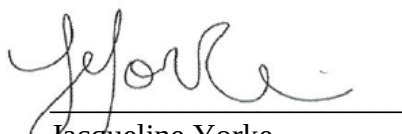


City of New York, State of New York, County of New York

I, Jacqueline Yorke, hereby certify that the document “**61862518 Provisional (1)**” is, to the best of my knowledge and belief, a true and accurate translation from Korean into English.

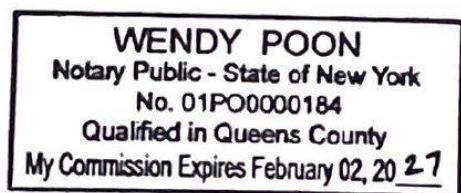


Jacqueline Yorke

Sworn to before me this  
December 20, 2024



Signature, Notary Public



Stamp, Notary Public

Petitioners' Exhibit 1019  
Google et al. v. KT Corporation et al.  
IPR2025-00292

PROVISIONAL APPLICATION FOR UNITED STATES PATENT  
IN THE NAMES OF

Hyangsun YOU, Joonkui AHN, Suckchel YANG, Yunjung YI and  
Dongyoun SEO

for

PDCCH AND PDSCH TRANSMISSION FOR MTC COVERAGE  
ENHANCEMENT

Customer Number: 67487

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Total Number of pages: 71 (including cover)

~~Provisional Application~~

|                    |                                                           |
|--------------------|-----------------------------------------------------------|
| Title of Invention | PDCCH and PDSCH transmission for MTC coverage enhancement |
|--------------------|-----------------------------------------------------------|

## 1. Purpose of Invention

The present invention proposes transmission methods of PDCCH and PDSCH for coverage enhancement of MTCUEs.

## 2. Prior Arts

Techniques, apparatus and systems described herein can be used in various wireless access technologies such as code division multiple access (CDMA), frequency division multiple access (FDMA), time division multiple access (TDMA), orthogonal frequency division multiple access (OFDMA), single carrier frequency division multiple access (SC-FDMA), etc. The CDMA may be implemented with a radio technology such as Universal Terrestrial Radio Access (UTRA) or CDMA2000. The TDMA may be implemented with a radio technology such as Global System for Mobile communications (GSM)/ General Packet Radio Service (GPRS)/ Enhanced Data Rates for GSM Evolution (EDGE). The OFDMA may be implemented with a radio technology such as institute of electrical and electronics engineers (IEEE) 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802-20, evolved-UTRA (E-UTRA) etc. The UTRA is a part of a universal mobile telecommunication system (UMTS). 3rd generation partnership project (3GPP) long term evolution (LTE) is a part of an evolved-UMTS (E-UMTS) using the E-UTRA. The 3GPP LTE employs the OFDMA in downlink and employs the SC-FDMA in uplink [1]. LTE-advanced (LTE-A) is an evolution of the 3GPP LTE. For clarity, this application focuses on the 3GPP LTE/LTE-A. However, technical features of the present invention are not limited thereto.

LTE system architecture

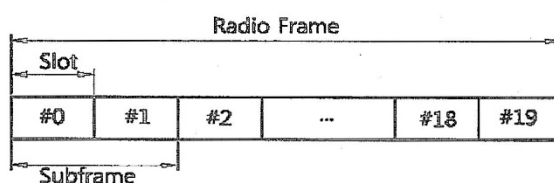


Figure 1. Structure of a radio frame of 3GPP LTE

In Figure 1, a radio frame includes 10 subframes. A subframe includes two slots in time domain. A time for transmitting one subframe is defined as a transmission time interval (TTI). For example, one subframe may have a length of 1 millisecond (ms), and one slot may have a length of 0.5 ms. One slot includes a plurality of orthogonal frequency division multiplexing (OFDM) symbols in time domain. Since the 3GPP LTE uses the OFDMA in the downlink, the OFDM symbol is for representing one symbol period. The OFDM symbol may also be referred to as an SC-FDMA symbol or a symbol period. A resource block (RB) is a resource allocation unit, and includes a plurality of contiguous subcarriers in one slot. The structure of the radio frame is shown for exemplary purposes only. Thus, the number of subframes included in the radio frame or the number of slots included in the subframe or the number of OFDM symbols included in the slot may be modified in various manners.

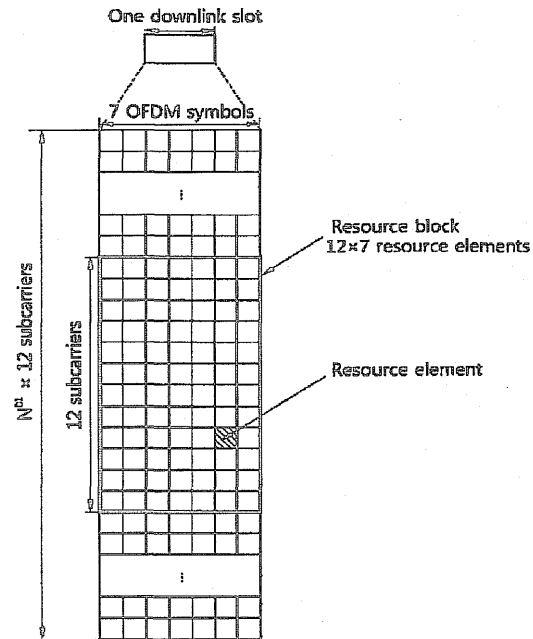


Figure 2. Resource grid for one downlink slot

In Figure 2, a downlink slot includes a plurality of OFDM symbols in time domain. It is described herein that one downlink slot includes 7 OFDM symbols, and one resource block (RB) includes 12 subcarriers in frequency domain as an example. However, the present invention is not limited thereto. Each element on the resource grid is referred to as a resource element (RE). One RB includes 12x7 REs. The number NDL of RBs included in the downlink slot depends on a downlink transmit bandwidth. The structure of an uplink slot may be same as that of the downlink slot.

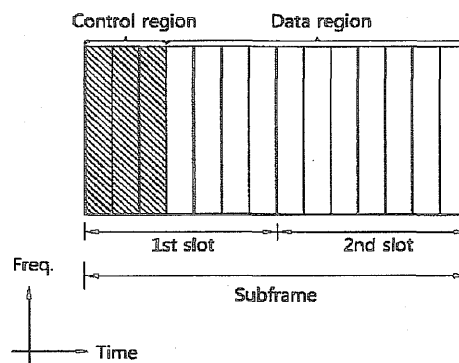


Figure 3. Structure of downlink subframe

In Figure 3, a maximum of three OFDM symbols located in a front portion of a first slot within a subframe correspond to a control region to be assigned with a control channel. The remaining OFDM symbols correspond to a data region to be assigned with a physical downlink shared channel (PDSCH). Examples of downlink control channels used in the 3GPP LTE includes a physical control format indicator channel (PCFICH), a physical downlink control channel (PDCCH), a physical hybrid ARQ indicator channel (PHICH), etc. The PCFICH is transmitted at a first OFDM symbol of a subframe and carries information regarding the number of OFDM symbols used for transmission of control channels within the subframe. The PHICH is a response of uplink transmission and carries an HARQ acknowledgment (ACK)/not-acknowledgment (NACK) signal. Control information transmitted through the PDCCH is referred to as downlink control information (DCI). The DCI includes uplink or downlink scheduling information or includes an uplink transmit (Tx) power control command for arbitrary UE groups.

The PDCCH may carry a transport format and a resource allocation of a downlink shared channel (DL-SCH), resource allocation information of an uplink shared channel (UL-SCH), paging information on a paging channel (PCH), system information on the DL-SCH, a resource allocation of an upper-layer control message such as a random access response transmitted on the PDSCH, a set of Tx power control commands on individual UEs within an arbitrary UE group, a Tx power control command, activation of a voice over IP (VoIP), etc. A plurality of PDCCHs can be transmitted within a control region. The UE can monitor the plurality of PDCCHs. The PDCCH is transmitted on an aggregation of one or several consecutive control channel elements (CCEs). The CCE is a logical allocation unit used to provide the PDCCH with a coding rate based on a state of a radio channel. The CCE corresponds to a plurality of resource element groups (REGs). A format of the PDCCH and the number of bits of the available PDCCH are determined according to a correlation between the number of CCEs and the coding rate provided by the CCEs. The BS determines a PDCCH format according to a DCI to be transmitted to the UE, and attaches a cyclic redundancy check (CRC) to control information. The CRC is masked with a unique identifier (referred to as a radio network temporary identifier (RNTI)) according to an owner or usage of the PDCCH. If the PDCCH is for a specific UE, a unique identifier (e.g., cell-RNTI (C-RNTI)) of the UE may be masked to the CRC. Alternatively, if the PDCCH is for a paging message, a paging indicator identifier (e.g., paging-RNTI (P-RNTI)) may be masked to the CRC. If the PDCCH is for system information (more specifically, a system information block (SIB) to be described below), a system information identifier and a system information RNTI (SI-RNTI) may be masked to the CRC. To indicate a random access response that is a response for transmission of a random access preamble of the UE, a random access-RNTI (RA-RNTI) may be masked to the CRC.

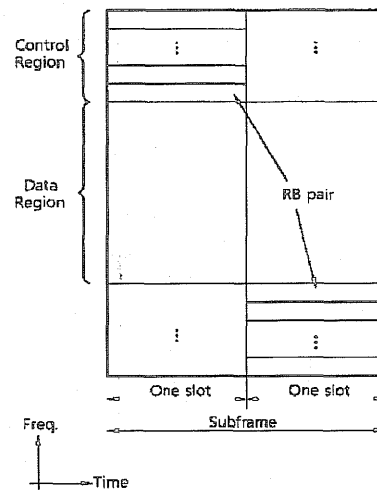


Figure 4. Structure of uplink subframe

In Figure 4, an uplink subframe can be divided in a frequency domain into a control region and a data region. The control region is allocated with a physical uplink control channel (PUCCH) for carrying uplink control information. The data region is allocated with a physical uplink shared channel (PUSCH) for carrying user data. To maintain a single carrier property, one UE does not simultaneously transmit the PUCCH and the PUSCH. The PUCCH for one UE is allocated to an RB pair in a subframe. RBs belonging to the RB pair occupy different subcarriers in respective two slots. This is called that the RB pair allocated to the PUCCH is frequency-hopped in a slot boundary.

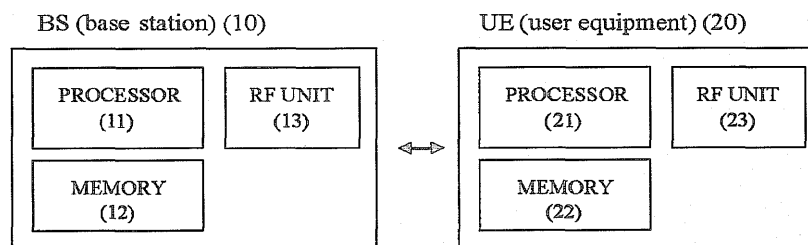


Figure 5. System for implementing present invention

In Figure 5, a wireless communication system includes a BS 10 and one or more UE 20. In downlink, a transmitter may be a part of the BS 10, and a receiver may be a part of the UE 20. In uplink, a transmitter may be a part of the UE 20, and a receiver may be a part of the BS 10. A BS 10 may include a processor 11, a memory 12, and a radio frequency (RF) unit 13. The processor 11 may be configured to implement proposed procedures and/or methods described in this application. The memory 12 is coupled with the processor 11 and stores a variety of information to operate the processor 11. The RF unit 13 is coupled with the processor 11 and transmits and/or receives a radio signal. A UE 20 may include a processor 21, a memory 22, and a RF unit 23. The processor 21 may be configured to implement proposed procedures and/or methods described in this application. The memory 22 is coupled with the processor 21 and stores a variety of information to operate the processor 21. The RF unit 23 is coupled with the processor 21 and transmits and/or receives a radio signal. The BS 10 and/or the UE 20 may have single antenna and multiple antennas. When at least one of the BS 10 and the UE 20 has multiple antennas, the wireless communication system may be called as multiple input multiple output (MIMO) system.

## Component carrier aggregation in LTE-A

As the increased demands for the high data rate transmission, the mobile communication system composed of aggregated multiple CCs (component carriers) is now being researched. For example, Figure 6 (b) illustrates the DL/UL subframe structure considered in 3GPP LTE-A (LTE Advanced) system where multiple CCs are aggregated (in this example, 3 carriers exist), while Figure 6 (a) illustrates a single carrier operation as in conventional systems. As shown in Figure 6 (b), a UE can monitor and receive DL signal/data from multiple DL CCs at the same time. However, even if a cell is managing  $N$  DL CCs, the network may configure a UE with  $M$  DL CCs where  $M \leq N$  so that the UE's monitoring of the DL signal/data is limited to those  $M$  DL CCs. In addition, the network may configure  $L$  DL CCs as the main DL CCs from which the UE should monitor/receive DL signal/data with a priority, either UE-specifically or cell-specifically, where  $L \leq M \leq N$ .

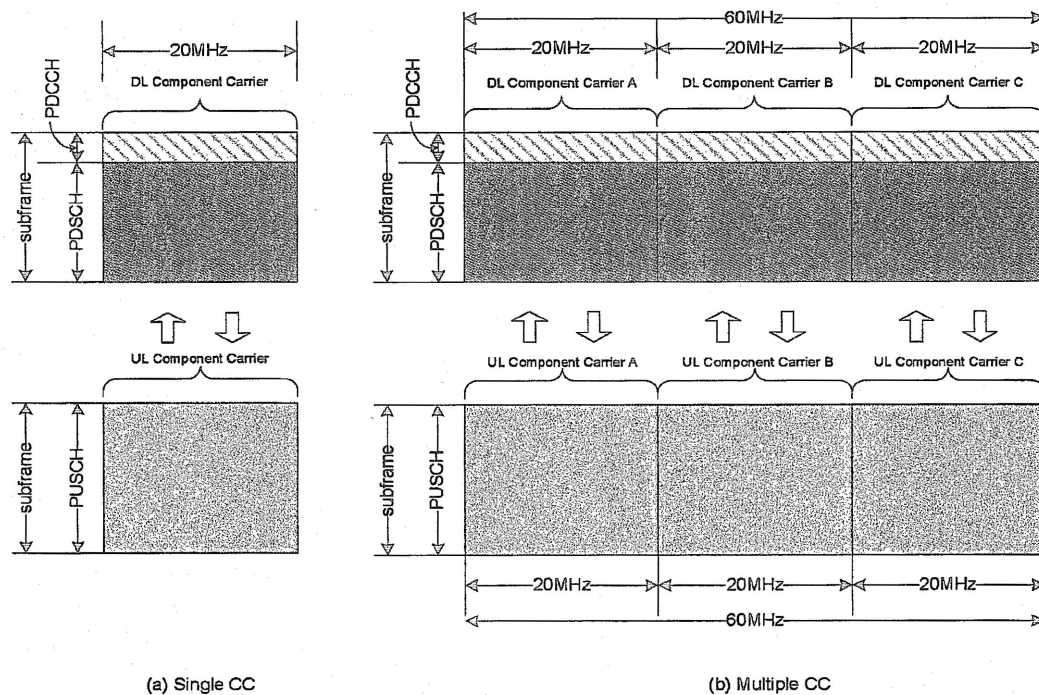


Figure 6. Subframe structure of 3GPP LTE Release-8 system and LTE-A system with CC aggregation

In a system that supports carrier aggregation, cells can be classified as shown in Figure 7.

As shown in Figure 7, the configured cells are set by UE as cells that allow carrier aggregation based on measurement report among the cells of the base station. The configured cells reserve resources in advance for ACK/NACK transmission for PDSCH transmission. Activated cells are cells that are set to actually transmit PDSCH/PUSCH among the configured cells and perform CSI report and SRS transmission for PDSCH/PUSCH transmission. De-activated cells are cells that do not transmit PDSCH/PUSCH due to commands or timer operation of the base station, and CSI report and SRS transmission are also interrupted.

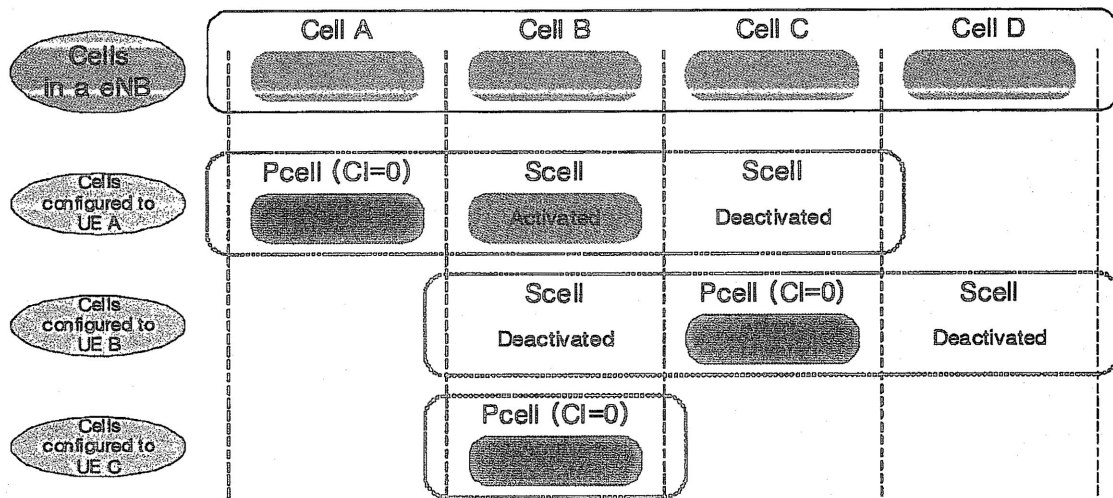
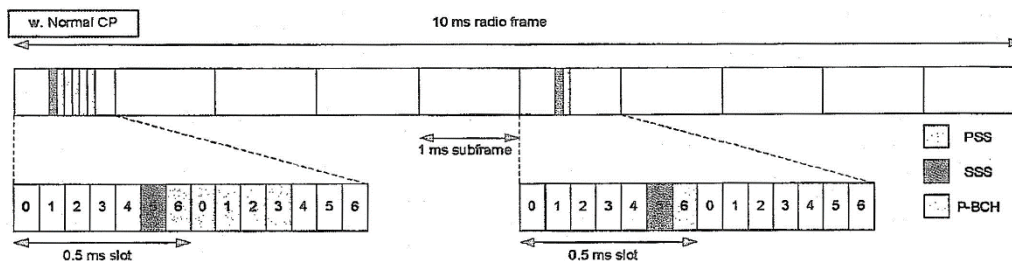


Figure 7. Configured cell, activated cell, de-activated cell

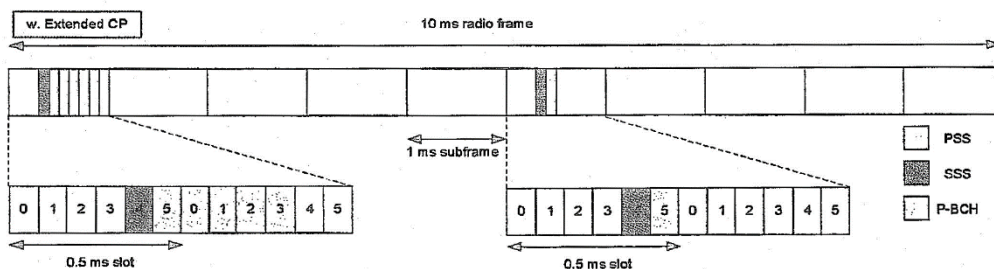
## Synchronization signal (SS) in LTE-A FDD

SS consists of P-SS and S-SS, which are signals used to perform cell discovery.

Figures 7(a) and (b) illustrate the frame structure for the transmission of SS in systems using a basic CP and an extended CP, respectively. For ease of inter-RAT measurement, the SS is transmitted in the second slot of subframe 0 and subframe 5, respectively, taking into account the GSM frame length of 4.6 ms, and the boundaries for the corresponding radio frame are detectable via S-SS. The P-SS is transmitted in the last OFDM symbol in the slot, and the S-SS is transmitted in the OFDM symbol right next to the P-SS. SS may transmit a total of 504 physical cell IDs via a combination of three P-SSs and 168 S-SSs. In addition, SS and PBCH are transmitted within 6RB in the middle of the system bandwidth, allowing the UE to detect or decode regardless of the transmission bandwidth.



(a) For Basic CPs



(b) For Extended CP

Figure 7. Frame structure for SS transmission

The transmission diversity method of SS uses only a single antenna port and is not separately defined in the standard. In other words, a single antenna transmission or a transmission method that is transparent to the UE (e.g., PVS, TSTD, CDD) can be used.

## a. P-SS Code

A ZC (Zadoff-Chu) sequence of length 63 is defined in the frequency domain and used as the sequence of P-SS. The ZC sequence is defined by Equation (1), and the sequence element corresponding to the DC subcarrier,  $n=31$ , is punctured.  $N_{zc} = 63$  in Equation (1).

$$d_u(n) = e^{-j\frac{\pi u n(n+1)}{N_{zc}}} \quad (1)$$

9 remaining subcarriers out of the 6RB (=72 subcarriers) in the middle are always transmitted at a value of 0, which facilitates the design of filters for synchronization performance. To define a total of three P-SSs, the values of  $u=25$ , 29, and 34 are used in Equation (1). At this time, 29 and 34 have a conjugate symmetry, so that two correlations can be performed simultaneously. Here, the conjugate asymmetry means the relationship in the following Equation (2), and this characteristic can be used to implement a one-shot correlator for  $u=29$  and for 34, which can reduce the overall computational amount by about 33.3%.

$$\begin{aligned} d_u(n) &= (-1)^n (d_{N_{zc}-u}(n))^*, \text{ when } N_{zc} \text{ is even number.} \\ d_u(n) &= (d_{N_{zc}-u}(n))^*, \text{ when } N_{zc} \text{ is odd number.} \end{aligned} \quad (2)$$

## b. S-SS Code

The sequence used for S-SS is an interleaved concatenation of two m-sequences of length 31, and the two sequences are combined to transmit 168 cell group IDs. As a sequence of S-SS, the m-sequence is robust in a frequency selective environment, and the amount of computation can be reduced by using the fast m-sequence transform using the fast Hadamard transform. In addition, configuring S-SS with two short codes has been proposed to reduce the computational burden of the terminal. Figure 8 is a diagram showing how two sequences in the logical domain are interleaved and mapped in the physical domain. When two m-sequences used for S-SS code generation are defined as S1 and S2, respectively, if the S-SS of subframe 0 transmits the cell group ID in two combinations of (S1, S2), the S-SS of subframe 5 can be transmitted by swapping them for (S2, S1), thereby distinguishing a 10 ms frame boundary. At this time, the S-SS code used uses a generating polynomial of  $x^5 + x^2 + 1$ , and a total of 31 codes can be generated through different circular shifts.

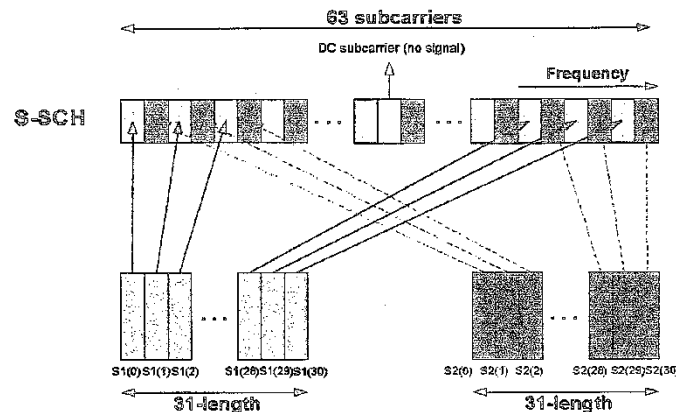


Figure 8. S-SS Code Generation Method

To improve reception performance, two different sequences are defined based on P-SS, scrambled to S-SS, but scrambled to S1 and S2 with different sequences. After that, an S1-based scrambling code is defined and scrambling is performed on S2. At this time, the S-SS codes are exchanged in 5 ms, but the P-SS-based scrambling codes are not exchanged. The P-SS-based scrambling code is defined as six cyclic shift versions according to the P-SS index in the m-sequence generated from the generating polynomial of  $x^5+x^3+1$ , and the S1-based scrambling code is defined as eight cyclic shift versions according to the index of S1 in the m-sequences generated from the polynomial of  $x^5+x^4+x^2+x+1$ .

#### Reference signal (RS) in LTE-A

In general, data can suffer from easily through wireless channel (so called frequency selective channel. So reference signal that already known to both Tx and Rx should be transmitted with data information at the same time for channel estimation. There are two kinds of roles which RS should do: demodulation and channel measurement. Depending on the knowledge of the existence of RS, RS can be classified into a dedicated RS (DRS) and a common RS (CRS). That is to say, the DRS is known to specific UE and the CRS is known to all UEs. We call a RS for CQI/PMI/RI reporting channel quality indicator CRS (CSI-RS). The DRS can be called as UE-specific RS.

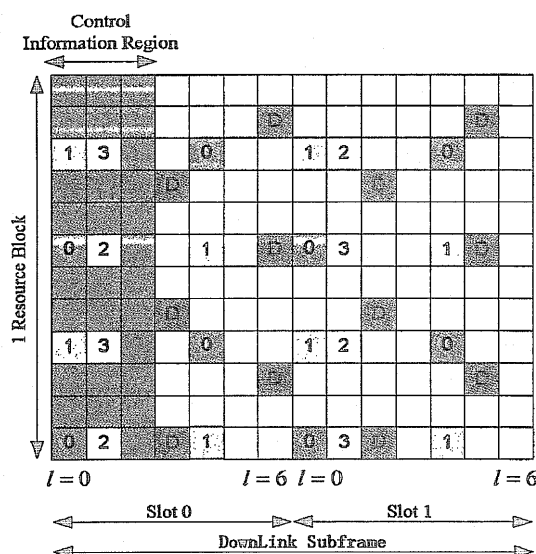


Figure 9

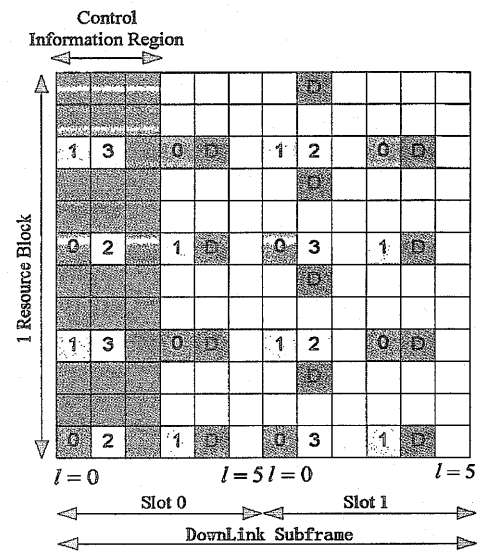


Figure 10

Figure 9 and Figure 10 show the RS structure of both normal CP case and extended CP case, respectively for 3GPP LTE system which supports up to four numbers of antenna. Here, 0, 1, 2, 3 mean cell specific common RS to be transmitted for channel measurement and data demodulation commonly for each antenna port 0-3. In addition, UE-specific RS D, is supported for single-antenna port transmission of PDSCH. The UE is informed by higher layers whether the UE-specific RS is present or not and is a valid when only corresponding PDSCH is mapped. The UE specific RS is just transmitted in resource elements if data demodulation is needed.

On the other hand, RS mapping rules into resource block are following as Equation 1.

[Equation 1]

CRS

$$\begin{aligned}
 k &= 6m + (v + v_{\text{shift}}) \bmod 6 \\
 l &= \begin{cases} 0, N_{\text{symb}}^{\text{DL}} - 3 & \text{if } p \in \{0, 1\} \\ 1 & \text{if } p \in \{2, 3\} \end{cases} \\
 m &= 0, 1, \dots, 2 \cdot N_{\text{RB}}^{\text{DL}} - 1 \\
 m' &= m + N_{\text{RB}}^{\text{max,DL}} - N_{\text{RB}}^{\text{DL}}
 \end{aligned}
 \quad
 v = \begin{cases} 0 & \text{if } p=0 \text{ and } l=0 \\ 3 & \text{if } p=0 \text{ and } l \neq 0 \\ 3 & \text{if } p=1 \text{ and } l=0 \\ 0 & \text{if } p=1 \text{ and } l \neq 0 \\ 3(n_s \bmod 2) & \text{if } p=2 \\ 3 + 3(n_s \bmod 2) & \text{if } p=3 \end{cases}$$

$$v_{\text{shift}} = N_{\text{ID}}^{\text{cell}} \bmod 6$$

DRS

Normal CP

Extend CP

$$k = (k') \bmod N_{sc}^{RB} + N_{sc}^{RB} \cdot n_{PRB}$$

$$k' = \begin{cases} 4m' + v_{\text{shift}} & \text{if } l \in \{2,3\} \\ 4m' + (2 + v_{\text{shift}}) \bmod 4 & \text{if } l \in \{5,6\} \end{cases}$$

$$l = \begin{cases} 3 & l' = 0 \\ 6 & l' = 1 \\ 2 & l' = 2 \\ 5 & l' = 3 \end{cases}$$

$$l' = \begin{cases} 0,1 & \text{if } n_s \bmod 2 = 0 \\ 2,3 & \text{if } n_s \bmod 2 = 1 \end{cases}$$

$$m' = 0,1,\dots,3N_{RB}^{PDSCH} - 1$$

$$k = (k') \bmod N_{sc}^{RB} + N_{sc}^{RB} \cdot n_{PRB}$$

$$k' = \begin{cases} 3m' + v_{\text{shift}} & \text{if } l = 4 \\ 3m' + (2 + v_{\text{shift}}) \bmod 3 & \text{if } l = 1 \end{cases}$$

$$l = \begin{cases} 4 & l' \in \{0,2\} \\ 1 & l' = 1 \end{cases}$$

$$l' = \begin{cases} 0 & \text{if } n_s \bmod 2 = 0 \\ 1,2 & \text{if } n_s \bmod 2 = 1 \end{cases}$$

$$m' = 0,1,\dots,4N_{RB}^{PDSCH} - 1$$

$$v_{\text{shift}} = N_{ID}^{\text{cell}} \bmod 3$$

Here,  $k$  and  $P$  mean subcarrier index and antenna port. And  $N_{RB}^{DL}$ ,  $n_s$ ,  $N_{ID}^{\text{cell}}$  mean number of RB allocated for DL, slot index, cell ID. Note that given RS positioning depends on V-shift values in terms of frequency domain.

#### Reference signal (RS) in LTE-A

The SRS, which are not associated with uplink data and/or control transmission, are primarily used for channel quality estimation to enable frequency-selective scheduling on the uplink. However, they can be used for other purposes such as to enhance power control or to support various start-up functions for UEs not recently scheduled. Some examples include initial Modulation and Coding Scheme (MCS) selection, initial power control for data transmissions, timing advance, and so-called frequency semi-selective scheduling in which the frequency resource is assigned selectively for the first slot of a subframe and hops pseudorandomly to a different frequency in the second slot. In addition, SRS can be used for downlink channel quality estimation under the assumption that the wireless channel is reciprocal between the uplink and downlink. This assumption is particularly valid in a time division duplex (TDD) system where the uplink and downlink share the same frequency spectrum and are separated in time domain. The subframes in which SRS are transmitted by any UE within the cell are indicated by cell-specific broadcast signaling. A 4-bit cell-specific 'srsSubframeConfiguration' parameter indicates 15 possible sets of subframes in which SRS may be transmitted within each radio frame. This configurability provides flexibility in adjusting the SRS overhead depending on the deployment scenario. A 16th configuration switches the SRS off completely in the cell, which may for example be appropriate for a cell serving primarily high-speed UEs. The SRS transmissions are always in the last SC-FDMA symbol in the configured subframes, as shown in Figure 11. Thus the SRS and DM RS are located in different SC-FDMA symbols. PUSCH data transmission is not permitted on the SC-FDMA symbol designated for SRS, resulting in a worst-case sounding overhead (with an SRS symbol in every subframe) of ~7%.

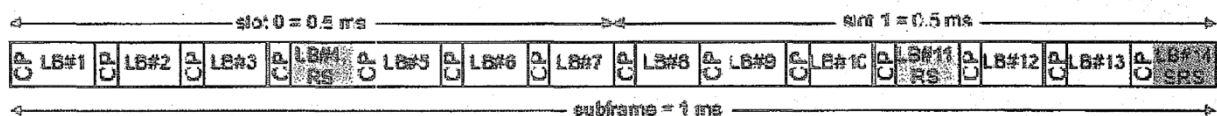


Figure 11. Uplink subframe configuration with SRS symbol

Each SRS symbol is generated by basis sequences (random sequence or ZC-based sequence set) where for a given time instance and bandwidth all the UEs in a cell use a same basis sequence while SRS transmissions from multiple UEs in a same time and band in a cell are distinguished orthogonally by different cyclic shifts of the basis sequence assigned to different UEs. SRS sequences from different cells can be distinguished by assigning different basis sequences in different cells where orthogonality is not guaranteed between different basis sequences.

CoMP (coordinated multiple point transmission and reception)

In order to reach the requirement of LTE-advanced, coordinated multipoint (CoMP) transmission (it is usually renamed as co-MIMO, collaborative MIMO, network MIMO, etc.) has been proposed so far for system performance enhancement. CoMP is expected to increase cell-edge UE performance and enhance average sector throughput. In general, inter-cell interference (ICI) reduces cell-edge UE performance and average sector throughput under multi-cell environment with frequency reuse factor 1. To mitigate ICI, the simple passive technique (i.e., fractional frequency reuse (FFR) with UE specific power control) was employed in LTE system in order to provide reasonable throughput performance for the cell-edge UEs in the interference-limited environment. Instead of reducing frequency resource usage per cell, it is more beneficial to reuse ICI as a desired signal or mitigate the ICI.

For downlink case, CoMP schemes can be categorized as follows:

Joint Processing (JP): data is available at each point in CoMP cooperating set

Joint Transmission: PDSCH is transmitted from multiple points (part of or entire CoMP cooperating set) at a time. Data to a single UE is simultaneously transmitted from *multiple* transmission points, e.g. to (coherently or non-coherently) improve the received signal quality and/or cancel actively interference for other UEs

Dynamic cell selection: PDSCH is transmitted from one point at a time (within CoMP cooperating set)

Dynamic cell selection with muting: PDSCH is transmitted from one point and some points within CoMP cooperating set do not transmit any data and control signal on the resource elements where PDSCH is transmitted.

Coordinated Scheduling/Beamforming (CS/CB): Data is only available at serving cell (data transmission from that point) but user scheduling/beamforming decisions are made with coordination among cells corresponding to the CoMP cooperating set.

For uplink case, coordinated multi-point reception implies reception of the transmitted signal at coordination among multiple, geographically separated points and CoMP schemes can be categorized as follows:

Joint reception (JR): Transmitted signal of PUSCH is received at multiple reception points.

Coordinated Scheduling/Beamforming (CS/CB): PUSCH is received only at a one point but user scheduling/beamforming decisions are made with coordination among cells corresponding to the CoMP cooperating set.

Downlink channel state information (CSI) feedback

In the current LTE standard, there are two transmission methods: open-loop MIMO, which operates without channel information, and closed-loop MIMO. In closed-loop MIMO, the transmitting and receiving ends perform beamforming based on channel information, i.e., CSI, to obtain the multiplexing gain of the MIMO antenna. The base station instructs the UE to feed back downlink CSI by allocating a Physical Uplink Control CHannel (PUCCH) or Physical Uplink Shared CHannel (PUSCH) to obtain CSI.

CSI is classified into three types of information: Rank Indicator (RI), Precoding Matrix Index (PMI), and Channel Quality Indication (CQI). RI represents the rank information of the channel and means the number of streams that the UE receives through the same frequency time resource. Since this value is determined to be dominant by long term fading of the channel, it is usually fed back from the UE to the base station with a longer cycle than the PMI and CQI value. Second, PMI is a value that reflects the spatial characteristics of the channel and indicates the precoding index of the base station preferred by the UE based on metric such as SINR. CQI is a value indicating the strength of a channel, and usually refers to the reception SINR that a base station can obtain when using PMI.

In more advanced communication systems such as LTE-A, additional multi-user diversity has been added using MU-MIMO (multi-user MIMO). For this purpose, higher accuracy is required from a channel feedback perspective. This is because in MU-MIMO, there is an interference channel between multiplexed UEs in the antenna domain, so the feedback channel accuracy has a significant impact not only on the UE that provided the feedback but also on the interference of other multiplexed UEs.

Therefore, in order to increase the feedback channel accuracy in LTE-A, it was decided to design the final PMI by dividing it into two: long term and/or wideband PMI, W1, and short term and/or sub-band PMI, W2.

An example of a hierarchical codebook transformation method that constructs a single final PMI from the two channel information is to transform the codebook using the long-term covariance matrix of the channel, as shown below.

$$W = \text{norm}(W1W2) \quad (1)$$

In the above equation, W2 (=short term PMI) is the codeword of the codebook created to reflect the short-term channel information, W is a codeword of the final transformed codebook, and norm(A) means a matrix in which the norm of each column of matrix A is normalized to 1.

The specific structures of the existing W1 and W2 are as follows:

(Equation 0)

$$W1(i) = \begin{bmatrix} X_i & 0 \\ 0 & X_i \end{bmatrix}, \text{ where } X_i \text{ is } Nt/2 \text{ by } M \text{ matrix.}$$

$$W2(j) = \begin{bmatrix} e_M^k & e_M^l & e_M^m \\ \alpha_j e_M^k & \beta_j e_M^l & \gamma_j e_M^m \end{bmatrix} \quad (\text{if rank} = r), \text{ where } 1 \leq k, l, m \leq M \text{ and } k, l, m \text{ are integer.}$$

The above codeword structure is designed to reflect the correlation characteristics of the channels that occur when cross polarized antennas are used and the spacing between antennas is close (usually when the distance between adjacent antennas is less than half the signal wavelength). In the case of cross polarized antennas, the antennas can be divided into a horizontal antenna group and a vertical antenna group, each antenna group has the characteristics of a ULA (uniform linear array) antenna, and the two antenna groups are co-located. Therefore, the correlation between the antennas of each group has the same linear phase increment characteristics, and the correlation between the antenna groups has a phase rotation characteristics. Since the codebook is ultimately a value that quantizes the channel, it is necessary to design the codebook to reflect the characteristics of the channel corresponding to the source. For convenience of explanation, the rank 1 codeword created with the above structure can be used as an example to confirm that these channel characteristics have been reflected in the codeword satisfying Equation 0.

$$W1(i) * W2(j) = \begin{bmatrix} X_i(k) \\ \alpha_j X_i(k) \end{bmatrix}$$

In the above equation, the codeword is expressed as a vector of  $N_t$  (the number of Tx antennas) by 1, and is structured with the upper  $X_i(k)$  and lower vectors, each of which shows the correlation characteristics of the horizontal antenna group and the vertical antenna group.  $\alpha_j X_i(k)$   $X_i(k)$  It is advantageous to express it as a vector with linear phase increments to reflect the correlation characteristics between the antennas of each antenna group, and the DFT matrix can be used as a representative example.

Higher channel accuracy is also required for CoMP. In the case of CoMPJT, multiple base stations cooperatively transmit the same data to a specific UE, so it can theoretically be considered a MIMO system with geographically distributed antennas. In other words, when MU-MIMO is performed in JT, a high level of channel accuracy is required to avoid interference between co-scheduled UEs, just like single-cell MU-MIMO. In the case of CoMP CB, sophisticated channel information is also required to avoid interference from adjacent cells to the serving cell.

#### Restricted RLM and RRM/CSI measurement

Time domain inter-cell interference coordination is possible, whereby the aggressor cell uses silent subframes (also called almost blank subframes; ABS) to reduce the transmission power/activity of some physical channels (including the operation of setting them to zero power), and the victim cell schedules UEs taking this into account. In this case, from the victim cell UE's perspective, the interference level varies significantly depending on the subframe. In this situation, in order to perform more accurate radio link monitoring (RLM) or radio resource management (RRM) operations, which measure RSRP/RSRQ, etc., in each subframe, or to measure channel state information (CSI) for link adaptation, the monitoring/measurement should be limited to sets of subframes with uniform interference characteristics. In the 3GPP LTE system, restricted RLM and RRM/CSI measurements are defined as follows:

#### UE procedure for reporting Channel State Information (CSI)

The time and frequency resources that can be used by the UE to report CSI which consists of channel quality indicator (CQI), precoding matrix indicator (PMI), precoding type indicator (PTI), and/or rank indication (RI) are controlled by the eNB. For spatial multiplexing, as given in [3], the UE shall determine a RI corresponding to the number of useful transmission layers. For transmit diversity as given in [3], RI is equal to one.

A UE in transmission mode 8 or 9 is configured with or without PMI/RI reporting by the higher layer parameter *pmi-RI-Report*.

A UE is configured with resource-restricted CSI measurements if the subframe sets  $C_{CSI,0}$  and  $C_{CSI,1}$  are configured by higher layers.

CSI reporting is periodic or aperiodic.

If the UE is configured with more than one serving cell, it transmits CSI for activated serving cell(s) only.

If a UE is not configured for simultaneous PUSCH and PUCCH transmission, it shall transmit periodic CSI reporting on PUCCH as defined hereafter in subframes with no PUSCH allocation.

If a UE is not configured for simultaneous PUSCH and PUCCH transmission, it shall transmit periodic CSI reporting on PUSCH of the serving cell with smallest *ServCellIndex* as defined hereafter in subframes with a PUSCH allocation, where the UE shall use the same PUCCH-based periodic CSI reporting format on PUSCH.

A UE shall transmit aperiodic CSI reporting on PUSCH if the conditions specified hereafter are met. For aperiodic CQI/PMI reporting, RI reporting is transmitted only if the configured CSI feedback type supports RI reporting.

#### Aperiodic CSI reporting using PUSCH

A UE shall perform aperiodic CSI reporting using the PUSCH in subframe  $n+k$  on serving cell  $c$ , upon decoding in subframe  $n$  either:

- an uplink DCI format, or
- a Random Access Response Grant,

for serving cell  $c$  if the respective CSI request field is set to trigger a report and is not reserved. If the CSI request field is 1 bit [4], a report is triggered for serving cell  $c$  if the CSI request field is set to '1'. If the CSI request field size is 2 bits [4], a report is triggered according to the value in Table 7.2.1-1A corresponding to aperiodic CSI reporting.

A UE is not expected to receive more than one aperiodic CSI report request for a given subframe.

Table 7.2.1-1A: CSI Request field for PDCCH with uplink DCI format in UE specific search space

| Value of CSI request field | Description                                                            |
|----------------------------|------------------------------------------------------------------------|
| '00'                       | No aperiodic CSI report is triggered                                   |
| '01'                       | Aperiodic CSI report is triggered for serving cell $c$                 |
| '10'                       | Aperiodic CSI report is triggered for a 1 <sup>st</sup> set of serving |

|      |                                                                                                          |
|------|----------------------------------------------------------------------------------------------------------|
|      | cells configured by higher layers                                                                        |
| '11' | Aperiodic CSI report is triggered for a 2 <sup>nd</sup> set of serving cells configured by higher layers |

#### PDCCH assignment procedure in LTE-A

The control region of each serving cell (i.e. CC) consists of a set of CCEs, numbered from 0 to  $N_{\text{CCE},k} - 1$ , where  $N_{\text{CCE},k}$  is the total number of CCEs in the control region of subframe  $k$ . The UE shall monitor a set of PDCCH candidates on one or more activated serving cells as configured by higher layer signaling for control information in every non-DRX subframe, where monitoring implies attempting to decode each of the PDCCHs in the set according to all the monitored DCI formats.

The set of PDCCH candidates to monitor are defined in terms of search spaces, where a search space  $S_k^{(L)}$  at aggregation level  $L \in \{1, 2, 4, 8\}$  is defined by a set of PDCCH candidates. For each serving cell on which PDCCH is monitored, the CCEs corresponding to PDCCH candidate  $m$  of the search space  $S_k^{(L)}$  are given by

$$L \left\{ (Y_k + m') \bmod \left\lfloor N_{\text{CCE},k} / L \right\rfloor \right\} + i$$

where  $Y_k$  is defined below,  $i = 0, \dots, L - 1$ . For the common search space  $m' = m$ . For the UE specific search space, for the serving cell on which PDCCH is monitored, if the monitoring UE is configured with carrier indicator field then  $m' = m + M^{(L)} \cdot n_{\text{CI}}$  where  $n_{\text{CI}}$  is the carrier indicator field value, else if the monitoring UE is not configured with carrier indicator field then  $m' = m$ , where  $m = 0, \dots, M^{(L)} - 1$ .  $M^{(L)}$  is the number of PDCCH candidates to monitor in the given search space.

The UE shall monitor one common search space at each of the aggregation levels 4 and 8 on the primary cell (i.e. PCC). A UE not configured with a carrier indicator field shall monitor one UE-specific search space at each of the aggregation levels 1, 2, 4, 8 on each activated serving cell. A UE configured with a carrier indicator field shall monitor one or more UE-specific search spaces at each of the aggregation levels 1, 2, 4, 8 on one or more activated serving cells as configured by higher layer signaling. The common and UE-specific search spaces on the primary cell may overlap.

A UE configured with the carrier indicator field associated with monitoring PDCCH on serving cell  $c$  shall monitor PDCCH configured with carrier indicator field and with CRC scrambled by C-RNTI in the UE specific search space of serving cell  $c$ . A UE configured with the carrier indicator field associated with monitoring PDCCH on the primary cell shall monitor PDCCH configured with carrier indicator field and with CRC scrambled by SPS C-RNTI in the UE specific search space of the primary cell.

The UE shall monitor the common search space for PDCCH without carrier indicator field. For the serving cell on which PDCCH is monitored, if the UE is not configured with a carrier indicator field, it shall monitor the UE specific

search space for PDCCH without carrier indicator field, if the UE is configured with a carrier indicator field it shall monitor the UE specific search space for PDCCH with carrier indicator field.

A UE is not expected to monitor the PDCCH of a secondary cell (i.e. SCC) if it is configured to monitor PDCCH with carrier indicator field corresponding to that secondary cell in another serving cell. For the serving cell on which PDCCH is monitored, the UE shall monitor PDCCH candidates at least for the same serving cell.

A UE configured with carrier indicator field for a given serving cell and configured to monitor PDCCH candidates with CRC scrambled by C-RNTI with a common payload size and with the same first CCE index  $n_{\text{CCE}}$  in the

- common search space
- UE specific search space

may assume that only the PDCCH in the common search space is transmitted by the primary cell.

A UE configured to monitor PDCCH candidates in a given serving cell with a given DCI format size with CIF, and CRC scrambled by C-RNTI, where the PDCCH candidates may have one or more possible values of CIF for the given DCI format size, shall assume that a PDCCH candidate with the given DCI format size may be transmitted in the given serving cell in any UE specific search space corresponding to any of the possible values of CIF for the given DCI format size.

The aggregation levels defining the search spaces are listed in Table 12. The DCI formats that the UE shall monitor depend on the configured transmission mode per each serving cell.

For the common search spaces,  $Y_k$  is set to 0 for the two aggregation levels  $L = 4$  and  $L = 8$ . For the UE-specific search space  $S_k^{(L)}$  at aggregation level  $L$ , the variable  $Y_k$  is defined by

$$Y_k = (A \cdot Y_{k-1}) \bmod D$$

where  $Y_{-1} = n_{\text{RNTI}} \neq 0$ ,  $A = 39827$ ,  $D = 65537$  and  $k = \lfloor n_s/2 \rfloor$ ,  $n_s$  is the slot number within a radio frame. The RNTI value used for  $n_{\text{RNTI}}$  is defined in [3] as a kind of UE's ID.

Table 12: PDCCH candidates monitored by a UE

| Type        | Search space $S_k^{(L)}$ |                | Number of PDCCH candidates $M^{(L)}$ |
|-------------|--------------------------|----------------|--------------------------------------|
|             | Aggregation level $L$    | Size [in CCEs] |                                      |
| UE-specific | 1                        | 6              | 6                                    |
|             | 2                        | 12             | 6                                    |
|             | 4                        | 8              | 2                                    |
|             | 8                        | 16             | 2                                    |
| Common      | 4                        | 16             | 4                                    |
|             | 8                        | 16             | 2                                    |

ACK/NACK transmission for LTE-A

In the LTE-A system, we are considering transmitting multiple ACK/NACK information/signals for multiple PDSCHs transmitted through multiple DLCCs through a specific UL CC. For this purpose, unlike ACK/NACK transmission using PUCCH format 1a/1b in the existing Rel-8 LTE, after channel coding multiple ACK/NACK information (e.g. Reed-Muller code, Tail-biting convolutional code, etc.), it may be considered to transmit multiple ACK/NACK information/signals using PUCCH format 2 or a new PUCCH format (i.e. E-PUCCH format) that has been modified based on the following Block-spreading.

#### - Block-spreading

Block-spreading technique is a method of modulating control information/signal (e.g. ACK/NACK, etc.) transmission using SC-FDMA, unlike PUCCH format 1 or 2 series in existing LTE. In this method, as shown in Figure 10, the symbol sequence is transmitted in the time-domain spreading manner by OCC (Orthogonal Cover Code), and control signals of multiple UEs can be multiplexed in the same RB by using OCC. In the above PUCCH format 2, one symbol sequence is transmitted over the time domain and UE multiplexing is performed using the cyclic shift (i.e. CCS) of the CAZAC sequence, whereas in the case of the block-spreading-based E-PUCCH format, one symbol sequence is transmitted over the frequency domain and UE multiplexing is performed using OCC-based time-domain spreading. As an example, Figure 10 shows a method of transmitting a symbol sequence by generating five SC-FDMA symbols using an OCC of length-5 ( $SF = 5$ ). In the example in the figure, a total of 2 RS symbols are used during 1 slot, but various applications can be considered, such as using 3 RS symbols and using OCC with  $SF = 4$ . Here, the RS symbols can be generated from a CAZAC sequence with a specific cyclic shift, and can be transmitted in a form in which a specific OCC is applied (multiplied) to multiple RS symbols in the time domain.

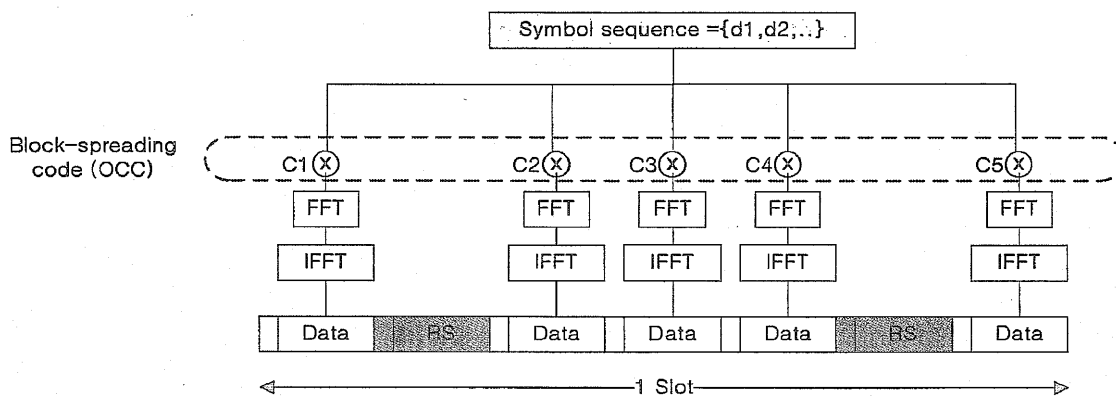


Figure 10. Example of E-PUCCH format based on block-spreading (i.e. PUCCH format 3)

For convenience of explanation, this channel coding-based multiple ACK/NACK transmission method using PUCCH format 2 or E-PUCCH format is referred to as a “multi-bit ACK/NACK coding” transmission method. This method represents a method of transmitting an ACK/NACK coded blocks generated by channel coding ACK/NACK or DTX information (meaning that PDCCH was not received/detected) for PDSCH of multiple DL CCs. For example, if a terminal operates in SU-MIMO mode on a DLCC and receives two codewords (CW), it can transmit a total of four feedback states of ACK/ACK, ACK/NACK, NACK/ACK, NACK/NACK for each CW for that CC, or it can have a maximum of five feedback states, including DTX. Also, if the terminal receives a single CW, it can have up to three states: ACK, NACK, and DTX (if NACK is processed in the same way as DTX, it can have a total of two states: ACK, NACK/DTX).

Therefore, if the terminal aggregates up to 5 DL CCs and operates in SU-MIMO mode on all CCs, it can have up to  $5^5$  transmittable feedback states, and the ACK/NACK payload size to express them becomes a total of 12 bits (if DTX is processed in the same way as NACK, the number of feedback states becomes  $4^5$ , and the ACK/NACK payload size to express them becomes a total of 10 bits).

In the previous ACK/NACK multiplexing (i.e. ACK/NACK selection) method applied to the existing Rel-8 TDD system, an implicit ACK/NACK selection method is basically considered, which uses an implicit PUCCH resource corresponding to a PDCCH that schedules each PDSCH of the corresponding UE (i.e. linked to the lowest CCE index) to secure PUCCH resources for each UE. Meanwhile, in the LTE-A FDD system, multiple ACK/NACK transmissions for multiple PDSCHs transmitted through multiple DL CCs through a specific UL CC that is basically configured UE-specifically are considered, and for this purpose, an "ACK/NACK selection" method is considered that uses an implicit PUCCH resource linked to a PDCCH that schedules specific, some, or all DLCCs (i.e. linked to the lowest CCE index  $n_{CCE}$ , or linked to  $n_{CCE}$  and  $n_{CCE}+1$ ), or a combination of the implicit PUCCH resource and an explicit PUCCH resource reserved in advance for each UE through an RRC signal.

Meanwhile, in the LTE-ATDD system, a situation in which multiple CCs are aggregated (CA) can be considered, and accordingly, multiple ACK/NACK information/signals for multiple PDSCHs transmitted through multiple DL subframes and multiple CCs are considered to be transmitted through a specific CC (i.e. A/N CC) in the UL subframe corresponding to the multiple DL subframes. Here, unlike in the previous LTE-A FDD, we can consider a method of transmitting multiple ACK/NACKs corresponding to the maximum number of CWs that can be transmitted over all CCs assigned to the UE for all DL subframes (i.e. full ACK/NACK), or we can consider a method of reducing the total number of ACK/NACKs transmitted by applying ACK/NACK bundling for CW and/or CC and/or SF domains (i.e. bundled ACK/NACK) (here, CW bundling means applying ACK/NACK bundling for CW per CC for each DL SF, CC bundling means applying ACK/NACK bundling for all or some CCs for each DLSF, and SF bundling means applying ACK/NACK bundling for all or some DL SFs for each CC). As a characteristic SF bundling method, we can consider the "ACK-counter" method that reports the number of ACKs per CC (or some number of ACKs) for all PDSCHs or DL grant PDCCHs received for each CC. At this time, an ACK/NACK transmission technique based on "multi-bit ACK/NACK coding" or "ACK/NACK selection" can be configurably applied depending on the size of the ACK/NACK payload per UE, i.e., the ACK/NACK payload for full or bundled ACK/NACK transmission set for each UE.

#### UE procedure for determining PUCCH assignment in LTE-A

For TDD and a UE that does not support aggregating more than one serving cell, two HARQ-ACK feedback modes are supported by higher layer configuration.

- HARQ-ACK bundling and
- HARQ-ACK multiplexing

For TDD UL-DL configuration 5 and a UE that does not support aggregating more than one serving cell, only HARQ-ACK bundling is supported.

For TDD, a UE that supports aggregating more than one serving cell is configured by higher layers to use either PUCCH format 1b with channel selection or PUCCH format 3 for transmission of HARQ-ACK when configured with more than one serving cell.

For TDD, a UE that supports aggregating more than one serving cell is configured by higher layers to use HARQ-ACK bundling, PUCCH format 1b with channel selection according to the set of Tables 13-1/2/3 or according to the set of Tables 14-1/2/3, or PUCCH format 3 for transmission of HARQ-ACK when configured with one serving cell.

PUCCH format 1b with channel selection according to the set of Tables 13-1/2/3 or according to the set of Tables 14-1/2/3 is not supported for TDD UL-DL configuration 5.

TDD HARQ-ACK bundling is performed per codeword across  $M$  multiple DL subframes associated with a single UL subframe  $n$ , where  $M$  is the number of elements in the set  $K$  defined in Table 12, by a logical AND operation of all the individual PDSCH transmission (with and without corresponding PDCCH) HARQ-ACKs and ACK in response to PDCCH indicating downlink SPS release. For one configured serving cell the bundled 1 or 2 HARQ-ACK bits are transmitted using PUCCH format 1a or PUCCH format 1b, respectively.

For TDD HARQ-ACK multiplexing and a subframe  $n$  with  $M > 1$ , where  $M$  is the number of elements in the set  $K$  defined in Table 12, spatial HARQ-ACK bundling across multiple codewords within a DL subframe is performed by a logical AND operation of all the corresponding individual HARQ-ACKs. PUCCH format 1b with channel selection is used in case of one configured serving cell. For TDD HARQ-ACK multiplexing and a subframe  $n$  with  $M = 1$ , spatial HARQ-ACK bundling across multiple codewords within a DL subframe is not performed, 1 or 2 HARQ-ACK bits are transmitted using PUCCH format 1a or PUCCH format 1b, respectively for one configured serving cell.

In the case of TDD and more than one configured serving cell with PUCCH format 1b with channel selection and more than 4 HARQ-ACK bits for  $M$  multiple DL subframes associated with a single UL subframe  $n$ , where  $M$  is the number of elements in the set  $K$  defined in Table 12 and for the configured serving cells, spatial HARQ-ACK bundling across multiple codewords within a DL subframe for all configured cells is performed and the bundled HARQ-ACK bits for each configured serving cell is transmitted using PUCCH format 1b with channel selection. For TDD and more than one configured serving cell with PUCCH format 1b with channel selection and up to 4 HARQ-ACK bits for  $M$  multiple DL subframes associated with a single UL subframe  $n$ , where  $M$  is the number of elements in the set  $K$  defined in Table 12 and for the configured serving cells, HARQ-ACK bundling is not performed and the HARQ-ACK bits are transmitted using PUCCH format 1b with channel selection.

In the case of TDD and more than one configured serving cell with PUCCH format 3 and more than 20 HARQ-ACK bits for  $M$  multiple DL subframes associated with a single UL subframe  $n$ , where  $M$  is the number of elements in the set  $K$  defined in Table 12 and for the configured serving cells, spatial HARQ-ACK bundling across multiple codewords within a DL subframe is performed for each serving cell by a logical AND operation of all of the corresponding individual HARQ-ACKs and PUCCH format 3 is used. For TDD and more than one configured serving cell with PUCCH format 3 and up to 20 HARQ-ACK bits for  $M$  multiple DL subframes associated with a single UL subframe  $n$ , where  $M$  is the number of elements in the set  $K$  defined in Table 12 and for the configured serving cells, spatial HARQ-ACK bundling is not performed and the HARQ-ACK bits are transmitted using PUCCH format 3.

For TDD with PUCCH format 3, a UE shall determine the number of HARQ-ACK bits,  $O$ , associated with an UL subframe  $n$  based on the number of configured serving cells, the downlink transmission modes configured for each serving cell and  $M$  which is the number of elements in the set  $K$  defined in Table 12 according to

$O = \sum_{c=1}^C O_c^{ACK}$  where  $C$  is the number of configured cells, and  $O_c^{ACK}$  is the number of HARQ-bits for the  $c$ -th serving cell.

TDD HARQ-ACK feedback procedures for one configured serving cell are given in section 2-7-1 and procedures for more than one configured serving cell are given in section 2-7-2.

TDD HARQ-ACK procedure for one configured serving cell

HARQ-ACK transmission on two antenna ports ( $p \in [p_0, p_1]$ ) is supported for PUCCH format 1a/1b with TDD HARQ-ACK bundling feedback mode and for PUCCH format 3.

The TDD HARQ-ACK procedure for a UE configured with PUCCH format 3 is as described in section 2-7-2-2 when the UE receives PDSCH and/or SPS release PDCCH only on the primary cell.

For TDD HARQ-ACK bundling or TDD HARQ-ACK multiplexing for one configured serving cell and a subframe  $n$  with  $M = 1$  where  $M$  is the number of elements in the set  $K$  defined in Table 12, the UE shall use PUCCH resource  $n_{PUCCH}^{(1,p)}$  for transmission of HARQ-ACK in subframe  $n$  on antenna port  $p$  for PUCCH format 1a/1b, where

If there is PDSCH transmission indicated by the detection of corresponding PDCCH or there is PDCCH indicating downlink SPS release within subframe(s)  $n - k$ , where  $k \in K$  and  $K$  (defined in Table 12) is a set of  $M$  elements  $\{k_0, k_1, \dots, k_{M-1}\}$  depending on the subframe  $n$  and the UL-DL configuration, the UE first selects a  $c$  value out of  $\{0, 1, 2, 3\}$  which makes  $N_c \leq n_{CCE} < N_{c+1}$  and shall use

$n_{PUCCH}^{(1,p=p_0)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{CCE} + N_{PUCCH}^{(1)}$  for antenna port  $p = p_0$ , where  $N_{PUCCH}^{(1)}$  is configured by higher layers,  $N_c = \max\left\{0, \left\lfloor \frac{N_{RB}^{DL} \cdot (N_{sc}^{RB} \cdot c - 4)}{36} \right\rfloor\right\}$ , and  $n_{CCE}$  is the number of the first CCE used for transmission of the corresponding PDCCH in subframe  $n - k_m$  and the corresponding  $m$ , where  $k_m$  is the smallest value in set  $K$  such that UE detects a PDCCH in subframe  $n - k_m$ . For two antenna port transmission the PUCCH resource for HARQ-ACK bundling for antenna port  $p = p_1$  is given by

$n_{PUCCH}^{(1,p=p_1)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{CCE} + 1 + N_{PUCCH}^{(1)}$  [where  $c$  value out of  $\{0, 1, 2, 3\}$  is chosen which makes  $N_c \leq n_{CCE} + 1 < N_{c+1}$ ].

If there is only a PDSCH transmission where there is not a corresponding PDCCH detected within subframe(s)  $n - k$ , where  $k \in K$  and  $K$  is defined in Table 12, the UE shall use PUCCH format 1a/1b and PUCCH resource  $n_{PUCCH}^{(1,p)}$  with the value of  $n_{PUCCH}^{(1,p)}$  is determined according to higher layer configuration. For a UE configured for two antenna port transmission, a PUCCH resource value maps to two PUCCH resources with the first PUCCH resource  $n_{PUCCH}^{(1,p=p_0)}$  for antenna port  $p_0$  and the second PUCCH resource  $n_{PUCCH}^{(1,p=p_1)}$  for antenna port  $p_1$ , otherwise, the PUCCH resource value maps to a single PUCCH resource  $n_{PUCCH}^{(1,p=p_0)}$  for antenna port  $p_0$ .

Table 12: Downlink association set index  $K : \{k_0, k_1, \dots, k_{M-1}\}$  for TDD

| UL-DL<br>Configuration | Subframe $n$ |   |                              |            |      |   |   |            |   |   |
|------------------------|--------------|---|------------------------------|------------|------|---|---|------------|---|---|
|                        | 0            | 1 | 2                            | 3          | 4    | 5 | 6 | 7          | 8 | 9 |
| 0                      | -            | - | 6                            | -          | 4    | - | - | 6          | - | 4 |
| 1                      | -            | - | 7, 6                         | 4          | -    | - | - | 7, 6       | 4 | - |
| 2                      | -            | - | 8, 7, 4, 6                   | -          | -    | - | - | 8, 7, 4, 6 | - | - |
| 3                      | -            | - | 7, 6, 11                     | 6, 5       | 5, 4 | - | - | -          | - | - |
| 4                      | -            | - | 12, 8, 7, 11                 | 6, 5, 4, 7 | -    | - | - | -          | - | - |
| 5                      | -            | - | 13, 12, 9, 8, 7, 5, 4, 11, 6 | -          | -    | - | - | -          | - | - |
| 6                      | -            | - | 7                            | 7          | 5    | - | - | 7          | 7 | - |

For TDD HARQ-ACK multiplexing and sub-frame  $n$  with  $M > 1$  and one configured serving cell, where  $M$  is the number of elements in the set  $K$  defined in Table 12, denote  $n_{\text{PUCCH},i}^{(1)}$  as the PUCCH resource derived from sub-frame  $n-k_i$  and HARQ-ACK( $i$ ) as the ACK/NACK/DTX response from sub-frame  $n-k_i$ , where  $k_i \in K$  (defined in Table 12) and  $0 \leq i \leq M-1$ .

For a PDSCH transmission or a PDCCH indicating downlink SPS release in sub-frame  $n-k_i$  where  $k_i \in K$ , the PUCCH resource  $n_{\text{PUCCH},i}^{(1)} = (M-i-1) \cdot N_c + i \cdot N_{c+1} + n_{\text{CCE},i} + N_{\text{PUCCH}}^{(1)}$ , where  $c$  is selected from  $\{0, 1, 2, 3\}$  such that  $N_c \leq n_{\text{CCE},i} < N_{c+1}$ ,  $N_c = \max\left\{0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor \right\}$ ,  $n_{\text{CCE},i}$  is the number of the first CCE used for transmission of the corresponding PDCCH in subframe  $n-k_i$ , and  $N_{\text{PUCCH}}^{(1)}$  is configured by higher layers.

For a PDSCH transmission where there is not a corresponding PDCCH detected in subframe  $n-k_i$ , the value of  $n_{\text{PUCCH},i}^{(1)}$  is determined according to higher layer configuration.

Based on higher layer signalling a UE configured with a single serving cell will either perform channel selection either according to the set of Tables 13-1, 13-2, and 13-3 or according to the set of Tables 14-1, 14-2, and 14-3. For the selected table set indicated by higher layer signalling, the UE shall transmit  $b(0), b(1)$  on PUCCH resource  $n_{\text{PUCCH}}^{(1)}$  in sub-frame  $n$  using PUCCH format 1b. The value of  $b(0), b(1)$  and the PUCCH resource  $n_{\text{PUCCH}}^{(1)}$  are generated by channel selection according to the selected set of Tables for  $M = 2, 3$ , and 4 respectively.

Table 13-1: Transmission of HARQ-ACK multiplexing for  $M = 2$ 

| HARQ-ACK(0), HARQ-ACK(1) | $n_{\text{PUCCH}}^{(1)}$   | $b(0), b(1)$ |
|--------------------------|----------------------------|--------------|
| ACK, ACK                 | $n_{\text{PUCCH},1}^{(1)}$ | 1, 1         |
| ACK, NACK/DTX            | $n_{\text{PUCCH},0}^{(1)}$ | 0, 1         |
| NACK/DTX, ACK            | $n_{\text{PUCCH},1}^{(1)}$ | 0, 0         |
| NACK/DTX, NACK           | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0         |
| NACK, DTX                | $n_{\text{PUCCH},0}^{(1)}$ | 1, 0         |
| DTX, DTX                 | No transmission            |              |

Table 13-2: Transmission of HARQ-ACK multiplexing for  $M = 3$

| HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2) | $n_{\text{PUCCH}}^{(1)}$   | $b(0), b(1)$ |
|---------------------------------------|----------------------------|--------------|
| ACK, ACK, ACK                         | $n_{\text{PUCCH},2}^{(1)}$ | 1, 1         |
| ACK, ACK, NACK/DTX                    | $n_{\text{PUCCH},1}^{(1)}$ | 1, 1         |
| ACK, NACK/DTX, ACK                    | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1         |
| ACK, NACK/DTX, NACK/DTX               | $n_{\text{PUCCH},0}^{(1)}$ | 0, 1         |
| NACK/DTX, ACK, ACK                    | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0         |
| NACK/DTX, ACK, NACK/DTX               | $n_{\text{PUCCH},1}^{(1)}$ | 0, 0         |
| NACK/DTX, NACK/DTX, ACK               | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0         |
| DTX, DTX, NACK                        | $n_{\text{PUCCH},2}^{(1)}$ | 0, 1         |
| DTX, NACK, NACK/DTX                   | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0         |
| NACK, NACK/DTX, NACK/DTX              | $n_{\text{PUCCH},0}^{(1)}$ | 1, 0         |
| DTX, DTX, DTX                         | No transmission            |              |

Table 13-3: Transmission of HARQ-ACK multiplexing for  $M = 4$

| HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2), HARQ-ACK(3) | $n_{\text{PUCCH}}^{(1)}$   | $b(0), b(1)$ |
|----------------------------------------------------|----------------------------|--------------|
| ACK, ACK, ACK, ACK                                 | $n_{\text{PUCCH},1}^{(1)}$ | 1, 1         |
| ACK, ACK, ACK, NACK/DTX                            | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0         |
| NACK/DTX, NACK/DTX, NACK, DTX                      | $n_{\text{PUCCH},2}^{(1)}$ | 1, 1         |
| ACK, ACK, NACK/DTX, ACK                            | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0         |
| NACK, DTX, DTX, DTX                                | $n_{\text{PUCCH},0}^{(1)}$ | 1, 0         |
| ACK, ACK, NACK/DTX, NACK/DTX                       | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0         |
| ACK, NACK/DTX, ACK, ACK                            | $n_{\text{PUCCH},3}^{(1)}$ | 0, 1         |
| NACK/DTX, NACK/DTX, NACK/DTX, NACK                 | $n_{\text{PUCCH},3}^{(1)}$ | 1, 1         |
| ACK, NACK/DTX, ACK, NACK/DTX                       | $n_{\text{PUCCH},2}^{(1)}$ | 0, 1         |
| ACK, NACK/DTX, NACK/DTX, ACK                       | $n_{\text{PUCCH},0}^{(1)}$ | 0, 1         |
| ACK, NACK/DTX, NACK/DTX, NACK/DTX                  | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1         |
| NACK/DTX, ACK, ACK, ACK                            | $n_{\text{PUCCH},3}^{(1)}$ | 0, 1         |
| NACK/DTX, NACK, DTX, DTX                           | $n_{\text{PUCCH},1}^{(1)}$ | 0, 0         |
| NACK/DTX, ACK, ACK, NACK/DTX                       | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0         |
| NACK/DTX, ACK, NACK/DTX, ACK                       | $n_{\text{PUCCH},3}^{(1)}$ | 1, 0         |
| NACK/DTX, ACK, NACK/DTX, NACK/DTX                  | $n_{\text{PUCCH},1}^{(1)}$ | 0, 1         |
| NACK/DTX, NACK/DTX, ACK, ACK                       | $n_{\text{PUCCH},3}^{(1)}$ | 0, 1         |
| NACK/DTX, NACK/DTX, ACK, NACK/DTX                  | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0         |
| NACK/DTX, NACK/DTX, NACK/DTX, ACK                  | $n_{\text{PUCCH},3}^{(1)}$ | 0, 0         |
| DTX, DTX, DTX, DTX                                 | No transmission            |              |

Table 14-1: Transmission of HARQ-ACK multiplexing for  $M = 2$ 

| HARQ-ACK(0), HARQ-ACK(1) | $n_{\text{PUCCH}}^{(1)}$   | $b(0)b(1)$ |
|--------------------------|----------------------------|------------|
| ACK, ACK                 | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0       |
| ACK, NACK/DTX            | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1       |
| NACK/DTX, ACK            | $n_{\text{PUCCH},1}^{(1)}$ | 0, 1       |
| NACK, NACK/DTX           | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0       |
| DTX, NACK/DTX            | No Transmission            |            |

Table 14-2: Transmission of HARQ-ACK multiplexing for  $M = 3$ 

| HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2) | $n_{\text{PUCCH}}^{(1)}$   | $b(0)b(1)$ |
|---------------------------------------|----------------------------|------------|
| ACK, ACK, ACK                         | $n_{\text{PUCCH},2}^{(1)}$ | 1, 1       |

|                          |                            |      |
|--------------------------|----------------------------|------|
| ACK, ACK, NACK/DTX       | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0 |
| ACK, NACK/DTX, ACK       | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0 |
| ACK, NACK/DTX, NACK/DTX  | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1 |
| NACK/DTX, ACK, ACK       | $n_{\text{PUCCH},2}^{(1)}$ | 0, 1 |
| NACK/DTX, ACK, NACK/DTX  | $n_{\text{PUCCH},1}^{(1)}$ | 0, 1 |
| NACK/DTX, NACK/DTX, ACK  | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0 |
| NACK, NACK/DTX, NACK/DTX | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0 |
| DTX, NACK/DTX, NACK/DTX  | No Transmission            |      |

Table 14-3: Transmission of HARQ-ACK multiplexing for  $M = 4$ 

| HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2), HARQ-ACK(3) | $n_{\text{PUCCH}}^{(1)}$   | $b(0)b(1)$ |
|----------------------------------------------------|----------------------------|------------|
| ACK, ACK, ACK, ACK                                 | $n_{\text{PUCCH},1}^{(1)}$ | 1, 1       |
| ACK, ACK, ACK, NACK/DTX                            | $n_{\text{PUCCH},2}^{(1)}$ | 1, 1       |
| ACK, ACK, NACK/DTX, ACK                            | $n_{\text{PUCCH},0}^{(1)}$ | 1, 0       |
| ACK, ACK, NACK/DTX, NACK/DTX                       | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0       |
| ACK, NACK/DTX, ACK, ACK                            | $n_{\text{PUCCH},3}^{(1)}$ | 1, 1       |
| ACK, NACK/DTX, ACK, NACK/DTX                       | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0       |
| ACK, NACK/DTX, NACK/DTX, ACK                       | $n_{\text{PUCCH},0}^{(1)}$ | 0, 1       |
| ACK, NACK/DTX, NACK/DTX, NACK/DTX                  | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1       |
| NACK/DTX, ACK, ACK, ACK                            | $n_{\text{PUCCH},1}^{(1)}$ | 0, 0       |
| NACK/DTX, ACK, ACK, NACK/DTX                       | $n_{\text{PUCCH},2}^{(1)}$ | 0, 1       |
| NACK/DTX, ACK, NACK/DTX, ACK                       | $n_{\text{PUCCH},3}^{(1)}$ | 1, 0       |
| NACK/DTX, ACK, NACK/DTX, NACK/DTX                  | $n_{\text{PUCCH},1}^{(1)}$ | 0, 1       |
| NACK/DTX, NACK/DTX, ACK, ACK                       | $n_{\text{PUCCH},3}^{(1)}$ | 0, 1       |
| NACK/DTX, NACK/DTX, ACK, NACK/DTX                  | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0       |
| NACK/DTX, NACK/DTX, NACK/DTX, ACK                  | $n_{\text{PUCCH},3}^{(1)}$ | 0, 0       |
| NACK, NACK/DTX, NACK/DTX, NACK/DTX                 | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0       |
| DTX, NACK/DTX, NACK/DTX, NACK/DTX                  | No Transmission            |            |

TDD HARQ-ACK procedure for more than one configured serving cell

The TDD HARQ-ACK feedback procedures for more than one configured serving cell are either based on a PUCCH format 1b with channel selection HARQ-ACK procedure as described in section 2-7-2-1 or a PUCCH format 3 HARQ-ACK procedure as described in section 2-7-2-2.

HARQ-ACK transmission on two antenna ports ( $p \in [p_0, p_1]$ ) is supported for PUCCH format 3 and TDD with more than one configured serving cell. TDD UL-DL configuration 5 with PUCCH format 3 is only supported for up to two configured serving cells. TDD UL-DL configuration 5 with channel selection for two configured serving cells is not supported.

#### PUCCH format 1b with channel selection HARQ-ACK procedure

For TDD HARQ-ACK multiplexing with PUCCH format 1b with channel selection and two configured serving cells and a subframe  $n$  with  $M \leq 2$  where  $M$  is the number of elements in the set  $K$  defined in Table 12, the UE shall transmit  $b(0)b(1)$  on PUCCH resource  $n_{\text{PUCCH}}^{(1)}$  selected from  $A$  PUCCH resources,  $n_{\text{PUCCH},i}^{(1)}$  where  $0 \leq i \leq A-1$  and  $A \in \{2,3,4\}$ , according to Tables 15-1, 15-2, and 15-3 in subframe  $n$  using PUCCH format 1b. For a subframe  $n$  with  $M=1$ , HARQ-ACK( $j$ ) denotes the ACK/NACK/DTX response for a transport block or SPS release PDCCH associated with serving cell  $c$ , where the transport block and serving cell for HARQ-ACK( $j$ ) and  $A$  PUCCH resources are given by Table 18. For a subframe  $n$  with  $M=2$ , HARQ-ACK( $j$ ) denotes the ACK/NACK/DTX response for a PDSCH transmission or SPS release PDCCH within subframe(s) given by set  $K$  on each serving cell, where the subframes on each serving cell for HARQ-ACK( $j$ ) and  $A$  PUCCH resources are given by Table 16. The UE shall determine the  $A$  PUCCH resources,  $n_{\text{PUCCH},i}^{(1)}$  where  $0 \leq i \leq A-1$  ordered according to the serving cell in increasing order of  $j$  given in Table 18 for  $M=1$  and Table 16 for  $M=2$ , according to

- for a PDSCH transmission indicated by the detection of a corresponding PDCCH within subframe(s)  $n-k_m$ , where  $k_m \in K$  on the primary cell, or for a PDCCH indicating downlink SPS release within subframe(s)  $n-k_m$ , where  $k_m \in K$  on the primary cell, the PUCCH resource is  $n_{\text{PUCCH},i}^{(1)} = (M-m-1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$ , where  $c$  is selected from  $\{0, 1, 2, 3\}$  such that  $N_c \leq n_{\text{CCE},m} < N_{c+1}$ ,  $N_c = \max\{0, \lfloor [N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)] / 36 \rfloor \}$ , and for a subframe  $n$  with  $M=1$  and a transmission mode that supports up to two transport blocks on the serving cell where the corresponding PDSCH transmission occurs, the PUCCH resource  $n_{\text{PUCCH},i+1}^{(1)}$  is given by  $n_{\text{PUCCH},i+1}^{(1)} = (M-m-1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + 1 + N_{\text{PUCCH}}^{(1)}$  where  $n_{\text{CCE},m}$  is the number of the first CCE used for transmission of the corresponding DCI assignment and  $N_{\text{PUCCH}}^{(1)}$  is configured by higher layers.
- for a PDSCH transmission on the primary cell where there is not a corresponding PDCCH detected within subframe(s)  $n-k$ , where  $k \in K$ , the value of  $n_{\text{PUCCH},i}^{(1)}$  is determined according to higher layer configuration.
- for a PDSCH transmission indicated by the detection of a corresponding PDCCH within subframe(s)  $n-k$ , where  $k \in K$  on the secondary cell, the value of  $n_{\text{PUCCH},i}^{(1)}$ , and the value of  $n_{\text{PUCCH},i+1}^{(1)}$  for a subframe  $n$  with  $M=2$  or for a subframe  $n$  with  $M=1$  and a transmission mode on the secondary cell that supports up to two transport blocks is determined according to higher layer configuration. The TPC field in the DCI format

of the corresponding PDCCH shall be used to determine the PUCCH resource values from one of the four resource values configured by higher layers. For a UE configured for a transmission mode on the secondary cell that supports up to two transport blocks and a subframe  $n$  with  $M=1$ , or for a subframe  $n$  with  $M=2$ , a PUCCH resource value maps to two PUCCH resources ( $n_{\text{PUCCH},i}^{(1)}, n_{\text{PUCCH},i+1}^{(1)}$ ), otherwise, the PUCCH resource value maps to a single PUCCH resource  $n_{\text{PUCCH},i}^{(1)}$ . A UE shall assume that the same HARQ-ACK PUCCH resource value is transmitted in the TPC field on all PDCCH assignments on the secondary cells in a given subframe.

Table 15-1: Transmission of HARQ-ACK multiplexing for  $A = 2$ 

| HARQ-ACK(0), HARQ-ACK(1) | $n_{\text{PUCCH}}^{(1)}$   | $b(0)b(1)$ |
|--------------------------|----------------------------|------------|
| ACK, ACK                 | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0       |
| ACK, NACK/DTX            | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1       |
| NACK/DTX, ACK            | $n_{\text{PUCCH},1}^{(1)}$ | 0, 1       |
| NACK, NACK/DTX           | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0       |
| DTX, NACK/DTX            | No Transmission            |            |

Table 15-2: Transmission of HARQ-ACK multiplexing for  $A = 3$ 

| HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2) | $n_{\text{PUCCH}}^{(1)}$   | $b(0)b(1)$ |
|---------------------------------------|----------------------------|------------|
| ACK, ACK, ACK                         | $n_{\text{PUCCH},2}^{(1)}$ | 1, 1       |
| ACK, ACK, NACK/DTX                    | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0       |
| ACK, NACK/DTX, ACK                    | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0       |
| ACK, NACK/DTX, NACK/DTX               | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1       |
| NACK/DTX, ACK, ACK                    | $n_{\text{PUCCH},2}^{(1)}$ | 0, 1       |
| NACK/DTX, ACK, NACK/DTX               | $n_{\text{PUCCH},1}^{(1)}$ | 0, 1       |
| NACK/DTX, NACK/DTX, ACK               | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0       |
| NACK, NACK/DTX, NACK/DTX              | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0       |
| DTX, NACK/DTX, NACK/DTX               | No Transmission            |            |

Table 15-3: Transmission of HARQ-ACK multiplexing for  $A = 4$ 

| HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2), HARQ-ACK(3) | $n_{\text{PUCCH}}^{(1)}$   | $b(0)b(1)$ |
|----------------------------------------------------|----------------------------|------------|
| ACK, ACK, ACK, ACK                                 | $n_{\text{PUCCH},1}^{(1)}$ | 1, 1       |
| ACK, ACK, ACK, NACK/DTX                            | $n_{\text{PUCCH},2}^{(1)}$ | 1, 1       |
| ACK, ACK, NACK/DTX, ACK                            | $n_{\text{PUCCH},0}^{(1)}$ | 1, 0       |
| ACK, ACK, NACK/DTX, NACK/DTX                       | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0       |
| ACK, NACK/DTX, ACK, ACK                            | $n_{\text{PUCCH},3}^{(1)}$ | 1, 1       |

|                                    |                            |      |
|------------------------------------|----------------------------|------|
| ACK, NACK/DTX, ACK, NACK/DTX       | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0 |
| ACK, NACK/DTX, NACK/DTX, ACK       | $n_{\text{PUCCH},0}^{(1)}$ | 0, 1 |
| ACK, NACK/DTX, NACK/DTX, NACK/DTX  | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1 |
| NACK/DTX, ACK, ACK, ACK            | $n_{\text{PUCCH},1}^{(1)}$ | 0, 0 |
| NACK/DTX, ACK, ACK, NACK/DTX       | $n_{\text{PUCCH},2}^{(1)}$ | 0, 1 |
| NACK/DTX, ACK, NACK/DTX, ACK       | $n_{\text{PUCCH},3}^{(1)}$ | 1, 0 |
| NACK/DTX, ACK, NACK/DTX, NACK/DTX  | $n_{\text{PUCCH},1}^{(1)}$ | 0, 1 |
| NACK/DTX, NACK/DTX, ACK, ACK       | $n_{\text{PUCCH},3}^{(1)}$ | 0, 1 |
| NACK/DTX, NACK/DTX, ACK, NACK/DTX  | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0 |
| NACK/DTX, NACK/DTX, NACK/DTX, ACK  | $n_{\text{PUCCH},3}^{(1)}$ | 0, 0 |
| NACK, NACK/DTX, NACK/DTX, NACK/DTX | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0 |
| DTX, NACK/DTX, NACK/DTX, NACK/DTX  | No Transmission            |      |

Table 16: Mapping of subframes on each serving cell to HARQ-ACK(*j*) for PUCCH format 1b HARQ-ACK channel selection for TDD with  $M = 2$

| A | HARQ-ACK( <i>j</i> )               |                                     |                                      |                                       |
|---|------------------------------------|-------------------------------------|--------------------------------------|---------------------------------------|
|   | HARQ-ACK(0)                        | HARQ-ACK(1)                         | HARQ-ACK(2)                          | HARQ-ACK(3)                           |
| 4 | The first subframe of Primary cell | The second subframe of Primary cell | The first subframe of Secondary cell | The second subframe of Secondary cell |

For TDD HARQ-ACK multiplexing with PUCCH format 1b with channel selection and sub-frame  $n$  with  $M > 2$  and two configured serving cells, where  $M$  is the number of elements in the set  $K$  defined in Table 12, denotes  $n_{\text{PUCCH},i}^{(1)}$   $0 \leq i \leq 3$  as the PUCCH resource derived from the transmissions in  $M$  DL sub-frames associated with the UL subframe  $n$ .  $n_{\text{PUCCH},0}^{(1)}$  and  $n_{\text{PUCCH},1}^{(1)}$  are associated with the PDSCH transmission(s) on the primary cell and  $n_{\text{PUCCH},2}^{(1)}$  and  $n_{\text{PUCCH},3}^{(1)}$  are associated with the PDSCH transmission(s) on the secondary cell.

For Primary cell:

- If for a PDSCH transmission on the primary cell where there is not a corresponding PDCCH detected within the subframe(s)  $n - k$ , where  $k \in K$ ,
  - the value of  $n_{\text{PUCCH},0}^{(1)}$  is determined according to higher layer configuration.
  - for a PDSCH transmission on the primary cell indicated by the detection of a corresponding PDCCH within the subframe(s)  $n - k_m$ , where  $k_m \in K$  with the DAI value in the PDCCH equal to '1' (defined in Table 9) or a PDCCH indicating downlink SPS release within the subframe(s)  $n - k_m$ , where  $k_m \in K$  with the DAI value in the PDCCH equal to '1', the PUCCH resource
 
$$n_{\text{PUCCH},1}^{(1)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$$
 where  $c$  is selected from {0, 1, 2, 3} such

- that  $N_c \leq n_{\text{CCE},m} < N_{c+1}$ ,  $N_c = \max\left\{0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor \right\}$ , where  $n_{\text{CCE},m}$  is the number of the first CCE used for transmission of the corresponding PDCCH in subframe  $n - k_m$  and  $N_{\text{PUCCH}}^{(1)}$  is configured by higher layers.
- HARQ-ACK(0) is the ACK/NACK/DTX response for the PDSCH transmission without a corresponding PDCCH. HARQ-ACK(j),  $1 \leq j \leq M - 1$ , is the ACK/NACK/DTX response for the PDSCH transmission with corresponding PDCCH and DAI value in the PDCCH equal to 'j'.
  - Otherwise,
    - for a PDSCH transmission on the primary cell indicated by the detection of a corresponding PDCCH within the subframe(s)  $n - k_m$ , where  $k_m \in K$  with the DAI value in the PDCCH equal to either '1' or '2' or a PDCCH indicating downlink SPS release within the subframe(s)  $n - k_m$ , where  $k_m \in K$  with the DAI value in the PDCCH equal to either '1' or '2', the PUCCH resource  $n_{\text{PUCCH},i}^{(1)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$ , where  $c$  is selected from {0, 1, 2, 3} such that  $N_c \leq n_{\text{CCE},m} < N_{c+1}$ ,  $N_c = \max\left\{0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor \right\}$ , where  $n_{\text{CCE},m}$  is the number of the first CCE used for transmission of the corresponding PDCCH in subframe  $n - k_m$ ,  $N_{\text{PUCCH}}^{(1)}$  is configured by higher layers,  $i = 0$  for the corresponding PDCCH with the DAI value equal to '1' and  $i = 1$  for the corresponding PDCCH with the DAI value equal to '2'.
    - HARQ-ACK(j),  $0 \leq j \leq M - 1$ , is the ACK/NACK/DTX response for the PDSCH transmission with corresponding PDCCH and DAI value in the PDCCH equal to 'j + 1'.

For Secondary cell:

- for a PDSCH transmission on the secondary cell indicated by the detection of a corresponding PDCCH on the primary cell within the subframe(s)  $n - k_m$ , where  $k_m \in K$  with the DAI value in the PDCCH equal to either '1' or '2', the PUCCH resources  $n_{\text{PUCCH},i}^{(1)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$ , where  $c$  is selected from {0, 1, 2, 3} such that  $N_c \leq n_{\text{CCE},m} < N_{c+1}$ ,  $N_c = \max\left\{0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor \right\}$ , where  $n_{\text{CCE},m}$  is the number of the first CCE used for transmission of the corresponding PDCCH in subframe  $n - k_m$ ,  $N_{\text{PUCCH}}^{(1)}$  is configured by higher layers,  $i = 2$  for the corresponding PDCCH with the DAI value equal to '1' and  $i = 3$  for the corresponding PDCCH with the DAI value equal to '2'.
- for a PDSCH transmission indicated by the detection of a corresponding PDCCH within the subframe(s)  $n - k$ , where  $k \in K$  on the secondary cell, the value of  $n_{\text{PUCCH},2}^{(1)}$  and  $n_{\text{PUCCH},3}^{(1)}$  is determined according to higher layer configuration. The TPC field in the DCI format of the corresponding PDCCH shall be used to determine the PUCCH resource values from one of the four resource values configured by higher layers. A UE shall assume that the same HARQ-ACK PUCCH resource value is transmitted in the TPC field on all PDCCH assignments on the secondary cell in a given subframe.
- HARQ-ACK(j),  $0 \leq j \leq M - 1$ , is the ACK/NACK/DTX response for the PDSCH transmission with corresponding PDCCH and DAI value in the PDCCH equal to 'j + 1'.

A UE shall perform channel selection according to the Tables 17-1, and 17-2 and transmit  $b(0), b(1)$  on PUCCH resource  $n_{\text{PUCCH}}^{(1)}$  in sub-frame  $n$  using PUCCH format 1b. The value of  $b(0), b(1)$  and the PUCCH resource  $n_{\text{PUCCH}}^{(1)}$  are generated by channel selection according to Tables 17-1, and 17-2 for  $M = 3$ , and 4 respectively.

Table 17-1: Transmission of HARQ-ACK multiplexing for  $M = 3$ 

| Primary Cell                          | Secondary Cell                        | Resource                   | Constellation | RM Code Input Bits       |
|---------------------------------------|---------------------------------------|----------------------------|---------------|--------------------------|
| HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2) | HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2) | $n_{\text{PUCCH}}^{(1)}$   | $b(0), b(1)$  | $o(0), o(1), o(2), o(3)$ |
| ACK, ACK, ACK                         | ACK, ACK, ACK                         | $n_{\text{PUCCH},1}^{(1)}$ | 1, 1          | 1,1,1,1                  |
| ACK, ACK, NACK/DTX                    | ACK, ACK, ACK                         | $n_{\text{PUCCH},1}^{(1)}$ | 0, 0          | 1,0,1,1                  |
| ACK, NACK/DTX, any                    | ACK, ACK, ACK                         | $n_{\text{PUCCH},3}^{(1)}$ | 1, 1          | 0,1,1,1                  |
| NACK/DTX, any, any                    | ACK, ACK, ACK                         | $n_{\text{PUCCH},3}^{(1)}$ | 0, 1          | 0,0,1,1                  |
| ACK, ACK, ACK                         | ACK, ACK, NACK/DTX                    | $n_{\text{PUCCH},0}^{(1)}$ | 1, 0          | 1,1,1,0                  |
| ACK, ACK, NACK/DTX                    | ACK, ACK, NACK/DTX                    | $n_{\text{PUCCH},3}^{(1)}$ | 1, 0          | 1,0,1,0                  |
| ACK, NACK/DTX, any                    | ACK, ACK, NACK/DTX                    | $n_{\text{PUCCH},0}^{(1)}$ | 0, 1          | 0,1,1,0                  |
| NACK/DTX, any, any                    | ACK, ACK, NACK/DTX                    | $n_{\text{PUCCH},3}^{(1)}$ | 0, 0          | 0,0,1,0                  |
| ACK, ACK, ACK                         | ACK, NACK/DTX, any                    | $n_{\text{PUCCH},2}^{(1)}$ | 1, 1          | 1, 1, 0, 1               |
| ACK, ACK, NACK/DTX                    | ACK, NACK/DTX, any                    | $n_{\text{PUCCH},2}^{(1)}$ | 0, 1          | 1, 0, 0, 1               |
| ACK, NACK/DTX, any                    | ACK, NACK/DTX, any                    | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0          | 0, 1, 0, 1               |
| NACK/DTX, any, any                    | ACK, NACK/DTX, any                    | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0          | 0, 0, 0, 1               |
| ACK, ACK, ACK                         | NACK/DTX, any, any                    | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0          | 1, 1, 0, 0               |
| ACK, ACK, NACK/DTX                    | NACK/DTX, any, any                    | $n_{\text{PUCCH},1}^{(1)}$ | 0, 1          | 1, 0, 0, 0               |
| ACK, NACK/DTX, any                    | NACK/DTX, any, any                    | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1          | 0, 1, 0, 0               |
| NACK, any, any                        | NACK/DTX, any, any                    | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0          | 0, 0, 0, 0               |
| DTX, any, any                         | NACK/DTX, any, any                    | No Transmission            |               | 0, 0, 0, 0               |

Table 17-2: Transmission of HARQ-ACK multiplexing for  $M = 4$ 

| Primary Cell                                       | Secondary Cell                                     | Resource                   | Constellation | RM Code Input Bits       |
|----------------------------------------------------|----------------------------------------------------|----------------------------|---------------|--------------------------|
| HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2), HARQ-ACK(3) | HARQ-ACK(0), HARQ-ACK(1), HARQ-ACK(2), HARQ-ACK(3) | $n_{\text{PUCCH}}^{(1)}$   | $b(0), b(1)$  | $o(0), o(1), o(2), o(3)$ |
| ACK, ACK, ACK, NACK/DTX                            | ACK, ACK, ACK, NACK/DTX                            | $n_{\text{PUCCH},1}^{(1)}$ | 1, 1          | 1, 1, 1, 1               |
| ACK, ACK, NACK/DTX, any                            | ACK, ACK, ACK, NACK/DTX                            | $n_{\text{PUCCH},1}^{(1)}$ | 0, 0          | 1, 0, 1, 1               |
| ACK, DTX, DTX, DTX                                 | ACK, ACK, ACK, NACK/DTX                            | $n_{\text{PUCCH},3}^{(1)}$ | 1, 1          | 0, 1, 1, 1               |

|                                                            |                                                            |                            |      |            |
|------------------------------------------------------------|------------------------------------------------------------|----------------------------|------|------------|
| ACK, ACK, ACK, ACK                                         | ACK, ACK, ACK, NACK/DTX                                    | $n_{\text{PUCCH},3}^{(1)}$ | 1, 1 | 0, 1, 1, 1 |
| NACK/DTX, any, any, any                                    | ACK, ACK, ACK, NACK/DTX                                    | $n_{\text{PUCCH},3}^{(1)}$ | 0, 1 | 0, 0, 1, 1 |
| (ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX) | ACK, ACK, ACK, NACK/DTX                                    | $n_{\text{PUCCH},3}^{(1)}$ | 0, 1 | 0, 0, 1, 1 |
| ACK, ACK, ACK, NACK/DTX                                    | ACK, ACK, NACK/DTX, any                                    | $n_{\text{PUCCH},0}^{(1)}$ | 1, 0 | 1, 1, 1, 0 |
| ACK, ACK, NACK/DTX, any                                    | ACK, ACK, NACK/DTX, any                                    | $n_{\text{PUCCH},3}^{(1)}$ | 1, 0 | 1, 0, 1, 0 |
| ACK, DTX, DTX, DTX                                         | ACK, ACK, NACK/DTX, any                                    | $n_{\text{PUCCH},0}^{(1)}$ | 0, 1 | 0, 1, 1, 0 |
| ACK, ACK, ACK, ACK                                         | ACK, ACK, NACK/DTX, any                                    | $n_{\text{PUCCH},0}^{(1)}$ | 0, 1 | 0, 1, 1, 0 |
| NACK/DTX, any, any, any                                    | ACK, ACK, NACK/DTX, any                                    | $n_{\text{PUCCH},3}^{(1)}$ | 0, 0 | 0, 0, 1, 0 |
| (ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX) | ACK, ACK, NACK/DTX, any                                    | $n_{\text{PUCCH},3}^{(1)}$ | 0, 0 | 0, 0, 1, 0 |
| ACK, ACK, ACK, NACK/DTX                                    | ACK, DTX, DTX, DTX                                         | $n_{\text{PUCCH},2}^{(1)}$ | 1, 1 | 1, 1, 0, 1 |
| ACK, ACK, ACK, NACK/DTX                                    | ACK, ACK, ACK, ACK                                         | $n_{\text{PUCCH},2}^{(1)}$ | 1, 1 | 1, 1, 0, 1 |
| ACK, ACK, NACK/DTX, any                                    | ACK, DTX, DTX, DTX                                         | $n_{\text{PUCCH},2}^{(1)}$ | 0, 1 | 1, 0, 0, 1 |
| ACK, ACK, NACK/DTX, any                                    | ACK, ACK, ACK, ACK                                         | $n_{\text{PUCCH},2}^{(1)}$ | 0, 1 | 1, 0, 0, 1 |
| ACK, DTX, DTX, DTX                                         | ACK, DTX, DTX, DTX                                         | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0 | 0, 1, 0, 1 |
| ACK, DTX, DTX, DTX                                         | ACK, ACK, ACK, ACK                                         | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0 | 0, 1, 0, 1 |
| ACK, ACK, ACK, ACK                                         | ACK, DTX, DTX, DTX                                         | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0 | 0, 1, 0, 1 |
| ACK, ACK, ACK, ACK                                         | ACK, ACK, ACK, ACK                                         | $n_{\text{PUCCH},2}^{(1)}$ | 1, 0 | 0, 1, 0, 1 |
| NACK/DTX, any, any, any                                    | ACK, DTX, DTX, DTX                                         | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0 | 0, 0, 0, 1 |
| NACK/DTX, any, any, any                                    | ACK, ACK, ACK, ACK                                         | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0 | 0, 0, 0, 1 |
| (ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX) | ACK, DTX, DTX, DTX                                         | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0 | 0, 0, 0, 1 |
| (ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX) | ACK, ACK, ACK, ACK                                         | $n_{\text{PUCCH},2}^{(1)}$ | 0, 0 | 0, 0, 0, 1 |
| ACK, ACK, ACK, NACK/DTX                                    | NACK/DTX, any, any, any                                    | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0 | 1, 1, 0, 0 |
| ACK, ACK, ACK, NACK/DTX                                    | (ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX) | $n_{\text{PUCCH},1}^{(1)}$ | 1, 0 | 1, 1, 0, 0 |
| ACK, ACK, NACK/DTX, any                                    | NACK/DTX, any, any, any                                    | $n_{\text{PUCCH},1}^{(1)}$ | 0, 1 | 1, 0, 0, 0 |
| ACK, ACK, NACK/DTX, any                                    | (ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX) | $n_{\text{PUCCH},1}^{(1)}$ | 0, 1 | 1, 0, 0, 0 |

|                                                            |                                                               |                            |      |            |
|------------------------------------------------------------|---------------------------------------------------------------|----------------------------|------|------------|
| ACK, DTX, DTX, DTX                                         | NACK/DTX, any, any, any                                       | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1 | 0, 1, 0, 0 |
| ACK, DTX, DTX, DTX                                         | (ACK, NACK/DTX, any, any),<br>except for (ACK, DTX, DTX, DTX) | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1 | 0, 1, 0, 0 |
| ACK, ACK, ACK, ACK                                         | NACK/DTX, any, any, any                                       | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1 | 0, 1, 0, 0 |
| ACK, ACK, ACK, ACK                                         | (ACK, NACK/DTX, any, any),<br>except for (ACK, DTX, DTX, DTX) | $n_{\text{PUCCH},0}^{(1)}$ | 1, 1 | 0, 1, 0, 0 |
| NACK, any, any, any                                        | NACK/DTX, any, any, any                                       | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0 | 0, 0, 0, 0 |
| NACK, any, any, any                                        | (ACK, NACK/DTX, any, any),<br>except for (ACK, DTX, DTX, DTX) | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0 | 0, 0, 0, 0 |
| (ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX) | NACK/DTX, any, any, any                                       | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0 | 0, 0, 0, 0 |
| (ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX) | (ACK, NACK/DTX, any, any),<br>except for (ACK, DTX, DTX, DTX) | $n_{\text{PUCCH},0}^{(1)}$ | 0, 0 | 0, 0, 0, 0 |
| DTX, any, any, any                                         | NACK/DTX, any, any, any                                       | No Transmission            |      | 0, 0, 0, 0 |
| DTX, any, any, any                                         | (ACK, NACK/DTX, any, any),<br>except for (ACK, DTX, DTX, DTX) | No Transmission            |      | 0, 0, 0, 0 |

Table 18: Mapping of Transport Block and Serving Cell to HARQ-ACK(j) for PUCCH format 1b HARQ-ACK channel selection

| A | HARQ-ACK(j)       |                    |                    |                    |
|---|-------------------|--------------------|--------------------|--------------------|
|   | HARQ-ACK(0)       | HARQ-ACK(1)        | HARQ-ACK(2)        | HARQ-ACK(3)        |
| 2 | TB1 Primary cell  | TB2 Secondary cell | NA                 | NA                 |
| 3 | TB1 Serving cell1 | TB2 Serving cell1  | TB3 Serving cell2  | NA                 |
| 4 | TB1 Primary cell  | TB2 Primary cell   | TB3 Secondary cell | TB4 Secondary cell |

#### PUCCH format 3 HARQ-ACK procedure

For TDD HARQ-ACK transmission with PUCCH format 3 and sub-frame  $n$  with  $M \geq 1$  and more than one configured serving cell, where  $M$  is the number of elements in the set  $K$  defined in Table 12, the UE shall use PUCCH resource  $n_{\text{PUCCH}}^{(3,p)}$  or  $n_{\text{PUCCH}}^{(1,p)}$  for transmission of HARQ-ACK in subframe  $n$  on antenna port  $p$  where

- for a single PDSCH transmission only on the primary cell indicated by the detection of a corresponding PDCCH within subframe(s)  $n - k_m$ , where  $k_m \in K$  with the DAI value in the PDCCH equal to '1' (defined in Table 9), or for a PDCCH indicating downlink SPS release within subframe(s)  $n - k_m$ , where  $k_m \in K$  with the DAI value in the PDCCH equal to '1', the UE shall use PUCCH format 1a/1b and PUCCH resource  $n_{\text{PUCCH}}^{(1,p)}$  with  $n_{\text{PUCCH}}^{(1,p=p_0)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$  for antenna port  $p = p_0$ , where  $N_{\text{PUCCH}}^{(1)}$  is configured by higher layers,  $c$  is selected from  $\{0, 1, 2, 3\}$  such that  $N_c \leq n_{\text{CCE},m} < N_{c+1}$ ,

$N_c = \max\left\{0, \left\lfloor \frac{N_{RB}^{DL} \cdot (N_{sc}^{RB} \cdot c - 4)}{36} \right\rfloor \right\}$ , and  $n_{CCE,m}$  is the number of the first CCE used for transmission of the corresponding PDCCH in subframe  $n - k_m$  where  $k_m \in K$ . For two antenna port transmission the PUCCH resource for  $p = p_1$  is given by  $n_{PUCCH}^{(1,p=p_1)} = n_{PUCCH}^{(1,p=p_0)} + 1$

for a single PDSCH transmission only on the primary cell where there is not a corresponding PDCCH detected within subframe(s)  $n - k_m$ , where  $k_m \in K$  and no PDCCH indicating downlink SPS release within subframe(s)  $n - k_m$ , where  $k_m \in K$ , the UE shall use PUCCH format 1a/1b and PUCCH resource  $n_{PUCCH}^{(1,p)}$  with the value of  $n_{PUCCH}^{(1,p)}$  is determined according to higher layer configuration. For a UE configured for two antenna port transmission, a PUCCH resource value maps to two PUCCH resources with the first PUCCH resource  $n_{PUCCH}^{(1,p=p_0)}$  for antenna port  $p_0$  and the second PUCCH resource  $n_{PUCCH}^{(1,p=p_1)}$  for antenna port  $p_1$ , otherwise, the PUCCH resource value maps to a single PUCCH resource  $n_{PUCCH}^{(1,p=p_0)}$  for antenna port  $p_0$ .

- for  $M > 1$  and a PDSCH transmission only on the primary cell where there is not a corresponding PDCCH detected within subframe(s)  $n - k_m$ , where  $k_m \in K$  and an additional PDSCH transmission only on the primary cell indicated by the detection of a corresponding PDCCH within subframe(s)  $n - k_m$ , where  $k_m \in K$  with the DAI value in the PDCCH equal to '1' (defined in Table 9) or a PDCCH indicating downlink SPS release within the subframe(s)  $n - k_m$ , where  $k_m \in K$  with the DAI value in the PDCCH equal to '1', the UE shall transmit  $b(0), b(1)$  in subframe  $n$  using PUCCH format 1b on PUCCH resource  $n_{PUCCH}^{(1)}$  selected from  $A$  PUCCH resources  $n_{PUCCH,i}^{(1)}$  where  $0 \leq i \leq A - 1$ , according to Table 15-1 and Table 15-2 for  $A = 2$  and  $A = 3$ , respectively. For a UE configured with a transmission mode that supports up to two transport blocks on the primary cell,  $A = 3$ ; otherwise,  $A = 2$ .

- The PUCCH resource  $n_{PUCCH,0}^{(1)}$  is determined according to higher layer configuration. The PUCCH resource  $n_{PUCCH,1}^{(1)}$  is determined as  $n_{PUCCH,1}^{(1)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{CCE,m} + N_{PUCCH}^{(1)}$ , where  $N_{PUCCH}^{(1)}$  is configured by higher layers,  $c$  is selected from  $\{0, 1, 2, 3\}$  such that  $N_c \leq n_{CCE,m} < N_{c+1}$ ,  $N_c = \max\left\{0, \left\lfloor \frac{N_{RB}^{DL} \cdot (N_{sc}^{RB} \cdot c - 4)}{36} \right\rfloor \right\}$ , and  $n_{CCE,m}$  is the number of the first CCE used for transmission of the corresponding PDCCH in subframe  $n - k_m$  where  $k_m \in K$ . For a UE configured with a transmission mode that supports up to two transport blocks on the primary cell, the PUCCH resource  $n_{PUCCH,2}^{(1)}$  is determined as  $n_{PUCCH,2}^{(1)} = n_{PUCCH,1}^{(1)} + 1$ . HARQ-ACK(0) is the ACK/NACK/DTX response for the PDSCH without a corresponding PDCCH detected. HARQ-ACK(1) is the ACK/NACK/DTX response for the first transport block of the PDSCH indicated by the detection of a corresponding PDCCH for which the value of the DAI field in the corresponding DCI format is equal to '1' or for the PDCCH indicating downlink SPS release for which the value of the DAI field in the corresponding DCI format is equal to '1'. HARQ-ACK(2) is the ACK/NACK/DTX response for the second transport block of the PDSCH indicated by the detection of a corresponding PDCCH for which the value of the DAI field in the corresponding DCI format is equal to '1'.

- for  $M > 1$  and a PDSCH transmission only on the primary cell indicated by the detection of a corresponding PDCCH within subframe(s)  $n - k_m$ , where  $k_m \in K$  with the DAI value in the PDCCH greater than '1' (defined in Table 9) or a PDCCH indicating downlink SPS release within the subframe(s)  $n - k_m$ , where  $k_m \in K$  with the

DAI value in the PDCCH greater than '1', the UE shall use PUCCH format 3 and PUCCH resource  $n_{\text{PUCCH}}^{(3,p)}$  where the value of  $n_{\text{PUCCH}}^{(3,p)}$  is determined according to higher layer configuration and the TPC field in a PDCCH assignment with DAI value greater than '1' shall be used to determine the PUCCH resource value from one of the four PUCCH resource values configured by higher layers. A UE shall assume that the same HARQ-ACK PUCCH resource value is transmitted on all PDCCH assignments used to determine the PUCCH resource values within the subframe(s)  $n - k_m$ , where  $k_m \in K$ .

- for a PDSCH transmission on the secondary cell indicated by the detection of a corresponding PDCCH within subframe(s)  $n - k_m$ , where  $k_m \in K$ , the UE shall use PUCCH format 3 and PUCCH resource  $n_{\text{PUCCH}}^{(3,p)}$  where the value of  $n_{\text{PUCCH}}^{(3,p)}$  is determined according to higher layer configuration and the TPC field in the corresponding PDCCH shall be used to determine the PUCCH resource value from one of the four resource values configured by higher layers. If a PDCCH corresponding to a PDSCH on the primary cell within subframe(s)  $n - k_m$ , where  $k_m \in K$ , or a PDCCH indicating downlink SPS release within subframe(s)  $n - k_m$ , where  $k_m \in K$ , is detected, the TPC field in the PDCCH with the DAI value greater than '1' shall be used to determine the PUCCH resource value from one of the four resource values configured by higher layers. A UE shall assume that the same HARQ-ACK PUCCH resource value is transmitted on all PDCCH assignments in the primary cell and in each secondary cell that are used to determine the PUCCH resource value within the subframe(s)  $n - k_m$ , where  $k_m \in K$ .

For PUCCH format 3 and PUCCH resource  $n_{\text{PUCCH}}^{(3,p)}$  and a UE configured for two antenna port transmission, a PUCCH resource value maps to two PUCCH resources with the first PUCCH resource  $n_{\text{PUCCH}}^{(3,p=p_0)}$  for antenna port  $p_0$  and the second PUCCH resource  $n_{\text{PUCCH}}^{(3,p=p_1)}$  for antenna port  $p_1$ , otherwise, the PUCCH resource value maps to a single PUCCH resource  $n_{\text{PUCCH}}^{(3,p=p_0)}$  for antenna port  $p_0$ .

FDD HARQ-ACK procedures for more than one configured serving cell

The FDD HARQ-ACK feedback procedures for more than one configured serving cell are either based on a PUCCH format 1b with channel selection HARQ-ACK procedure as described.

HARQ-ACK transmission on two antenna ports ( $p \in [p_0, p_1]$ ) is supported for PUCCH format 3.

PUCCH format 1b with channel selection HARQ-ACK procedure

For FDD with two configured serving cells and PUCCH format 1b with channel selection, the UE shall transmit  $b(0)b(1)$  on PUCCH resource  $n_{\text{PUCCH}}^{(1)}$  selected from  $A$  PUCCH resources,  $n_{\text{PUCCH},j}^{(1)}$  where  $0 \leq j \leq A-1$  and  $A \in \{2,3,4\}$ , according to Table 19-3, Table 19-4, Table 19-5 in subframe  $n$  using PUCCH format 1b. HARQ-ACK( $j$ ) denotes the ACK/NACK/DTX response for a transport block or SPS release PDCCH associated with serving cell  $c$ , where the transport block and serving cell for HARQ-ACK( $j$ ) and  $A$  PUCCH resources are given by Table 19-1.

A UE configured with a transmission mode that supports up to two transport blocks on serving cell,  $c$ , shall use the same HARQ-ACK response for both the transport blocks in response to a PDSCH transmission with a single transport block or a PDCCH indicating downlink SPS release associated with the serving cell  $c$ .

Table 19-1: Mapping of Transport Block and Serving Cell to HARQ-ACK( $j$ ) for PUCCH format 1b HARQ-ACK channel selection

| A | HARQ-ACK( $j$ )   |                    |                    |                    |
|---|-------------------|--------------------|--------------------|--------------------|
|   | HARQ-ACK(0)       | HARQ-ACK(1)        | HARQ-ACK(2)        | HARQ-ACK(3)        |
| 2 | TB1 Primary cell  | TB1 Secondary cell | NA                 | NA                 |
| 3 | TB1 Serving cell1 | TB2 Serving cell1  | TB1 Serving cell2  | NA                 |
| 4 | TB1 Primary cell  | TB2 Primary cell   | TB1 Secondary cell | TB2 Secondary cell |

The UE shall determine the  $A$  PUCCH resources,  $n_{\text{PUCCH},j}^{(1)}$  associated with HARQ-ACK( $j$ ) where  $0 \leq j \leq A-1$  in Table 19-1, according to

for a PDSCH transmission indicated by the detection of a corresponding PDCCH in subframe  $n-4$  on the primary cell, or for a PDCCH indicating downlink SPS release in subframe  $n-4$  on the primary cell, the PUCCH resource is  $n_{\text{PUCCH},j}^{(1)} = n_{\text{CCE}} + N_{\text{PUCCH}}^{(1)}$ , and for transmission mode that supports up to two transport blocks, the PUCCH resource  $n_{\text{PUCCH},j+1}^{(1)}$  is given by  $n_{\text{PUCCH},j+1}^{(1)} = n_{\text{CCE}} + 1 + N_{\text{PUCCH}}^{(1)}$  where  $n_{\text{CCE}}$  is the number of the first CCE used for transmission of the corresponding PDCCH and  $N_{\text{PUCCH}}^{(1)}$  is configured by higher layers.

for a PDSCH transmission on the primary cell where there is not a corresponding PDCCH detected in subframe  $n-4$ , the value of  $n_{\text{PUCCH},j}^{(1)}$  is determined. For transmission mode that supports up to two transport blocks, the PUCCH resource  $n_{\text{PUCCH},j+1}^{(1)}$  is given by  $n_{\text{PUCCH},j+1}^{(1)} = n_{\text{PUCCH},j}^{(1)} + 1$

for a PDSCH transmission indicated by the detection of a corresponding PDCCH in subframe  $n-4$  on the secondary cell, the value of  $n_{\text{PUCCH},j}^{(1)}$ , and the value of  $n_{\text{PUCCH},j+1}^{(1)}$  for the transmission mode that supports up to two transport blocks is determined according to higher layer configuration and Table 19-2. The TPC field in the DCI format of the corresponding PDCCH shall be used to determine the PUCCH resource values from one of the four resource values configured by higher layers, with the mapping defined in Table 19-2. For a UE configured for a transmission mode that supports up to two transport blocks a PUCCH resource value in Table 19-2 maps to two PUCCH resources ( $n_{\text{PUCCH},j}^{(1)}, n_{\text{PUCCH},j+1}^{(1)}$ ), otherwise, the PUCCH resource value maps to a single PUCCH resource  $n_{\text{PUCCH},j}^{(1)}$ .

Table 19-2: PUCCH Resource Value for HARQ-ACK Resource for PUCCH

| Value of 'TPC command for PUCCH' | $n_{\text{PUCCH},j}^{(1)}$ or<br>$(n_{\text{PUCCH},j}^{(1)}, n_{\text{PUCCH},j+1}^{(1)})$ |
|----------------------------------|-------------------------------------------------------------------------------------------|
| '00'                             | The 1 <sup>st</sup> PUCCH resource value configured by the higher layers                  |
| '01'                             | The 2 <sup>nd</sup> PUCCH resource value configured by the higher layers                  |
| '10'                             | The 3 <sup>rd</sup> PUCCH resource value configured by the higher layers                  |
| '11'                             | The 4 <sup>th</sup> PUCCH resource value configured by the higher layers                  |

Table 19-3: Transmission of Format 1b HARQ-ACK channel selection for  $A = 2$ 

| HARQ-ACK(0) | HARQ-ACK(1) | $n_{\text{PUCCH}}^{(1)}$   | $b(0)b(1)$ |
|-------------|-------------|----------------------------|------------|
| ACK         | ACK         | $n_{\text{PUCCH},1}^{(1)}$ | 1,1        |
| ACK         | NACK/DTX    | $n_{\text{PUCCH},0}^{(1)}$ | 1,1        |
| NACK/DTX    | ACK         | $n_{\text{PUCCH},1}^{(1)}$ | 0,0        |
| NACK        | NACK/DTX    | $n_{\text{PUCCH},0}^{(1)}$ | 0,0        |
| DTX         | NACK/DTX    | No Transmission            |            |

Table 19-4: Transmission of Format 1b HARQ-ACK channel selection for  $A = 3$ 

| HARQ-ACK(0) | HARQ-ACK(1) | HARQ-ACK(2) | $n_{\text{PUCCH}}^{(1)}$   | $b(0)b(1)$ |
|-------------|-------------|-------------|----------------------------|------------|
| ACK         | ACK         | ACK         | $n_{\text{PUCCH},1}^{(1)}$ | 1,1        |
| ACK         | NACK/DTX    | ACK         | $n_{\text{PUCCH},1}^{(1)}$ | 1,0        |
| NACK/DTX    | ACK         | ACK         | $n_{\text{PUCCH},1}^{(1)}$ | 0,1        |
| NACK/DTX    | NACK/DTX    | ACK         | $n_{\text{PUCCH},2}^{(1)}$ | 1,1        |
| ACK         | ACK         | NACK/DTX    | $n_{\text{PUCCH},0}^{(1)}$ | 1,1        |
| ACK         | NACK/DTX    | NACK/DTX    | $n_{\text{PUCCH},0}^{(1)}$ | 1,0        |
| NACK/DTX    | ACK         | NACK/DTX    | $n_{\text{PUCCH},0}^{(1)}$ | 0,1        |
| NACK/DTX    | NACK/DTX    | NACK        | $n_{\text{PUCCH},2}^{(1)}$ | 0,0        |
| NACK        | NACK/DTX    | DTX         | $n_{\text{PUCCH},0}^{(1)}$ | 0,0        |
| NACK/DTX    | NACK        | DTX         | $n_{\text{PUCCH},0}^{(1)}$ | 0,0        |
| DTX         | DTX         | DTX         | No Transmission            |            |

Table 19-5: Transmission of Format 1b HARQ-ACK channel selection for  $A = 4$

| HARQ-ACK(0) | HARQ-ACK(1) | HARQ-ACK(2) | HARQ-ACK(3) | $n_{\text{PUCCH}}^{(1)}$   | $b(0)b(1)$ |
|-------------|-------------|-------------|-------------|----------------------------|------------|
| ACK         | ACK         | ACK         | ACK         | $n_{\text{PUCCH},1}^{(1)}$ | 1,1        |
| ACK         | NACK/DTX    | ACK         | ACK         | $n_{\text{PUCCH},2}^{(1)}$ | 0,1        |
| NACK/DTX    | ACK         | ACK         | ACK         | $n_{\text{PUCCH},1}^{(1)}$ | 0,1        |
| NACK/DTX    | NACK/DTX    | ACK         | ACK         | $n_{\text{PUCCH},3}^{(1)}$ | 1,1        |
| ACK         | ACK         | ACK         | NACK/DTX    | $n_{\text{PUCCH},1}^{(1)}$ | 1,0        |
| ACK         | NACK/DTX    | ACK         | NACK/DTX    | $n_{\text{PUCCH},2}^{(1)}$ | 0,0        |
| NACK/DTX    | ACK         | ACK         | NACK/DTX    | $n_{\text{PUCCH},1}^{(1)}$ | 0,0        |
| NACK/DTX    | NACK/DTX    | ACK         | NACK/DTX    | $n_{\text{PUCCH},3}^{(1)}$ | 1,0        |
| ACK         | ACK         | NACK/DTX    | ACK         | $n_{\text{PUCCH},2}^{(1)}$ | 1,1        |
| ACK         | NACK/DTX    | NACK/DTX    | ACK         | $n_{\text{PUCCH},2}^{(1)}$ | 1,0        |
| NACK/DTX    | ACK         | NACK/DTX    | ACK         | $n_{\text{PUCCH},3}^{(1)}$ | 0,1        |
| NACK/DTX    | NACK/DTX    | NACK/DTX    | ACK         | $n_{\text{PUCCH},3}^{(1)}$ | 0,0        |
| ACK         | ACK         | NACK/DTX    | NACK/DTX    | $n_{\text{PUCCH},0}^{(1)}$ | 1,1        |
| ACK         | NACK/DTX    | NACK/DTX    | NACK/DTX    | $n_{\text{PUCCH},0}^{(1)}$ | 1,0        |
| NACK/DTX    | ACK         | NACK/DTX    | NACK/DTX    | $n_{\text{PUCCH},0}^{(1)}$ | 0,1        |
| NACK/DTX    | NACK        | NACK/DTX    | NACK/DTX    | $n_{\text{PUCCH},0}^{(1)}$ | 0,0        |
| NACK        | NACK/DTX    | NACK/DTX    | NACK/DTX    | $n_{\text{PUCCH},0}^{(1)}$ | 0,0        |
| DTX         | DTX         | NACK/DTX    | NACK/DTX    | No Transmission            |            |

## PUCCH format 3 HARQ-ACK procedure

For FDD with PUCCH format 3, the UE shall use PUCCH resource  $n_{\text{PUCCH}}^{(3,\tilde{p})}$  or  $n_{\text{PUCCH}}^{(1,\tilde{p})}$  for transmission of HARQ-ACK in subframe  $n$  for  $\tilde{p}$  mapped to antenna port  $p$  where

- for a PDSCH transmission only on the primary cell indicated by the detection of a corresponding PDCCH in subframe  $n-4$ , or for a PDCCH indicating downlink SPS release (defined in section 9.2) in subframe  $n-4$  on the primary cell, the UE shall use PUCCH format 1a/1b and PUCCH resource  $n_{\text{PUCCH}}^{(1,\tilde{p})}$  with  $n_{\text{PUCCH}}^{(1,\tilde{p}_0)} = n_{\text{CCE}} + N_{\text{PUCCH}}^{(1)}$  for antenna port  $p_0$  where  $n_{\text{CCE}}$  is the number of the first CCE (i.e. lowest CCE index used to construct the PDCCH) used for transmission of the corresponding PDCCH and  $N_{\text{PUCCH}}^{(1)}$  is configured by higher layers. When two antenna port transmission is configured for PUCCH format 1a/1b, the PUCCH resource for antenna port  $p_1$  is given by  $N_{\text{PUCCH}}^{(1,p_1)} = n_{\text{CCE}} + 1 + N_{\text{PUCCH}}^{(1)}$ .
- for a PDSCH transmission only on the primary cell where there is not a corresponding PDCCH detected in subframe  $n-4$ , the UE shall use PUCCH format 1a/1b and PUCCH resource  $N_{\text{PUCCH}}^{(1,p)}$  where the value of  $N_{\text{PUCCH}}^{(1,p)}$

is determined according to higher layer configuration and Table 9.2-2. For a UE configured for two antenna port transmission for PUCCH format 1a/1b, a PUCCH resource value maps to two PUCCH resources with the first PUCCH resource  $N_{\text{PUCCH}}^{(1,p_0)}$  for antenna port  $p_0$  and the second PUCCH resource  $N_{\text{PUCCH}}^{(1,p_1)}$  for antenna port  $p_1$  otherwise, the PUCCH resource value maps to a single PUCCH resource  $N_{\text{PUCCH}}^{(1,p_0)}$  for antenna port  $p_0$

- for a PDSCH transmission on the secondary cell indicated by the detection of a corresponding PDCCH in subframe  $n-4$ , the UE shall use PUCCH format 3 and PUCCH resource  $N_{\text{PUCCH}}^{(3,p)}$  where the value of  $N_{\text{PUCCH}}^{(3,p)}$  is determined according to higher layer configuration and Table 20-1. The TPC field in the DCI format of the corresponding PDCCH shall be used to determine the PUCCH resource values from one of the four resource values configured by higher layers, with the mapping defined in Table 20-1. For a UE configured for two antenna port transmission for PUCCH format 3, a PUCCH resource value in Table 20-1 maps to two PUCCH resources with the first PUCCH resource  $N_{\text{PUCCH}}^{(3,p_0)}$  for antenna port  $p_0$  and the second PUCCH resource  $N_{\text{PUCCH}}^{(3,p_1)}$  for antenna port  $p_1$  otherwise, the PUCCH resource value maps to a single PUCCH resource  $N_{\text{PUCCH}}^{(3,p_0)}$  for antenna port  $p_0$ . A UE shall assume that the same HARQ-ACK PUCCH resource value is transmitted in each DCI format of the corresponding secondary cell PDCCH assignments in a given subframe.

Table 20-1: PUCCH Resource Value for HARQ-ACK Resource for PUCCH

| Value of 'TPC command for PUCCH' | $n_{\text{PUCCH}}^{(3,p)}$                                               |
|----------------------------------|--------------------------------------------------------------------------|
| '00'                             | The 1st PUCCH resource value configured by the higher layers             |
| '01'                             | The 2 <sup>nd</sup> PUCCH resource value configured by the higher layers |
| '10'                             | The 3 <sup>rd</sup> PUCCH resource value configured by the higher layers |
| '11'                             | The 4 <sup>th</sup> PUCCH resource value configured by the higher layers |

#### Random access procedure in LTE

An LTE UE can only be scheduled for UL transmission if its UL transmission timing is synchronized. The LTE random access channel (RACH) therefore plays a key role as an interface between non-synchronized UEs and the orthogonal transmission scheme of the LTE UL radio access [3]. LTE uses the RACH for initial network access, but in LTE the RACH cannot carry any user data. Instead, the LTE RACH is used to achieve UL time synchronization for a UE which either has not yet acquired, or has lost, its UL synchronization. Once UL synchronization is achieved for a UE, the eNB can schedule orthogonal UL transmission resources for it.

The LTE random access procedure comes in two forms, allowing access to be either contention-based (implying an inherent risk of collision) or contention-free. A UE initiates a contention-based random access procedure for all use-cases including the initial access. In this procedure, a RACH preamble signature is randomly chosen by the UE, with the result that it is possible for more than one UE simultaneously to transmit the same signature, leading to a need for a subsequent contention resolution process. For the use-cases such as handover, the eNB has the option of

preventing contention occurring by allocating a dedicated signature to a UE, resulting in contention-free access (namely, dedicated random access). This is faster than contention-based access - a factor which is particularly important for the case of handover, which is time-critical. These two procedures are outlined in Figure 11.

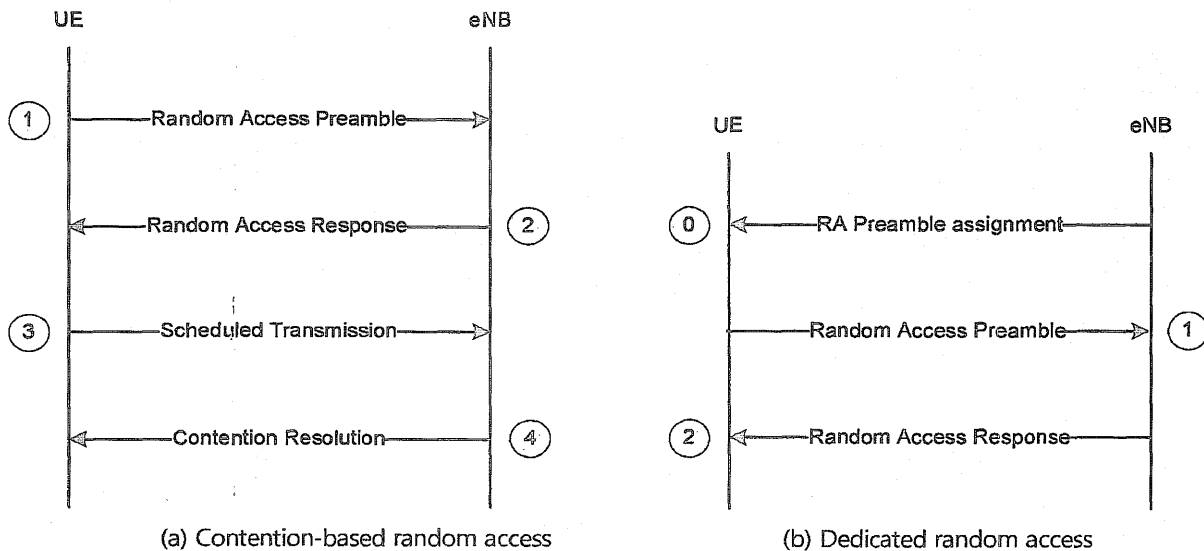


Figure 11. Random access procedures of 3GPP LTE Release-8 system

The four steps of the contention-based random access procedure are provided as below:

- Step 1: RACH preamble transmission (from UE to eNB in UL)
- Step 2: Random access response (from eNB to UE in DL)
- Step 3: Layer 2 / Layer 3 message (from UE to eNB in UL)
- Step 4: Contention resolution message (from eNB to UE in DL)

On the other hand, the dedicated random access procedure consists of the following three steps:

- Step 0: RACH preamble assignment via dedicated signalling (from eNB to UE in DL)
- Step 1: RACH preamble transmission (from UE to eNB in UL)
- Step 2: Random access response (from eNB to UE in DL)

The Random Access Response (RAR) is sent by the eNodeB on the Physical Downlink Shared CHannel (PDSCH), and addressed with an ID, the Random Access Radio Network Temporary Identifier (RA-RNTI), identifying the time-frequency slot in which the preamble was detected. If multiple UEs had collided by selecting the same signature in the same preamble time-frequency resource, they would each receive the RAR. The RAR conveys the identity of the detected preamble, a timing alignment instruction (i.e. TA: Timing Advance) to synchronize subsequent uplink transmissions from the UE, an initial uplink resource grant for transmission of the Step 3 message, and an

assignment of a Temporary Cell Radio Network Temporary Identifier (C-RNTI) (which may or may not be made permanent as a result of the next step – contention resolution).

#### Quasi co-located antenna ports

The term "quasi co-located (QC)" (or "quasi co-location (QC)") is defined and used as follows:

"If two antenna ports are "quasi co-located (QC)", the UE may assume that large-scale properties of the signal received from the first antenna port can be inferred from the signal received from the other antenna port".

The "large-scale properties" mentioned in the above definition consist of some or all of;

Delay spread

Doppler spread

Frequency shift

Average received power

Received Timing

Alternatively, the above definition can be similarly modified to be used as a representation of the channel as follows:

*"If two antenna ports are "quasi co-located (QC)", the UE may assume that large-scale properties of the channel over which a symbol on one antenna port is conveyed can be inferred from the channel over which a symbol on the other antenna port is conveyed".*

The "large-scale properties" mentioned in the above definition consist of some or all of:

*Delay spread*

*Doppler spread*

*Doppler shift*

*Average gain*

*Average delay*

The above definition related to QC is not distinguished in the present invention. In other words, the QC concept can follow one of the above definitions. Alternatively, in another similar form, the QC concept definition may be modified in a form where it can be assumed that antenna ports for which the QC assumption holds are transmitting in co-location (e.g., the UE can assume that the antenna ports are transmitting from the same transmission point, etc.), and the idea of the present invention includes such similar modified examples. For convenience of explanation, the above definitions related to QC are used interchangeably in the present invention.

By the above definition, the UE cannot assume the same large-scale channel properties between the antenna ports (APs) for the non-quasi-co-located (NQC antenna ports). In other words, in this case, a typical UE receiver must perform independent processing for each configured non-quasi-co-located (NQC) AP for timing acquisition and tracking, frequency offset estimation and compensation, delay estimation, and Doppler estimation.

With respect to APs that can assume QC, the UE has the advantage of being able to perform the following actions:

For *Delay spread & Doppler spread*, the UE may equally apply the power-delay-profile, delay spread and Doppler spectrum, and Doppler spread estimates for one port to the Wiener filter, etc. used to estimate the channel for another port.

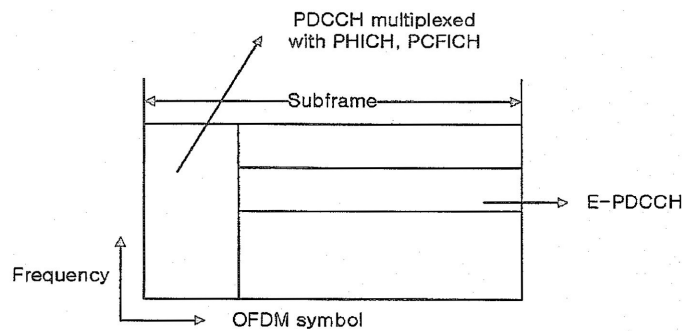
For *frequency shift & Received Timing*, after the UE performs time and frequency synchronization for one port, it can apply the same synchronization to the demodulation of other ports.

For *average received power*, the UE can average RSRP measurements over two or more antenna ports.

When the UE receives a specific DMRS-based DL-related DCI format (e.g., DCI 2C) via PDCCH (or ePDCCH), the UE performs a channel estimation for the scheduled PDSCH via configured DMRS sequence and then performs data demodulation. For example, if the UE can make a QC assumption that the DMRS ports configuration it received from such DL scheduling grant is related to specific RS (e.g., specific CSI-RS or specific CRS or its own DL serving-cell CRS, etc.) ports, the UE can improve the DMRS-based receiver processing performance by applying the large-scale channel properties estimation, such as delay spread, estimated from the specific RS (e.g., specific CSI-RS or specific CRS or its own DL serving-cell CRS, etc.) ports when estimating the channel through the DMRS ports.

#### ePDCCH

Here, the E-PDCCH is assumed to be transmitted in the existing PDSCH region, as shown in the figure, that is, after the PDCCH is transmitted when viewed on the time axis. Here, the E-PDCCH is assumed to be transmitted in the existing PDSCH region, as shown in the figure, that is, after the PDCCH is transmitted when viewed on the time axis. In the figure, E-PDCCH is shown to be transmitted using continuous frequency resources, but this is only an example, and it is also possible to transmit using discontinuous frequency resources for frequency diversity.



CSS (Cell-specific search space) and USS (UE-specific search space)

The set of PDCCH candidates to monitor are defined in terms of search spaces, where a search space  $S_k^{(L)}$  at aggregation level  $L \in \{1, 2, 4, 8\}$  is defined by a set of PDCCH candidates. For each serving cell on which PDCCH is monitored, the CCEs corresponding to PDCCH candidate  $m$  of the search space  $S_k^{(L)}$  are given by

$$L \left\{ (Y_k + m') \bmod \lfloor N_{\text{CCE},k} / L \rfloor \right\} + i$$

where  $Y_k$  is defined below,  $i = 0, \dots, L-1$ . For the common search space  $m' = m$ . For the PDCCH UE specific search space, for the serving cell on which PDCCH is monitored, if the monitoring UE is configured with carrier indicator field then  $m' = m + M^{(L)} \cdot n_{\text{CI}}$  where  $n_{\text{CI}}$  is the carrier indicator field value, else if the monitoring UE is not configured with carrier indicator field then  $m' = m$ , where  $m = 0, \dots, M^{(L)} - 1$ .  $M^{(L)}$  is the number of PDCCH candidates to monitor in the given search space.

For the common search spaces,  $Y_k$  is set to 0 for the two aggregation levels  $L=4$  and  $L=8$ .

For the UE-specific search space  $S_k^{(L)}$  at aggregation level  $L$ , the variable  $Y_k$  is defined by

$$Y_k = (A \cdot Y_{k-1}) \bmod D$$

where  $Y_{-1} = n_{\text{RNTI}} \neq 0$ ,  $A = 39827$ ,  $D = 65537$  and  $k = \lfloor n_s / 2 \rfloor$ ,  $n_s$  is the slot number within a radio frame.

The aggregation levels defining the search spaces are listed in Table 9.1.1-1. The number of PDCCH candidates to monitor in the given search space (i.e.  $M^{(L)}$ ) is also shown in Table 9.1.1-1.

Table 9.1.1-1: PDCCH candidates monitored by a UE.

| Type        | Search space $S_k^{(L)}$ |                | Number of PDCCH candidates $M^{(L)}$ |
|-------------|--------------------------|----------------|--------------------------------------|
|             | Aggregation level $L$    | Size [in CCEs] |                                      |
| UE-specific | 1                        | 6              | 6                                    |
|             | 2                        | 12             | 6                                    |
|             | 4                        | 8              | 2                                    |
|             | 8                        | 16             | 2                                    |
| Common      | 4                        | 16             | 4                                    |
|             | 8                        | 16             | 2                                    |

### 3. Invention Summary

The next-generation LTE-A system is considering configuring low-cost/low-spec terminals that focus on data communications such as meter reading, water level measurement, surveillance camera utilization, and vending machine inventory reporting. These terminals are collectively referred to as MachineType Communication (MTC) terminals for convenience. In the case of MTC terminals, since the amount of data to be transmitted is small and uplink/downlink data transmission and reception occurs occasionally, it is efficient to lower the unit price of the terminal and reduce battery consumption to match this low data transmission rate. These MTC terminals are characterized by low mobility and thus have the characteristic that the channel environment hardly changes. Currently, LTE-A is considering enabling these MTC terminals to have wider coverage than before, and various coverage enhancement techniques for MTC terminals are being discussed for this purpose.

When eNodeB transmits PDCCH and PDSCH to MTC UEs in the same way as it transmits them to legacy UEs, MTC UEs with coverage issues will have difficulty receiving them. To address this, when the eNodeB transmits an MTC UE PDCCH or PDSCH with a coverage issue, techniques for coverage enhancement, such as subframe repetition and subframe bundling, can be applied and transmitted.

Therefore, for MTC UEs with coverage issues, PDCCH and PDSCH can be transmitted through a large number of subframes of about 100. In this case, if the PDSCH is transmitted through the subframe where PDCCH is transmitted in the same way as before, a problem occurs in that the UE must buffer the PDSCH for all subframes in which the PDCCH is transmitted until the UE successfully receives the PDCCH. In addition, when PDCCH is transmitted over multiple subframes and the UE receives PDCCHs successfully using multiple subframes, a problem occurs in that the UE cannot know the subframe in which the transmission of the PDCCH starts. The present invention proposes methods for solving transmission problems of PDCCH and PDSCH for MTC UEs where such coverage issue exists.

In the present invention, for convenience, the content of the invention is explained limited to PDCCH transmission, but the techniques proposed in the present invention can be applied equally even when ePDCCH is used instead of PDCCH.

#### A. PDCCH over multiple subframes

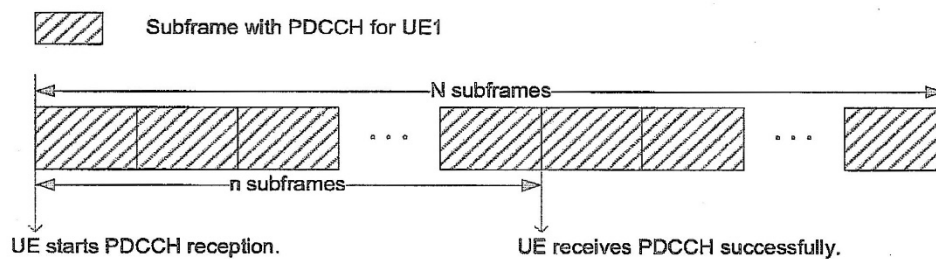
- Transmission of PDCCH

PDCCHs for MTC UEs can be repeatedly transmitted over a large number of subframes for coverage enhancement. The UE can receive PDCCH from bundles of multiple subframes and use the signals of PDCCH transmitted to multiple subframes together to successfully receive PDCCH. For example, as shown in <FIG. 1>, PDCCH can be transmitted via N subframe bundles. The UE can successfully receive PDCCHs using n ( $1 \leq n \leq N$ ) of these subframes.

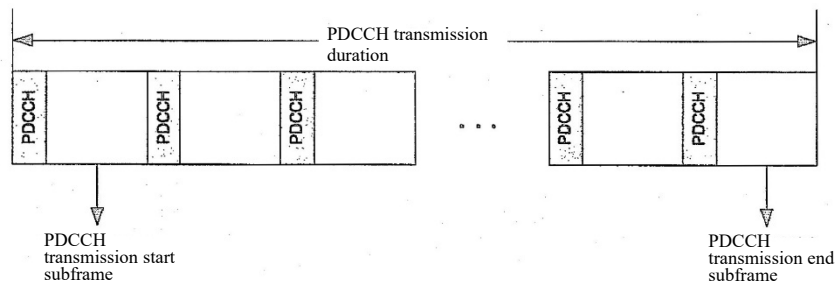
N, the number of subframe bundles to which PDCCH is transmitted, can always be a cell-specific value. Therefore, the number of subframe bundles for transmission of PDCCH for cell-specific data transmission such as SIB or for transmission of PDCCH for UE-specific data transmission can be all cell-specific. At this time, N, the number of subframe bundles to which PDCCH is transmitted, can be a predefined fixed value. Or it can be a value that is configured to the UE through a master information block (MIB) or a system information block (SIB). These PDCCH transmission subframe bundles may consist of consecutive subframes, but may also consist of non-consecutive subframes.

N, the number of subframe bundles to which PDCCH is transmitted, has a cell-specific value for transmission of PDCCH for cell-specific data transmission such as SIB, but can have a UE-specific value for transmission of PDCCH for UE-specific data transmission. At this time, N, the number of subframe bundles to which UE-specific PDCCH is transmitted, can be configured to the UE through higher-layer signals such as RRC signals. Or it can be fixed to a pre-fixed value.

In order for a UE to receive PDCCH transmitted over multiple subframe bundles, it is necessary to know the starting position of the subframe bundle to which PDCCH is transmitted. For this purpose, the subframe location in which transmission of PDCCH is started is not as free as before, and transmission of PDCCH can only be initiated through a subframe location agreed upon in advance. The transmission start subframe location of this PDCCH bundle can be defined as a fixed value. This fixed value may be transmitted via the MIB. For example, assuming that it starts only at SF  $N \% N = 0$  (e.g.  $N = 20$ ), we can transmit the  $N$  value via the MIB. In addition, offsets (assuming that  $N = \text{offset}$  is the only starting point) may also come as MIBs. For example, PDCCH transmission for an MTC UE with coverage issue can only be initiated through subframes or SFN positions that are multiples of 100 (0, 100, 200, 300, ...). At this time, the UE may attempt to receive PDCCHs via  $N$  subframes starting from a subframe or SFN position corresponding to a multiple of 100. In particular, the subframe location at which transmission of PDCCH bundle can start can be UE-specific. In this case, information about the subframe location in which transmission of PDCCH bundle can start can be configured through higher-layer signals such as RRC.



&lt;Figure 1&gt;



&lt;Figure 11&gt;

When PDCCH is transmitted through multiple subframe bundles, the PDCCH is transmitted through all or some subframes during the PDCCH transmission duration, as shown in <Figure 11>. At this time, the present invention proposes to place a limit on the UE-specific search space region of the PDCCH transmitted during the PDCCH transmission duration from the PDCCH transmission start subframe to the PDCCH transmission end subframe or on the PDCCH transmission resources.

The set of PDCCH candidates to monitor are defined in terms of search spaces, where a search space  $S_k^{(L)}$  at aggregation level  $L \in \{1, 2, 4, 8\}$  is defined by a set of PDCCH candidates. For each serving cell on which PDCCH is monitored, the CCEs corresponding to PDCCH candidate  $m$  of the search space  $S_k^{(L)}$  are given by

$$L \left\{ (Y_k + m') \bmod \left\lfloor N_{\text{CCE},k} / L \right\rfloor \right\} + i$$

where  $Y_k$  is defined below,  $i = 0, \dots, L-1$ . For the common search space  $m' = m$ . For the PDCCH UE specific search space, for the serving cell on which PDCCH is monitored, if the monitoring UE is configured with carrier indicator field then  $m' = m + M^{(L)} \cdot n_{\text{CI}}$  where  $n_{\text{CI}}$  is the carrier indicator field value, else if the monitoring UE is not configured with carrier indicator field then  $m' = m$ , where  $m = 0, \dots, M^{(L)} - 1$ .  $M^{(L)}$  is the number of PDCCH candidates to monitor in the given search space.

For the common search spaces,  $Y_k$  is set to 0 for the two aggregation levels  $L = 4$  and  $L = 8$ .

For the UE-specific search space  $S_k^{(L)}$  at aggregation level  $L$ , the variable  $Y_k$  is defined by

$$Y_k = (A \cdot Y_{k-1}) \bmod D$$

where  $Y_{-1} = n_{\text{RNTI}} \neq 0$ ,  $A = 39827$ ,  $D = 65537$  and  $k = \lfloor n_s / 2 \rfloor$ ,  $n_s$  is the slot number within a radio frame.

At this time, if the PDCCH is transmitted through multiple subframe bundles and the PDCCH can be transmitted through different PDCCH resources for each subframe, the complexity of the UE for receiving the PDCCH increases exponentially as the number of PDCCH transmission subframes increases. Therefore, the present invention proposes to use the following method when PDCCH is transmitted through multiple subframe bundles.

- When an eNodeB transmits a PDCCH to a UE over multiple subframes during a PDCCH transmission duration, the PDCCH may be transmitted over CCE resources that use the same  $m$  value ( $m=0, \dots, M^{(L)}-1$ ) over one of the CSS regions or USS regions during the duration. In other words, the UE can assume that the PDCCH is transmitted through the USS resource or CSS resource corresponding to the same  $m$  value during the subframe region in which the same PDCCH is transmitted.
- When an eNodeB transmits a PDCCH to a UE over multiple subframes during a PDCCH transmission duration, the PDCCH may be transmitted using  $m=0$  over one of the CSS region or the USS region during the duration. In other words, the UE can assume that the PDCCH is transmitted through the USS resource or CSS resource corresponding to  $m=0$  during the subframe region in which the same PDCCH is transmitted.
- When an eNodeB transmits a UE-specific PDCCH to a UE over multiple subframes during a PDCCH transmission duration, the UE-specific PDCCH may be transmitted over the same CCE (or EREG or RE) resource during the duration. Specifically, when a UE-specific PDCCH is transmitted over the same CCE (or EREG or RE) resource during the PDCCH transmission duration, the UE may assume that the CCE (or EREG or RE) resource on which the UE-specific PDCCH is transmitted is the same as the CCE (or EREG or RE) resource transmitted from the PDCCH transmission start subframe.

- At this time, the CCE (or EREG or RE) resource that configures the UE-specific search space in which the UE-specific PDCCH can be transmitted during the PDCCH transmission duration can be configured identically to the CCE (or EREG or RE) resource that is applied in the PDCCH transmission start subframe. CCE (or EREG or RE) resources applied in the PDCCH transmission start subframe can be obtained by the same expression in the same way as before.  $L \left\{ (Y_k + m') \bmod \left\lfloor N_{\text{CCE},k} / L \right\rfloor \right\} + i$
- Or, at this time, the CCE (or EREG or RE) resource that configures the UE-specific search space in which the UE-specific PDCCH may be transmitted during the PDCCH transmission duration is obtained by the expression  $L \left\{ (Y_k + m') \bmod \left\lfloor N_{\text{CCE},k} / L \right\rfloor \right\} + i$ , and the value of  $Y_k$  can be used by being fixed to a specific non-zero value.

#### - Transmission of PDSCH/PUSCH

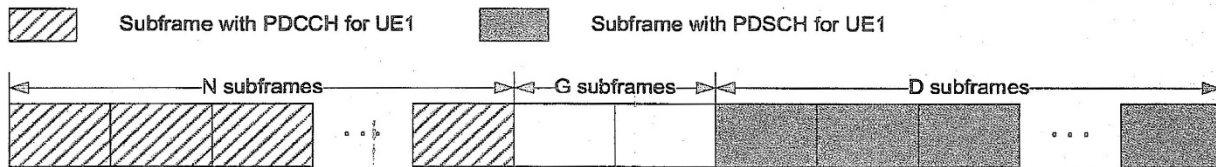
PDSCH/PUSCH can also be transmitted via multiple subframe bundles for MTC UEs with coverage issues. For example, PDSCH is transmitted through D subframes, and the UE can successfully receive the PDSCH using n subframes ( $1 \leq n \leq D$ ) among the D PDSCH subframes. Or, for example, the UE can transmit PUSCH over D subframes. These PDSCH/PUSCH transmission subframe bundles may consist of consecutive subframes, but may also consist of non-consecutive subframes.

According to the current LTE specification, the UE can decode the PDSCH transmitted to the same subframe after decoding the PDCCH (if it is not SPS PDSCH). For MTC UEs that are experiencing coverage issues, both PDCCH and PDSCH may be transmitted across multiple subframes, so a new definition of the timing of when PDSCH is received after PDCCH is received may be required. Similar to the way PDCCH and PDSCH are transmitted in the past, the PDSCH transmitted to the UE and the PDCCH containing DL grant information for the corresponding PDSCH can be transmitted through the same subframes. In this case, since the UE cannot receive the PDSCH until it successfully receives the PDCCH, a problem arises in that it must store all PDSCHs it receives until it successfully receives the PDCCH.

Therefore, for MTC UEs where cost saving is important even if the delay in data transmission increases, the present invention proposes a transmission method as illustrated in <Figure 2>. The eNodeB can transmit a PDCCH to the UE using a total of N subframe bundles. At this time, the PDSCH/PUSCH associated with the corresponding PDCCH can be transmitted from the subframe following G subframes after all PDCCH bundles are transmitted. In other words, for example, if the last PDCCH is transmitted through subframe N-1, PDSCH/PUSCH can be transmitted through D subframe bundles starting from subframe N+G. At this time, the values of N and D can be set to always be the same. Or, information about the value of D may be included in the PDCCH and transmitted.

In this case, the value of G corresponding to the subframe interval between the transmission of the PDCCH subframe bundle and the PDSCH/PUSCH subframe bundle may be fixed or configured to the UE via higher-layer signals such as MID, SIB, or RRC signals. At this time, the value of G, which corresponds to the subframe interval between the transmission of the PDCCH subframe bundle and the PDSCH subframe bundle, may be fixed to 0. In other words, after the transmission of the PDCCH subframe bundle is completed, the PDSCH/PUSCH subframe bundle can be transmitted continuously from the next subframe. In addition, the value of G, which corresponds to the subframe interval between the transmission of the PDCCH subframe bundle and the PUSCH subframe bundle, may be fixed to 4 or the same value as when subframe bundling for the PDCCH is not set.

In particular, after the transmission of the PDCCH subframe bundle is completed, if the location of the subframe where the PDSCH/PUSCH subframe bundle transmission is to start is a subframe in which the PDSCH/PUSCH cannot be transmitted, the transmission of the PDSCH/PUSCH bundle can start in the subframe in which the nearest PDSCH/PUSCH can be transmitted among the subframes following that subframe.



<Figure 2>

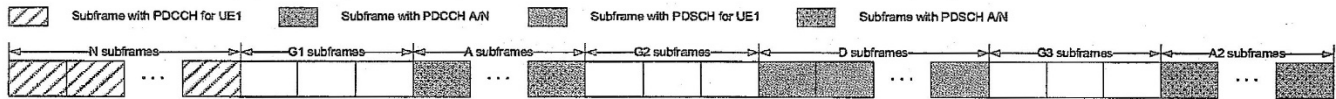
Another way to know where the PDSCH/PUSCH pointed to by the PDCCH is transmitted after receiving the PDCCH is to assume that the bundling of the PDSCH/PUSCH starts after a certain period of time after transmitting the PDCCH as a bundle. If the difference between the subframe location where the transmission of this PDCCH bundle starts and the subframe location where the transmission of the PDSCH/PUSCH bundle starts is K subframe (e.g.,  $K = 100, 200$ ), the UE needs to know which subframe the PDCCH starts from. For example, if  $K = \text{PDSCH/PUSCH starting subframe index} - \text{PDCCH starting subframe index}$  is defined, the UE must know when the PDCCH starts in order to successfully recognize when the PDSCH/PUSCH starts.

In this case, the value of K can be fixed or configured to the UE through higher-layer signals such as MID, SIG, or RRC signals. At this time, the value of K can be set to always be equal to the number of PDCCH subframe bundles. In other words, after the transmission of the PDCCH subframe bundle is completed, the PDSCH/PUSCH subframe bundle can be transmitted from the next subframe. Or, when a PDCCH bundle is configured with N subframes, the subframe location where the transmission of the PDCCH bundle starts and the subframe position where the transmission of the PDSCH/PUSCH bundle starts, K, can be fixed to N-1. In other words, the transmission of a PDSCH/PUSCH subframe bundle can start in the subframe where transmission of the PDCCH subframe bundle ends.

Specifically, when a UE receives a UE-specific PDCCH bundle, or receives a PDCCH bundle through a USS (UE-specific search space), the UE can transmit A/N information about PDCCH reception to the eNodeB using uplink resources after G1 subframes as illustrated in <Figure 3>. Specifically, when a UE receives a UE-specific PDCCH bundle, or receives a PDCCH bundle through a USS (UE-specific search space), the UE can transmit A/N information about PDCCH reception to the eNodeB using uplink resources after G1 subframes as illustrated in <Figure 3>. At this time, the G1 value can be 4, and the A/N information can be transmitted through the A uplink subframe bundle.

As shown in <Figure 3>, an eNodeBs that receive A/N information for PDCCH from the UE can transmit a PDSCH through D subframe bundles after a G2 subframe after receiving A/N subframe bundles if the A/N information is ACK. The UE that has received a PDSCH bundle can transmit A/N information for the PDSCH through the A2 uplink subframe bundles after a G3 subframe after receiving all the PDSCHs. At this time, the values of G1, G2, G3, A, and A1 may be fixed respectively, or configured to the UE through higher-layer signals such as MID, SIG, or RRC signals. Or, after the UE transmits the entire PUSCH bundle to the eNodeB, it can receive A/N information for the PUSCH through A2 uplink subframe bundles starting from the subframe after the G3 subframe.

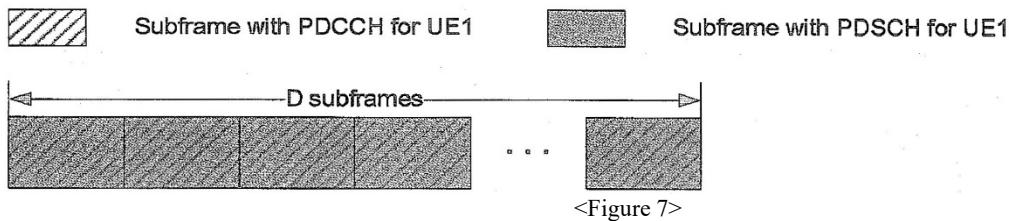
At this time, the values of  $G1$ ,  $G2$ ,  $G3$ ,  $A$ , and  $A1$  may be fixed respectively, or configured to the UE through higher-layer signals such as MID, SIG, or RRC signals. At this time, the values of  $N$ ,  $D$ ,  $A$  and  $A2$  can be set to always be the same. At this time, the  $G2$  value can be 4, and the  $G3$  value can be 4 or the same value as when subframe bundling for PDSCH/PUSCH is not set.



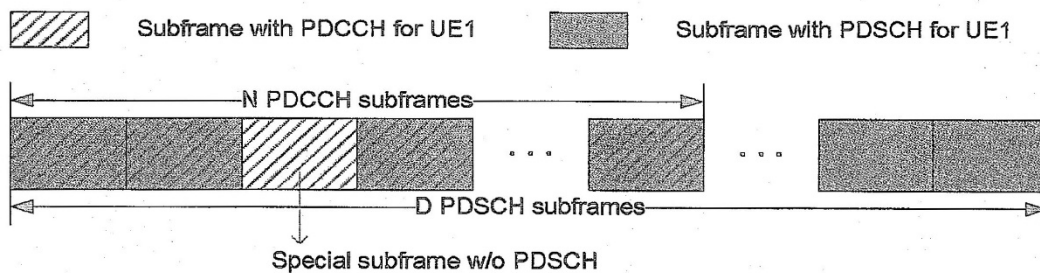
&lt;Figure 3&gt;

Another way for an MTC UE with a coverage issue to transmit PDSCH may be as follows: PDCCHs transmitted through multiple subframe bundles for MTC UEs with coverage issues can only be transmitted through pre-agreed subframe locations. At this time, transmission of the PDSCH bundle through which the grant is transmitted via the corresponding PDCCH can start simultaneously from the subframe in which transmission of the corresponding PDCCH starts, as illustrated in <Figure 7>.

At this time, during the subframe duration during which PDCCH and PDSCH are to be transmitted, the subframe may be included in a subframe in which PDSCH cannot be transmitted, such as a special subframe in which PDSCH cannot be transmitted in a TDD environment (e.g. special subframe configuration 0, 5). In this case, the following methods can be used for transmission of PDCCH and PDSCH. First, when PDCCH must be transmitted through  $N$  subframe bundles and PDSCH must be transmitted through  $D$  subframe bundles, PDCCH can be transmitted through  $N$  subframes in which PDCCH can be transmitted, as shown in <Figure 8>. At this time, the PDSCH can be transmitted through  $D$  subframes to which the PDSCH can be transmitted, except for subframes (e.g. special subframes) where the PDSCH cannot be transmitted.



&lt;Figure 7&gt;



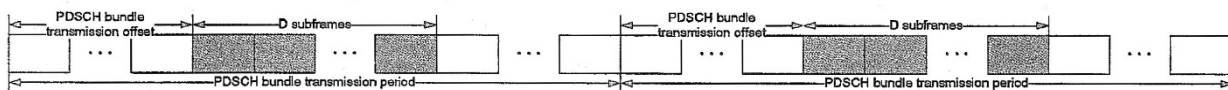
&lt;Figure 8&gt;

## B. No PDCCH transmission

When performing repetitive PDCCH transmissions to transmit PDCCHs to MTC UEs with coverage issues, there is a problem that the transmission delay and energy consumption for receiving them become too large. To address this, the present invention proposes that an MTC UE with coverage issue receives the PDSCH directly without receiving the PDCCH. Or, it is proposed that an MTC UE with a coverage issue transmits PUSCH directly without receiving PDCCH.

For this purpose, an MTC UE with coverage issue can receive PDSCH transmitted itself through a specified area or transmit a PUSCH. At this time, the subframe area where the PDSCH is transmitted for the MTC UE with coverage issue can be defined by the PDSCH bundle transmission period, PDSCH bundle transmission offset, and PDSCH bundle size 'D' as shown in <Figure 4>. The UE additionally needs to know the RB area where PDSCH is transmitted in the subframe.

At this time, each element defining PDSCH/PUSCH for MTC UEs where issue exists may be cell-specific or UE-specific. For cell-specific PDSCH/PUSCH transmission areas, they can be defined as predefined fixed areas. Or, it may be a value configured to a UE through a higher-layer signal such as a master information block (MIB), a system information block (SIB), or RRC signal. In the case of the transmission area of UE-specific PDSCH/PUSCH, it can be configured to the UE through higher-layer signals such as RRC signals. At this time, even if a UE-specific PDSCH/PUSCH area is used, two or more UEs can be designated to use the same PDSCH/PUSCH area. For example, in order to set the PDSCH area for an MTC UE with a coverage issue, the value of the PDSCH bundle transmission period may be set cell-specifically and configured to the UE through higher-layer signals such as a master information block (MIB), a system information block (SIB), or RRC signal. In addition, PDSCH bundle transmission offset, PDSCH bundle size 'D', and RB region where PDSCH is transmitted within a subframe are set UE-specifically and can be configured to the UE through higher-layer signals such as RRC signals. At this time, the bundle transmission offset value can be specified in association with the UE's ID (e.g. C-RNTI). For example, if a UE knows its own UE ID (e.g. C-RNTI), it can use it to estimate the bundle transmission offset value.



<Figure 4>

The PDSCH area for cell-specific data transmission, such as SIB, can be designated cell-specifically. The PDSCH area for UE-specific data transmission, such as data transmission to a specific UE, may be designated cell-specifically or UE-specifically. In particular, when a UE receives cell-specific data through a cell-specific PDSCH area, the UE can use SI-RNTI (i.e. MTC-SI-RNTI) for MTC UEs with coverage issues to receive it. Or, when the UE receives UE-specific data through a cell-specific or UE-specific PDSCH area, the UE may use the C-RNTI to receive it. For example, MTC-SI-RNTI or C-RNTI can be used for the following processes:

- Used for scrambling bits within the transport block or code block of the corresponding PDSCH
- Used in the CRC attachment process for bits within the transport block or code block of the corresponding PDSCH.

- Scrambling the pseudo-random sequence for generating DM-RS transmitted through the RB area of the corresponding PDSCH using MTC-SI- RNTI

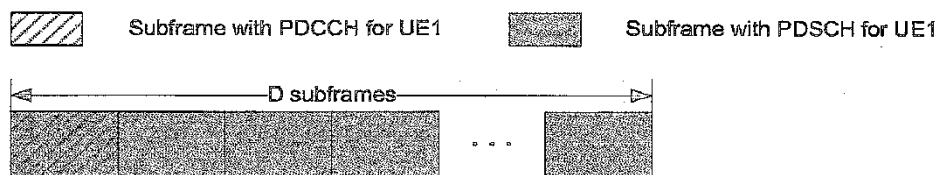
Specifically, when a UE receives a UE-specific PDSCH bundle, it can transmit the A/N information about PDSCH reception to the eNodeB using uplink resources after G3 subframes. At this time, the G3 value can be 4 or the same value as when subframe bundling for PDSCH/PUSCH is not set, and the A/N information can be transmitted through the A1 uplink subframe bundle. Alternatively, characteristically, after the UE transmits the entire PUSCH bundle to the eNodeB, it can receive A/N information for the PUSCH through A2 uplink subframe bundles starting from the subframe after the G3 subframe. The values of G3 and A1 can be fixed, respectively or configured to the UE through higher-layer signals such as MID, SIG, or RRC signals.

### C. Shortened PDCCH

When performing repetitive PDCCH transmissions to transmit PDCCHs to MTC UEs with coverage issues, there is a problem that the transmission delay and energy consumption for receiving them become too large.

To this end, the present invention proposes to transmit shortened PDCCHs containing only information about whether PDSCH is transmitted or whether PDSCH is transmitted to MTC UEs with coverage issues. The UEs are provided with a small amount of information to determine whether PDSCH is transmitted to itself through shortened PDCCHs, and receive data through a defined PDSCH area when a PDSCH is transmitted to itself. For example, a shortened PDCCH may only contain information about the UE's ID (e.g. C-RNTI) receiving the PDCCH. When a UE receives a PDCCH containing information about its UE ID (e.g. C-RNTI), it can assume that a PDSCH is transmitted to it.

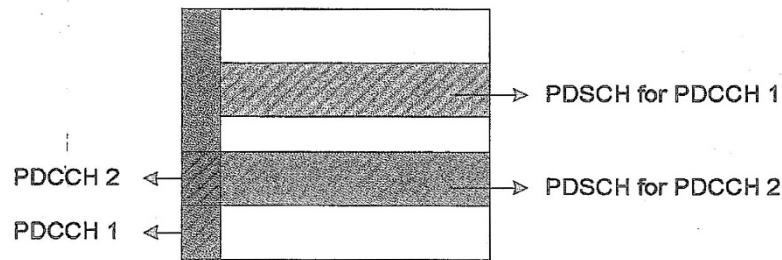
When transmitting data to an MTC UE with a coverage issue, if a shortened PDCCH is used, as illustrated in <FIG. 5>, if a shortened PDCCH for a specific UE is transmitted through a specific subframe, the PDSCH can be transmitted through D subframe bundles starting from the subframe in which the PDCCH is transmitted. In the case of Uplink, if shortened PDCCH for a particular UE is transmitted through a specific subframe, the UE that receives the PDCCH can transmit a PUSCH through D subframe bundles after 4 subframes. Shortened PDCCHs can be transmitted with information about the value of D, which is the number of bundles in which PDSCH is transmitted.



<Figure 5>

A UE that receives a shortened PDCCH can receive data transmitted to it through a designated PDSCH area. In order to designate a PDSCH area and to transmit data through the PDSCH area, the techniques mentioned in 'B. No PDCCH transmission' can be applied. The PDSCH area can be cell-specific or UE-specific. In addition, the PDSCH area for cell-specific data transmission, such as SIB, can be designated cell-specifically. The PDSCH area for UE-specific data transmission, such as data transmission to a specific UE, may be designated cell-specifically or UE-specifically.

Or, the PDSCH area for an MTC UE with coverage issue may be determined based on the PDCCH area to which the shortened PDCCH is transmitted. For example, there may be a PDSCH area determined according to the PDCCH area, as shown in <FIG. 6>. At this time, if the UE receives a shortened PDCCH transmitted to itself through the PDCCH 1 region, it can receive data through the PDSCH region associated with the PDCCH 1 region, and if the UE receives a shortened PDCCH transmitted to itself through the PDCCH 2 region, it can receive data through the PDSCH region associated with the PDCCH 2 region.



&lt;Figure 6&gt;

Specifically, when a UE receives a UE-specific PDSCH bundle, it can transmit A/N information about PDSCH reception to the eNodeB using uplink resources after G3 subframes. At this time, the G3 value can be 4 or the same value as when subframe bundling for PDSCH/PUSCH is not set, and the A/N information can be transmitted through the A1 uplink subframe bundle. Or, after the UE transmits the entire PUSCH bundle to the eNodeB, it can receive A/N information for the PUSCH through A2 uplink subframe bundles starting from the subframe after the G3 subframe. The values of G3 and A1 can be fixed, respectively or configured to the UE through higher-layer signals such as MID, SIG, or RRC signals.

#### D. Conflict issue between PDCCH and PDSCH

As mentioned above, for MTC UEs, PDCCHs can be transmitted in the form of PDCCH bundles via multiple consecutive or non-consecutive subframes, and the transmission of such PDCCH bundles can start from a pre-determined subframe location.

At this time, a problem may arise where the subframe in which the UE must receive the PDSCH bundle overlaps with the subframe where transmission of a new PDCCH bundle can begin.

In this case, the UE can assume that no new PDCCH (which it should receive) is transmitted while receiving one PDSCH bundle as shown in (a) of <FIG. 9>.

Or, if the subframe in which the UE is to receive a PDSCH bundle overlaps with the subframe in which transmission of a new PDCCH bundle can begin, the UE may stop receiving the PDSCH bundle it is receiving and attempt to receive a new PDCCH bundle, as illustrated in (b) of <FIG. 9>. Or, the UE may assume that a PDCCH bundle for another UE may be transmitted during the period in which the PDCCH bundle can be transmitted, and may stop receiving the PDSCH bundle that it is receiving and may not attempt to receive the PDCCH bundle. After completing the reception of the PDCCH bundle or after the subframe in which the PDCCH bundle is transmitted has elapsed, the UE can resume receiving the PDSCH bundle that was temporarily suspended. At this time, if the subframe in which the UE must receive the PDSCH bundle overlaps with the subframe in which transmission of a new PDCCH bundle can begin, and the UE stops receiving the PDSCH bundle and attempts to receive a new PDCCH bundle, the DL grant cannot be transmitted for the UE in the PDCCH bundle, and only the UL grant can be transmitted.

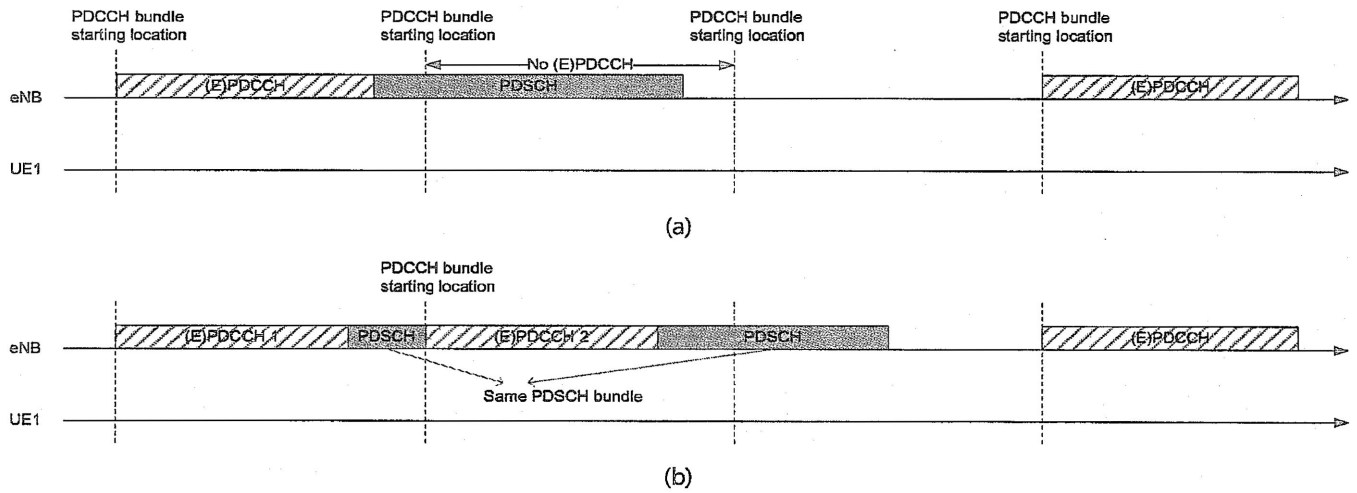
When PDCCH is transmitted in the form of PDCCH bundles for MTCUE, and transmission of PDCCH bundle starts at a pre-determined subframe location, a problem may occur where the timing of the subframe in which the UE is transmitting the PUSCH bundle overlaps with the timing of the subframe in which transmission of a new PDCCH bundle may start.

In this case, the UE may assume that the PDCCH that it should receive is not transmitted while transmitting the PUSCH bundle, as shown in (a) of <FIG. 10>.

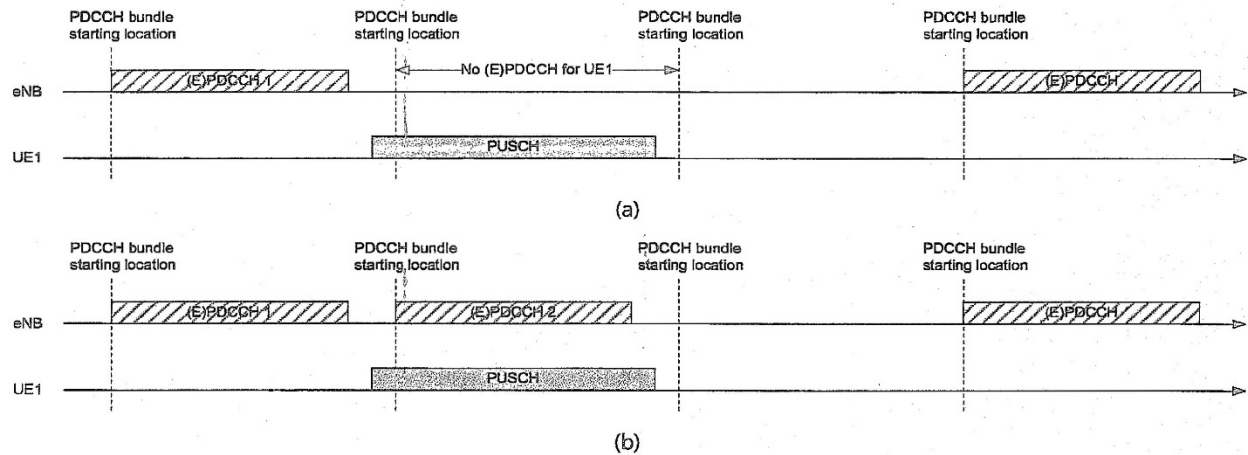
Or, if the timing of the subframe in which the PUSCH bundle must be transmitted overlaps with the timing of a subframe in which the transmission of a new PDCCH bundle can begin, the UE may attempt to transmit a PUSCH bundle and receive a new PDCCH bundle at the same time as illustrated in (b) of <FIG. 10>. At this time, the UE may assume that the UL grant is not transmitted to itself through the PDCCH bundle received while transmitting the PUSCH bundle.

Or, in this case, the UE may attempt to receive a new PDCCH bundle at the same time as transmitting the PUSCH bundle, and at this time, the UE may assume that the UL grant is not transmitted to itself if the transmission of the PDCCH bundle is terminated before the transmission of the PUSCH bundle is terminated. Or, the UE can assume that the UL grant is not

transmitted to itself if the transmission of the PDCCH bundle ends  $X$  subframes (e.g.  $X = 4$ ) before the subframe in which the transmission of the PUSCH bundle ends.

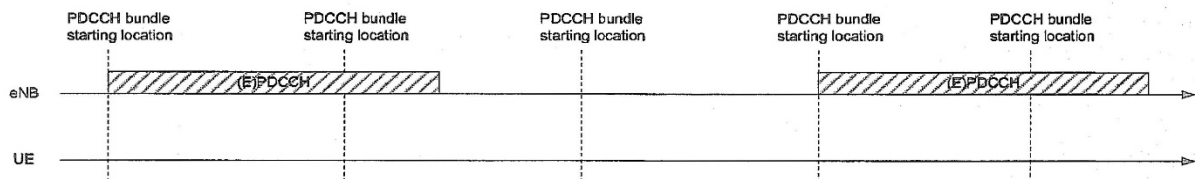


<Figure 9>



&lt; FIG. 10&gt;

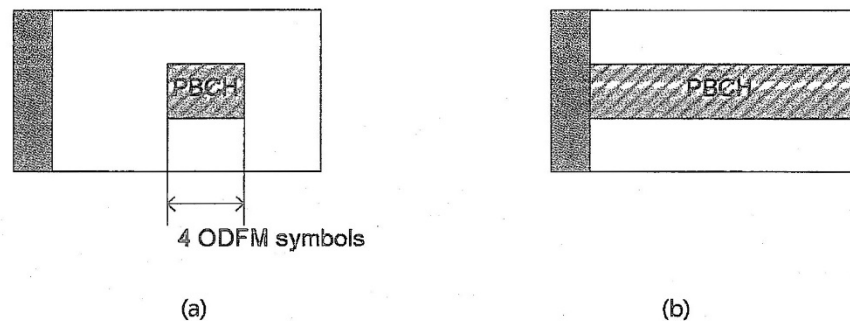
As shown in <FIG. 10>, the length of PDCCH bundle may have a value greater than the interval between subframe locations in which transmission of PDCCH bundle can start. In this case, the UE can assume that only one PDCCH is transmitted to it at a time.



&lt;FIG. 10&gt;

#### E. Conflict issue between PBCH and PDSCH

As mentioned earlier, for MTC UEs that require coverage enhancement, PDSCH can be transmitted over multiple consecutive or non-consecutive subframes. Similarly, for coverage enhancement of the MTC UE, PBCH can be transmitted over multiple subframes. At this time, in addition to the existing PBCH transmitted to the center 6RB of 4 OFDM symbols (OFDM symbols #7 to #10), as shown in (a) of <Figure 12> on the OFDM symbol #0 in each 10 msec radio frame, an additional PBCH can be transmitted in subframes (subframes #1 to #9 in each 10 msec radio frame) where the existing PBCH is not transmitted. At this time, the PBCHs that are transmitted to additional subframes may be transmitted through the RE resources through which the existing PBCH is transmitted, as shown in (a) of <FIG. 12>, or may be transmitted through the entire OFDM symbol area excluding the PDCCH area within the corresponding subframe, as illustrated in (b) of <Fig. 12>. At this time, in the present invention, a PBCH for an MTC UE that performs coverage enhancement transmitted as an additional subframe rather than the existing transmitted PBCH is called an additional PBCH.



&lt; FIG. 12&gt;

When PBCH is transmitted over multiple subframes for MTC UEs that require coverage enhancement, legacy UEs are unaware of the existence of additional PBCHs transmitted through subframes where PBCH was not previously transmitted. Therefore, when the eNodeB transmits PDSCH (or EPDCCH) to a legacy UE in a subframe where an additional PBCH for an MTC UE performing coverage enhancement is transmitted, the eNodeB must perform scheduling of the PDSCH (or EPDCCH) by avoiding the PRB region (e.g. center 6 PRB) where the additional PBCH is transmitted.

When PBCH is transmitted over multiple subframes for an MTC UE requiring coverage enhancement, if PDSCH (or EPDCCH) is transmitted to the MTC UE in the subframe where the additional PBCH is transmitted, scheduling of the PDSCH (or EPDCCH) can be performed by avoiding the PRB area (e.g. center 6 PRB) where the additional PBCH is transmitted.

When a PBCH is transmitted over multiple subframes for an MTC UE that requires coverage enhancement, the MTC UE may be aware of the transmission of these additional PBCHs and the transmission resources. In this case, if the transmission PRB area of the additional PBCH and the PDSCH overlap when transmitting the PDSCH to the MTC UE, the eNodeB may not transmit the PDSCH to the MTC UE in that subframe. In other words, if the PRB area of the additional PBCH and the PDSCH overlap, the UE can assume that no PDSCH is transmitted in the subframe (it may not expect transmission of the PDSCH). Or, when transmitting a PDSCH to an MTCUE, if the transmission PRB area of the additional PBCH and the PDSCH overlap, the eNodeB can transmit the PDSCH to the MTC UE by rate-matching it for the RE area where the additional PBCH is transmitted in the corresponding subframe. In other words, if the PRB area of the additional PBCH and the PDSCH overlap, the UE can assume that the PDSCH is transmitted in a rate-matched manner for the additional PBCH resource area in the corresponding subframe.

### DESCRIPTION OF THE RELATED ART

[0001] Universal mobile telecommunications system (UMTS) is a 3rd Generation (3G) asynchronous mobile communication system operating in wideband code division multiple access (WCDMA) based on European systems, global system for mobile communications (GSM) and general packet radio services (GPRS). The long-term evolution (LTE) of UMTS is under discussion by the 3rd generation partnership project (3GPP) that standardized UMTS.

[0002] The 3GPP LTE is a technology for enabling high-speed packet communications. Many schemes have been proposed for the LTE objective including those that aim to reduce user and provider costs, improve service quality, and expand and improve coverage and system capacity. The 3G LTE requires reduced cost per bit, increased service availability, flexible use of a frequency band, a simple structure, an open interface, and adequate power consumption of a terminal as an upper-level requirement.

[0003] FIG. 1 is a block diagram illustrating network structure of an evolved universal mobile telecommunication system (E-UMTS). The E-UMTS may be also referred to as an LTE system. The communication network is widely deployed to provide a variety of communication services such as voice (VoIP) through IMS and packet data.

[0004] As illustrated in FIG. 1, the E-UMTS network includes an evolved UMTS terrestrial radio access network (E-UTRAN), an Evolved Packet Core (EPC) and one or more user equipment. The E-UTRAN may include one or more evolved NodeB (eNodeB) 20, and a plurality of user equipment (UE) 10 may be located in one cell. One or more E-UTRAN mobility management entity (MME)/system architecture evolution (SAE) gateways 30 may be positioned at the end of the network and connected to an external network.

[0005] As used herein, "downlink" refers to communication from eNodeB 20 to UE 10, and "uplink" refers to communication from the UE to an eNodeB. UE 10 refers

to communication equipment carried by a user and may be also referred to as a mobile station (MS), a user terminal (UT), a subscriber station (SS) or a wireless device.

[0006] An eNodeB 20 provides end points of a user plane and a control plane to the UE 10. MME/SAE gateway 30 provides an end point of a session and mobility management function for UE 10. The eNodeB and MME/SAE gateway may be connected via an S1 interface.

[0007] The eNodeB 20 is generally a fixed station that communicates with a UE 10, and may also be referred to as a base station (BS) or an access point. One eNodeB 20 may be deployed per cell. An interface for transmitting user traffic or control traffic may be used between eNodeBs 20.

[0008] The MME provides various functions including NAS signalling to eNodeBs 20, NAS signalling security, AS Security control, Inter CN node signalling for mobility between 3GPP access networks, Idle mode UE Reachability (including control and execution of paging retransmission), Tracking Area list management (for UE in idle and active mode), PDN GW and Serving GW selection, MME selection for handovers with MME change, SGSN selection for handovers to 2G or 3G 3GPP access networks, Roaming, Authentication, Bearer management functions including dedicated bearer establishment, Support for PWS (which includes ETWS and CMAS) message transmission. The SAE gateway host provides assorted functions including Per-user based packet filtering (by e.g. deep packet inspection), Lawful Interception, UE IP address allocation, Transport level packet marking in the downlink, UL and DL service level charging, gating and rate enforcement, DL rate enforcement based on APN-AMBR. For clarity MME/SAE gateway 30 will be referred to herein simply as a "gateway," but it is understood that this entity includes both an MME and an SAE gateway.

[0009] A plurality of nodes may be connected between eNodeB 20 and gateway 30 via the S1 interface. The eNodeBs 20 may be connected to each other via an X2 interface and neighboring eNodeBs may have a meshed network structure that has the X2 interface.

[0010] FIG. 2 is a block diagram depicting architecture of a typical E-UTRAN and a typical EPC. As illustrated, eNodeB 20 may perform functions of selection for gateway 30, routing toward the gateway during a Radio Resource Control (RRC)

activation, scheduling and transmitting of paging messages, scheduling and transmitting of Broadcast Channel (BCCH) information, dynamic allocation of resources to UEs 10 in both uplink and downlink, configuration and provisioning of eNodeB measurements, radio bearer control, radio admission control (RAC), and connection mobility control in LTE\_ACTIVE state. In the EPC, and as noted above, gateway 30 may perform functions of paging origination, LTE-IDLE state management, ciphering of the user plane, System Architecture Evolution (SAE) bearer control, and ciphering and integrity protection of Non-Access Stratum (NAS) signaling.

[0011] FIGS. 3(a) and 3(b) are block diagrams depicting the user-plane protocol and the control-plane protocol stack for the E-UMTS. As illustrated, the protocol layers may be divided into a first layer (L1), a second layer (L2) and a third layer (L3) based upon the three lower layers of an open system interconnection (OSI) standard model that is well known in the art of communication systems.

[0012] The physical layer, the first layer (L1), provides an information transmission service to an upper layer by using a physical channel. The physical layer is connected with a medium access control (MAC) layer located at a higher level through a transport channel, and data between the MAC layer and the physical layer is transferred via the transport channel. Between different physical layers, namely, between physical layers of a transmission side and a reception side, data is transferred via the physical channel.

[0013] The MAC layer of Layer 2 (L2) provides services to a radio link control (RLC) layer (which is a higher layer) via a logical channel. The RLC layer of Layer 2 (L2) supports the transmission of data with reliability. It should be noted that the RLC layer illustrated in FIGS. 3(a) and 3(b) is depicted because if the RLC functions are implemented in and performed by the MAC layer, the RLC layer itself is not required. The PDCP layer of Layer 2 (L2) performs a header compression function that reduces unnecessary control information such that data being transmitted by employing Internet protocol (IP) packets, such as IPv4 or IPv6, can be efficiently sent over a radio (wireless) interface that has a relatively small bandwidth.

[0014] A radio resource control (RRC) layer located at the lowest portion of the third layer (L3) is only defined in the control plane and controls logical channels,

transport channels and the physical channels in relation to the configuration, reconfiguration, and release of the radio bearers (RBs). Here, the RB signifies a service provided by the second layer (L2) for data transmission between the terminal and the UTRAN.

[0015] As illustrated in FIG. 3(a), the RLC and MAC layers (terminated in an eNodeB 20 on the network side) may perform functions such as Scheduling, Automatic Repeat Request (ARQ), and Hybrid Automatic Repeat Request (HARQ). The PDCP layer (terminated in eNodeB 20 on the network side) may perform the user plane functions such as header compression, integrity protection, and ciphering.

[0016] As illustrated in FIG. 3(b), the RLC and MAC layers (terminated in an eNodeB 20 on the network side) perform the same functions for the control plane. As illustrated, the RRC layer (terminated in an eNodeB 20 on the network side) may perform functions such as broadcasting, paging, RRC connection management, Radio Bearer (RB) control, mobility functions, and UE measurement reporting and controlling. The NAS control protocol (terminated in the MME of gateway 30 on the network side) may perform functions such as a SAE bearer management, authentication, LTE\_IDLE mobility handling, paging origination in LTE\_IDLE, and security control for the signaling between the gateway and UE 10.

[0001] The RRC state may be divided into two different states such as a RRC\_IDLE and a RRC\_CONNECTED. In RRC\_IDLE state, the UE 10 may receive broadcasts of system information and paging information while the UE specifies a Discontinuous Reception (DRX) configured by NAS, and the UE has been allocated an identification (ID) which uniquely identifies the UE in a tracking area and may perform PLMN selection and cell re-selection. Also, in RRC-IDLE state, no RRC context is stored in the eNodeB.

[0002] In RRC\_CONNECTED state, the UE 10 has an E-UTRAN RRC connection and a context in the E-UTRAN, such that transmitting and/or receiving data to/from the network (eNodeB) becomes possible. Also, the UE 10 can report channel quality information and feedback information to the eNodeB.

[0003] In RRC\_CONNECTED state, the E-UTRAN knows the cell to which the UE 10 belongs. Therefore, the network can transmit and/or receive data to/from UE 10,

the network can control mobility (handover and inter-RAT cell change order to GERAN with NACC) of the UE, and the network can perform cell measurements for a neighboring cell.

[0004] In RRC\_IDLE mode, the UE 10 specifies the paging DRX (Discontinuous Reception) cycle. Specifically, the UE 10 monitors a paging signal at a specific paging occasion of every UE specific paging DRX cycle.

[0005] The paging occasion is a time interval during which a paging signal is transmitted. The UE 10 has its own paging occasion.

[0006] A paging message is transmitted over all cells belonging to the same tracking area. If the UE 10 moves from one tracking area to another tracking area, the UE will send a tracking area update message to the network to update its location.

[0007] A physical channel transfers signaling and data between layer L1 of a UE and eNB. As illustrated in FIG. 4, the physical channel transfers the signaling and data with a radio resource, which consists of one or more sub-carriers in frequency and one more symbols in time.

[0008] One sub-frame, which is 1.0 ms. in length, consists of several symbols. The particular symbol(s) of the sub-frame, such as the first symbol of the sub-frame, can be used for downlink control channel(PDCCH). PDCCHs carries dynamic allocated resources, such as PRBs and MCS

[0009] A transport channel transfers signaling and data between the L1 and MAC layers. A physical channel is mapped to a transport channel.

[0010] Downlink transport channel types include a Broadcast Channel (BCH), a Downlink Shared Channel (DL-SCH), a Paging Channel (PCH) and a Multicast Channel (MCH). The BCH is used for transmitting system information. The DL-SCH supports HARQ, dynamic link adaptation by varying the modulation, coding and transmit power, and both dynamic and semi-static resource allocation. The DL-SCH also may enable broadcast in the entire cell and the use of beamforming. The PCH is used for paging a UE. The MCH is used for multicast or broadcast service transmission.

[0011] Uplink transport channel types include an Uplink Shared Channel (UL-SCH) and Random Access Channel(s) (RACH). The UL-SCH supports HARQ and dynamic link adaptation by varying the transmit power and potentially modulation and

coding. The UL-SCH also may enable the use of beamforming. The RACH is normally used for initial access to a cell.

[0012] The MAC sublayer provides data transfer services on logical channels. A set of logical channel types is defined for different data transfer services offered by MAC. Each logical channel type is defined according to the type of information transferred.

[0013] Logical channels are generally classified into two groups. The two groups are control channels for the transfer of control plane information and traffic channels for the transfer of user plane information.

[0014] Control channels are used for transfer of control plane information only. The control channels provided by MAC include a Broadcast Control Channel (BCCH), a Paging Control Channel (PCCH), a Common Control Channel (CCCH), a Multicast Control Channel (MCCH) and a Dedicated Control Channel (DCCH). The BCCH is a downlink channel for broadcasting system control information. The PCCH is a downlink channel that transfers paging information and is used when the network does not know the location cell of a UE. The CCCH is used by UEs having no RRC connection with the network. The MCCH is a point-to-multipoint downlink channel used for transmitting MBMS control information from the network to a UE. The DCCH is a point-to-point bi-directional channel used by UEs having an RRC connection that transmits dedicated control information between a UE and the network.

[0015] Traffic channels are used for the transfer of user plane information only. The traffic channels provided by MAC include a Dedicated Traffic Channel (DTCH) and a Multicast Traffic Channel (MTCH). The DTCH is a point-to-point channel, dedicated to one UE for the transfer of user information and can exist in both uplink and downlink. The MTCH is a point-to-multipoint downlink channel for transmitting traffic data from the network to the UE.

[0016] Uplink connections between logical channels and transport channels include a DCCH that can be mapped to UL-SCH, a DTCH that can be mapped to UL-SCH and a CCCH that can be mapped to UL-SCH. Downlink connections between logical channels and transport channels include a BCCH that can be mapped to BCH or DL-SCH, a PCCH that can be mapped to PCH, a DCCH that can be mapped to DL-

SCH, and a DTCH that can be mapped to DL-SCH, a MCCH that can be mapped to MCH, and a MTCH that can be mapped to MCH.

[0017] It is known that different cause values may be mapped on the signature sequence used to send messages between a UE and eNB and that either Channel Quality Indicator (CQI) or path loss and cause or message size are candidates for inclusion in the initial preamble. FIG. 5 illustrates different messages exchanged between a UE and eNB during initial access.

[0018] When a UE wishes to access the network and determines a message to be transmitted, the message may be linked to a purpose and a cause value may be determined. The size of the ideal message number 3 illustrated in FIG. 5 may also be determined by identifying all optional information and different alternative sizes, such as by removing optional information, or an alternative "scheduling request" message may be used.

[0019] The UE acquires necessary information for the transmission of the preamble, UL interference, Pilot Transmit power and required Signal-to-Noise Ratio (SNR) for the preamble detection at the receiver or combinations thereof. This information must allow the calculation of the initial transmit power of the preamble. It is beneficial to transmit the uplink message in the vicinity of the preamble from a frequency point of view in order to ensure that the same channel is used for the transmission of the message.

[0020] The UE should take into account the uplink interference and the uplink path loss in order to ensure that the network receives the preamble with a minimum SNR. The uplink interference can be determined only in the ENodeB and, therefore, must be broadcast by the ENodeB and received by the UE prior to the transmission of the preamble. The uplink path loss can be considered to be similar to the downlink path loss and can be estimated by the UE from the received Rx (receiver) signal strength when the transmit power of some pilot sequence of the cell is known to the UE.

[0021] The required uplink SNR for the detection of the preamble would typically depend on the NodeB configuration, such as a number of Rx antennas and receiver performance. There may be advantages to transmitting the rather static Transmit power of the pilot and the necessary uplink SNR separately from the varying uplink

interference and possibly the power offset required between the preamble and the message.

[0022] The initial transmission power of the preamble can be roughly calculated according to the following formula:

[0023]  $\text{Transmit power} = \text{TransmitPilot} - \text{RxPilot} + \text{ULInterference} + \text{Offset} + \text{SNRRequired}$ .

[0024] Therefore, any combination of SNRRequired, ULInterference, TransmitPilot and Offset can be broadcast. In principle, only one value must be broadcast. This is essentially the method in current UMTS systems, although the UL interference in LTE will mainly be neighboring cell interference that is probably more constant than in UMTS.

[0025] The UE determines the initial uplink transmit power for the transmission of the preamble as explained above. The receiver in the eNB is able to estimate the absolute received power as well as the relative received power compared to the interference in the cell. The eNB will consider a preamble detected if the received signal power compared to the interference is above an eNB known threshold.

[0026] The UE performs power ramping in order to ensure that a UE can be detected even if the initially estimated transmission power for the preamble is not adequate. Another preamble will most likely be transmitted if no acknowledgement or a negative acknowledgement is received by the UE before the next random access attempt. The transmit power of the preamble can be increased, and / or the preamble can be transmitted on a different uplink frequency in order to increase the probability of detection. Therefore, the actual transmit power of the preamble that will be detected does not necessarily correspond to the initial transmit power of the preamble as initially calculated by the UE.

[0027] The UE must determine the possible uplink transport format. The transport format, which may include Modulation and Coding Scheme (MCS) and a number of resource blocks that should be used by the UE, depends mainly on two parameters, specifically the SNR at the eNB and the required size of the message to be transmitted.

[0028] In practice, a maximum UE message size, or payload, and a required minimum SNR correspond to each transport format. In UMTS, the UE determines before the transmission of the preamble whether a transport format can be chosen for the transmission according to the estimated initial preamble transmit power, the required offset between preamble and the transport block, the maximum allowed or available UE transmit power, a fixed offset and additional margin. The preamble in UMTS need not contain any information regarding the transport format selected by the UE since the network does not need to reserve time and frequency resources and, therefore, the transport format is indicated together with the transmitted message.

[0029] The eNB must be aware of the size of the message that the UE intends to transmit and the SNR achievable by the UE in order to select the correct transport format upon reception of the preamble and then reserve the necessary time and frequency resources. Therefore, the eNB cannot estimate the SNR achievable by the UE according to the received preamble because the UE transmit power compared to the maximum allowed or possible UE transmit power is not known to the eNB, given that the UE will most likely consider the measured path loss in the downlink or some equivalent measure for the determination of the initial preamble transmission power.

[0030] The eNB could calculate a difference between the path loss estimated in the downlink compared and the path loss of the uplink. However, this calculation is not possible if power ramping is used and the UE transmit power for the preamble does not correspond to the initially calculated UE transmit power. Furthermore, the precision of the actual UE transmit power and the transmit power at which the UE is intended to transmit is very low. Therefore, it has been proposed to code the path loss or CQI estimation of the downlink and the message size or the cause value in the uplink in the signature.

[0031]

[0032]

[0033] Brief Description of the Drawings

[0034] FIG. 1 illustrates a block diagram illustrating network structure of an evolved universal mobile telecommunication system (E-UMTS).

[0035] FIG. 2 illustrates a block diagram depicting architecture of a typical E-UTRAN and a typical EPC.

[0036] FIG. 3(a) illustrates the user-plane protocol for the E-UMTS.

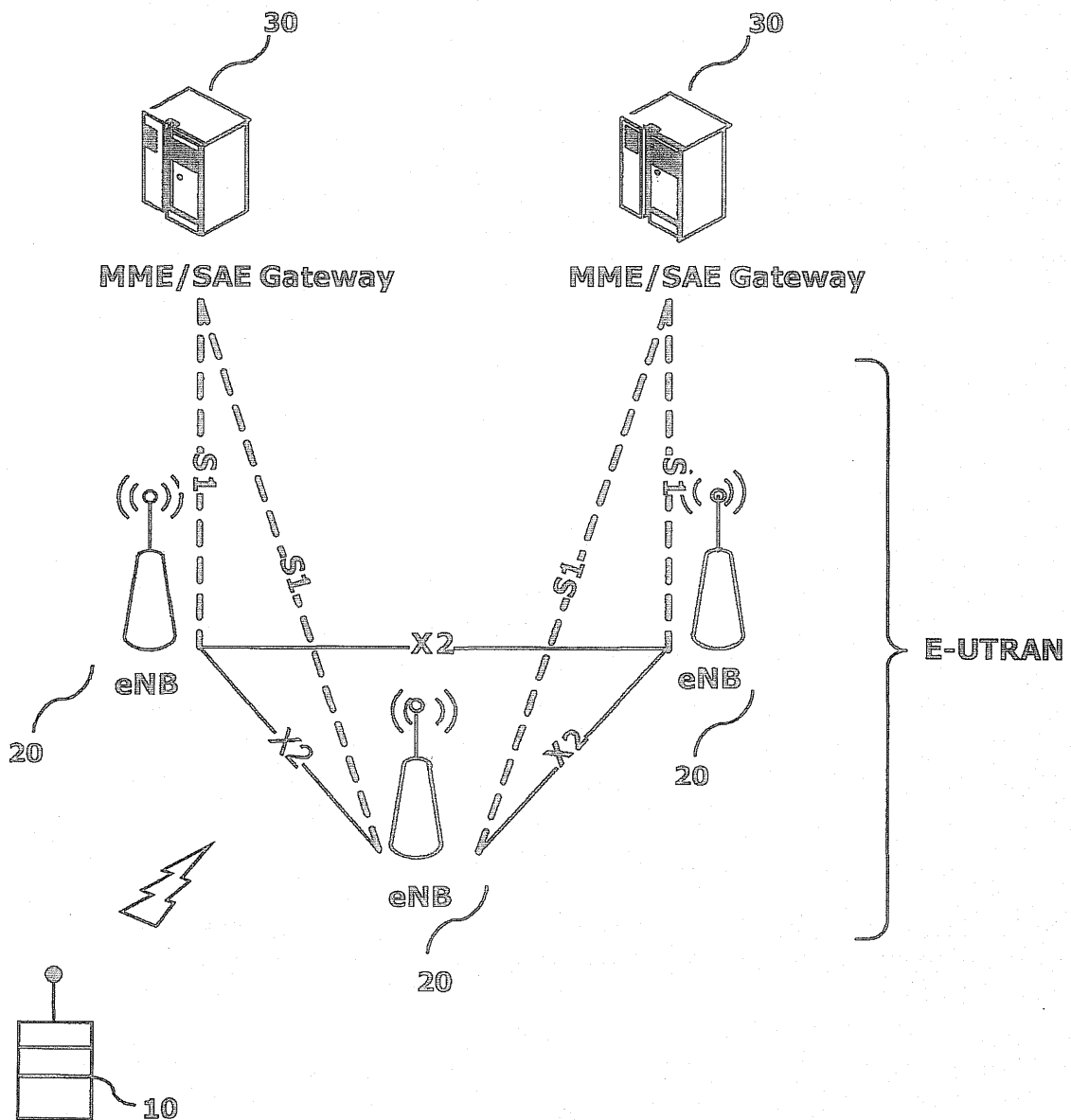
[0037] FIG. 3(b) illustrates the control-plane protocol stack for the E-UMTS

[0038] FIG. 4 illustrates a Structure of the physical channel.

[0039] FIG. 5 illustrates a Random Access procedure for E-UTRAN initial access.

[0040] FIG. 6 illustrates a block diagram of a mobile station (MS) or access terminal (AT) according to the present invention.

Fig. 1



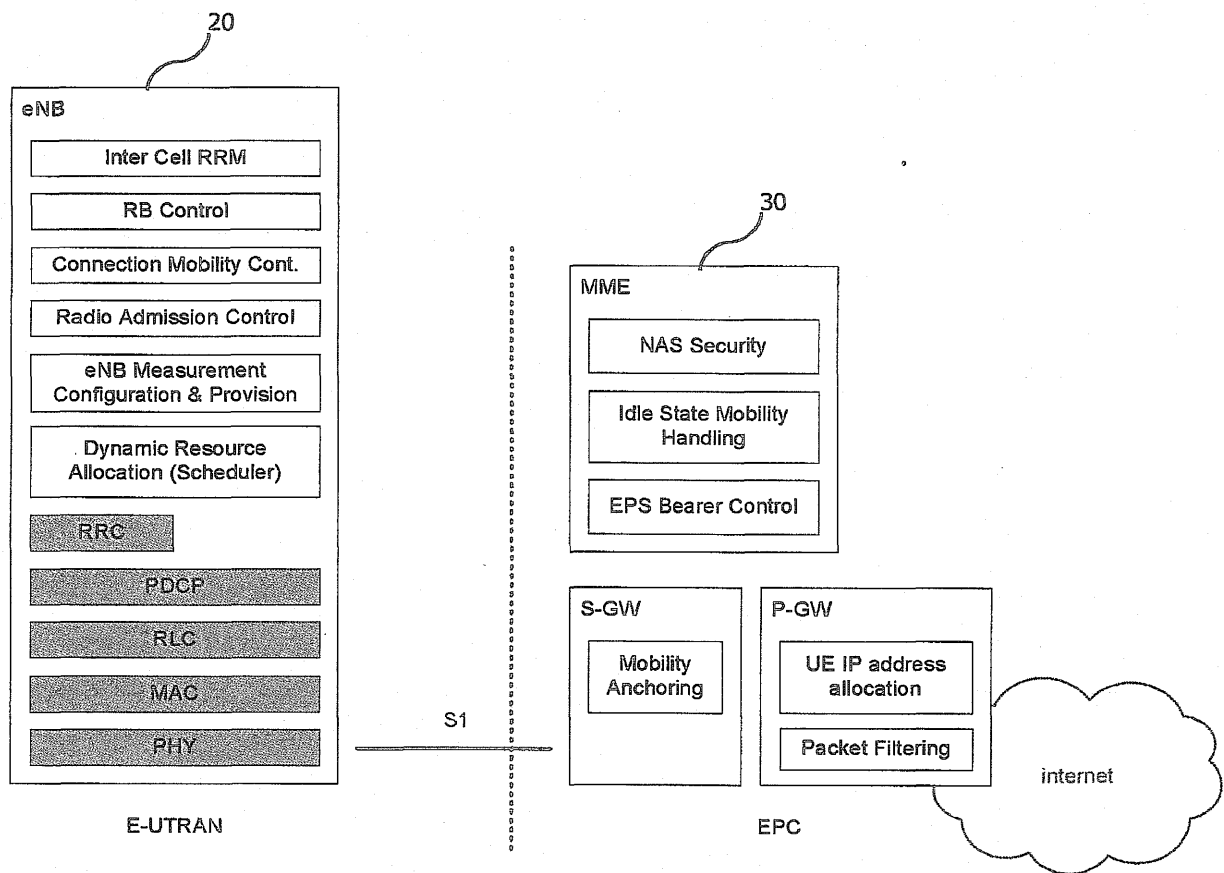


Fig. 3(a)

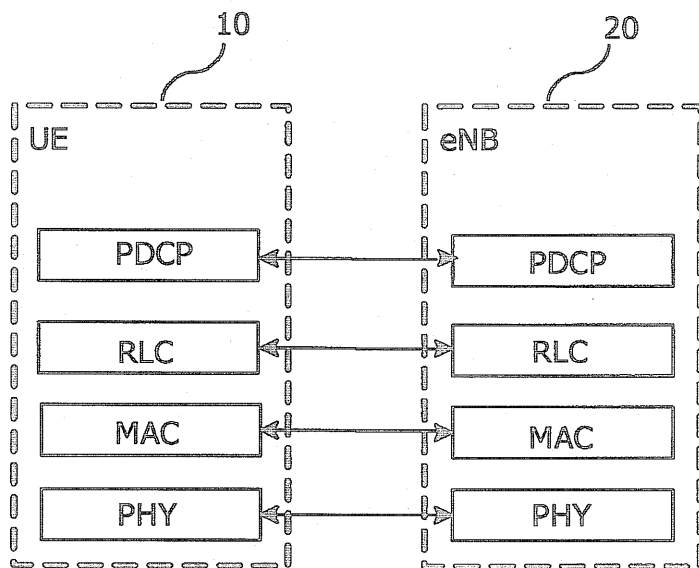


Fig. 3(b)

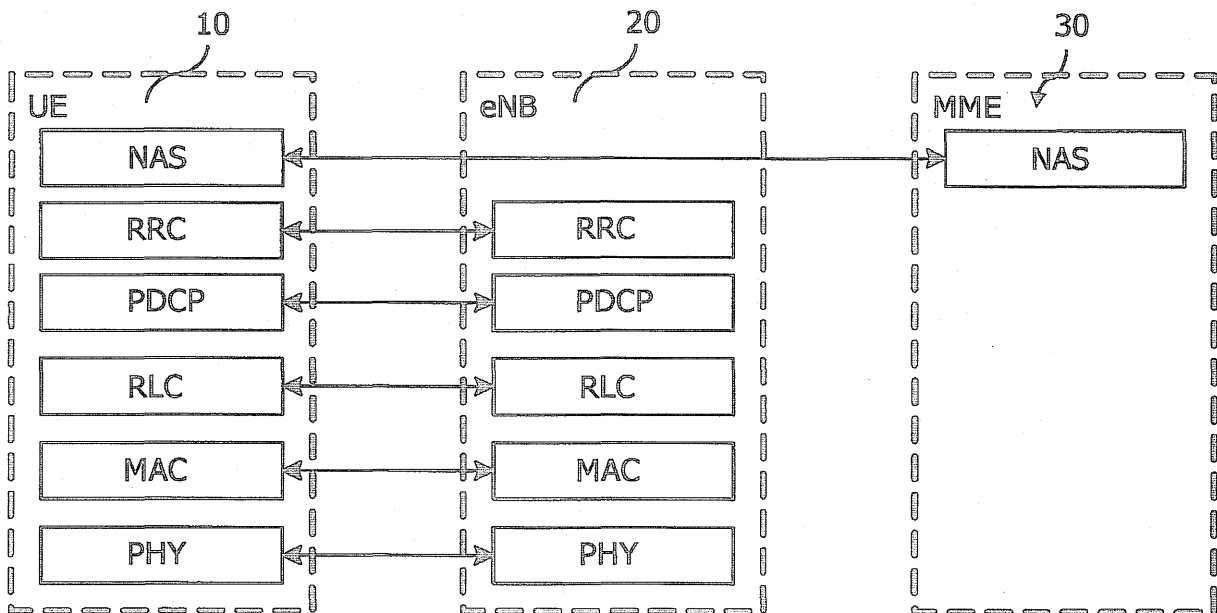


**Fig. 4**  
**Structure of the physical channel**

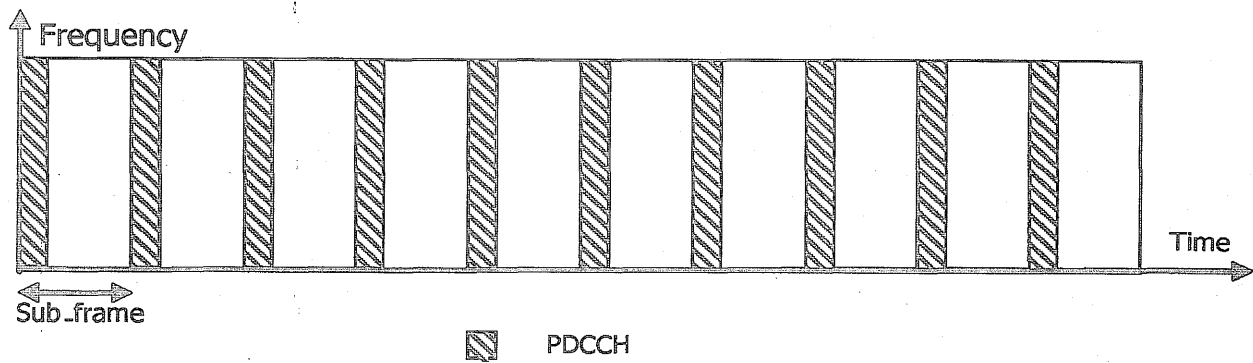


**Fig. 5**  
**Random Access procedure for E-UTRAN initial access**

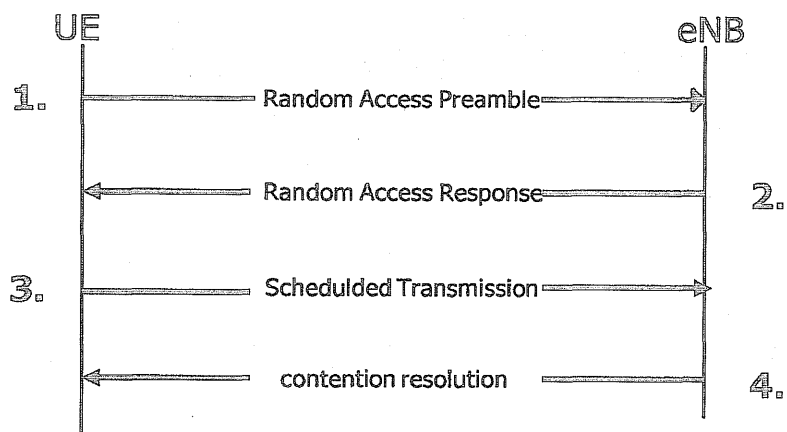


Fig. 6  
MOBILE STATION/ACCESS TERMINAL

