Technology Reports

Special Articles on LTE-Advanced Release 13 Standardization

# New Technologies for Achieving IoT in LTE Release 13

*As IoT services grow, elemental UE technologies and network control technologies have been intensively studied specifically for IoT. In contrast to past trends in high-speed data communications, UE in the IoT era has distinct requirements such as lower costs suitable for mass production and mass introduction and a battery replacement period of more than ten years. Against this background, 3GPP has formulated new specifications for IoT in LTE Release 13. This article describes key technologies for achieving low costs, wide coverage, and low power consumption in IoT terminals and optimization of the core network for IoT services as introduced in LTE Release 13.*

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## 1. Introduction

In addition to achieving high-speed, large-capacity radio access in LTE to meet the needs of smartphone users, the 3rd Generation Partnership Project (3GPP) has been studying elemental technologies and network control technologies specifically for the Internet of Things (IoT)*1 as extensions to LTE. Release 13 specifications, in particular, involved extensive studies on elemental technologies for achieving low costs, wide coverage, and low power consumption in terminals and on optimization of the core network to meet the high market demand for IoT services. In this article, we describe new technologies for IoT specified by Release 13.

## 2. UE Categories for IoT in Release 13

### 2.1 Overview

1) Category 0

Recently, a variety of organizations have taken up the study of terminals (hereinafter referred to as “User Equipment (UE)”) for IoT services such as smart meters (electricity and gas meters

*1 **IoT:** General term for a type of control and communication where various “things” are connected via the Internet or cloud services.

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with communication functions). In LTE, Release 12 specifications supported a low-price UE category for IoT (Category 0) featuring (1) a maximum data rate of up to 1 Mbps, (2) support for Frequency Division Duplex (FDD) Half Duplex*2, and (3) support for single-antenna reception.

2) Category M1 and NB-IoT

Release 13 specifications support two new terminal categories to further lower UE price and provide extended coverage (**Table 1**).

- The first is Category M1 that supplements Category 0 features with (1) reduced UE transmission bandwidth of 1.08 MHz and (2) coverage extension by approximately 15 dB compared to Category 1. This limitation of transmission bandwidth results in a significant cost reduction for the UE chip [1].
- The second category is Narrow-Band (NB)-IoT. Although the studies originally targeted the frequency bands of the Global System for Mobile communications (GSM)*3, NB-IoT has been specified so that LTE frequency bands could be used as well. This category features (1) UE transmission bandwidth of 180 kHz and (2) coverage extension by approximately 20 dB compared to Category 1. Compared with Category M1, NB-IoT is inferior in data rate and spectrum efficiency*4, but the use of an even narrower band is expected to further reduce the price of the UE chip. The following provides an overview of the functions supported by UE Category M1 and NB-IoT.

## 2.2 Category M1

Category M1 features the transmitting and receiving of signals using a 1.08-MHz portion of the LTE transmission bandwidth, as shown in **Figure 1** (a). The frequency location for Category M1 can be flexibly changed within the LTE system band, and operation using another 1.08-MHz segment is also possible as long as that segment is within the LTE system band.

However, in terms of the Physical Resource Block (PRB)*5, Category M1 UE can only receive downlink signals within six PRBs corresponding to 1.08 MHz, which means that it cannot receive signals transmitted over a bandwidth

**Table 1 UE categories for IoT**

| | Category 1 | Category 0 | Category M1 | NB-IoT |
|---|---|---|---|---|
| Release | Release 8 | Release 12 | Release 13 | Release 13 |
| Operating band | LTE band in use (if using a dedicated frequency band, an area for dedicated-frequency use must be constructed.) | | | |
| | | | | Outside of LTE band (in guard band) |
| Transmission bandwidth | 20 MHz | 20 MHz | 1.08 MHz | 180 kHz |
| Spectrum efficiency | Same as existing LTE | Same as existing LTE | Less than Category 1 (due to single antenna reception, limited bandwidth) | Less than Category M1 (due to further bandwidth limitation) |
| Coverage | Same as existing LTE | Same as existing LTE | Category 1 + 15 dB | Category 1 + 20 dB |
| Mobility | Same as existing LTE | Same as existing LTE | Same as existing LTE (slower under coverage extension) | Handover non-supported Mobility in idle mode supported |
| Power consumption | Same as existing LTE | Same as existing LTE | (less than Category 1 and 0) | |
| Transmission power | Same as existing LTE | Same as existing LTE | Less than 3 dB | Less than 3 dB (under study) |

*2 **FDD Half Duplex:** A method for transmitting signals using different carrier frequencies and bands in the uplink and downlink. Simultaneously transmitting and receiving signals on different frequencies is called FDD Full Duplex and temporally switching transmission and reception on different frequencies is called FDD Half Duplex.

*3 **GSM:** A second-generation mobile communications system used by digital mobile phones.

*4 **Spectrum efficiency:** The number of data bits that can be transmitted per unit time and unit frequency band.

*5 **PRB:** A unit for allocating radio resources consisting of one subframe and 12 subcarriers.

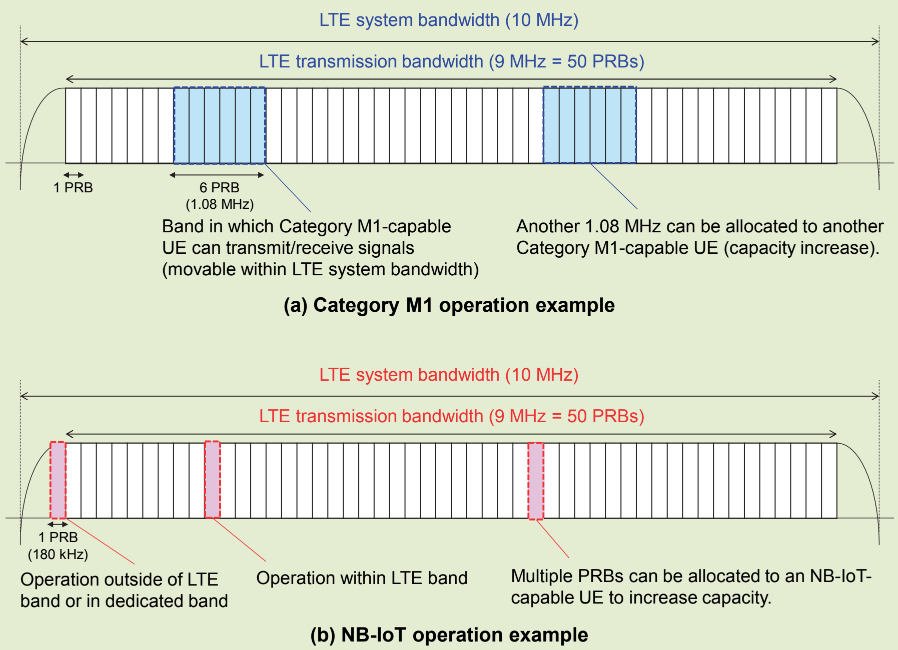


**Figure 1 Operation example of Category M1 and NB-IoT in LTE**

greater than six PRBs on the LTE system band. Specifically, this prevents reception of the Physical Downlink Control CHannel (PDCCH)*6, which is used for allocating the Physical Downlink Shared CHannel (PDSCH) consisting of data and the System Information Block (SIB)*7. As a result, the UE cannot receive LTE system information, as shown in **Figure 2** (1).

1) Newly Specified M-PDCCH and SIB

Taking the characteristics of Category M1 UE into account, Release 13 specifies Machine Type Communication (MTC)*8 -PDCCH (M-PDCCH) as a physical downlink control channel mapped within six PRBs to allocate SIB, etc. as well as a new SIB specific to Category M1 UE. Introducing a new downlink control channel and upper layer signals confined to six PRBs in this way makes it possible to limit the Category M1 transmission band to 1.08 MHz and lower the price of the module. Because of this bandwidth limitation, as only six PRBs are available, PDSCH is allocated using an M-PDCCH in a different subframe*9, as shown in Fig. 2 (2). Moreover, as described above, the Category M1 transmission band is flexibly changed within the LTE transmission band, so PDSCH (or Physical Uplink Shared CHannel (PUSCH)) can be allocated to a different set of six PRBs in a different subframe, as also shown in Fig. 2 (2). This scheme enables PDSCH and PUSCH to be transmitted and received using a set of six PRBs with good receiving quality.

2) Newly Specified Power Class

Additionally, as a method for achieving low-price modules, Release 12 specifies a new transmission power class that is 3 dB lower than the power of existing LTE modules.

3) New Function for Coverage Extension

As shown in Fig. 2 (3), Release 13 also specifies a function for extending coverage by repeating the transmission of the same signal using multiple subframes. This type of repeated transmission enables Category M1 UE to transmit

*6 **PDCCH:** Control channel for the physical layer in the LTE downlink.

*7 **SIB:** Various types of information broadcast from base stations to surrounding cells, such as the location code required for judging whether location registration is needed for a mobile terminal, surrounding cell information, and information for restricting and controlling outgoing calls.

*8 **MTC:** A collective term for 3GPP machine communication with no intervening communication operations performed by humans.

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

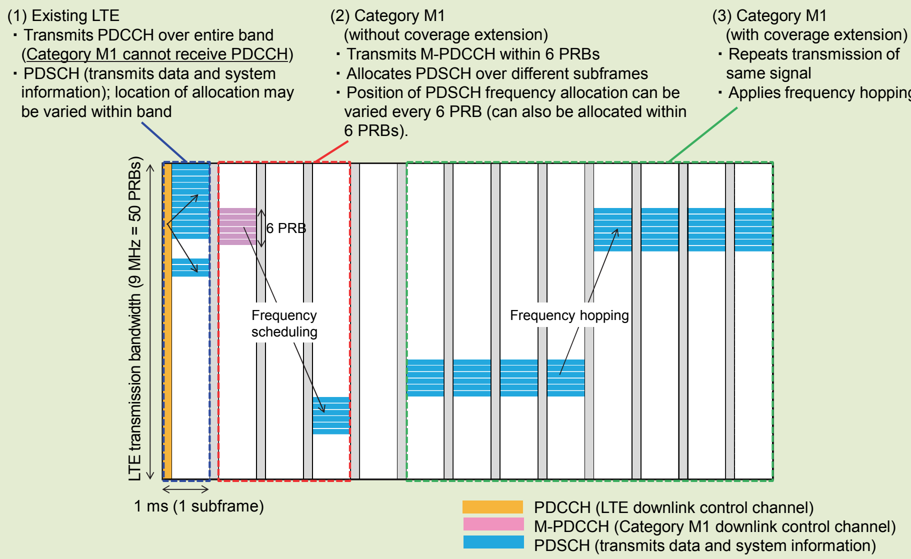


**Figure 2 Configuration of Category M1 physical layer channel**

and receive signals for MTC purposes even in an environment with low Signal-to-Interference plus Noise power Ratio (SINR)*10. On the other hand, the same signal would have to be transmitted over 100 subframes to achieve coverage extension of about 15 dB, which would significantly degrade throughput*11 and spectrum efficiency. For this reason, Release 13 also supports frequency hopping*12 that transmits the same signal using a different set of six PRBs within the LTE transmission band. Again, referring to Fig. 2 (3), having the frequency of the transmission signal hop at fixed intervals (for example, every four subframes) can exploit a frequency diversity*13 effect, which means that throughput and spectrum efficiency can be greatly improved while improving received SINR and extending coverage.

## 2.3 NB-IoT

In contrast to Category M1 UE that operates within the LTE transmission band, the NB-IoT category supports UE operation outside the LTE band (hereinafter referred to as "guard band*14") and in a dedicated "standalone" frequency band for only NB-IoT UE. It also supports the coexistence of NB-IoT UE and existing LTE UE (such as smartphones) within the LTE band. Here, operation within the LTE band requires that physical layer signals be designed taking into account PDCCH and other signals transmitted for LTE use as described above. However, operation in the guard band or in a dedicated frequency band differs in that there is no need to transmit LTE physical layer signals.

1) Newly Specified NB-PSS/SSS and NB-PBCH

To further reduce costs compared with Category M1, the NB-IoT category transmits and receives signals using a narrow 180-kHz band (corresponding to one PRB) as shown in Fig. 1 (b). As a result, this category can receive neither control signals such as PDCCH or the Primary Synchronization Signal/Secondary Synchronization Signal (PSS/SSS)*15 and Physical Broadcast CHannel (PBCH)*16 transmitted over six PRBs for LTE and Category M1. To resolve this issue, Release 13

*10 **SINR:** The ratio of desired-signal power to the sum of all other interference-signal power and noise power.

*11 **Throughput:** Effective amount of data transmitted without error per unit time.

*12 **Frequency hopping:** A transmission method using a different frequency or frequency resource for each transmission.

*13 **Frequency diversity:** A diversity method for improving reception quality by using different frequencies. Diversity improves reception quality by using multiple paths and selecting the one with the best quality.

*14 **Guard band:** A frequency band set between the signal frequency bands of systems to prevent radio signal interference between systems.

*15 **PSS/SSS:** A synchronization channel for performing cell detection, time/frequency synchronization, etc.

*16 **PBCH:** A physical channel for broadcasting main radio parameters such as downlink system bandwidth and system frame number.

newly specifies NB-PSS/SSS and NB-PBCH that can be transmitted within one PRB for the NB-IoT category.

2) Enhanced Functionality for Coverage Extension

Functions for the uplink, which has even stricter requirements, have been enhanced for extending coverage. To begin with, Release 13 specifies transmission in subcarrier*17 (15 kHz) units smaller than one PRB (one PRB consists of 12 subcarriers) (hereinafter referred to as "single tone transmission"). Given that UE transmission power is limited in the uplink, single tone transmission can improve receive SINR by concentrating transmission power in one subcarrier at the expense of data rate. Release 13 also supports a 3.75-kHz subcarrier interval that narrows down the 15-kHz subcarrier even further.

3) Support of π/4-QPSK and π/2-BPSK Modulation

With the aim of reducing the Peak-to-Average Power Ratio (PAPR)*18, Release 13 adds phase rotation to conventional Quadrature Phase Shift Keying (QPSK)*19 modulation by supporting π/4-QPSK modulation and π/2-Binary Phase Shift Keying (BPSK)*20 modulation. Adding phase rotation in this way can avoid a zero point in the amplitude of the modulation signal and suppress amplitude fluctuation thereby reducing PAPR.

## 3. eDRX Technology for Power Savings

One of the key requirements in IoT scenarios is a battery replacement period of at least ten years for IoT modules [2]. There is therefore a need for technology that can provide a high battery-saving gain compared to the power consumption of conventional LTE UE.

Discontinuous Reception (DRX) has been specified as a power saving technology since 3GPP Release 8. Making use of intermittent signal reception, DRX minimizes power consumption by shutting down the Radio Frequency (RF) function*21 and putting the UE into a sleep state during the period of no reception. DRX is applied when receiving the PDCCH signal intermittently in Radio Resource Control (RRC)_IDLE*22 and RRC_CONNECTED*23. Pre-Release 13 specifications specify a maximum DRX cycle of 2.56 s. In order to satisfy battery requirements in IoT scenarios, the DRX cycle needs to be extended on the order of minutes or even hours, so Release 13 specifies extended DRX (eDRX) that greatly extends the period of DRX cycle.

### 3.1 eDRX Operation Overview

The eDRX function specified in Release 13 improves the battery-saving gain by lengthening the sleep state. In RRC_CONNECTED, a maximum eDRX cycle can be extended up to 10.24 s. In RRC_IDLE, the maximum eDRX cycle is extended up to 43.96 min for Category M1 and up to 2.91 h for NB-IoT, respectively. The state of a UE applying the eDRX function is called the eDRX state. A UE in eDRX state attempts to receive signals every eDRX cycle as configured by the network. Many IoT scenarios have the following communication pattern: small amounts of data transmission, long intervals (e.g., once every 24 hours) between outgoing calls, small number of incoming calls compared with ordinary smartphones, and infrequent updating of system information. In such a communication pattern, the RRC_CONNECTED period is extremely short compared to that of smartphones. It is therefore considered that the operation of eDRX during RRC_IDLE can make a greater contribution to the battery-saving effect than eDRX during RRC_CONNECTED. In addition, different IoT scenarios may have different requirements in terms of paging*24 response time. Consequently, even in an IoT scenario with infrequent outgoing calls (e.g., once every 24 hours), it is necessary to set an eDRX cycle of a certain time to ensure that the UE can satisfy the paging response time requirements. For example, given a paging response requirement within 2 min, an appropriate eDRX cycle value of around 2 min may be set.

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*17 **Subcarrier:** Individual carrier for transmitting signals with multi-carrier transmission such as OFDM.

*18 **PAPR:** Ratio of peak power to average power used as an index for evaluating performance and power consumption of a power amplifier.

*19 **QPSK:** A digital modulation method that uses a combination of signals with four different phases to enable the simultaneous transmission of two bits of data.

*20 **BPSK:** A digital modulation method that allows transmission of 1 bit of information at the same time by assigning one value to each of two phrases.

*21 **RF function:** The functional section that transmits and receives radio signals.

*22 **RRC_IDLE:** A RRC state in an LTE UE in which the UE is not known on cell level within the eNB, the eNB stores no UE context, and the MME stores UE context.

*23 **RRC_CONNECTED:** A RRC state in an LTE UE in which the UE is known on cell level within the eNB and the eNB stores UE context.

*24 **Paging:** A procedure and signal for calling a UE while camped in a cell in standby mode at time of an incoming call.

1) Definition of H-SFN

In LTE, System Frame Number (SFN)*25 is defined as a time reference for synchronization between the UE and evolved Node B (eNB)*26. The UE obtains SFN from the eNB when it camps into the eNB's cell and uses that information to synchronize with the eNB. For eDRX, the concept of a Hyper SFN (H-SFN) is introduced based on the abovementioned legacy SFN. As in the case of SFN, H-SFN is provided via system information.

In this regard, an SFN is defined as having a length of 10 ms with SFN numbering running from 0 to 1023, so the length of a total SFN cycle is 10.24 s. Consequently, to specify a long-term eDRX cycle, a single H-SFN is defined as having a length equivalent to that of an SFN cycle (10.24 s) with H-SFN numbering likewise running from 0 to 1023.

2) Setting of eDRX Cycle

The network can set an eDRX cycle for each UE. An eDRX cycle consists of a sequence of H-SFN frames, which means that the length of the cycle is an integral multiple of the length of a single H-SFN. A Mobility Management Entity (MME)*27 determines the eDRX cycle of each UE and notifies the eNB of that value via the S1 interface. Since the UE attempts to receive paging in every eDRX cycle, the network transmits paging signals according to that cycle.

### 3.2 Receiving Paging Message during RRC_IDLE

1) UE Operation

The method for receiving a paging message during RRC_IDLE is shown in **Figure 3**. The eNB and UE is synchronized at the SFN level. Additionally, to achieve eDRX, synchronization must be performed among MME, eNB, and UE at the H-SFN level (within several seconds). As a result, the H-SFN start time may have an offset by several seconds between the MME and UE and between the MME and eNB, but the MME, eNB, and UE will all have the same H-SFN number.

The UE attempts to receive paging during a specific H-SFN in every eDRX cycle. This H-SFN is called a Paging Hyperframe (PH)*28. Here, the UE uses the International Mobile Subscriber Identity (IMSI)*29 and the eDRX cycle to calculate which H-SFN number should become the PH to receive paging. Then, within that PH, the UE attempts to receive the paging message during the period of a Paging Time Window (PTW)*30. Furthermore, to increase the probability of receiving paging, the MME or eNB can repeat paging transmissions within the PTW. The PTW start timing can be distributed over four starting times within the H-SFN corresponding to that PH. The MME determines the PTW and signals it to the eNB together with the eDRX cycle via the S1 interface.

Within the PH, taking into account the PTW start timing, paging reception follows the legacy mechanism. That is, the UE uses the Default Paging DRX cycle to calculate which SFN number will be the Paging Frame (PF)*31 to receive paging and which subframe within that PF qualifies as a Paging Occasion (PO)*32. The UE then attempts to receive the paging message accordingly.

In addition, a UE that applies the coverage extension function will repeatedly transmit and receive the same signal. If eDRX operation is also being performed, the UE will begin receiving a repetition of paging messages from the first PO/PF subframe determined by the above calculations.

2) MME and eNB Operation

The MME and eNB calculates the H-SFN number that corresponds to the PH for each UE using a method similar to the PH calculation method in the UE as described above. The MME transmits the paging message to the eNB via the S1 interface before the timing of that H-SFN so that the eNB can transmit the paging message based on that timing. The eNB transmits the paging message received via the S1 interface to the UE in the relevant H-SFN number and PO/PF subframe. To enable the above operation, it is recommended that the MME and eNB be synchronized on the H-SFN

*25 **SFN:** Reference time in a UE and eNB in LTE.

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

*27 **MME:** A logical node accommodating a base station (eNB) and providing mobility management and other functions.

*28 **PH:** The H-SFN in which a UE in eDRX attempts to receive a paging message.

*29 **IMSI:** A number used in mobile communications that is unique to each user and stored on a User Identity Module (UIM) card.

*30 **PTW:** Length of time that a UE in eDRX will attempt to receive a paging message.

*31 **PF:** The SFN in which a UE in DRX will attempt to receive a paging message when in IDLE mode.

*32 **PO:** The subframe within the SFN in which a UE in DRX will attempt to receive a paging message when in IDLE mode.

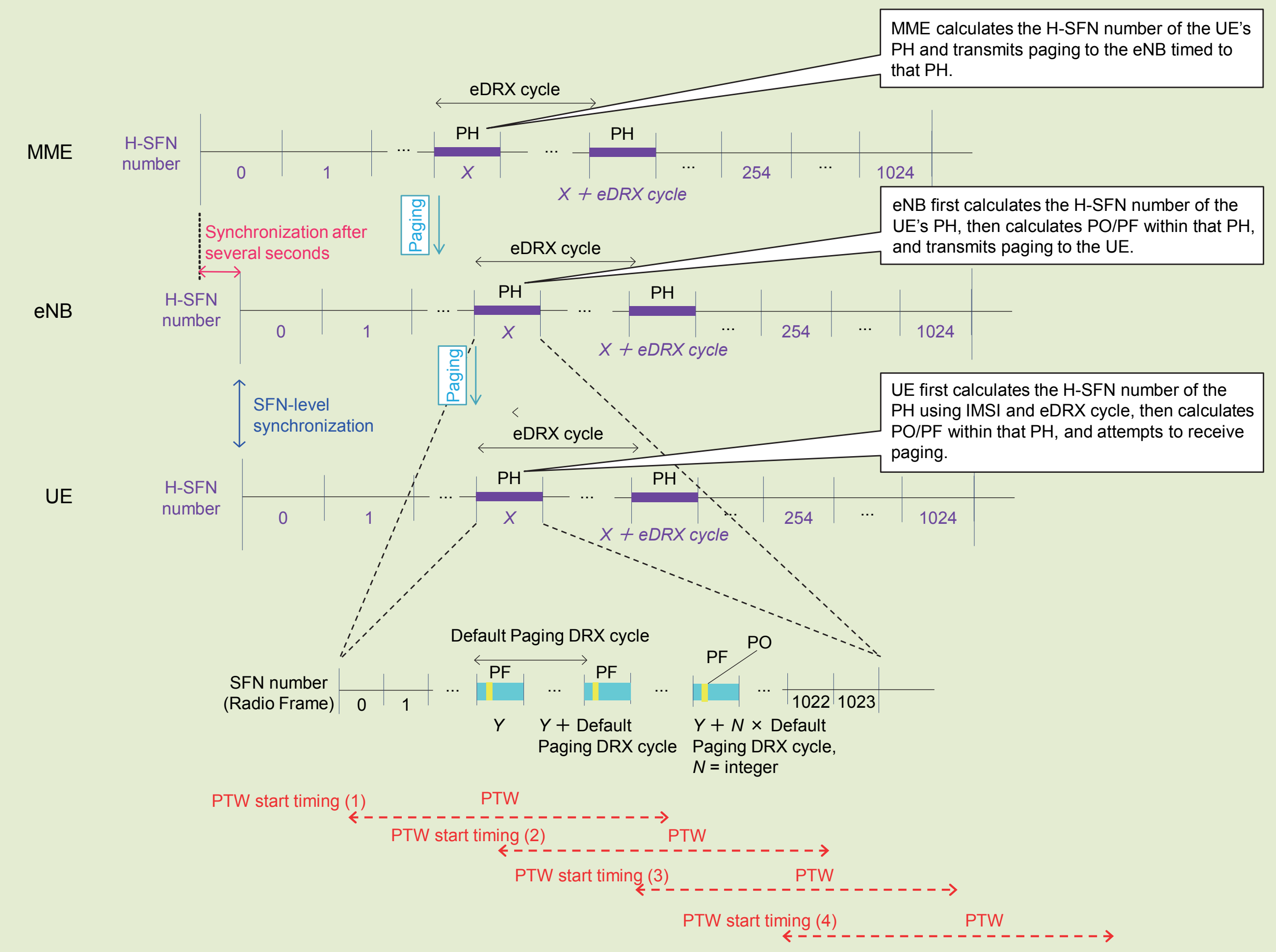


**Figure 3 Method for receiving paging message during RRC_IDLE**

level (several seconds). On receiving a paging message from the MME, the eNB needs to store that message until the H-SFN for transmitting the message begins. If the synchronization precision between the MME and eNB is high, the time difference of the H-SFN in the eNB and in the MME is short and the buffer capacity*33 needed for storing the paging message in the eNB until the relevant H-SFN timing occurs will be small.

### 3.3 HLCom

Functional extensions to the MME and upper-layer core network*34 nodes to support eDRX are specified as High Latency Communication (HLCom) functions. In HLCom, these functions are used to process paging for incoming data, SMS*35, and LoCation Service (LCS)*36. In this article, we focus on and describe HLCom functions for paging of incoming data.

As described above, the MME knows the PH of each UE. When the Serving GateWay (S-GW)*37 indicates that incoming data is received, the MME, which is aware that the target UE is in eDRX state and therefore not reachable,

*33 **Buffer capacity:** Size of the location for temporarily saving user data, signaling, etc.

*34 **Core network:** A network consisting of switching equipment, subscriber information management equipment, etc. A mobile terminal communicates with the core network via a radio access network.

*35 **SMS:** A service for sending/receiving short text-based messages mainly between mobile terminals.

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

*37 **S-GW:** A packet switch on the LTE network for sending/receiving user data to/from P-GW (see *56).

understands that a paging message cannot be transmitted to the UE. It therefore estimates the time until a bearer*38 connection can be made between the UE and the network and requests the S-GW to buffer the message for as long as the estimated time. The MME stores the buffering time requested to the S-GW for the UE, and if MME is aware that the UE accessed the network within that time, it establishes a User Plane (U-Plane)*39 Data. Furthermore, if during the estimated timing the UE moves and relocates to another MME, the estimated buffering time information is forwarded from the old MME to the new MME so that the new MME can preserve the timer and perform the above operation. The S-GW, in turn, will store the incoming data for as long as the buffering time requested by the MME.

## 4. Optimization of Core Network for IoT

The NB-IoT category is specified as radio technology for intermittent transmission of small amounts of data. On the other hand, the Evolved Packet System (EPS)*40 in the core network is applicable to the transmission of large amounts of data. There is therefore a need for optimizing EPS for NB-IoT applications, and this topic was discussed at the 3GPP Service and System Aspects (SA) Plenary*41 meeting in March 2015. As a result of these discussions, an architecture study on optimizing EPS for Cellular IoT (CIoT) got under way in July 2015 at SA2. The following describes the specifications resulting from this study for CIoT EPS optimization.

### 4.1 Overview of CIoT EPS Optimization

1) Features

CIoT EPS optimization supports the features listed below.

- Ultra-low UE power consumption
- Large number of devices per cell
- Narrowband spectrum Radio Access Technologies (RATs)
- Enhanced coverage level

2) Two Methods of CIoT EPS Optimization

Two methods of CIoT EPS optimization have been standardized [3].

(1) The first is Control Plane (C-Plane)*42 CIoT EPS optimization, in which user data is subjected to encapsulation*43 in C-Plane signaling messages in the form of a Non-Access Stratum Protocol Data Unit (NAS PDU)*44.

(2) The second is U-Plane CIoT EPS optimization. Here, while the user data transmission method uses a U-Plane bearer the same as EPS, efficient U-Plane bearer control applicable to the intermittent transfer of user data can be achieved by introducing Suspend and Resume as new states on the RRC layer and having the NB-IoT UE, eNB, and MME store connection information.

An architecture overview of each method is shown in **Figure 4**. At SA2, it was decided that support for method (1) would be mandatory while support for method (2) would be optional on NB-IoT UEs.

3) Selecting Method of CIoT EPS Optimization

An NB-IoT UE must determine which CIoT EPS optimization method to use with the core network. For this reason, the NB-IoT UE first sends information on the methods it supports to the core network by including that information in the Attach*45/Tracking Area Update (TAU)*46/Routing Area Update (RAU)*47 Request signals. Then, based on that information, the core network returns information on the method it has selected to the NB-IoT UE by including that information in the Attach/TAU/RAU Accept signals. However, if the NB-IoT UE should request connection by a method not supported by the core network, the core network sets an appropriate code and performs an Attach/TAU/RAU Reject operation.

4) Function for Allocating UEs to Core Network

CIoT EPS optimization is being specified with the objective of making data

*38 **Bearer:** In this article, the path taken by user data packets.

*39 **U-Plane:** The transmission path of user data, in contrast to the C-Plane, the transmission path of control signals.

*40 **EPS:** Generic term for an IP-based packet network specified by 3GPP for LTE or other access technologies.

*41 **SA Plenary:** The highest level of 3GPP TSG SA meetings.

*42 **C-Plane:** A sequence of exchanged control processes for establishing communications, etc.

*43 **Encapsulation:** Technology for embedding data in a different protocol so that communications can be performed even in a network with limited protocol.

*44 **NAS PDU:** The functional layer between the mobile terminal and core network located above the Access Stratum (AS) (see *62).

*45 **Attach:** A process for registering a mobile terminal with the network such as when turning the terminal's power on.

*46 **TAU:** Process for changing network equipment to reregister or register a mobile terminal with the network when the mobile terminal moves into LTE.

*47 **RAU:** Process for changing network equipment to reregister or register a mobile terminal with the network when the mobile terminal moves into 3G.

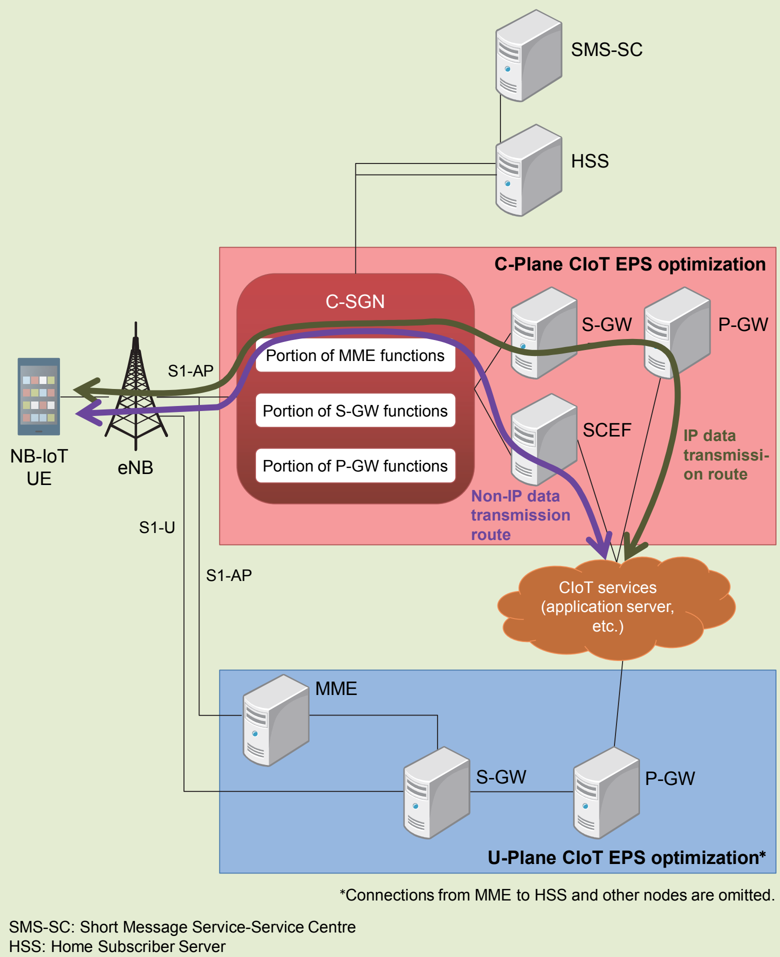


**Figure 4 Architecture overview of CIoT EPS optimization**

transfer from NB-IoT UEs as efficient as possible. The assumption here is that NB-IoT UEs do not connect to the existing EPS. For this reason, a function is implemented whereby the eNB discriminates between existing EPS and EPS optimized for CIoT and allocates conventional UEs to existing EPS and NB-IoT UEs to EPS optimized for CIoT. This function is linked to the RRC signal. We note here that this function is achieved by a mechanism different from the allocation of a Dedicated Core Network (DCN)*48 [4] specified in Release 13 the same as this function. However, a core network with EPS optimized for CIoT may also be deployed as a DCN.

5) Unsupported Functions

At the same time, considering that NB-IoT UEs and CIoT EPS optimization were developed with function simplification in mind, they do not support some of the functions provided by existing UEs and EPS. Some examples are given below.

- Emergency call services are not provided.
- Offload technologies such as Local IP Access (LIPA)*49 and Selected IP Traffic Offload (SIPTO)*50

*48 **DCN:** A dedicated core network separate from the core network that groups together mobile terminals having the same terminal identifier indicating the type of mobile terminal.

*49 **LIPA:** A type of offload technology specified by 3GPP. A method for connecting to the Internet and sending/receiving certain types of packets via a wireless access network without having to pass through the core network.

*50 **SIPTO:** A type of offload technology specified by 3GPP. A method for connecting to the Internet and sending/receiving certain types of packets via a wireless access network using only part of the core network.

cannot be applied.

- Only mobility in EPS Connection Management (ECM)_IDLE*51 mode is supported; handover*52 in ECM_CONNECTED*53 mode is not.
- Establishment of a Guaranteed Bit Rate (GBR) bearer*54 and a dedicated bearer*55 is not supported.

## 4.2 C-Plane CIoT EPS Optimization

1) Features

As described above, C-Plane CIoT EPS optimization is a method for transferring encapsulated user data via C-Plane messages. This method decreases the number of C-Plane messages when transferring small amounts of data, and as a result, it can be expected to contribute to ultra-low UE power consumption and reduction of bands for use by narrowband devices. This method supports the following functions the same as existing EPS (with the exception of non-IP data transfer):

- Transport of user data (IP and Non-IP)
- Local mobility anchor point
- Header compression (for IP user data)
- Ciphering and integrity protection of user data
- Lawful interception of user traffic

2) C-SGN

The CIoT Serving Gateway Node (C-SGN) is specified as a new node for the C-Plane CIoT EPS optimization (see Fig. 4). This node consolidates a minimum of functions from C-Plane node MME and from U-Plane nodes S-GW and Packet data network GateWay (P-GW)*56 in existing EPS and is defined as a single logical entity*57. C-SGN functions may also be deployed in the MME of existing EPS.

Transfer of user data by this method can be performed via C-SGN using the S1-AP interface. This means that there is no need to establish a U-Plane bearer by the S1-U interface between the eNB and S-GW in relation to IP data transfer. As a result, the NB-IoT UE can set dummy data in the EPS Session Management (ESM) container*58 of the Attach Request and omit establishment of a U-Plane bearer by the S1-U interface. However, if U-Plane CIoT EPS optimization to be described in section 4.3 is simultaneously supported, a U-Plane bearer can also be established by the S1-U interface and IP data transferred as usual.

3) Application of HLCom

In IoT communications, we can envision the application of intermittent reception through the joint use of functions such as Power Saving Mode (PSM)*59 and eDRX. In this case, as well, HLCom functions can be applied to C-Plane CIoT EPS optimization. In other words, incoming IP data can be buffered at the S-GW. First, the S-GW sends a Downlink Data Notification message to the C-SGN on receiving downlink packets. Next, the C-SGN sends a response signal to the S-GW indicating the length of time until the NB-IoT UE enters the ECM_CONNECTED state. This information enables the S-GW to extend buffer capacity (time and quantity of packets). It is also shared between C-SGNs when a TAU occurs. In the case of non-IP data, the Service Capability Exposure Function (SCEF)*60 can be used to buffer incoming and outgoing data, but we omit description of this function in this article.

## 4.3 U-Plane CIoT EPS Optimization

As shown in Fig. 4, U-Plane CIoT EPS optimization uses the same architecture and control/data-transfer methods as existing EPS. However, in terms of RRC connections and bearer control, it also provides for the storage of state information on the NB-IoT UE and various nodes to make RRC reconnection and bearer reestablishment quick and efficient. With this method, a bearer can be established in an on-demand manner, so we can expect positive effects such as ultra-low UE power consumption and a large number of devices per cell. In addition to functions supporting existing EPS, this method can support the

*51 **ECM_IDLE:** State in which resources between the mobile terminal and radio network have been released.

*52 **Handover:** A technology for switching base stations without interrupting a call in progress when a terminal straddles two base stations while moving.

*53 **ECM_CONNECTED:** State in which resources between the mobile terminal and radio network are secured and data can be sent and received.

*54 **GBR bearer:** A bearer established for providing a bandwidth guaranteed service.

*55 **Dedicated bearer:** The second or later bearer established at each APN. In IMS-APN, this type of bearer is used for sending/receiving data in Realtime Transport Protocol (RTP) or RTP Control Protocol (RTCP).

*56 **P-GW:** A gateway acting as a point of connection to a PDN, allocating IP addresses and transporting packets to the S-GW.

*57 **Entity:** A constituent element providing a function in logical architecture.

*58 **ESM container:** An area containing a message related to bearer construction, modification, and disconnection in session management (ESM), as in mobility (EMM) messages Attach and TAU.

transfer of non-IP data via the P-GW.

As described above, U-Plane CIoT EPS optimization introduces Suspend and Resume as two new states in RRC control [5]. The state-transition procedure for each of these is described below (**Figure 5**).

1) RRC Suspend Procedure

This procedure, activated by the eNB,

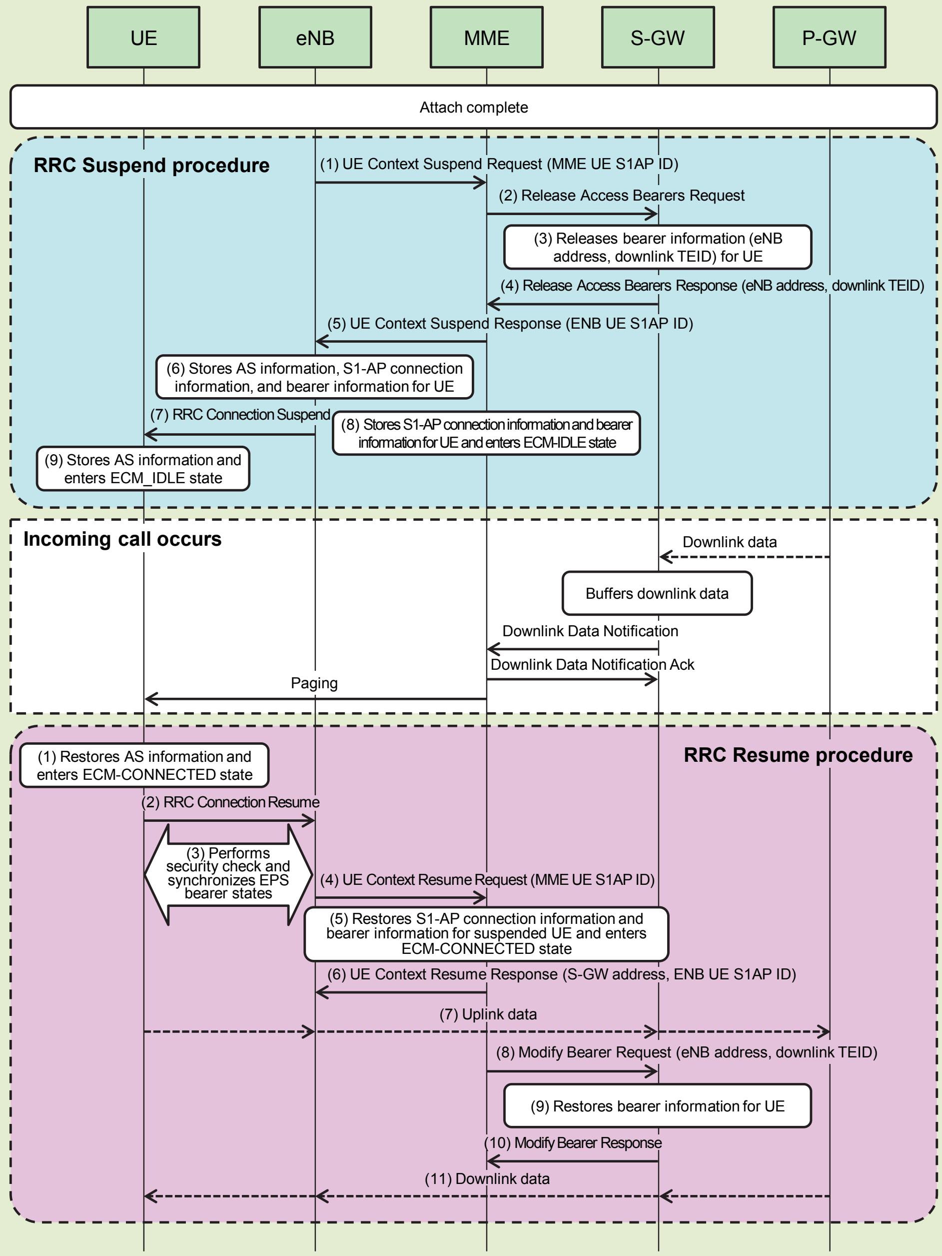


**Figure 5 Overview of RRC Suspend/Resume procedures in U-Plane CIoT EPS optimization**

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*59 **PSM:** A type of low power consumption technology. While maintaining registration with the network, the UE enters a pseudo power cutoff state for a certain period of time.

*60 **SCEF:** A logical node installed in a 3GPP mobile network having a standard interface for providing a number of 3GPP services to third-party application providers.

releases the RRC connection between the target NB-IoT UE and eNB and the S1-U bearer between the eNB and S-GW. To begin with, the eNB sends a UE Context Suspend Request and releases bearer information related to the NB-IoT UE at S-GW via MME (steps (1) and (2) in Fig. 5). Next, the S-GW releases the S1-U bearer with the eNB related to the NB-IoT UE. Specifically, the S-GW releases only the eNB address and downlink Tunnel Endpoint IDentifier (TEID)*61 and continues to store other information (step (3)). On completion of S1-U bearer release at the S-GW, the eNB receives notification of that by a UE Context Suspend Response via MME (steps (4) and (5)). The eNB then stores Access Stratum (AS)*62 information, S1-AP connection information, and bearer information for that NB-IoT UE and sends a RRC Connection Suspend message to the UE (steps (6) and (7)). The MME also stores S1-AP connection information and bearer information for that NB-IoT UE and enters the ECM_IDLE state (step (8)). Finally, on receiving the RRC Connection Suspend message from the eNB, the NB-IoT UE stores AS information and likewise enters the ECM_IDLE state ((step (9)).

2) RRC Resume Procedure

This procedure reestablishes (resumes) the RRC connection between the NB-IoT UE and eNB in Suspend state and the released S1-U bearer between the eNB and S-GW. When resuming a connection at UE startup, the NB-IoT UE activates this procedure. It begins by resuming the connection with the network using the AS information stored by the RRC Suspend procedure (steps (1) and (2) in Fig. 5). At this time, the eNB performs a security check on the NB-IoT UE to resume the RRC connection. It also provides a list of resumed radio bearers to the NB-IoT UE and synchronizes the EPS bearer state between the NB-IoT UE and eNB (step (3)). If the above process completes normally, the eNB sends a UE Context Resume Request to the MME to notify it that the connection with the NB-IoT UE has safely resumed (step (4)). On receiving this resumption notification from the eNB, the MME restores the S1-AP connection information and bearer information for the suspended NB-IoT UE, enters the ECM_CONNECTED state, and sends to the eNB a UE Context Resume Response that includes the S-GW address and related S1-AP connection information for the NB-IoT UE (steps (5) and (6)). Uplink data transfers can now take place from the NB-IoT UE toward the S-GW (step (7)). The MME, in turn, sends the eNB address and downlink TEID to the S-GW by a bearer correction request to reestablish (resume) the S1-U bearer between the NB-IoT UE and S-GW on the downlink (steps (8) and (9)). Once this resumption completes, the S-GW sends a bearer correction request to MME enabling downlink packet transfers to the eNB to start immediately (steps (10) and (11)).

In the event that downlink packets are received at the S-GW while the NB-IoT UE is in Suspend state, the S-GW buffers the downlink packets and initiates a Downlink Data Notification procedure between the S-GW and MME the same as in existing EPS. The MME can now page the NB-IoT UE thereby activating the connection resume procedure by UE startup (see "Incoming call occurs" in Fig. 5).

3) Deletion of S1-AP Connection Information

To minimize the effects of inter-cell movement by an NB-IoT UE, AS information is transferred between eNBs [5] [6]. Thus, in the case that the eNB changes, the suspended connection established by procedure (1) above by the old eNB can be resumed by procedure (2) by the new eNB. However, if any of the following events should occur while the MME is in a state storing S1-AP connection information related to a certain NB-IoT UE, the MME and related eNB will delete the stored S1-AP connection information by a S1 release procedure [3] [7].

- MME receives a new EPS Mobility Management (EMM)*63 procedure via a different logical S1 connection related to that NB-IoT UE.

*61 **TEID:** A connection path identifier used in GRPS Tunneling Protocol (GTP).

*62 **AS:** The function layer between the mobile terminal and radio network.

*63 **EMM:** Management information used in LTE on UE location state, concealment, authentication, connection, etc. or processes related to the registration, modification, or deletion of that information.

- A TAU procedure is activated in conjunction with a MME change.
- A UE capable of 3G/LTE connections with NB-IoT ability receives a Context Request from a Serving General packet radio service Support Node (SGSN)*64 when reattaching by 3G and making a transition to LTE by TAU.
- UE performs a Detach*65.

4) Application of HLCom

If, in communications using intermittent reception functions such as PSM and eDRX, the S-GW receives downlink packets while the NB-IoT UE is in Suspend state, the S-GW can extend buffer capacity by the same type of method as used in C-Plane CIoT EPS optimization described above. Furthermore, if a TAU occurs, that time-related information is shared between MMEs.

## 5. Conclusion

In this article, we described new technologies for IoT services as specified in LTE Release 13. These technologies satisfy core service requirements, and we expect them to be introduced in earnest as those services began to spread. Going forward, 3GPP intends to further enhance Release 13 specifications, and NTT DOCOMO plans to be actively involved in standardization activities for other technologies that need to be provided to further promote the proliferation of IoT services.

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*64 **SGSN:** A logical node in 3GPP standard specifications providing functions such as packet switching and mobility management for mobile terminals performing packet communications.

*65 **Detach:** Procedure to remove registration of a terminal from the network at certain times such as when its power is switched off.