the modulated signal. Lowering PAPR can reduce the power consumption of the mobile terminal.

of the orthogonality between subcarriers (**Figure 6**). The following describes important capacity enhancement technologies newly applied to Super 3G (LTE).

1) Frequency-domain Packet Scheduling

In broadband transmission, the key to reducing the effect of frequency-selective fading in which received signal level fluctuates in the frequency domain due to multipath interference is to make effective use of it. Super 3G (LTE) applies frequency-domain packet scheduling using fluctuation in the propagation path within the frequency domain as a data-channel transmission method. Here, UE measures, for each defined unit of frequency, the Channel Quality Indicator (CQI) indicating the received signal quality on the downlink channel and reports the measured CQI to evolved Node B (eNB), i.e., the base station, via the control channel on the uplink. The eNB, in turn, uses CQI information so obtained from multiple users as a basis for allocating radio Resource Blocks (RBs)*6 to selected users (**Figure 7**). The optimal allocation to individual users of frequency blocks having high received signal levels in accordance with each user's CQI enables a diversity effect (multiuser diversity) to be obtained and user throughput and throughput per cell to be improved.

2) High-speed Signal Transmission Using MIMO Multiplexing Transmission

Multiple-Input Multiple-Output (MIMO) multiplexing transmission achieves high-speed transmission by using multiple transmit and receive antennas to transmit and recieve different signals on the same frequency at the same time thereby improving user and cell throughput. The mobile terminal separates transmit signals on the basis of measured channel fluctuation using the orthogonal reference signal*7 of

Table 1 Basic specifications of Super 3G trial equipment

Frequency		1.7 GHz
Access system	Uplink	SC-FDMA
	Downlink	OFDMA
Bandwidth		5, 10, 15, 20 MHz
Sub-frame length		1 ms
Subcarrier spacing		15 kHz
Guard interval	Short	4.7 μs
	Long	16.7 μs
Modulation method		QPSK, 16QAM, 64QAM*
Channel coding		Turbo coding
Multi-antenna		1×2, 2×2 (4×2) MIMO, 4×4 MIMO

* Supported only in the downlink

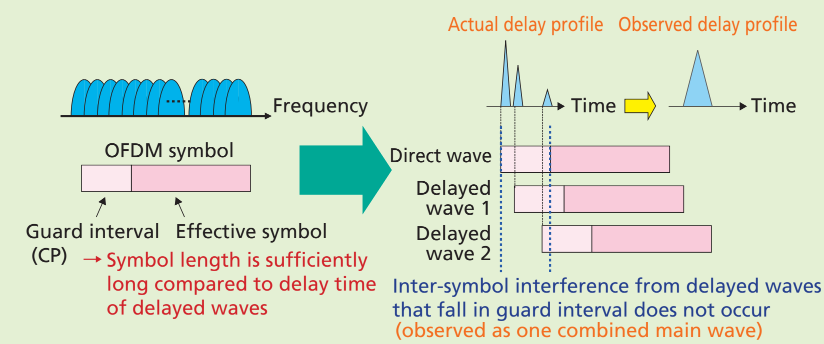

Figure 6 OFDM

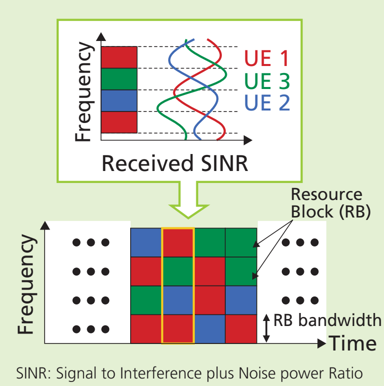

Figure 7 Frequency-domain scheduling

*6 **RB**: Smallest radio-resource unit for performing frequency-domain packet scheduling.

*7 **Orthogonal reference signal**: A reference signal used in cell level detection and for channel estimation during demodulation. This reference is orthogonal between multiple antennas.

each transmit antenna. In contrast to single-carrier radio access like Direct Sequence - Code Division Multiple Access (DS-CDMA)[*8], OFDMA can perform highly accurate signal separation with respect to other transmit antenna signals without being affected by multipath interference making it highly compatible with MIMO multiplexing transmission and applicable to high-speed signal transmission. Also applied here is rank adaptation that controls the number of transmit streams according to receive conditions (**Figure 8**). This control scheme improves quality by decreasing the number of transmit streams when receive level is low or channel correlation is high, and achieves high-speed transmission by transmitting multiple streams simultaneously when receive level is high and channel correlation is low.

3.2 SC-FDMA Uplink Radio Access

One aspect in which the uplink differs from the downlink is that reducing power consumption at the mobile terminal is a vital requirement. In particular, given that the power amplifier in the transmit part of the mobile terminal consumes a large proportion of power, it is essential to adopt an access system applicable to an amplifier with high power efficiency. Furthermore, assuming power amplifiers with the same maximum transmission power, a coverage area that can achieve the same receive performance can be enlarged by lowering the PAPR of the access scheme. It is for these reasons that Super 3G (LTE) adopts SC-FDMA. The following describes the main features of SC-FDMA radio access.

1) Variable Bandwidth with SC-FDMA

In the uplink, data channel transmission is performed at the minimum transmission power corresponding to the data rate of the traffic required from the viewpoint of reducing power consumption in the mobile terminal as discussed above. We note here that increasing the transmit-signal bandwidth achieves the higher frequency diversity effect that averages out propagation-path fluctuation in the frequency domain. However, increasing transmit signal bandwidth above that which is necessary reduces the power density of reference signals needed for estimating the radio propagation path. As a result, performance at the receiver is degraded due to poor channel estimation accuracy. This is the reason for using SC-FDMA that is capable of variable bandwidth corresponding to the data rate of transmission traffic (**Figure 9**). A particular point in which the uplink differs from the downlink is that the former allows only the transmission of a single carrier. Here, to maintain the properties of a single carrier, consecutive frequency bands (consecutive RBs) must be allocated by frequency-domain packet scheduling as opposed to discrete fre-

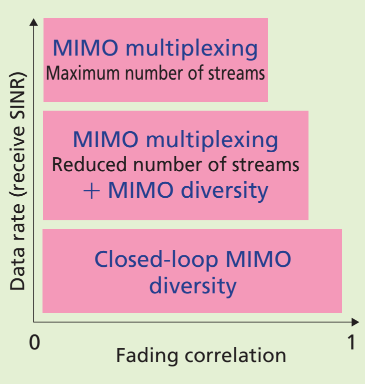

Figure 8 Application of rank adaptation (control example)

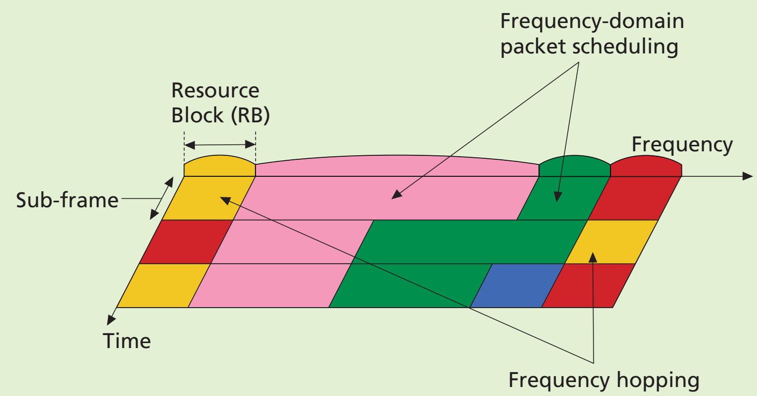

Figure 9 Allocating radio resources in SC-FDMA

*8 **DS-CDMA**: A method that enables multiple-user access in the same frequency band by using a different code for each user and performing direct spreading of a signal sequence. It is used in W-CDMA.

quency bands. In addition, the application of frequency hopping that allocates different frequency bands within a sub-frame or between sub-frames enables a frequency diversity effect to be obtained and high-quality reception to be achieved.

2) Frequency-domain SC-FDMA Signal Generation

Similar to the downlink, SC-FDMA radio access in the uplink allocates part of the system frequency band to each UE through frequency-domain packet scheduling. The scheme used here to generate SC-FDMA signals in the frequency domain is Discrete Fourier Transform (DFT) - Spread OFDM. **Figure 10** shows the block diagram in DFT-Spread OFDM. In this scheme, the UE subjects the post-modulation data symbol sequence to DFT processing and maps the data symbols following this DFT processing to only the frequency band allocated to it while mapping 0s to the non-allocated frequency band. The resulting data sequence is then subjected to an Inverse Fast Fourier Transform (IFFT)[*9] to generate the transmit signal. An important feature of using DFT-Spread OFDM is that the same clock frequency and subcarrier spacing as OFDMA in the downlink can be achieved.

3) Frequency Equalization Using CP

SC-FDMA radio access requires an equalizer to suppress interference from a delayed wave on its own channel (multipath interference). Equalization processing in the frequency domain is less computationally intensive than that in the time domain making the former more practical to implement. This equalization processing requires that the time-domain signal be converted to a frequency-domain signal in units of blocks, and as a consequence, a CP is incorporated into each Fast Fourier Transform (FFT) block to eliminate the effects of inter-block interference.

4) Fractional Transmission Power Control

Since orthogonalization between users can be achieved in the frequency domain in SC-FDMA as described above, interference in CDMA does not occur within the same cell (sector). For this reason, fractional Transmission Power Control (TPC) is applied to control the target value for each user's transmission power.

Fractional TPC sets high target values for users located close to the base station to increase throughput and sets low target values for users close to the edge of the cell to decrease interference with other cells thereby improving overall throughput (**Figure 11**).

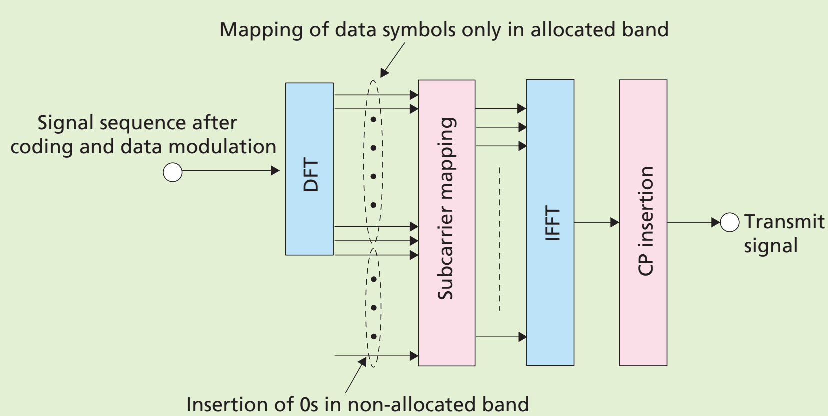

Figure 10 DFT-Spread OFDM

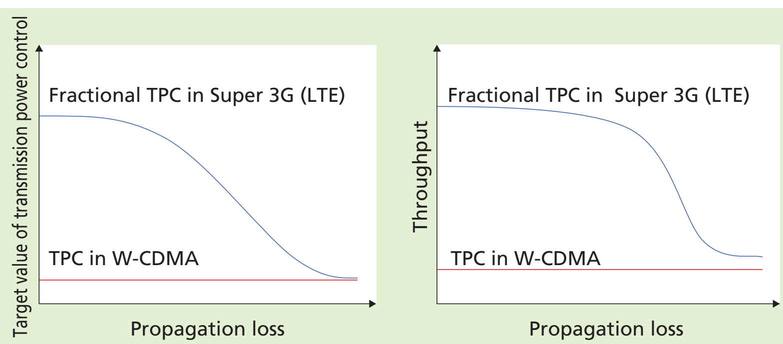

Figure 11 Fractional TPC

*9 **IFFT**: Inverse of the FFT, a high-speed computation method for extracting the frequency components and the ratios of those components included in a time domain signal. IFFT converts a frequency domain signal to a time domain signal and can be achieved by a computational technique the same as that of FFT.

4. Super 3G Trial Equipment and Experimental Results

The Super 3G trial equipment that we have developed aligns with 3GPP standard specifications and incorporates the functions covered in Chapter 3. This chapter outlines this Super 3G trial equipment and describes the results of radio transmission experiments.

4.1 Configuration of Trial Equipment

Photo 1 shows the configuration of indoor trial equipment consisting of eNB, UE and core network emulator. The eNB and UE are connected using a fading simulator to emulate radio propagation paths. Data transferred from the core network emulator is first multiplexed with a header for radio control at the eNB and then converted from a serial to a parallel data sequence for each Codeword[*10]. A Codeword is a retransmission unit in Hybrid-Automatic Repeat reQuest (H-ARQ)[*11] and a maximum of two are used. Next, the bit sequence following serial-to-parallel conversion is subjected to channel coding, data modulation mapping, and multiplication by a precoding matrix, and a transmit signal for each antenna is generated. Channel coding applies turbo coding with constraint length = 4 and coding rate R = 0.16 - 0. 89, and data modulation applies Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (QAM), and 64QAM. The maximum number of transmit antenna branches is four.

On the receiving side, the UE performs linear amplification and quadrature detection on the signal received at the four receive antenna branches by Automatic Gain Control (AGC) and performs an A/D conversion of the I/Q channel signal to a received digital signal. It then detects and updates received OFDM symbol timing based on the correlation between the pre-FFT received signal and orthogonal reference signal multiplexed within the frame. Next, based on the received OFDM symbol timing so obtained, the UE removes the guard interval in the received digital signal and separates the signal into subcarrier components by FFT. The UE then estimates the channel estimation value between transmit and receive antenna branches using the reference signal and then uses this value to perform signal detection in the signal separation part using the Maximum Likelihood Detection with QR decomposition and M-algorithm (QRM-MLD) and Adaptive SElection of Surviving Symbol replica (ASESS) techniques [8], and calculates Log Likelihood Ratio (LLR) of each bit for soft-decision turbo decoding in the LLR calculation part. Finally, the UE inputs the LLR for each bit into the turbo decoder (Max-Log-MAP decoding), performs a parallel-to-serial conversion on decoded data corresponding to each transmit antenna branch, and regenerates the transmit signal sequence.

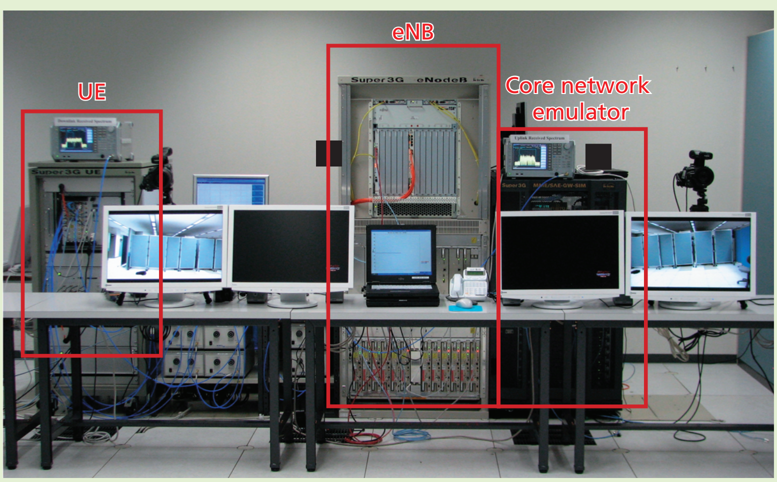

Photo 1 Configuration of trial equipment

4.2 Indoor Experiment Results

1) Downlink Throughput Performance

Figure 12 shows experimental results of throughput performance versus the signal energy per symbol to noise power spectrum density ratio

*10 **Codeword**: A unit of error correction coding; one or more codewords will be transmitted when applying MIMO multiplexing transmission.

*11 **H-ARQ**: Technique for controlling the retransmission of packets combining Forward Error Correction (FEC) and Automatic Repeat reQuest (ARQ) schemes.

E_s/N_0 for one receive antenna when transmitting by one antenna with Modulation and channel Coding Scheme (MCS)*12 as a parameter. The bandwidth used here is 20 MHz, the maximum bandwidth of Super 3G (LTE), and the channel model is extended Vehicular A 3 km/h*13. Also, for the purpose of comparison, the figure shows the results of computer simulations for the same channel model. The results in the figure show that the experimental results agree well with the simulation results, i.e., the loss in the required average received E_s/N_0 is within 1 dB due to the quantization error by A/D converters and the non-linearity of RF receiver circuitry including the AGC amplifier.

Figure 13 shows throughput performance when transmitting by multiple antennas (MIMO). Here, the number of transmit and receive antennas is four each and the number of transmit streams (rank number) is a parameter. The channel model is a six-path exponential decaying model whereby average received power attenuates by 2 dB per path and speed is 3 km/h. We also applied Adaptive Modulation and channel Coding (AMC) that selects the optimal combination of modulation order and coding rate according to receive level and H-ARQ that retransmits packets in the event of errors and combines them at the receiver side. Incremental Redundancy (IR) that transmits different redundant bits to improve error correction performance during retransmissions is used as the H-ARQ scheme. Other conditions are the same as those in Fig. 12, and fading correlation between antennas is 0. The results in the figure show that a throughput of 100 Mbit/s was achieved for rank 2 at average received E_s/N_0 = 18 dB and that a maximum throughput of 240 Mbit/s was reached in a fading environment for rank 4.

2) Uplink Throughput Performance

Figure 14 shows experimental results of throughput performance versus average received E_s/N_0 with MCS as parameter. The bandwidth used here is 20 MHz, the maximum bandwidth of Super 3G (LTE), and the channel model is extended Vehicular A 3 km/h the same as in the downlink. The figure also shows the results of computer simulations for the same channel model for the purpose of comparison. These results show that the experimental results agree well with the simulation results, i.e., the loss in the required average received E_s/N_0 is within 1 dB.

Figure 15 shows throughput performance versus normalized propagation loss from the eNB. In the experiment, we used the Okumura-Hata for-

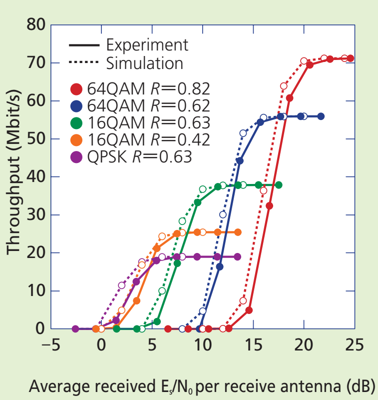

Figure 12 Downlink throughput performance (transmission by one antenna)

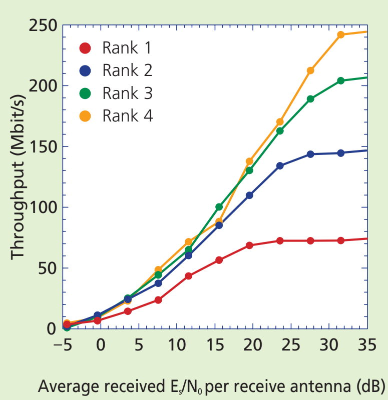

Figure 13 Downlink throughput performance (transmission by multiple antennas (MIMO))

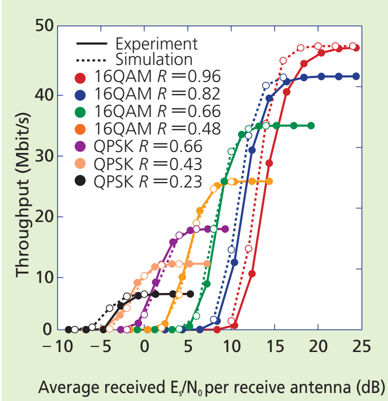

Figure 14 Uplink throughput performance

*12 **MCS**: Combinations of modulation scheme and coding rate decided on beforehand when performing AMC.

*13 **Extended Vehicular A 3 km/h**: One of the path models simulating a mobile environment defined by 3GPP.

mula to calculate normalized propagation loss with respect to distance from the eNB and we adjusted signal attenuation level to evaluate throughput performance as a parameter equivalent to distance from eNB. In the figure, we use normalized values such that propagation loss at a point 35 m from the eNB is 0 dB. Here, maximum UE transmission power is taken to be 24 dBm and parameter N_{RB} denotes the number of RBs used (allocated bandwidth). In addition, we use the fractional TPC technique described above in transmission power control and set transmission power according to propagation loss, and we apply AMC and H-ARQ the same as in the downlink. Examining the results in the figure, we can see that applying a bandwidth of N_{RB} = 96 (17.2 MHz) in the vicinity of the cell can achieve a throughput of about 50 Mbit/s while decreasing the number of RBs allocated to users at the edge of the cell can increase coverage.

3) Delay Performance

Figure 16 shows the configuration of a delay measurement experiment for testing the shortening of transmission delay, one of the most important technical requirements in Super 3G (LTE), and **Photo 2** shows round-trip transmission delay values as measured using a ping command. Round-trip transmission delay was found to be about 12 - 13 ms, and taking into account the transfer delay between the eNB and server and the processing delay at the core network emulator and server, these results indicate that the 5-ms one-way transmission delay target of Super 3G (LTE) is practically satisfied.

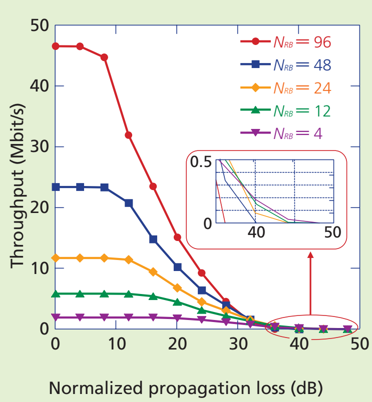

Figure 15 Throughput performance versus propagation loss

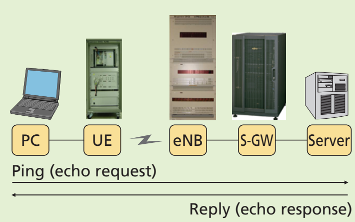

Figure 16 Configuration of delay measurement experiment

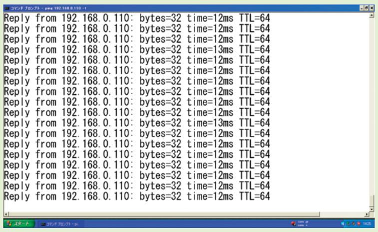

Photo 2 Delay performance

4.3 Field Trial Results

Field trials commenced in February 2008 in two areas: Yokosuka City in Kanagawa prefecture and Kofu City (and its suburbs) in Yamanashi prefecture. **Figure 17** shows the field trial course in Yokosuka City. In this area, we tested radio performance for actual radio propagation channels. **Photo 3** shows a screen shot of field trial performance, and in particular, receive performance on the downlink when transmit-

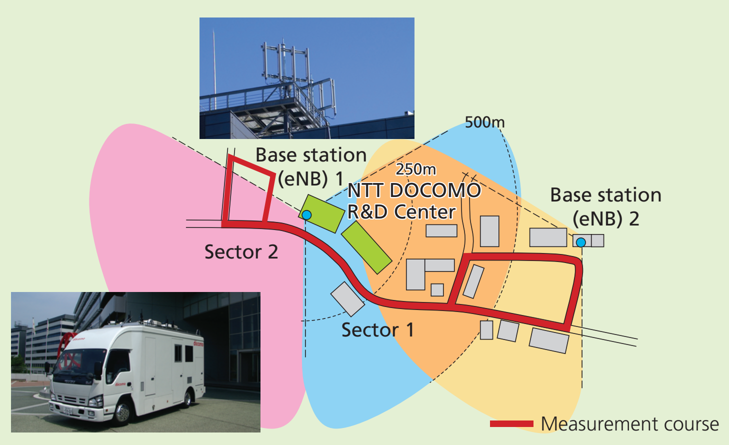

Figure 17 Field trial course

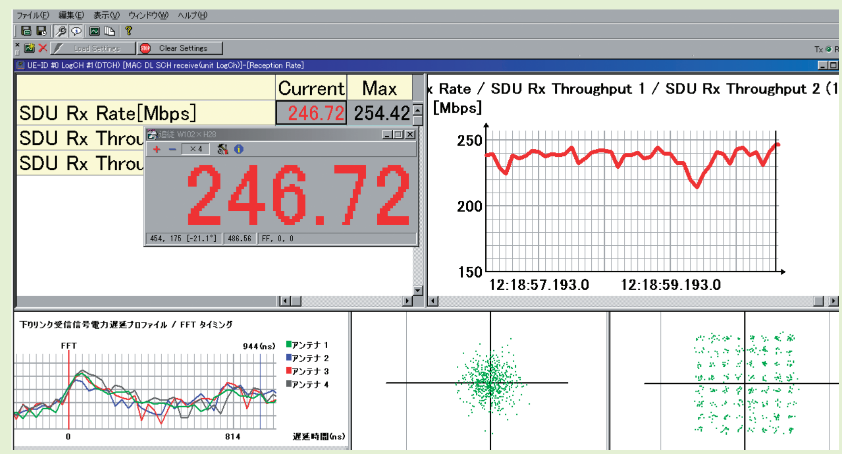

Photo 3 Example of field trial performance

ting by four antennas on the eNB. It was confirmed that a throughput of about 250 Mbit/s was achieved even in a field trial environment.

5. Conclusion

In this article, we outlined the Super 3G (LTE) system planned for commercialization with the aim of achieving a significant reduction in cost per bit. We described the state of its development and performance of transmission experiments using trial equipment and demonstrated the effectiveness of the system. We plan to test a frequency-domain scheduler function for simultaneously connecting multiple users and an inter-sector and inter-cell handover function, to perform tests toward practical deployment, and to work on optimizing the system.

References

[1] K. Kinoshita: "Current Status of "FOMA" 3G service and DoCoMo's B3G Activities," ICB3G-2004, pp.13-21, May 2004.

[2] T. Nakamura et. al: "Super 3G Technology Trends Part 1: Super 3G Overview and Standardization Activities," NTT DoCoMo Technical Journal, Vol.8, No.2, pp.52-56, Sep. 2006.

[3] 3GPP TR25.913: "Requirements for Evolved UTRA and UTRAN"

[4] 3GPP TR25.912: "FS for Evolved UTRA and UTRAN"

[5] 3GPP TS36.211: "Evolved Universal Terrestrial Radio Access (E-UTRA) Physical Channels and Modulation"

[6] 3GPP TS36.212: "Evolved Universal Terrestrial Radio Access (E-UTRA) Multiplexing and Channel Coding"

[7] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA) Physical Layer Procedures"

[8] K. Higuchi, H. Kawai, N. Maeda and M. Sawahashi: "Adaptive selection of surviving symbol replica candidates based on maximum reliability in QRM-MLD for OFCDM MIMO multiplexing," in Proc. IEEE Globecom2004, Vol.4, pp.2480-2486, Nov. 2004.