Enhanced Radio Control Channel | Power Consumption Optimization | Congestion Control Technology

Technology Reports

Further Development of LTE/LTE-Advanced – LTE Release 10/11 Standardization Trends –

Radio System Optimization toward Smartphone and Machine Communications for Further Development of LTE/LTE-Advanced

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Mobile traffic has jumped in recent years due to the penetration of smartphones in society, and looking forward, the market for machine communications is forecast to grow. With these trends in mind, the 3GPP international standards organization has specified elemental technologies in LTE Release 11 for extending the functions and raising the performance of LTE-Advanced accorded as the fourth-generation mobile communications system. These technologies consist of an enhanced physical downlink control channel, access control for machine communications, and optimized control of smartphone communications.

1. Introduction

The 3rd Generation Partnership Project (3GPP) has been studying elemental technologies for optimizing the radio system taking into account the dramatic increase in traffic accompanying the recent penetration of smartphones as well as the expansion of the machine communication market.

This article describes an enhanced physical downlink control channel, Extended Access Barring (EAB) for machine communications, and optimized control of smartphone communications as elemental technologies oriented to smartphone and machine communications. These technologies are specified as part of Long Term Evolution (LTE) Release 11 specifications (hereinafter referred to as "LTE Rel. 11").

2. Enhancement of Physical Downlink Control Channel

2.1 Overview of Physical Downlink Control Channel in LTE Release 10

LTE Release 8-11 specifications adopt a radio access method based on Orthogonal Frequency Division Multiple Access (OFDMA)[*1] on the downlink and Single-Carrier Frequency Divi-

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*1 **OFDMA**: A multiple access scheme that uses OFDM. OFDM uses multiple low data rate multi-carrier signals for the parallel transmission of wideband data with a high data rate, thereby implementing high-quality transmission that is highly robust to multipath interference (interference from delayed paths).

sion Multiple Access (SC-FDMA)*2 on the uplink. Both the downlink and uplink use a Physical Resource Block (PRB)*3 consisting of 12 subcarriers*4 as the minimum unit of allocation in frequency scheduling*5. The control of this frequency scheduling is performed on the downlink in each subframe*6 (1 msec), which is made up of 14 OFDM symbols*7. Accordingly, Downlink Control Information (DCI)*8 related to frequency scheduling (specifically, the PRB position) and channel coding of transmitted data and to Adaptive Modulation and Coding (AMC)*9 must be transmitted every subframe. Thus, in LTE up to Release 10 (hereinafter referred to as "Rel. 10"), DCI has been transmitted using the Physical Downlink Control CHannel (PDCCH)*10 allocated to a maximum of three OFDM symbols at the front of each subframe.

2.2 Overview of Enhanced Physical Downlink Control Channel in LTE Rel. 11

The recent expansion of smartphone use has generated a wide variety of data traffic and raised concerns that PDCCH capacity will eventually fall short. Specifically, it is predicted that the number of simultaneously connected users will increase significantly and that the amount of DCI will expand greatly not only because of large-packet data communications but also because of frequent, small-packet data communications as in control information generated by individual applications. The existing PDCCH scheme, however, can use only a maximum of three OFDM symbols, which implies that DCI capacity is not sufficiently large. In LTE Rel. 10, moreover, multiuser Multiple Input Multiple Output (MIMO)*11 is supported, which is a technology for multiplexing users using the same time and frequency resources. In this case, the number of simultaneously connected users per subframe also increases thereby increasing the amount of DCI.

Given the need to increase DCI capacity in the wake of these concerns, specifications for an enhanced type of physical downlink control channel, that is, Enhanced PDCCH (EPDCCH), came to be studied for LTE Rel. 11. The transmission frame configuration using EPDCCH is shown in **Figure 1**. Here, EPDCCH is subjected to frequen-

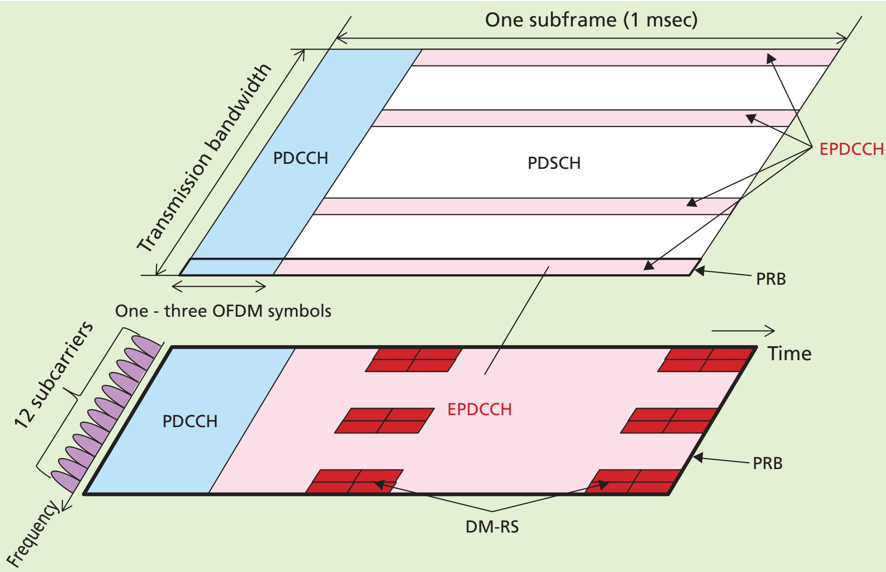

Figure 1 Configuration of transmission frame using EPDCCH

*2 **SC-FDMA**: A radio access method that implements multiple access by allocating the signals for different users to different frequencies while transmitting the signals for an individual user at a single frequency.

*3 **PRB**: A unit for allocating radio resources consisting of one subframe and 12 subcarriers (see *4).

*4 **Subcarrier**: One of the individual carrier waves used to transmit a signal in multi-carrier transmission schemes such as OFDM.

*5 **Frequency scheduling**: The process of allocating user-specific data to radio resources (such as PRB) with good channel quality using channel quality information in the frequency direction.

*6 **Subframe**: A unit of radio resources in the time domain consisting of multiple OFDM symbols (generally 14 OFDM symbols (see *7)).

*7 **OFDM symbol**: A unit of transmission data consisting of multiple subcarriers. A Cyclic Prefix (CP) is inserted at the front of each symbol.

*8 **DCI**: Control information transmitted on the downlink that includes scheduling information needed by each user to demodulate data and information on data modulation and channel coding rate.

cy division multiplexing[*12] with the Physical Downlink Shared CHannel (PDSCH)[*13] in units of PRBs. These PRBs for EPDCCH are configured for each UE by upper-layer signaling. Configuring PRBs for EPDCCH in the PDSCH in this way increases DCI capacity. In fact, further increases in DCI capacity can be expected by applying other technologies. Specifically, since EPDCCH is multiplexed with PDSCH in the frequency domain, inter-cell interference coordination[*14] and frequency scheduling can be applied in PRB units. In addition, transmission beamforming[*15] can be applied to each UE using the UE-specific DeModulation Reference Signal (DMRS)[*16].

The EPDCCH is UE specific, which means that UE-specific DCI such as scheduling information is transmitted via EPDCCH. On the other hand, the cell-wide control channel consisting, for example, of system information is transmitted via the conventional PDCCH.

2.3 EPDCCH Transmission Method

1) Distributed Transmission and Localized Transmission

Distributed transmission and localized transmission are supported as methods for transmitting DCI messages via EPDCCH. They are both established by upper-layer signaling. These EPDCCH transmission methods are shown in **Figure 2**. In general, the transmission of a control channel needs to be resistant to fluctuation on a fading channel[*17]. Thus, in distributed transmission, one DCI message is divided into multiple resources and mapped across different PRBs to achieve a frequency diversity[*18] effect. In localized transmission, in contrast, one DCI message is mapped to a PRB based on channel quality information reported from the UE to obtain a frequency scheduling effect. Additionally, a UE-specific transmission weight[*19] can be calculated according to channel quality information and each DCI message can be multiplied by this weight to obtain a transmission beamforming gain.

2) Support of Multiple EPDCCH Sets

With EPDCCH, a greater frequency diversity effect can be obtained the greater is the number of PRBs used for DCI mapping. However, given that EPDCCH makes use of the PDSCH transmission area, a smaller number of

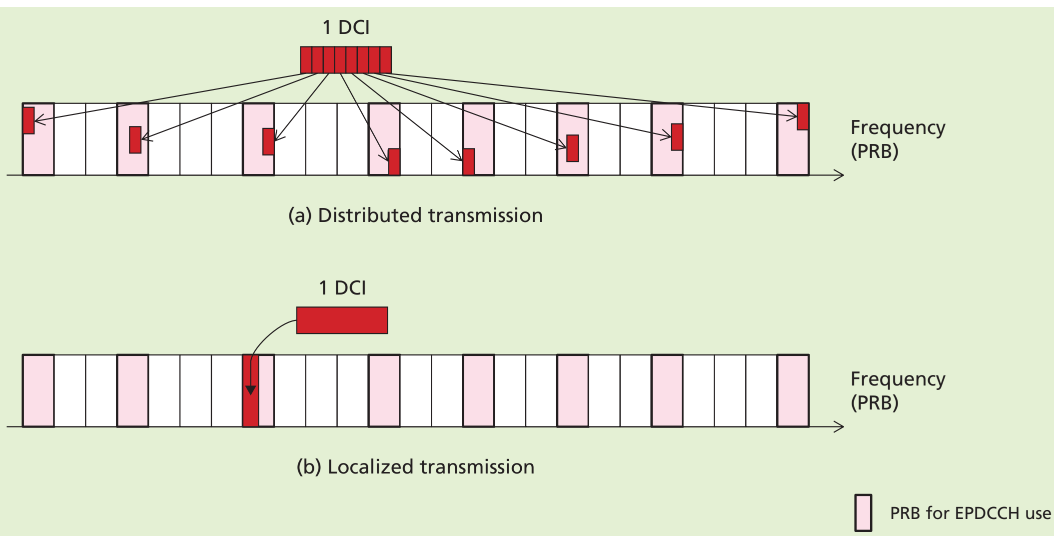

Figure 2 EPDCCH transmission methods and DCI mapping

*9 **AMC**: A method for adaptively controlling transmission speed by selecting an optimal data modulation scheme and channel coding rate according to reception quality as indicated, for example, by the signal-to-interference power ratio.

*10 **PDCCH**: A physical channel for transmitting downlink control information using a maximum of three symbols at the front of each subframe.

*11 **MIMO**: A signal transmission technology that improves communications quality and spectral efficiency by using multiple transmitter and receiver antennas for transmitting signals at the same time and same frequency.

*12 **Frequency division multiplexing**: A multiple access scheme in which radio frequencies are divided and allocated to mobile terminal radio channels.

*13 **PDSCH**: A physical channel for transmitting user data and control information from the upper layer using the OFDM symbols following those used for PDCCH in each subframe.

*14 **Inter-cell interference coordination**: Allocation of radio resources to each cell so that they do not interfere with each other (i.e., are orthogonal to each other).

PRBs for EPDCCH is desirable. A minimum number of PRBs that can obtain a sufficient frequency diversity effect should therefore be provided. It has been reported that a sufficient frequency diversity effect can be obtained with four PRBs, and with this in mind, two, four and eight PRBs are supported (two PRBs are supported for narrow-band use).

PRBs used for DCI mapping are defined as an EPDCCH set. As described above, however, such an EPDCCH set supports only a minimum number of PRBs, which would raise concerns that DCI capacity would not be able to be increased sufficiently. Accordingly, two EPDCCH sets per UE are supported.

A conceptual diagram of using two EPDCCH sets is shown in **Figure 3**. Two EPDCCH sets can be used for transmitting just EPDCCH or both EPDCCH and PDSCH depending on the amount of DCI messages. In a subframe having a small number of DCI messages, for example, one EPDCCH set can be used to transmit DCI and the other for transmitting PDSCH. However, in a subframe having a large number of DCI messages, two EPDCCH sets can be used to transmit DCI messages. Multiple EPDCCH sets are also useful in Coordinated Multi-Point (CoMP)[*20] transmission/reception specified in LTE Rel. 11. The idea behind CoMP is to improve throughput[*21] at the cell edge by using multiple base stations to send and receive data (where data is transmitted, for example, from optimal base stations). In this case, one EPDCCH set can be transmitted from base-station 1 and the other from base-station 2 thereby enabling EPDCCH to be transmitted from optimal base stations in the same manner as data. Additionally, since a UE has to perform blind decoding using a brute-force search of DCI sent by PDCCH or EPDCCH, the number of DCI search candidates is limited. When using two EPDCCH sets, the number of search candidates is divided between those two sets so as to keep the total number of blind decoding trials constant.

3. EAB Provisions

3.1 Background (Problem Points)

One major concern in communications between a LTE network and a terminal equipped with a LTE communications module (hereinafter referred to as "machine-communication terminal") such as a smart meter (electrical/gas meter) is the possibility of burst traffic generated when a huge number of machine-communication terminals

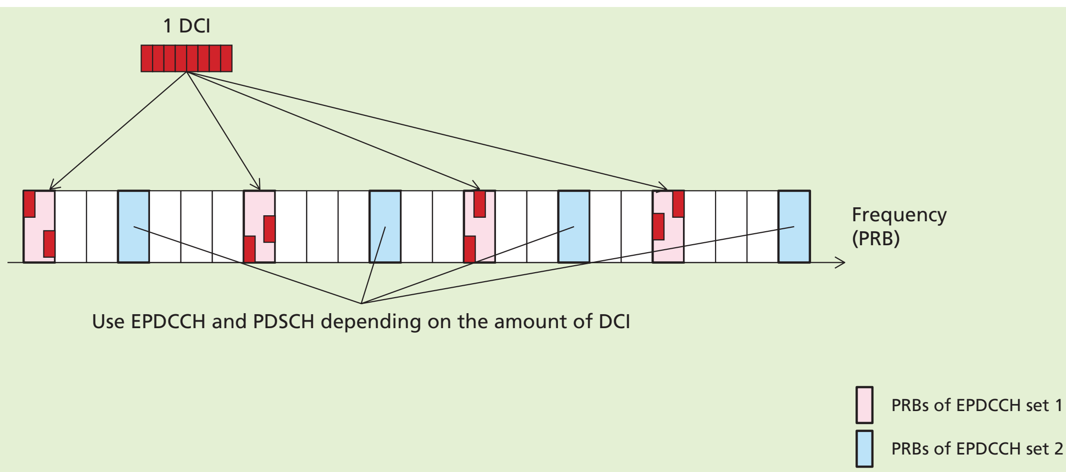

Figure 3 Two EPDCCH sets

*15 **Beamforming**: A method for improving signal separation performance at the receiving side by doing precoding on the transmitting side based on channel data or other feedback.

*16 **DMRS**: A user-specific reference (pilot) signal known by the base station and mobile station for estimating the fading channel used for data demodulation.

*17 **Fading channel**: The ever-changing fluctuation of received power at a moving terminal caused by the scattering and reflection of transmitted signals off of buildings.

*18 **Frequency diversity**: A diversity method for improving reception quality by using different frequencies.

*19 **Transmission weight**: A transmission weighting factor for forming a directional pattern by controlling the amplitude and phase of multiple antennas and for increasing/decreasing antenna gain in a specific direction.

*20 **CoMP**: Technology which sends and receives signals from multiple sectors or cells to a given UE. By coordinating transmission among multiple cells, interference from other cells can be reduced and the power of the desired signal can be increased.

transmit data at the same point in time. Such a situation may consume resources not only at base stations (eNodeB (eNB)[*22] equipment) but also in the Core Network (CN)[*23], and it could create a state of congestion[*24] that would make it difficult for ordinary terminals to gain access to the network and receive wireless communication services. To deal with this concern, a mechanism is needed for suppressing connection establishment request signals from machine-communication terminals. In this article, we focus on such a mechanism implemented between the Radio Access Network (RAN)[*25] and machine-communication terminals. A mechanism implemented between the CN and machine-communication terminals is described in Ref. [1].

3.2 Access Control in Rel. 10

LTE Rel. 10 specifications define an identifier within a connection-request signal indicating that the connection is requested for machine communications. Furthermore, Rel.10 specifications also specify a mechanism on the network side for deciding whether to reject that request based on that identifier [2]. The Rel. 10 method, however, requires that a connection-request signal from a machine-communication terminal be sent to and accepted by the network at least once, which means that network resources must be used for accepting the message, rejecting the request, etc.

3.3 Access Control in Rel. 11

1) EAB Overview

LTE Rel. 11 specifications define EAB as an access-control mechanism inherited from the existing Access Class Barring (ACB)[*26] method based on Access Class (AC) [3]. In EAB, the machine-communication terminal itself determines whether it is subject to barring based on EAB information broadcast from the network. If the terminal determines that it is in fact subject to barring, it refrains from sending a connection-request signal [2]. In EAB, the barring applies for machine-communication terminals in idle state, which is similar to ACB.

The broadcasting of EAB information and conventional ACB information are depicted in **Figure 4**. As shown, EAB information is broadcast by the network in a manner similar to ACB information, i.e., both types of access-control information are conveyed by a System Information Block (SIB)[*27]. However, ACB information is conveyed in particular by SIB2 while EAB information is conveyed by newly specified SIB14. To enable a machine-communication terminal to determine whether access barring applies, the network broadcasts the following EAB information [2]:

- ACs (bitmap information[*28]) targeted by EAB
- UE category targeted by EAB

Information indicating whether the machine-communication terminal needs to check its EAB status using the above EAB broadcast information is set

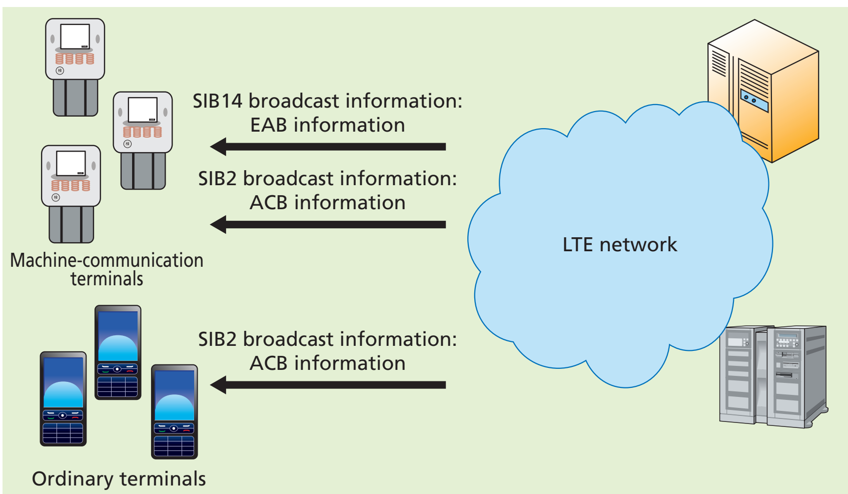

Figure 4 Broadcast of access-control information

*21 **Throughput**: The amount of data transmitted without error per unit time, i.e., the effective data transfer rate. In this article, throughput is defined as the (data rate on the transmission side) x (number of packets received without error per unit time) / (number of packets transmitted per unit time).

*22 **eNB**: A base station for the LTE radio access system.

*23 **CN**: A network comprising switching equipment, subscriber information management equipment, etc. A mobile terminal communicates with the core network via a radio access network.

*24 **Congestion**: A state where communication requests are concentrated inside a short time period and exceed the processing capabilities of the network, thereby obstructing communications.

*25 **RAN**: The network consisting of radio base stations and radio-circuit control equipment situated between the core network and mobile terminals.

beforehand in the terminal. This setting is made not on the Access Stratum (AS) layer but on the Device Management (DM) layer.

The algorithm used by a machine-communication terminal to evaluate EAB status using EAB information is shown in **Figure 5**. In this process, a machine-communication terminal that has been set beforehand as an EAB evaluation target first checks its own AC and category (see item (3) below in this section). For general ACs (AC 0-9), the above EAB-related ACs are expressed in the form of a bitmap indicating which ACs may or may not originate connection requests. Then, if the UE's AC and category match the indicated AC bitmap and category information broadcast by the network as a target of barred access, the terminal applies the connection-request barring and refrains from issuing a connection-request signal. In addition, a machine-communication terminal having a special AC (AC 11-15) evaluates whether it's a target of barred access according to conventional ACB information without applying EAB provided that ACB information is being broadcast. Furthermore, a machine-communication terminal that determines on the basis of EAB information that it is not a target of barred access will reevaluate its access status using ACB access-control information provided that ACB information is being broadcast. Thus, if the network is broadcasting both EAB and ACB information, a machine-communication terminal may evaluate its access status twice.

The machine-communication terminal's current access-control state remains in effect as long as the EAB information broadcast by the network has not been updated. If an update to EAB information occurs, the network will notify the terminal of such update using a paging message[*29]. Upon receiving a paging message containing an identifier indicating an EAB information update, the UE will receive broadcast information containing EAB information and perform the update.

2) EAB Access Control under Roaming Conditions

The Rel. 11 EAB access-control

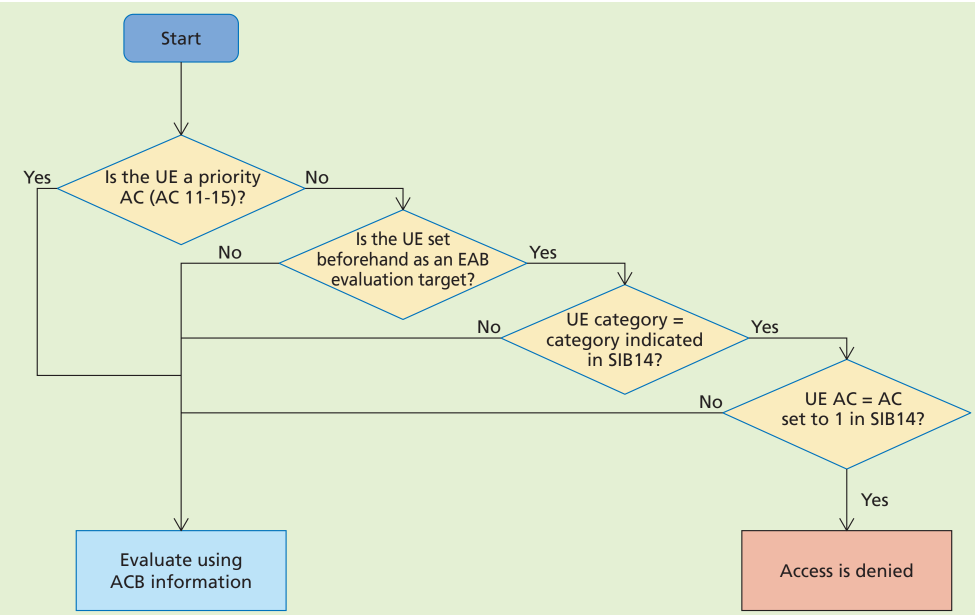

Figure 5 Algorithm for evaluating EAB access control

*26 **ACB**: A method for suppressing burst-like connection-request signals during natural disasters or major events (e.g., New Year celebrations, firework festivals). The terminal itself evaluates whether it's a target of access restriction using network-notified control parameters for each Access Class (AC) that individual terminals belong to, and refrains from issuing connection-request signals if its access is indeed being restricted.

*27 **SIB**: The unit block for sending broadcast information from a radio base station to mobile terminals in GSM and W-CDMA.

*28 **Bitmap information**: A method for representing information with a minimal amount of data by transmitting only 0s and 1s that express the state of parameters known on both the transmit and receive sides.

*29 **Paging message**: A signal used for calling a terminal in standby to establish a connection with the network.

method takes roaming cases into account and hence specifies the application of access controls distinguishing machine-communication terminals under different roaming conditions.

The UE category is information, based on the UEs roaming status, indicating that the terminal category is a target of EAB access control. The following three categories are defined in Rel. 11.

(1) Category A: All machine-communication terminals set beforehand as an EAB evaluation target

(2) Category B: Machine-communication terminals set beforehand as an EAB evaluation target and currently roaming

(3) Category C: Machine-communication terminals set beforehand as an EAB evaluation target and currently roaming outside the most preferred Public Land Mobile Network (PLMN)[*30] of each country set in the Universal Subscriber Identity Module (USIM)[*31].

The UE category based on the UE's roaming state is set beforehand by the network on the DM layer the same as the terminal-targeted-for-EAB-evaluation setting. If the machine-communication terminal's UE category corresponds to the UE-category information broadcast by the network, the terminal will evaluate whether it is a target of restricted access using EAB information (Fig. 5).

3) Congestion Prevention at Core Nodes

The EAB access-control method can be effective in preventing congestion not only at eNBs but also at core nodes in the network. In particular, for the case that core nodes of several operators are using a common radio network (eNBs), it will be necessary to define and apply separate EAB information to core nodes of different operators. For this reason, it has been made possible to set the above two types of EAB information (bitmap information and UE category information) for each operator's PLMN through broadcast information. Since current LTE specifications enable a maximum of six operators to share eNBs, the network can broadcast up to six sets of information each consisting of a PLMN IDentity (PLMN ID) and corresponding EAB information. In short, if the PLMN ID selected and registered by a UE is being broadcast, the UE shall evaluate whether it is a target of restricted access using the EAB access-control information corresponding to that PLMN ID.

4. Optimized Control of Smartphone Communications

A key feature of smartphones, which are now spreading through society at a rapid pace, is that individual mobile terminals can freely install and execute a wide variety of applications. This feature, however, is generating some problems: in addition to producing a dramatic jump in traffic, it is also increasing the amount of power consumed by mobile terminals for communication purposes.

To deal with this power problem, LTE Rel. 11 specifies controls that aim to optimize power consumption on a mobile terminal. Specifically, a function has been added to enable a mobile terminal to inform the base station of its need to reduce power consumption whenever it enters a state requiring a reduction in power consumption (hereinafter referred to as "low power state").

4.1 Optimized Control of Power Consumption

The specified procedure for achieving optimized control of power consumption as a countermeasure to increased consumption of power on a mobile terminal due to increased communications is shown in **Figure 6**. In this procedure, the base station first sends a Power Preference Indicator (PPI) enabling message to the mobile terminal targeted for this type of control. This action enables a function for notifying the base station of the need

*30 **Most preferred PLMN**: One type of information contained in a USIM. It specifies which telecommunication carrier the user's contracted telecommunication carrier has set as the priority connection destination during roaming.

*31 **USIM**: An IC card used to store information such as the phone number from the subscribed mobile operator. The module used to identify W-CDMA/LTE mobile communications subscribers under the 3GPP is called a USIM.

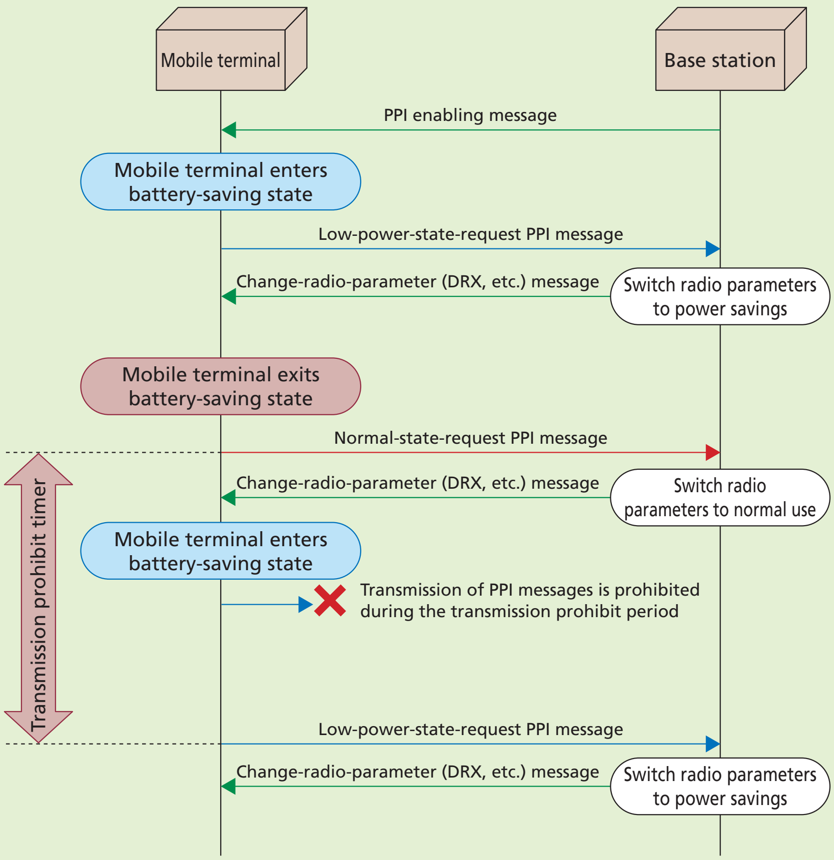

Figure 6 Procedure for optimized control of power consumption

for reducing power consumption. In this way, a mobile terminal for which PPI transmission has been enabled can notify the base station whether it's in a low power state through the PPI. Here, the criteria used by the mobile terminal for determining a low power state depends on that terminal's specific implementation, but conditions such as remaining battery power and the screen's ON/OFF state can be considered. A base station that has received the PPI and been notified of a mobile terminal's state now optimizes the radio parameters set in the mobile terminal based on that state. For example, the base station may set Discontinuous Reception (DRX)[*32] having long intervals of non-reception in a mobile terminal that is currently in a low power state to reduce power consumption. Conversely, the base station may set DRX having short intervals of non-reception in a mobile terminal that is currently in a normal state to shorten the delay when initiating communications. It should be noted here that a specific radio-parameter optimization method is not specified in a standard and depends on the implementation. Furthermore, if the mobile terminal is performing communications that place importance on quality as in voice calls, the base station may also consider requirements for guaranteeing communications quality in making radio-parameter settings even if the mobile terminal is in a low power state.

Since the above controls enable a base station to optimize radio parameters according to the current state of the mobile terminal, it is anticipated that a mobile terminal's power consumption can be reduced with almost no degradation of communications quality.

4.2 Function for Suppressing Control Signal Congestion

Given that PPI messages are transmitted based on the state of mobile terminals, there are concerns that control signal congestion can occur due to frequent PPI transmission from mobile terminals in the network. To prevent this from happening, a transmission prohibit timer[*33] is set in a mobile terminal when the base station enables the PPI on that terminal. As a result, once a mobile terminal has transmitted a PPI indicating a normal state, it cannot transmit a PPI indicating a low power state until the transmission prohibit timer has expired.

*32 **DRX**: Intermittent reception control used to reduce power consumption in UE.

*33 **Transmission prohibit timer**: A timer for preventing continuous transmission of a control signal. The mobile terminal is prohibited from transmitting the same control signal continuously during the period that this timer is set.

The continuous transmission of the same PPI is also prohibited. These provisions suppress control signal congestion.

5. Conclusion

In this article, we described elemental technologies specified in LTE Rel. 11 for optimizing the radio system toward smartphone and machine communications. Optimization of the radio system to meet the demand for new services brought on by the spread of smartphones and growth in machine communications is also an important issue at NTT DOCOMO. We will continue to promote standardization in this area with an eye to achieving greater functionality and economy in the radio system.

References

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[3] 3GPP TS22.011 V11.3.0: "Service accessibility," Mar. 2013.