Enhanced Uplink | FOMA Mobile Terminals | Maximum Uplink Speed of 5.7 Mbit/s

Technology Reports

HSUPA Services Achieving Maximum Uplink Speed of 5.7 Mbit/s

NTT DOCOMO launched HSUPA services in June 2009. The HSUPA transmission scheme enables uplink data speeds of up to 5.7 Mbit/s, enabling mobile users to more quickly send high-quality images and large-volume video files as email attachments and to update blogs in less time. HSUPA, in combination with the HSDPA high-speed downlink transmission scheme, provides faster-than-ever mobile Internet access. NTT DOCOMO has developed mobile terminals that support HSUPA, including the L-05A USB card terminal designed to meet the requirements of corporate users as well as consumers, the L-06A handset, L-07A ExpressCard terminal, and the latest winter/spring 2009 model terminals.

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1. Introduction

NTT DOCOMO's FOMA services, launched in October 2001, enable us to provide a variety of services that offer a high-speed broadband experience for mobile users. As we extended our lineup of terminals, improved the quality of services, and expanded the coverage area, the subscriber base grew, exceeding 51 million by the end of September 2009. Our subscribers have steadily migrated to Third-Generation (3G) FOMA services. In August 2006, NTT DOCOMO introduced commercial High-Speed Downlink Packet Access (HSDPA) [1] services to accommodate the growing needs of users for faster mobile access to transmit video files, enjoy music delivery services, and browse Web pages like PC users do. The HSDPA transmission scheme enables downlink data speeds of up to 3.6 Mbit/s while reducing costs and transmission delay. The maximum downlink speed was further raised to 7.2 Mbit/s in October 2007. **Figure 1** shows the availability of HSDPA services around the world.

While increasing the downlink speeds, we continued working to enhance uplink speeds. These efforts were aimed at satisfying the demand by users for faster uplink access so that they could email high-quality pictures taken with sophisticated cameras in their mobile terminals and to post such pictures to their blogs. The uplink speeds were in need of enhancement since the maximum was only 384 kbit/s, which was quite low compared to HSDPA's maximum downlink speed of 7.2 Mbit/s. In June 2005, 3rd Generation Partnership Project (3GPP) standardized the Enhanced Uplink (EUL) scheme in its Release 6 specifications, which provides uplink data speeds of up to 5.7 Mbit/s. EUL is the term 3GPP uses to refer to High-Speed Uplink Packet Access (HSUPA) in its specifications. Although both terms point to the same standard, hereinafter we use the term EUL instead of HSUPA.

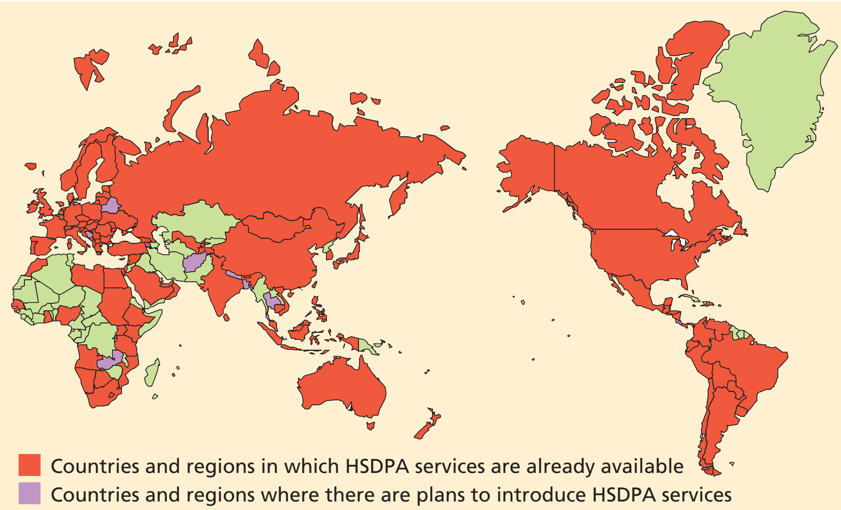
This article summarizes the technical features of EUL, introduces EUL-enabled terminals, and describes EUL throughput characteristics determined by field measurement.

2. EUL Overview

In the Wideband-Code Division Multiple Access (W-CDMA) scheme, different scrambling codes[*1] are assigned to the uplink channels to isolate the users from one another. The scrambling code signal interference from different users adds to the existing multipath interference[*2] and thus degrade the quality of the radio channels. A Transmit Power Control (TPC)[*3] technique was introduced to the W-CDMA uplink in an effort to maintain channel quality and to reduce the power consumption of the mobile terminals. With this technique, the base station measures the quality of the uplink channels in order to maintain a certain level of quality. EUL implements faster uplink speeds by using TPC as a basis and leveraging HSDPA's radio access technology.

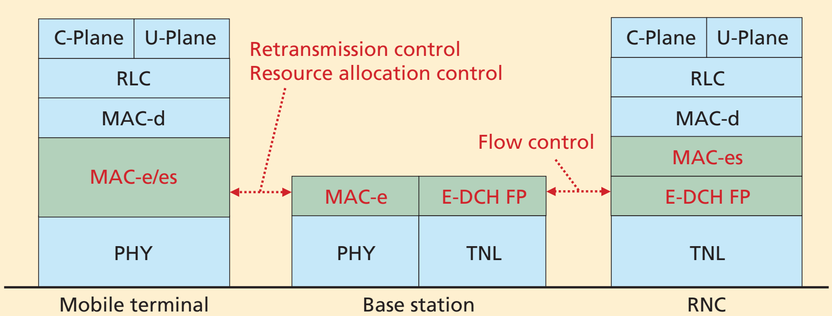
The EUL protocol stacks between system components are shown in **Figure 2**. An EUL communication system consists of mobile terminals, a base station, and a Radio Network Controller (RNC) located in an upper layer. In the Physical layer (PHY)[4] constituting the radio links between the mobile terminals and base station, two functions are used to reduce delay and enhance packet transmission: Medium Access Control-e/es (MAC-e/es) retransmission control and resource allocation, which is done on the basis of the uplink transmission power and the level of uplink interference. In the radio link between the base station and the RNC, MAC-dedicated channel (MAC-d) flow transmission is used in accordance with the Enhanced-Dedicated Channel Frame Protocol (E-DCH FP).

There are four main technical features of EUL.



Source: WCIS+, informa telecoms & media, October 2009

Figure 1 Adoption of HSDPA around the world



Transport Network Layer (TNL) : The transport network layer specified by the 3GPP standard

*Red indicates entities added by EUL. Entities are units of data sets in the protocol stack.

Figure 2 EUL protocol stack

*1 **Scrambling code**: In W-CDMA, a spreading code for identifying the cell in the downlink and the user in the uplink.

*2 **Multipath interference**: Interference created by signals reflected from distant buildings or other objects.

*3 **TPC**: Function for controlling transmission power so as to maintain constant signal quality by using the TPC bit to inform the transmitter of the channel quality, packet error rate, etc. measured at the receiver.

*4 **PHY**: The physical layer, in which actual communication with radio signals takes place.

1) Enhancement of Transport and Physical Channels

Figure 3 shows the mapping of the uplink channels in EUL. As with a conventional W-CDMA system, the control information on the Control-Plane (C-Plane) is carried in the Dedicated Control Channel (DCCH), while the user data on the User-Plane (U-Plane) is delivered over the Dedicated Traffic Channel (DTCH) and is multiplexed and mapped onto a new transport channel[*5] E-DCH [2]. An Enhanced Dedicated Physical Data Channel (E-DPDCH) [2] and an associated control channel were added to the lower physical channel[*6]. E-DPDCH is dedicated to transmission of physical data, and E-DPDCH uses a smaller spreading factor for a large volume of data. When a larger amount of data needs to be handled, the data is transmitted in a code multiplex manner. The optimum spreading factor and the number of multiplexing codes are selected in accordance with the transmission speed.

2) Hybrid ARQ

Hybrid Automatic Repeat Request (Hybrid ARQ) scheme is used to improve the quality of the received signals and to achieve efficient transmission. In Hybrid ARQ, the base station combines the data retransmitted from the mobile terminal with the data that the base station had received but failed to decode. By applying this scheme to EUL, as we originally did to HSDPA, we achieve faster retransmission over the uplink.

3) Resource Allocation Control at Base Station

With EUL, the uplink transmission power is allocated in accordance with the resource allocation requests from the terminals as well as the uplink Radio Frequency (RF) quality (level of interference) measured at the base station. Upon the start of EUL communication, a mobile terminal transmits a resource allocation request signal called Scheduling Information [3]. When the base station receives the request signal, it notifies the terminal of the Absolute Grant (AG) specifying the maximum transmission power the terminal is permitted to use over the downlink physical channel, the E-DCH AG Channel (E-AGCH) [3] (**Figure 4**). The base station determines the AG on the basis of the resource allocation request received from the terminal and the uplink RF conditions. The terminal then transmits whatever data it can send at the specified power within the limit shown by the value of the AG over the E-DPDCH physical channel.

As described above, an uplink W-CDMA channel is susceptible to interference among user signals. EUL uses resource allocation control based on the specification of AG values to maintain a certain level of RF channel quality and to flexibly control the data rate. The base station flexibly controls the

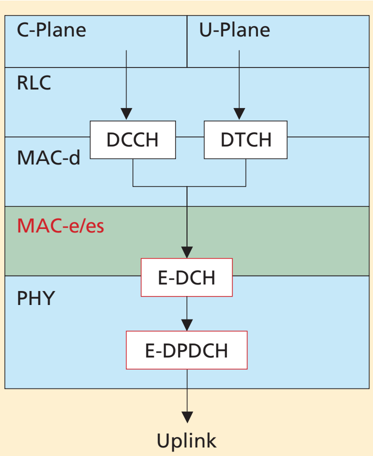


Figure 3 Uplink channel mapping in EUL at the mobile terminal

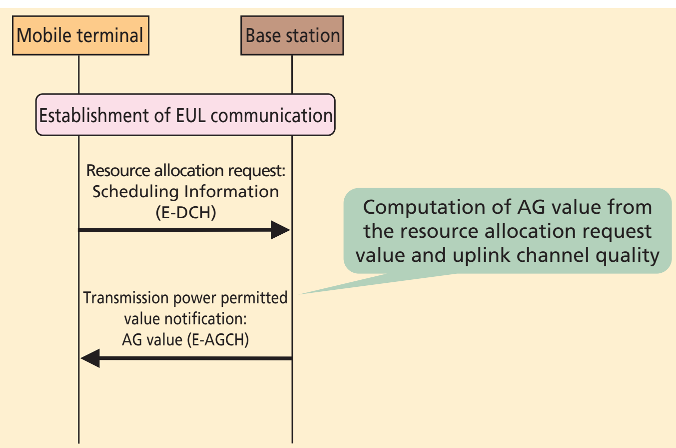


Figure 4 Resource allocation request and transmission power assignment

*5 **Transport channel**: Channels classified by their transmission characteristics (transmission speed, bit error rate) in the radio interface.

*6 **Physical channel**: Channels classified by physical resources (e.g., frequencies, time) in the radio interface.

assigned AG values. It increases the values when the level of interference is low (meaning a small number of users) and reduces them when the level is high (meaning a lot of users). The concept of resource allocation performed at the base station is shown in **Figure 5**.

4) New Terminal Categories

3GPP defines six terminal categories (**Table 1**) in accordance with the maximum data speed and the corresponding Transmission Time Interval (TTI)[*7] [4]. The maximum number of multiplexing codes represents the number of multiplexing codes applicable to the E-DPDCH, which carries the data, while the minimum spreading factor represents the minimum value of the spreading factor for the E-DPDCH. Terminals in all categories are required to support a 10-ms TTI for data transmission while those in even number categories are further required to have a 2-ms TTI. Terminals in higher number categories are able to support higher data speeds. The maximum data speeds specified for terminals in categories 2, 4 and 6 are 1.4, 2.9 and 5.7 Mbit/s, respectively. NTT DOCOMO started EUL services using Category 6, which is for terminals supporting data speeds up to 5.7 Mbit/s.

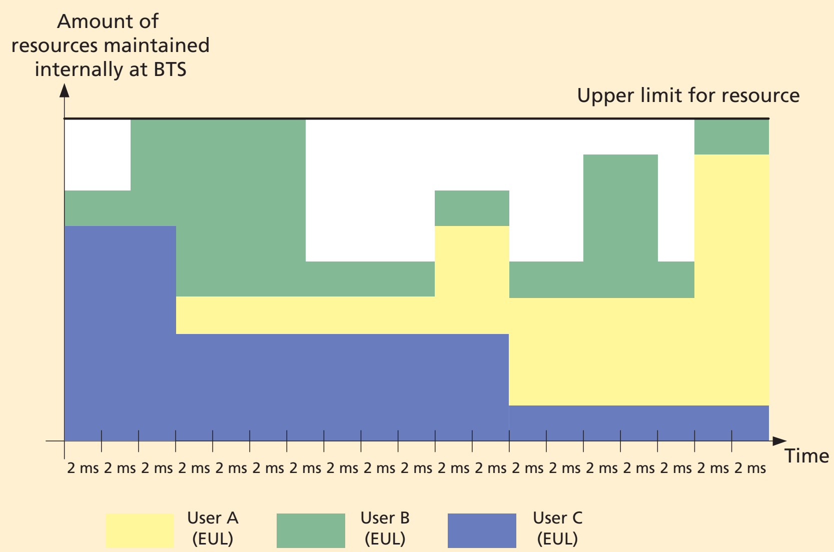


Figure 5 Concept of base station resource allocation (example for three users, A, B and C)

3. EUL-enabled Terminals

We have developed terminals supporting EUL such as the L-05A USB terminal (**Photo 1**(a)) aimed at providing EUL capabilities to corporate users as well as consumers and the L-06A handset terminal (Photo 1(b)) capable of high-speed transmission of high-quality images and large-volume video files in email attachments and of fast data uploads to blogs. We have also started to provide the L-07A Express-

Table 1 EUL terminal categories

Terminal categories	Maximum number of E-DCH codes transmitted	Minimum spreading factor	Maximum number of transmission bits 10 ms TTI	Maximum number of transmission bits 2 ms TTI	TTI	Maximum transmission speed
1	1	4	7,110	—	10 ms	0.7 Mbit/s
2	2	4	14,484	2,798	10 ms	1.4 Mbit/s
					2 ms	
3	2	4	14,484	—	10 ms	1.4 Mbit/s
4	2	2	20,000	5,772	10 ms	2 Mbit/s
					2 ms	2.9 Mbit/s
5	2	2	20,000	—	10 ms	2 Mbit/s
6	4	2	20,000	11,484	10 ms	2 Mbit/s
					2 ms	5.7 Mbit/s

*7 **TTI**: The time interval at which signals are transmitted.

Card terminal (Photo 1(c)) and a lineup of EUL-enabled terminals in the winter/spring 2009 models.

3.1 L-05A

The L-05A, the first EUL terminal offered by NTT DOCOMO, was introduced to the market in June 2009. **Table 2** shows its basic specifications. This model can be used not only in Japan but also in countries with packet data service areas that support Universal Mobile Telecommunications System (UMTS)[*8] in the 800/850/2,100 MHz bands or GSM[*9]/General Packet Radio Service (GPRS)[*10] in the 850/900/1,800/1,900 MHz bands. This model has a data card form factor with a USB connection and a two-axis rotation mechanism[*11], which enables it to be plugged in without obstructing other USB devices. The L-05A supports both the Windows and Mac OS environments, so it offers high-speed data communication to a broader range of PCs. The card is equipped with a "zero install capability" for Windows PCs, which means the setup screen automatically appears for installing its driver or connection software when the card is plugged into a Windows PC.

(a) L-05A (b) L-06A (c) L-07A

Photo 1 EUL terminals

3.2 L-06A

The L-06A handset terminal was launched in September 2009. It is equipped with a 3.0-inch-wide Video Graphics Array (VGA) LCD resistive touch screen and supports both intuitive touch screen panel operation and conventional keypad operation. The L-06A also has Google™[*12] service keys, which provide one-key access for users to the service menus including search, Gmail™[*13], maps and train transfer information. It also enables users to take advantage of its fast EUL speeds to upload video and pictures to YouTube™[*14] or Picasa™[*15] by simply pressing a shortcut key. In addition, it can determine whether the current service area supports EUL on the basis of the broadcast information it receives and displays the EUL support status on the screen.

3.3 L-07A

The L-07A is an ExpressCard EUL terminal that was launched in Novem-

Table 2 Basic specifications for L-05A, L-06A and L-07A

	L-05A	L-06A	L-07A
Size	80.0×32.0×13.0 mm (approx.)	110.0×52.0×15.4 mm (approx.)	112.0×34.0×5.0 mm (approx.)
Weight	Approx. 37 g	Approx. 131 g	Approx. 40 g
RF band (W-CDMA)	800/850/2,100 MHz	800/2,100 MHz	800/850/2,100 MHz
RF band (GSM/GPRS)	850/900/1,800/1,900 MHz	900/1,800/1,900 MHz	850/900/1,800/1,900 MHz
Data transfer speed	Maximum transmission speed: 5.7 Mbit/s (EUL category 6) Maximum reception speed: 7.2 Mbit/s (HSDPA category 8)		

*8 **UMTS**: 3G mobile communications technology. The most common form is W-CDMA, which is used by NTT DOCOMO and several Europe operators. It also covers TD-CDMA.

*9 **GSM**: Second-Generation (2G) mobile communications technologies widely used in Europe and Asia as well as in other regions of the world.

*10 **GPRS**: A packet switching service available on GSM network.

*11 **Two-axis rotating mechanism**: A mechanism that can rotate in two directions. When connected to a PC, it enables free selection of the terminal orientation.

*12 **Google™**: A trademark or registered trademark of Google, Inc.

*13 **Gmail™**: A trademark or registered trademark of Google, Inc.

ber 2009. It provides the same basic functions as the L-05A. The difference is that the L-05A is connected to a USB slot while the L-07A is connected to an ExpressCard slot. The L-07A can also be connected to a PC card slot via a separately sold L01 PC card adapter. This terminal thus provides the EUL capability for a wide variety of PCs.

4. EUL Throughput Characteristics in Outdoor Environments

We compared the peak uplink data throughputs and the i-mode mail file transfer times between the L-06A EUL terminal and a W-CDMA (FOMA) terminal not supporting EUL. The measured peak throughputs are shown in **Table 3**. We measured the throughputs at three different distances from the base station: directly below the station, at 400 m from the station, and at 800 m from the station. First we connected the mobile terminal to a PC and then via the PC to a content server. Next we had the terminal upload a large file to the server using the File Transfer Protocol (FTP). Finally we measured the peak throughputs over the Transmission Control Protocol (TCP) layer and compared the values measured for the two terminals.

The EUL terminal had a peak throughput of 3.9 Mbit/s at a point directly below the base station, where a line-of-sight environment and high downlink Received Signal Code Power (RSCP)[*16] were available. As the EUL terminal was moved from the base station by 400 m and then 800 m, the peak throughput dropped to less than 3 Mbit/s. This is attributed to increased interference due to multipath effects over the uplink and to a limitation caused by the uplink resource allocation. These effects continued as the terminal was moved further away and eventually lost a line-of-sight to the base station.

On the other hand, the conventional W-CDMA terminal had a peak throughput of 364 kbit/s at almost every point during our measurement. This is because the terminal was using TPC to maintain a constant channel quality. We found that the EUL terminal had peak throughputs about ten times higher in the line-of-sight environment directly below the base station and about seven times higher even in the non-line-of-sight environment compared to those measured for the W-CDMA terminal.

We also measured the time required for these mobile terminals to transfer a file in an i-mode mail attachment in order to compare the user experience on both terminals from the beginning to the end of data transmission. **Figure 6** shows the times required for the L-06A and a conventional W-CDMA terminal to transfer the file. The time was measured from when the key was pressed to start email transmission to when the transmission was completed. The files transferred were 100 KB, 500 KB, 1 MB and 2 MB in size.

There was little difference in the file transfer times when the 100-KB file was transferred (approx. 10 s for both terminals). This is attributed to the relatively longer time taken during i-mode mail transfer to connect to the network and get ready for sending the file compared to the time required for actual data transmission. The benefits of high-speed EUL are thus negligible when a small file is transferred. On the other hand, there was a significant difference in the file transfer times when the larger files (500-KB to 1-MB) were transferred. For the 2-MB file, the maximum size allowed for i-mode transfer, the file transfer time was cut in half. The W-CDMA terminal required approximately 80 s while the L-06A required less than 40 s.

Table 3 Comparison of peak uplink throughput for L-06A and conventional W-CDMA terminal

Distance from the base station	Downlink receiving channel quality (RSCP)	Peak throughput for L-06A	Peak throughput for the conventional W-CDMA terminal
Directly below	−59 dBm	3.9 Mbit/s	364 kbit/s
400 m	−77 dBm	2.6 Mbit/s	365 kbit/s
800 m	−89 dBm	2.8 Mbit/s	362 kbit/s

*14 **YouTube™**: A trademark or registered trademark of Google, Inc.

*15 **Picasa™**: A software application offered by Google that enables image organizing, editing, and photograph sharing. PICASA™ is a trademark or registered trademark of Google, Inc.

*16 **RSCP**: The received power measured at a mobile terminal. An index of signal sensitivity at the mobile terminal.

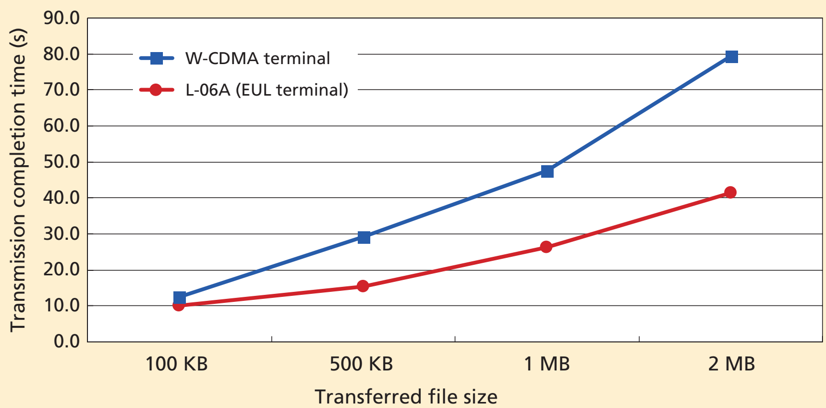


Figure 6 Comparison of mail transmission time for L-06A and conventional W-CDMA terminals

5. Conclusion

In this article, we summarized the technical features of the EUL service, which NTT DOCOMO launched in June 2009, and described in detail our EUL terminals. Field measurement using the L-06A EUL terminal clearly showed a tenfold increase in the peak data throughput on the uplink and a reduction by half in the transfer time for a 2-MB file in an i-mode mail attachment compared to a conventional W-CDMA terminal.

We will continue our studies and experiments on Long Term Evolution (LTE) in order to achieve even higher packet data speeds.

References

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[3] 3GPP TS25.321 V6.14.0: "Medium Access Control (MAC) protocol specification," 2007.

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