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Super 3G Technology Trends

Part 2: Research on Super 3G Technology

In this part 2 of the Super 3G research that is being conducted to achieve a smooth transition from 3G to 4G, we present technology that is currently being studied for standardization as technical details.

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1. Introduction

As explained in part1, Super 3G, the so-called Evolved URAN and UTRAN or Long term evolution by the 3rd Generation Partnership Project (3GPP) has been extensively studied since 2005. Agreement on the requirement was reached in June of 2005 to begin investigation of specific technologies. In June 2006, it was agreed that investigation of the feasibility of the basic approach for satisfying the requirements was essentially completed, and effort shifted to the work item phase to start the detailed specifications work. Here, we explain technology that has been proposed as study items.

2. Proposal for a Physical Layer Technology Concept

At the 3GPP TSG RAN WG1 meeting in June, 2005, six concepts were proposed for the Frequency Division Duplex (FDD)[*1] system and the Time Division Duplex (TDD)[*2] system (**Table 1**).

Table 1 Proposed wireless access system

Duplex system	Uplink	Downlink
FDD	SC-FDMA	OFDMA
	OFDMA	OFDMA
	MC-WCDMA	MC-WCDMA
TDD	MC-TD-SCDMA	MC-TD-SCDMA
	OFDMA	OFDMA
	SC-FDMA	OFDMA

MC-TD-SCDMA (MultiCarrier Time Division Synchronous Code Division Multiple Access): TD-SCDMA is planned for application to the Third-Generation mobile communication in China.

At the RAN WG1 meeting of November 2005, there was agreement by many companies that high commonality is extremely important and wireless access should be the same for FDD (paired spectrum) and TDD (unpaired spectrum). As this common wireless access system for FDD and TDD, Orthogonal Frequency Division Multiple Access (OFDMA), which features highly efficient frequency utilization was approved for the downlink and Single-Carrier Frequency Division Multiple Access (SC-FDMA) was approved for the uplink at the December 2005 Plenary Meeting.

The features of the wireless access system are described in detail below.

2.1 Downlink OFDMA

Orthogonal Frequency Division Multiplexing (OFDM) achieves a high data rate with broadband signal by parallel transmission of many narrow bandwidth sub-carrier signals. It is thus highly robust against multi-path interference (interference from delayed waves) and high-quality transmission can be realized. Furthermore, because OFDM uses a narrow bandwidth subcarrier signal, it can flexibly extend to a wide signal bandwidth spectrum of from 1.25 to 20 MHz by changing the number of subcarriers. Generally, each OFDM symbol[*3] is consisted with a guard interval that is called the Cyclic Prefix. The purpose of the prefix is to prevent symbol interference, in which the delayed waves of one symbol affect the next OFDM symbol, and subcarrier interference, which destroys the orthogonality between sub-carriers. In E-UTRA (Evolved UTRA), this Cyclic Prefix is used for a baseline in OFDM-based wireless

*1 FDD: One of bidirectional transmitting and receiving system. Different frequency bands are allocated to the up-link and down-link. Simultaneous sending and receiving is possible.

*2 TDD: One of bidirectional transmitting and receiving system. The same frequency band is used by the up-link and down-link. Bidirectional communication is possible by time allocation.

*3 Symbol: A unit of data for transmission. In OFDM, it comprises multiple subcarriers. Multiple bits (2 bits in the case of QPSK) map to each subcarrier.

access. The features of OFDM-based wireless access are explained below.

1) Signal transmission using frequency diversity

In broadband transmission, how to make full use of the effect of frequency selective fading[*4], in which the received level varies with the frequency due to multi-path propagation as described above, is a key question. There are two signal transmission methods for OFDM-based wireless access, Localized FDMA (**Figure 1**(a)) and Distributed FDMA (Fig. 1(b)). In the localized FDMA method, consecutive multiple subcarriers (a radio resource block) are allocated to a particular user; in Distributed FDMA, the entire band is used and distributed to multiple users in a spread fashion.

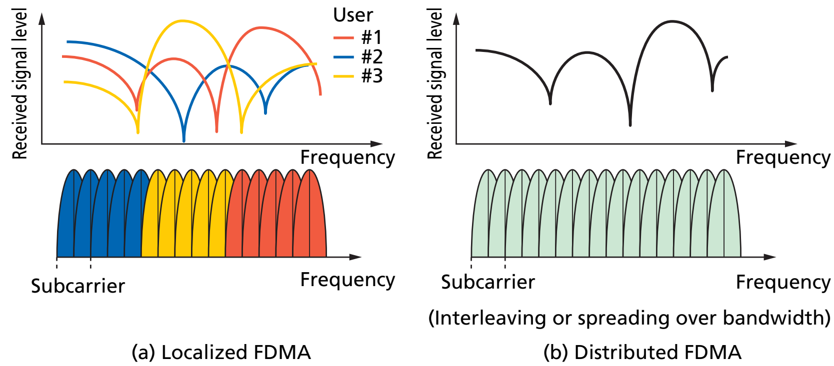


Figure 1 Localized and Distributed FDMA signal transmission methods

a) Localized FDMA

For the data channel, packet scheduling that makes use of the fluctuation in the propagation of the frequency domain is adopted. That is to say, users for which the received signal level is high in the frequency domain are selected. A mobile terminal measures the channel quality for each unit of frequency for transmitting one radio resource block, and the Channel Quality Indicator (CQI) data is reported to the base station via the control channel in the uplink. The base station transmits information data by the radio resource blocks in subframes, which are the smallest unit of a time frame, to the users selected by scheduling on the basis of the CQI data received from multiple users. Allocating the optimum localized FDMA signal according to the CQI of each user makes it possible to select the users that have the frequency blocks of high received signal level, as shown in Fig. 1(a). Thus, a diversity effect between users (i.e., the multi-user diversity) can be attained, and user throughput[*5] and cell throughput[*6] can be improved.

b) Distributed FDMA

For channels that broadcast to multiple users, such as the common control channel, the broadband frequency diversity effect can also be obtained for low data rate channels by transmitting the signal by Distributed FDMA using subcarriers that are spread in the frequency band. A signal transmission method that combines Localized and Distributed FDMA signals is also being studied.

2) High-speed signal transmission using a MIMO

To achieve the 100 Mbit/s target peak data rate for the E-UTRA downlink, the application of Multiple Input Multiple Output (MIMO) multiplexed transmission is being studied. In MIMO multiplexed transmission, user and cell throughput can be improved by using the same radio resources (time, frequency and code) to transmit different data from multiple transmitting antennas. Transmission signal separation is accomplished at the receiver by measuring the orthogonal pilot channel for each transmitting antenna and using the channel fluctuation value for each transmitting antenna. Using MIMO multiplexed transmission in OFDM brings high channel estimation and separation accuracy because there is no effect from multi-path interference as there is in single-carrier based wireless access such as Direct Sequence Code Division Multiple Access (DS-CDMA)[*7]. OFDM is thus highly compatible with MIMO multiplexed transmission and is therefore applied for high-speed signal transmission. The throughput performance for MIMO multiplexed transmission with two transmit and two receive antenna branches (2×2) with respect to average received E_s/N_0 are shown in **Figure 2**. The signal bandwidth is 20 MHz and the typical urban channel model is used for the multipath channel model. We can see from the figure that 2×2 MIMO multiplexed transmission can achieve a throughput of 100 Mbit/s or more, meeting one requirement for the 20 MHz signal band.

3) Multi-cast/Broadcast signal transmission using SFN combining

*4 Frequency selective fading: A phenomenon in which the received level is not uniform along the frequency axis of the received signal because signals (frequencies) arrive through various paths due to reflection from buildings, etc.

*5 User throughput: The amount of data that one user can transmit without error per unit time.

*6 Cell throughput: The amount of data that can be transmitted within one cell per unit time.

*7 DS-CDMA: A method that uses a different coding for each user to directly distribute a signal series to allow access by multiple users in the same frequency band. It is used in W-CDMA.

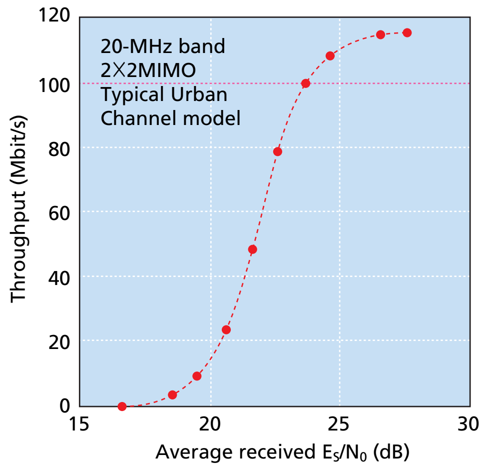


Figure 2 Throughput performance for 2 X 2 MIMO multiplexed transmission

In OFDM-based wireless access, delayed signals that arrive within the guard interval do not cause inter-symbol interference or subcarrier interference, so all of the effective signal power can be used. Accordingly, if the same radio resources from a different cell site transmit the same data, the signals arriving within the guard interval can be combined as desired signal similar to delayed signals from a single cell. Because the same data signals within the guard interval are input to the receiver as a composite signal, it is referred to as Single Frequency Network (SFN) combining or soft combining. Thus, signals from multiple base stations can easily be combined in OFDM, and multi-casting or broadcasting that adopts this SFN combining is being studied as an important OFDM technology. In multi-casting and broadcasting, transmission signals from multiple cell sites are combined for reception, so the guard interval must be longer than for unicasting, in which communication is generally with a single cell site. In this case, however, all of the signals from multiple sites that arrive within the guard interval as described above contribute to desired signal power, so high-quality reception at a high data rate is possible.

2.2 Up-link SC-FDMA

The uplink transmission differs from the downlink transmission in that low power consumption is an extremely important requirement for mobile terminals. The power amplifier of the transmitter, in particular, accounts for a large proportion of the power consumed by a mobile terminal. That is to say, assuming power amplifiers of the same maximum transmission power, lower Peak-to-Average Power Ratios (PAPR) allow for larger coverage areas for a given reception capability. Below, we describe the features of SC-FDMA wireless access.

1) Variable bandwidth SC-FDMA

For the uplink, the data channel transmission is done at the minimum transmission power that corresponds to the data rate of the traffic to be transmitted, considering reduction of mobile terminal power consumption as mentioned above. If the transmission signal bandwidths becomes wider, the frequency diversity effect will increase. However, if the signal bandwidth is expanded beyond what is necessary, the reception performance degrades because the power density of the pilot signal, which is needed to estimate the channel condition, is decreased and the accuracy of channel estimation decreases. Accordingly, SC-FDMA wireless access is adopted, because the bandwidth is varied according to the data rate of the transmission traffic (**Figure 3**).

2) Frequency-domain SC signal generation

In uplink SC-FDMA wireless access, Localized and Distributed FDMA bidirectional signal transmission methods can be used in the same way as in downlink OFDMA. Localized FDMA allocates a consecutive set of frequencies in the ordinary system band in the same way as FDMA. The difference with the downlink is that the uplink permits transmission with only a single carrier to reduce the PAPR. Localized FDMA is used mainly for data channels. Scheduling that adopts propagation path changes in the time and frequency domains has also been studied for the uplink, and subframes and frequency bands for transmitting from the base station by Localized

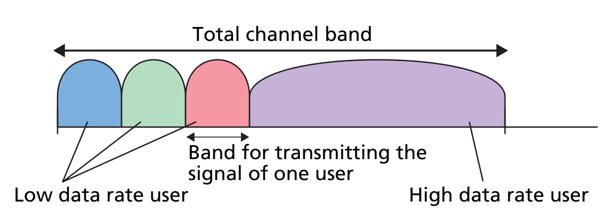


Figure 3 Variable bandwidth SC-FDMA wireless access

FDMA on the data channel have been allocated. Distributed FDMA, on the other hand, is a signal transmission method that uses spread frequency components (the spectrum is spread in a comb shape) as shown in Fig. 1(b). Differently from the case for downlink OFDMA, there is no fluctuation in the transmission signal level in the time domain as there is with multicarrier transmission, so there is no increase in PAPR. Distributed FDMA is able to achieve the frequency diversity effect by spreading the signal over a broadband in a comb shape fashion, so its application to the channel is being investigated. As the method for generating the SC Distributed FDMA signal in the frequency domain, Discrete Fourier Transform (DFT) -Spread OFDM has been proposed. The transmission block configuration of DFT-Spread OFDM is shown in **Figure 4**. Because DFT-Spread OFDM uses Fast Fourier Transform (FFT)[*8] processing, it can implement the same clock frequency and subcarrier interval as the downlink OFDM access, and so has the advantage of common generation of the SC Distributed FDMA signal and the OFDM signal.

3) Using the Cyclic Prefix for frequency equalization

SC-FDMA access requires an equalizer to suppress interference from delayed signals in the same channel (multi-path interference). The processing for frequency domain equalization is computationally lighter than time domain processing, so it is practical in application. Frequency domain equalization processing requires conversion of a time domain signal into a frequency domain signal in units of the block, so the effect of interference between blocks is eliminated by establishing a Cyclic Prefix for each FFT block.

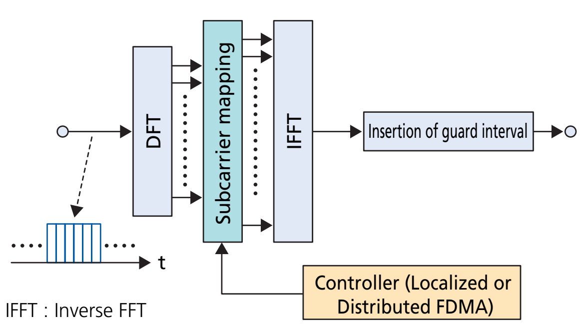


Figure 4 DFT-Spread OFDM block diagram

3. Wireless Access Network Architecture and Wireless Interface Protocol

The requirements approved in June 2005 that are relevant to the architecture and the wireless interface protocol include those listed below.

- Low control delay and low transmission delay
- Simplification
- Cost reduction
- Service provision capability that as good as or better than the current capability

To satisfy the above requirements, it is also necessary to investigate changes in the division of functions and to include new network architectures and protocols within the scope of study. The 3GPP is currently proceeding with vigorous work in these areas also. In the following sections, we describe the direction and status concerning the main items that are currently being discussed in 3GPP.

3.1 Super 3G Architecture

One technical feature of the 3G system is soft hand-over, which is achieved by simultaneous transmission/reception via multiple base stations. For architectural support of soft hand-over, the important radio functions have been centralized in the Radio Network Controller (RNC)[*9], which resides above the base station. The High Speed Downlink Packet Access (HSDPA), which is the enhanced system of W-CDMA in Release 5[*10], adopts a Shared CHannel (SCH), which has high compatibility with packet traffic. Thus, it can be realized the efficient transmission by base station packet scheduling making use of the channel variation. Although consistency with the previous Release 99[*10]architecture has been given due consideration for the functional additions to the HSDPA, there are many points of difference with the previous R.99 configuration. Some of the main differences are that the most of the resource control function shifted to the base station side in HSDPA and a hard hand-over, communicating with a single base station and switching base stations is applied for shared data channel.

*8 FFT: A high-speed computation method for extracting the frequency components of a time domain signal and the proportions of those frequencies. The method for obtaining a time domain signal from a frequency domain signal, on the other hand, is called the IFFT.

*9 RNC: A node defined by 3GPP for executing radio resource management, mobile terminal control and base station control.

*10 Release**: Indicates the version of the 3GPP specifications. Release 99 is the initial standard specification for 1999. The HSDPA functions were added in 2005 as Release 5.

Those differences result in functional duplication by the RNC and the base station and control become complex in some respects.

In Super 3G, on the other hand, the most important issue is to attain a large improvement in performance and reduction in equipment cost, so the basic policy is to achieve a functional arrangement that is suited to a shared channel access system and simplify radio control by not adopting soft hand-over.

A major feature of the system configuration is the distribution of the previous RNC functions over the evolved Node B (eNB) and the Mobile Management Entity/User Plane Entity (MME/UPE) of the core network node (**Figure 5**), with elimination of the RNC itself. Reducing the types of node also reduces the development scale and lightens the burden of operation and management. Reductions in hardware processing delay and other improvements in basic performance are also expected.

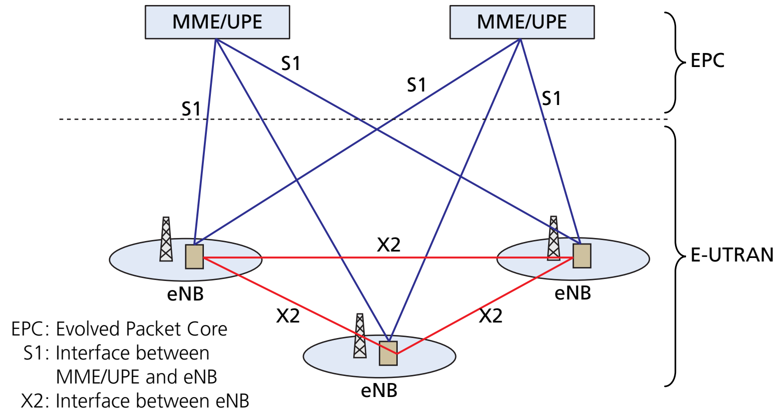


Figure 5 UTRAN architecture for the Super 3G system

The functions conventionally assigned to the RNC, Radio Resource Management (RRM), Radio Resource Control (RRC), Packet Data Convergence Protocol (PDCP)[*11], Radio Link Control (RLC), and Medium Access Control (MAC), are suitable for assignment to eNB and MME/UPE as shown in **Figure 6**. The main features of the protocols are explained below.

1) RRC and RRM functions

The RRC is an important function that works together with the RRM for call admission control and to control hand-over and other basic operations of a mobile terminal. In shared channel access systems, many of the radio resources are managed on the MAC function level. Assigning the RRC to the eNB like the MAC function, as shown in Fig. 6, facilitates cooperation with the RRM by reducing processing delay and improving spectral efficiency. Furthermore, hand-over between closed cells within the same eNB can be processed within the eNB, so a hardware configuration that accommodates many cells has great merit. On the other hand, hand-overs that extend across eNBs are executed by the exchange of RRC and RRM information between eNB.

2) RLC and MAC functions

RLC and MAC have functions for multiplexing/demultiplexing, retransmission, reordering and other tasks that govern effective throughput and transmission delay quality. The conventional 3G system assigns the retransmission function of the

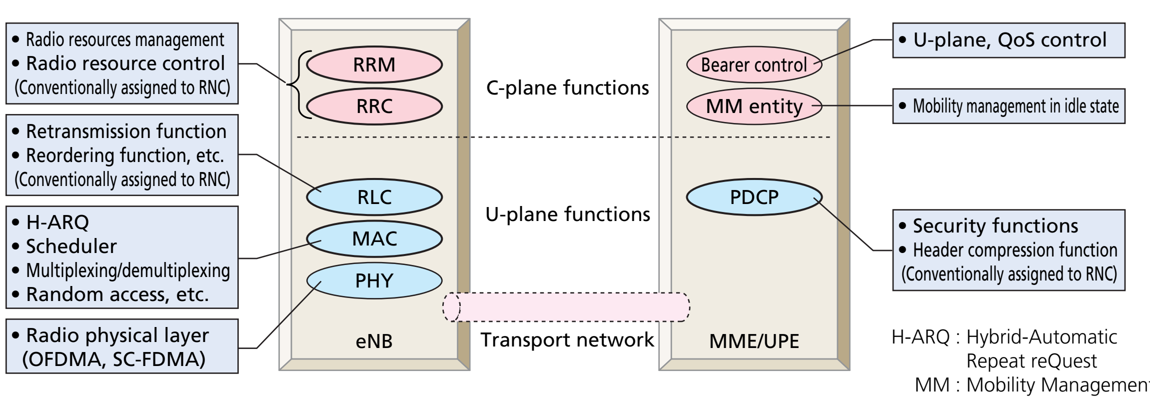


Figure 6 Functional arrangement in the Super 3G system

*11 PDCP: A sublayer of layer 2. A protocol for concealment, validation, ordering, header compression, etc.

RLC layer to the RNC, which creates the following problems for attaining high throughput.

- The retransmission processing involves a transmission delay between the RNC and the base station and a processing delay within the equipment, so it is difficult to achieve a short Round Trip Time (RTT)[*12].
- To attain optimum throughput, a high-speed flow control function is required between the RNC and the base station.

The peak data rate in Super 3G is 100 Mbit/s. To attain the same throughput in the TCP, it is extremely important to shorten the RTT. Therefore, Super 3G assigns RLC and MAC function only to eNB (Fig. 6), thus both minimizing the RTT and eliminating the need for flow control. Having both MAC and RLC functions in eNB, an additional new function for forwarding the data between eNB is needed to realize lossless handover.

3) Security functions

The ciphering for the user data and the Non-Access Stratum (NAS) is done at MME/UPE. The ciphering for RRC, however, is assumed to be executed at the eNB. The trend in recent years is to install the base station lower and closer the public space to maintain indoor area coverage and radio capacity for offices, etc. This leads to a higher risk of unexpected access to the base station by non-authorized users. Accordingly, to maintain the confidentiality of communication, user data that requires a high level of security and the NAS protocol are assigned to MME/UPE, which is installed within buildings maintained by the Operator.

In addition to functions 1) through 3), a pooling function[*13] between MME/UPE and eNB for the purposes of redundancy and distribution of load, transport network layer support for communication between base stations, and network synchronization for support of Multimedia Broadcast Multicast Service (MBMS)[*14] and LoCation Service (LCS)[*15] are also being studied.

3.2 Simplification of Channel Configuration

The conventional 3G system used the channel switching scheme, based on circuit switching, switching among multiple types of channels to realize efficient transmission in both circuit switching and packet switching (**Figure 7**). Here, the logical channels are classified according to the use of the transmitted data. For example, there are the Broadcast Control CHannel (BCCH), the Dedicated Control CHannel (DCCH) for individual user control signals, the Dedicated Traffic CHannel (DTCH) for individual user data traffic, and the MBMS Traffic CHannel (MTCH) for multicast and broadcast data. The transport channels, on the other hand, map those logical channels to physical channels; they include the shared channel (DL/UL SCH) and the channels that correspond to the UL Random Access CHannel (RACH), etc. In contrast to that, Super 3G is a system that targets packet switching, as described above. It can cope with various Quality of Service (QoS) levels while optimizing packet transport, so investigation is proceeding in the direction of using SCH for the transport of virtually all service and control information, as shown in Fig. 7. This approach reduces the number of channel types, simplifies the system and decreases the control load.

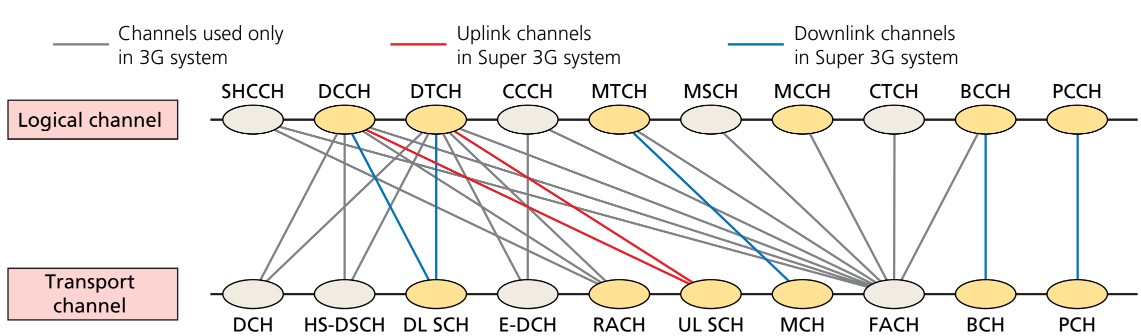


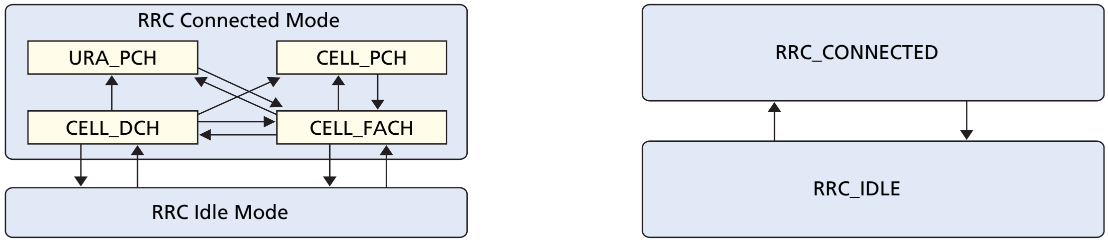
Figure 7 Channel configuration in 3G and Super 3G systems

*12 RTT: The delay time caused by the round-trip transmission of data between units of equipment; In the case of retransmission, it is the required time between the first transmission and the retransmission.

*13 Pooling function: A function that has connectivity with multiple units of equipment and allows the connection destination to be changed for each call.

*14 MBMS: A system for distribution of multimedia data by broadcasting to a large number of unspecified parties or multicasting to a number of specified parties.

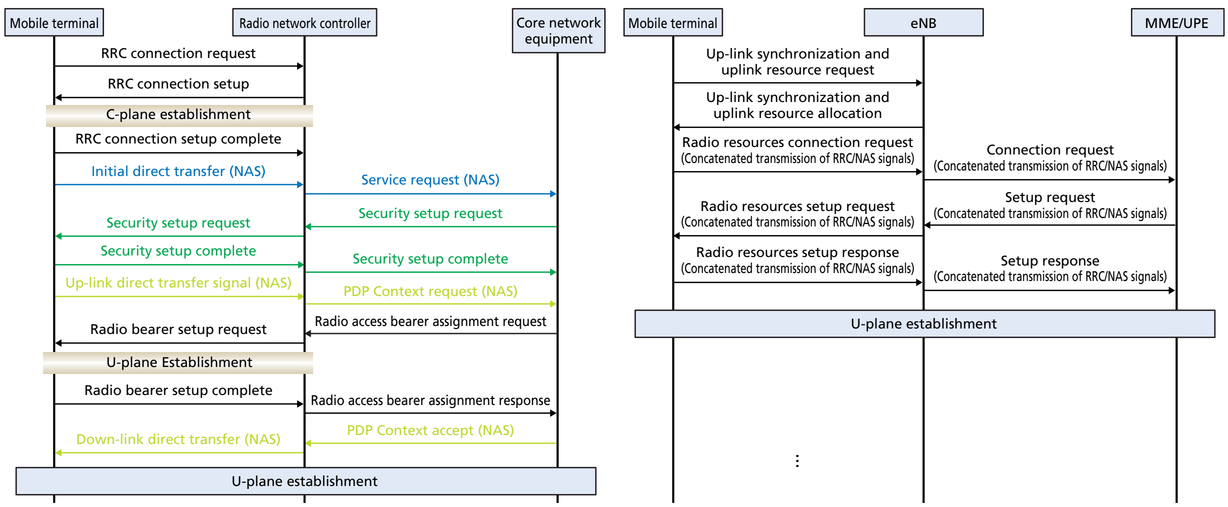
*15 LCS: A service that determines the location of a mobile terminal.



(a) RRC state transitions in the 3G system

(b) RRC state transitions in the Super 3G system

Figure 8 RRC states in 3G and Super 3G systems



(a) Connection setup sequence in 3G

(b) Example of a connection setup sequence in Super 3G

Figure 9 Example of connection sequences

Having fewer channel also reduces the number of patterns of state transitions between channels. Specifically, the RRC states are defined in the 3G system (**Figure 8**), and the states are switched during communication according to traffic volume so as to maintain high radio resource efficiency by the mobile terminal. In the Super 3G system, on the other hand, the number of states is decreased to two (RRC_IDLE and RRC_CONNECTED), so the processing load and the processing delay that are caused by state transitions can be reduced.

3.3 Optimization of Signaling

To shorten control delay and simplify the system in the conventional 3G system, ways of eliminating redundancy in control signals and the signaling protocol, making the various control signals as short as possible and making the number of signals as small as possible have been studied. Specific proposals include defining a bearer for which QoS negotiation is not required and beginning transmission of the signal at an early stage over that bearer, and transmission in which the control signal between the mobile terminal and the core network (NAS) is concatenated with the radio resource control signal (RRC). By making such improvements, the connection setup time up to the transmitting and receiving of data can be shortened greatly compared to the conventional 3G system. Conventionally, the RRC and NAS signals are independent, and are transmitted and received in order. The purpose of batch transmission of the RRC and NAS signals is to reduce the number of round-trip signals between the network and the mobile terminal to two, as shown in **Figure 9** (b) for example.

4. Conclusion

Super 3G technology has great significance both for a smooth migration to 4G and continuing competitive power through efficient use of the 3G spectrum over the long term through development of 3G technology. We can assume that various kinds of new technology and systems will arise in the future to both compete with the cell phone system and work in cooperation with it. As a mobile communication carrier, it is important to efficiently use both the radio spectrum that is currently available and the spectrum that will be allocated to future mobile terminals. As the development of technology and business proceed with the 3G system as the mainstream, Super 3G and 4G system development will play an important role.

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