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APPLICATION NUMBER: 61/843,456

FILING DATE: July 08, 2013

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| <b>EFS ID:</b>                              | 16245747                                       |
| <b>Application Number:</b>                  | 61843456                                       |
| <b>International Application Number:</b>    |                                                |
| <b>Confirmation Number:</b>                 | 6204                                           |
| <b>Title of Invention:</b>                  | DOWNLINK DATA TRANSMISSION FOR LOW-COST MTC UE |
| <b>First Named Inventor/Applicant Name:</b> | Hyangsun YOU                                   |
| <b>Customer Number:</b>                     | 67487                                          |
| <b>Filer:</b>                               | Andrew S. Park                                 |
| <b>Filer Authorized By:</b>                 |                                                |
| <b>Attorney Docket Number:</b>              | UT13-0772-US                                   |
| <b>Receipt Date:</b>                        | 08-JUL-2013                                    |
| <b>Filing Date:</b>                         |                                                |
| <b>Time Stamp:</b>                          | 04:17:32                                       |
| <b>Application Type:</b>                    | Provisional                                    |

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| Document Number | Document Description | File Name | File Size(Bytes)/<br>Message Digest | Multi Part /.zip | Pages (if appl.) |
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## Electronic Acknowledgement Receipt

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|---------------------------------------------|------------------------------------------------|
| <b>EFS ID:</b>                              | 16245751                                       |
| <b>Application Number:</b>                  | 61843456                                       |
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| <b>Confirmation Number:</b>                 | 6204                                           |
| <b>Title of Invention:</b>                  | DOWNLINK DATA TRANSMISSION FOR LOW-COST MTC UE |
| <b>First Named inventor/Applicant Name:</b> | Hyangsun YOU                                   |
| <b>Customer Number:</b>                     | 67487                                          |
| <b>Filer:</b>                               | Andrew S. Park                                 |
| <b>Filer Authorized By:</b>                 |                                                |
| <b>Attorney Docket Number:</b>              | UT13-0772-US                                   |
| <b>Receipt Date:</b>                        | 08-JUL-2013                                    |
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| <b>Time Stamp:</b>                          | 04:24:48                                       |
| <b>Application Type:</b>                    | Provisional                                    |

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| Document Number        | Document Description                               | File Name            | File Size(Bytes)/<br>Message Digest       | Multi Part<br>/.zip | Pages (if appl.) |
| 1                      | Authorization to access Appl. by Trilateral Office | UT13-0772_sb0039.pdf | 223197                                    | no                  | 2                |
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| Inventor 2                                                                                                                                  |             |                                                |                                               |       | Remove    |
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| All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the <b>Add</b> button. |             |                                                |                                               |       |           |
| Title of Invention                                                                                                                          |             | DOWNLINK DATA TRANSMISSION FOR LOW-COST MTC UE |                                               |       |           |
| Attorney Docket Number (if applicable)                                                                                                      |             | UT13-0772-US                                   |                                               |       |           |
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| <b>Entity Status</b><br>Applicant asserts small entity status under 37 CFR 1.27 or applicant certifies micro entity status under 37 CFR 1.29                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                  |           |      |                                      |            |
| <input type="radio"/> Applicant asserts small entity status under 37 CFR 1.27                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                  |           |      |                                      |            |
| <input type="radio"/> Applicant certifies micro entity status under 37 CFR 1.29. Applicant must attach form PTO/SB/15A or B or equivalent.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                  |           |      |                                      |            |
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| Signature                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | /Andrew S. Park/ |           |      | Date (YYYY-MM-DD)                    | 2013-07-08 |
| First Name                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Andrew           | Last Name | Park | Registration Number (If appropriate) | 47841      |
| This collection of information is required by 37 CFR 1.51. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. <b>This form can only be used when in conjunction with EFS-Web. If this form is mailed to the USPTO, it may cause delays in handling the provisional application.</b>                                                                                                                                                                                                                                                                                                         |                  |           |      |                                      |            |

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PROVISIONAL APPLICATION FOR UNITED STATES PATENT IN THE NAMES OF

**Hyangsun YOU, Yunjung YI and Suckchel YANG**

for

**DOWNLINK DATA TRANSMISSION FOR LOW-COST MTC UE**

Customer Number: 67487

Attorney Docket Number: UT13-0772-US

Total Number of pages: 69 (including cover)

## Provisional Application

|                    |                                                |
|--------------------|------------------------------------------------|
| Title of Invention | Downlink data transmission for low-cost MTC UE |
|--------------------|------------------------------------------------|

### 1. Purpose of Invention

The present invention proposes downlink data transmission techniques for MTC UE with reduced PDSCH transmission BW for low-cost characteristics.

### 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

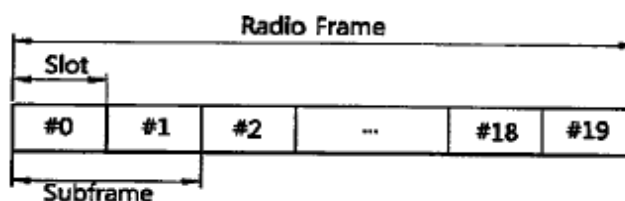


Figure 1. Structure of a radio frame of 3GPP LTE

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.

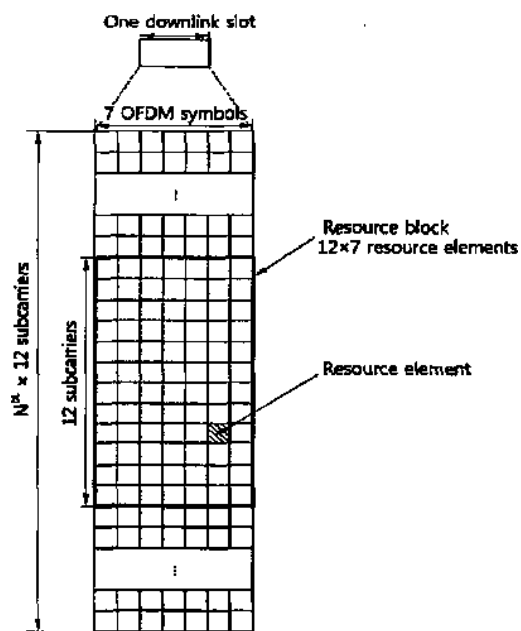


Figure 2. Resource grid for one downlink slot

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.

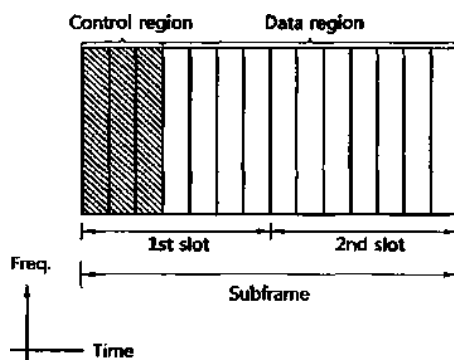


Figure 3. Structure of downlink subframe

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.

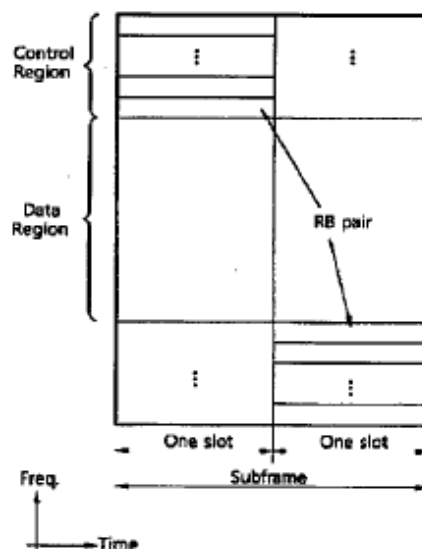


Figure 4. Structure of uplink subframe

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.

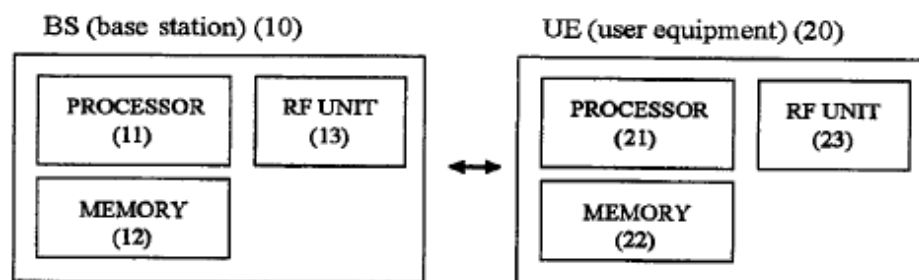


Figure 5. System for implementing present invention

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  $L \leq M \leq N$ .

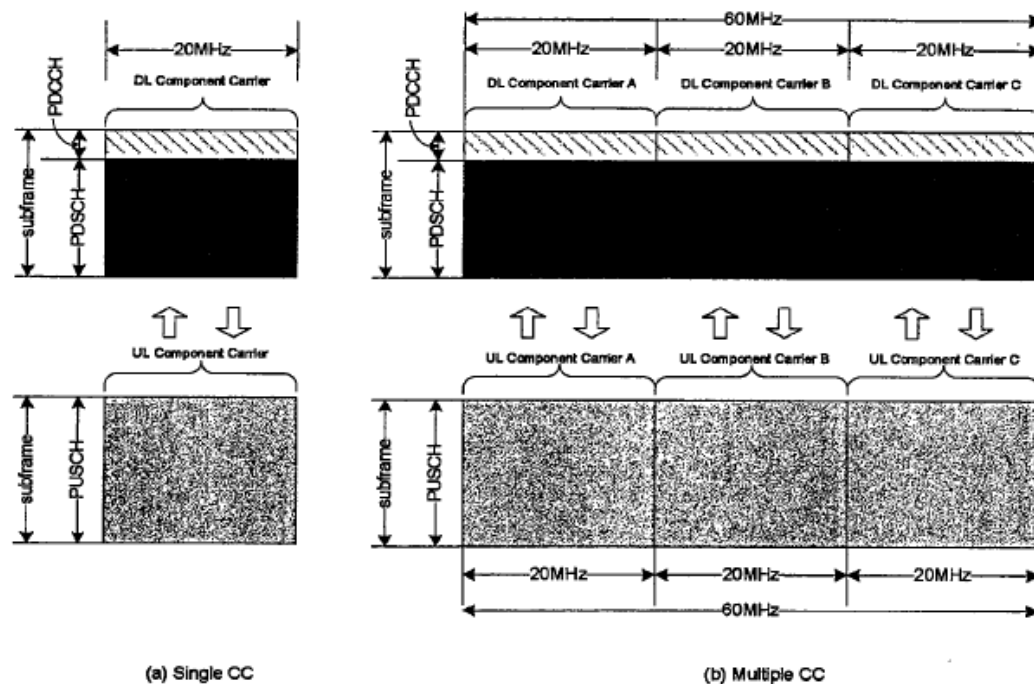


Figure 6. Subframe structure of 3GPP LTE Release-8 system and LTE-A system with CC aggregation

In a system supporting carrier aggregation, cells may be classified as shown in Figure 7 below.

A configured cell is a cell capable of carrier aggregation based on a measurement report among cells of a base station as shown in Figure 7 and is configured for each UE. The configured cell reserves, in advance, a resource for ACK/NACK transmission for PDSCH transmission. An activated cell is a cell configured to actually transmit PDSCH/PUSCH among configured cells, and performs CSI report and SRS transmission for PDSCH/PUSCH transmission. A de-activated cell is a cell that does not transmit PDSCH/PUSCH in response to a command from a base station or a timer operation, and, in this cell, CSI report and SRS transmission are stopped.

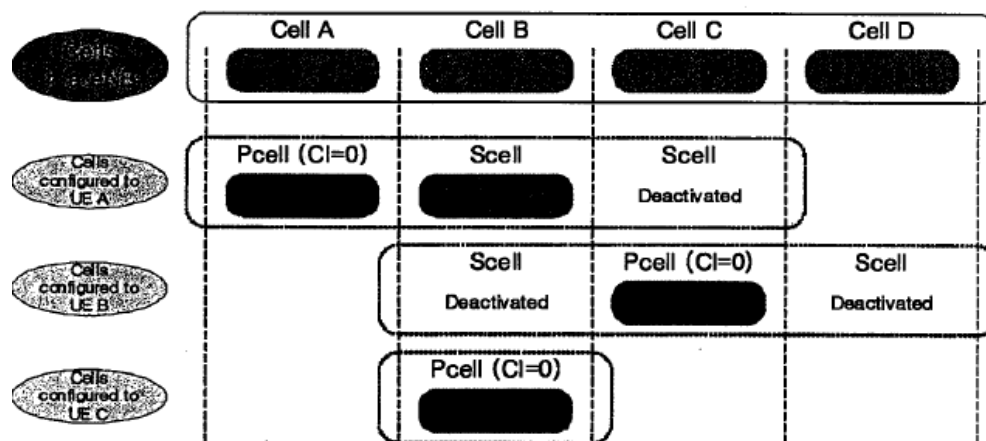


Figure 7. Configured cell, activated cell, de-activated cell

Synchronization signal (SS) in LTE-A FDD

SS is a signal configured with P-SS and S-SS and used to perform a cell search.

Figures 7 (a) and (b) are diagrams illustrating frame structures for the transmission of SS in the case of a system using basic CP and extended CP, respectively. SS is transmitted on the second slot of subframe 0 and subframe 5 in consideration of 4.6 ms that is a GSM frame length for facilitating inter-RAT measurement, and the boundary for a corresponding radio frame can be detected through S-SS. P-SS is transmitted on the last OFDM symbol of a corresponding slot, and S-SS is transmitted on the OFDM symbol immediately before P-SS. SS may transmit 504 physical cell IDs in total through a combination of 3 P-SSs and 168 S-SSs. Furthermore, SS and PBCH are transmitted within middle 6 RBs within a system bandwidth so as to be detected or decoded by a UE regardless of a transmission bandwidth.

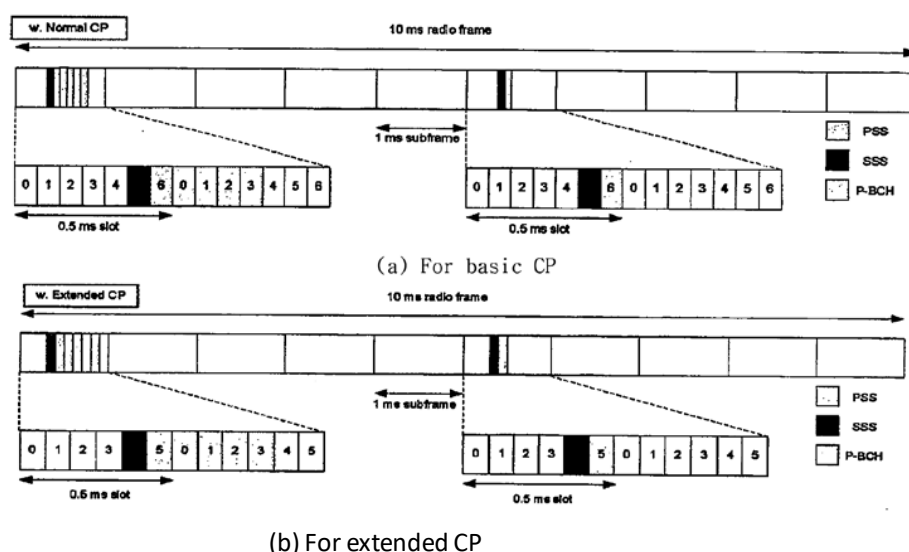


Figure 7. Frame structures of SS transmission

A transmission diversity method of SS only uses a single antenna port, and is not separately defined in a standard. That is, a single antenna transmission method or a transmission method transparent to a UE (e.g., PVS, TDTD, CDD) may be used.

#### a. P-SS code

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

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

9 remaining subcarriers in the middle 6 RBs (=72 subcarriers) are always transmitted as a value of 0, and facilitate the design of a filter for performing synchronization. In Equation (1), values of  $u=25, 29$ , and  $34$  are used in order to define 3 P-SSs in total.

Here, since 29 and 34 have a conjugate symmetry relationship, two correlations can be performed simultaneously. Here, the conjugate symmetry represent the relationship of following Equation (2), and by using this characteristic, a one-shot correlator for  $u=29$  and  $34$  can be implemented, and the overall amount of calculation can be reduced by about 33.3%.

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

b. S-SS code

For a sequence used for S-SS, two m-sequences having a length of 31 are interleaved bonded and two sequences are combined to transmit 168 cell group IDs. The m-sequence as the S-SS sequence is robust in a frequency selective environment, and may reduce the amount of calculation through fast m-sequence transform using Fast Hadamard Transform. Furthermore, configuring S-SS with two short codes has been proposed to reduce the amount of calculation of a terminal. Figure 8 is a diagram showing that two sequences in a logical domain are interleaved and mapped in a physical domain. When two m-sequences used for generating S-SS code are defined as S1 and S2, respectively, if S-SS of subframe 0 transmits a cell group ID with (S1, S2) two combinations, S-SS of subframe 5 is swapped and transmitted through (S2, S1), so that a 10 ms frame boundary can be identified. Here, the generation polynomial  $x^5+x^2+1$  is used as S-SS code, and a total of 31 codes can be generated through different circular shifts.

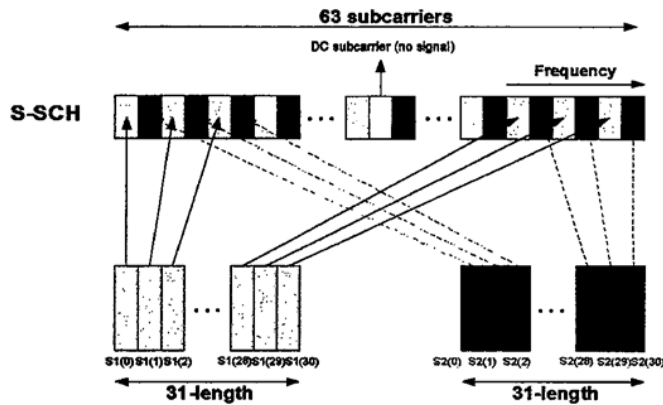


Figure 8. S-SS code generation method

In order to improve the performance of reception, two different P-SS-based sequences are defined and scrambled into S-SS, wherein two different sequences are scrambled into S1 and S2. Thereafter, S1-based scrambling code is defined, and scrambling is performed on S2. Here, the code of S-SS is swapped in units of 5 ms, but P-SS based scrambling code is not swapped. The P-SS-based scrambling code is defined as a 6-circular shift version based on a P-SS index in the m-sequence generated from the generation polynomial  $x^5+x^3+1$ . The S1-based scrambling code is defined as an 8-circular shift version based on the index of S1 in the m-sequence from the polynomial  $x^5+x^4+x^2+x^1+1$ .

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.

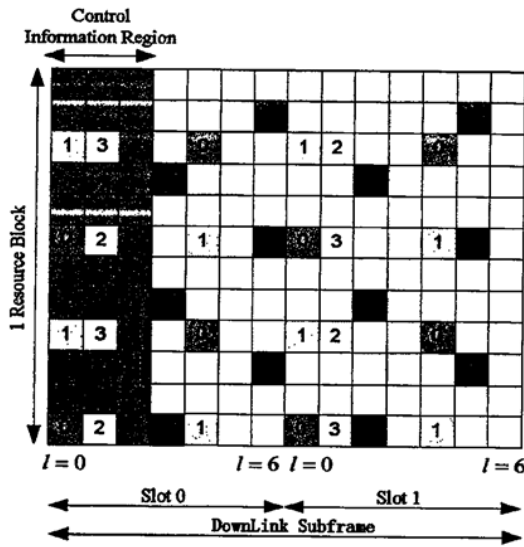


Figure 9

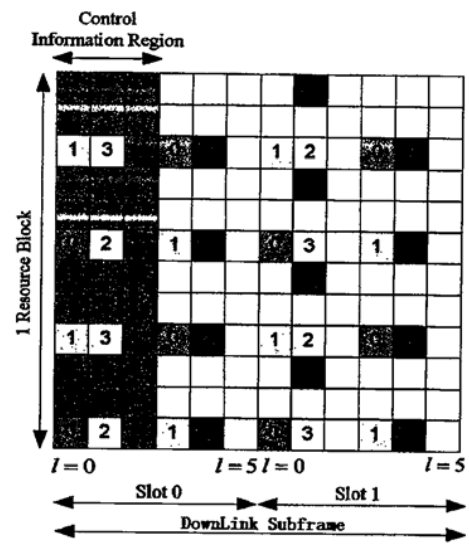


Figure 10

Figures 9 and 10 show the RS structure of both normal CP case and extended CP case, respectively for 3GPP LTE

system which supports up to four number of antenna. Here, , , ,  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, , 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

$$k = 6m + (v + v_{\text{shift}}) \bmod 6$$

$$l = \begin{cases} 0, N_{\text{symb}}^{\text{DL}} - 3 & \text{if } p \in \{0, 1\} \\ 1 & \text{if } p \in \{2, 3\} \end{cases}$$

$$m = 0, 1, \dots, 2 \cdot N_{\text{RB}}^{\text{DL}} - 1$$

$$m' = m + N_{\text{RB}}^{\text{max,DL}} - N_{\text{RB}}^{\text{DL}}$$

$$v = \begin{cases} 0 & \text{if } p = 0 \text{ and } l = 0 \\ 3 & \text{if } p = 0 \text{ and } l \neq 0 \\ 3 & \text{if } p = 1 \text{ and } l = 0 \\ 0 & \text{if } p = 1 \text{ and } l \neq 0 \\ 3(n_s \bmod 2) & \text{if } p = 2 \\ 3 + 3(n_s \bmod 2) & \text{if } p = 3 \end{cases}$$

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

DRS

Normal CP

Extend CP

$$\begin{aligned}
k &= (k') \bmod N_{sc}^{RB} + N_{sc}^{RB} \cdot n_{PRB} \\
k' &= \begin{cases} 4m' + v_{\text{shift}} & \text{if } l \in \{2,3\} \\ 4m' + (2 + v_{\text{shift}}) \bmod 4 & \text{if } l \in \{5,6\} \end{cases} \\
l &= \begin{cases} 3 & l' = 0 \\ 6 & l' = 1 \\ 2 & l' = 2 \\ 5 & l' = 3 \end{cases} \\
l' &= \begin{cases} 0,1 & \text{if } n_s \bmod 2 = 0 \\ 2,3 & \text{if } n_s \bmod 2 = 1 \end{cases} \\
m' &= 0,1,\dots,3N_{RB}^{PDSCH} - 1 \\
\end{aligned}
\quad
\begin{aligned}
k &= (k') \bmod N_{sc}^{RB} + N_{sc}^{RB} \cdot n_{PRB} \\
k' &= \begin{cases} 3m' + v_{\text{shift}} & \text{if } l = 4 \\ 3m' + (2 + v_{\text{shift}}) \bmod 3 & \text{if } l = 1 \end{cases} \\
l &= \begin{cases} 4 & l' \in \{0,2\} \\ 1 & l' = 1 \end{cases} \\
l' &= \begin{cases} 0 & \text{if } n_s \bmod 2 = 0 \\ 1,2 & \text{if } n_s \bmod 2 = 1 \end{cases} \\
m' &= 0,1,\dots,4N_{RB}^{PDSCH} - 1
\end{aligned}$$

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

Here,  $k$  and  $P$  means subcarrier index and antenna port. And  $N_{RB}^{DL}$ ,  $n_s$ ,  $N_{ID}^{\text{cell}}$  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 especially 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 signalling. 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%.

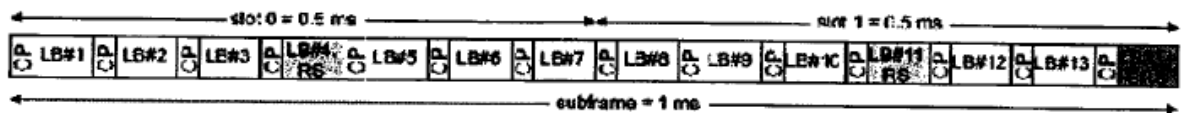


Figure 11. Uplink subframe configuration with SRS symbol

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 MIMO transmission schemes, i.e., open-loop MIMO operated without channel information and closed-loop MIMO. In the closed-loop MIMO, each of transmission/reception ends

performs beamforming based on channel information, i.e., CSI, in order to obtain multiplexing gain of MIMO antennas. In order to obtain CSI, a base station allocates a Physical Uplink Control Channel (PUCCH) or Physical Uplink Shared Channel (PUSCH) to the UE and instructs the UE to feed back downlink CSI.

CSI is classified into three types of information: Rank Indicator (RI), Precoding Matrix Index (PMI), and Channel Quality Indication (CQI). RI indicates rank information of a channel, and represents the number of streams that the UE receives via the same time-frequency resource. This value is determined to be dominant through long terms fading of a channel, and is thus fed back to the base station at a longer cycle than that of PMI and CQI values. Second, PMI is a value reflecting a spatial characteristic of a channel and indicates a precoding index of the base station preferred by the UE based on metrics such as SINR. CQI is a value indicating the strength of a channel and indicates a reception SINR that can be obtained when the base station uses PMI.

In an advanced communication system such as LTE-A, obtaining additional multi-user diversity using multi-user MIMO (MU-MIMO) is added. To this end, higher accuracy is required from the perspective of feedback. This is because since an interference channel is present between UEs multiplexed in an antenna domain in MU-MIMO, the feedback channel accuracy significantly affects interference with not only the UE that has provided feedback but also another UE multiplexed. Therefore, for LTE-A, it has been determined to separately design a final PMI as two types: long-term and/or wideband PMI, i.e., W1; and short-term and/or sub-band PMI, i.e., W2.

As an example of hierarchical codebook transformation that configures one final PMI from two pieces of channel information, there is codebook transformation using a long-term covariance matrix of a channel as below.

$$\mathbf{W} = \text{norm}(\mathbf{W}_1 \mathbf{W}_2) \quad (1)$$

In the above equation, W2 (=short term PMI) is a codeword of a codebook reflecting short-term channel information, W is a codeword of a final codebook, and norm(A) is a matrix obtained by normalizing each column of matrix A to 1.

Specific structures of existing W1 and W2 are as below.

(Equation 0)

$$\mathbf{W}_1(i) = \begin{bmatrix} \mathbf{X}_i & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_i \end{bmatrix}, \text{ where } \mathbf{X}_i \text{ is } N_t/2 \text{ by } M \text{ matrix.}$$

$$\mathbf{W}_2(j) = \begin{bmatrix} \mathbf{e}_M^k & \mathbf{e}_M^l & \mathbf{e}_M^m \\ \alpha_j \mathbf{e}_M^k & \beta_j \mathbf{e}_M^l & \gamma_j \mathbf{e}_M^m \end{bmatrix} \quad \text{(if rank=r), where } 1 \leq k, l, m \leq M \text{ and } k, l, m \text{ are integer.}$$

The codewords are designed so as to reflect correlation characteristics of a channel when cross-polarized antennas are used and densely arranged (when the distance between adjacent antennas is equal to or less than half a signal wavelength). The cross-polarized antennas may be classified into a horizontal antenna group and a vertical antenna group, wherein the two antenna groups are co-located and each have characteristics of a uniform linear array (ULA) antenna. Therefore, the correlations between antennas in each group have the same linear phase increment characteristic and the correlation between the antenna groups is characterized by phase rotation. Since a codebook is quantized values of channels, it is necessary to design a codebook reflecting channel characteristics corresponding to a source. For convenience of description, in the case of rank 1 codeword designed as the above structure, for example, it may be confirmed that such channel characteristics are reflected

in a codeword satisfying Equation 0.

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

In the above equation, a codeword is expressed as a vector of  $N_t$  (the number of Tx antennas) by 1, and composed of an upper vector  $\mathbf{X}_i(k)$  and a lower vector  $\alpha_j \mathbf{X}_i(k)$  representing the correlation characteristics of the horizontal antenna group and vertical antenna group, respectively. It is preferable that  $\mathbf{X}_i(k)$  is expressed as a vector having the linear phase increment characteristic reflecting the correlation characteristics between antennas in each antenna group, and for a representative example, a DFT matrix can be used.

Furthermore, higher channel accuracy is necessary for CoMP. In the case of CoMP JT, several base stations cooperatively transmit the same data to a specific UE. Therefore, the CoMP JT may be theoretically considered as a MIMO system in which antennas are geographically distributed. That is, also in the case of performing MU-MIMO in JT, channel accuracy of a high level is required in order to avoid interference between co-scheduled UE. Also in the case of CoMP CB, accurate channel information is necessary to avoid interference of a neighbor cell with a serving cell.

#### Restricted RLM and RRM/CSI measurement

As one interference coordination method, there is a time domain inter-cell interference coordination in which an aggressor cell uses a silent subframe (may also be referred to as an almost blank subframe (ABS)) for reducing the transmission power/activity of some physical channels (including an operation of setting to zero power) and a victim cell schedules a UE considering the above. In this case, from the standpoint of a victim cell UE, an interference level is significantly varies depending on a subframe. In this situation, in order to perform a radio resource management (RRM) operation of measuring more accurate radio link monitoring (RLM) or RSRP/RSRQ in each subframe or to measure channel state information (CSI) for link adaptation, the monitoring/measurement is required to be restricted to sets of subframes having a uniform interference characteristic. In the 3GPP LTE system, restricted RLM and RRM/CSI measurement have been defined as below.

#### 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 a periodic 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

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

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  $m' = m + M^{(L)} \cdot n_{CI}$  where  $n_{CI}$  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  $n_{CCE}$  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  $Y_1 = n_{RNTI} \neq 0$ ,  $A = 39827$ ,  $D = 65537$  and  $k = \lfloor n_s/2 \rfloor$ ,  $n_s$  is the slot number within a radio frame. The RNTI value used for  $n_{RNTI}$  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 $M^{(1)}$ |
|-------------|--------------------------|---------------|--------------------------------------|
|             | Aggregation level $L$    | Size [in CCs] |                                      |
| 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 an LTE-A system, it is considered to transmit, through a specific UL CC, a plurality of ACK/NACK information/signals for a plurality of PDSCHs transmitted through a plurality of DL CCs. To this end, unlike ACK/NACK transmission using PUCCH format 1a/1b in legacy Rel-8 LTE, it may be considered that the plurality of pieces of ACK/NACK information are channel-coded (e.g., Reed-Muller code, Tail-biting convolutional code, etc.) and the plurality of pieces of ACK/NACK information/signals are transmitted using PUCCH format 2 or a new PUCCH format (i.e., E-PUCCH format) of a modified type based on Block-spreading.

#### - Block-spreading

A block-spreading scheme modulates control information/signal (e.g., ACK/NACK, etc.) for transmission using an SC-FDMA scheme unlike PUCCH format 1 or 2 series of legacy LTE. In this scheme, a symbol sequence is time-domain spread by an orthogonal cover code (OCC) as illustrated in Figure 10, and, in this case, various control signals of multiple UEs may be multiplexed to the same RB using the OCC. In above PUCCH format 2, one symbol sequence is transmitted in the time domain and UE multiplexing is performed using a cyclic shift (i.e., CCS) of a CAZAC sequence, whereas, in a block-spreading based E-PUCCH format, one symbol sequence is transmitted in the frequency domain and UE multiplexing is performed using OCC based time-domain spreading. As an example, as illustrated in Figure 10, one symbol sequence is transmitted by generating five SC-FDMA symbols using a length-5 (SF=5) OCC. Although a total of two RS symbols are used during one slot in the example of the figure, a variety of applications, such as a scheme using three RS symbols and an OCC of SF=4, may be considered. Here, the RS symbols may be generated from a CAZAC sequence having a specific cyclic shift and may be transmitted in a form of applying (multiplying) a specific OCC to a plurality of RS symbols in the time domain.

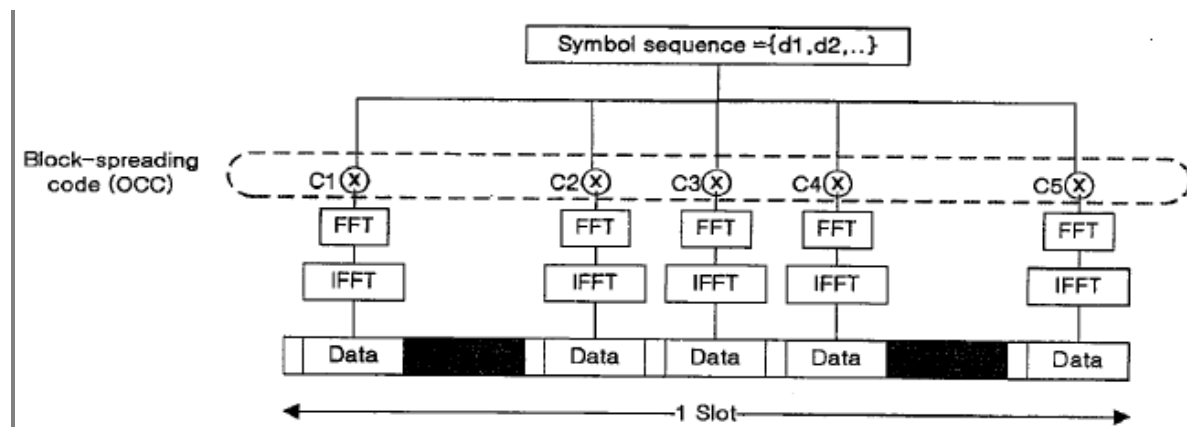


Figure 10. Block-spreading E-PUCCH format (i.e., PUCCH format 3)

For convenience of description, such a channel coding based scheme for transmitting a plurality of ACK/NACKs using PUCCH format 2 or E-PUCCH format is referred to as a “multi-bit ACK/NACK coding” transmission method. In this method, an ACK/NACK coded block generated by channel-coding ACK/NACK or DTX information (indicating that a PDCCH cannot be received/detected) for a PDSCH of multiple DL CCs is transmitted. For example, if the terminal receives two codewords (CWs) by operating in an SU-MIMO mode on a certain DL CC, the terminal may transmit a total of four feedback states of ACK/ACK, ACK/NACK, NACK/ACK, and NACK/NACK per CW on the CC or may have up to five feedback states including DTX. If the terminal receives a single CW, the terminal may have up to three states of ACK, NACK, and DTX (if NACK and DTX are identically processed, the terminal may have a total of two states of ACK and NACK/DTX). Therefore, if the terminal aggregates up to five DL CCs and operates in an SU-MIMO mode on all CCs, the terminal may have up to  $5^5$  transmittable feedback states and an ACK/NACK payload size for representing these states is a total of 12 bits (if DTX and NACK are identically processed, the number of feedback states is  $4^5$  and the ACK/NACK payload size for representing these states is a total of 10 bits). The above ACK/NACK multiplexing (i.e., ACK/NACK selection) method applied in a legacy Rel-8 TDD system basically considers an implicit ACK/NACK selection scheme which uses an implicit PUCCH resource corresponding to a PDCCH for scheduling each PDSCH of a corresponding UE (i.e., which is linked with a lowest CCE index) in order to secure a PUCCH resource of each UE.

Meanwhile, an LTE-A FDD system basically considers transmission of a plurality of ACK/NACKs for multiple PDSCHs transmitted on a plurality of DL CCs through one particular UE-specifically configured UL CC. To this end, an “ACK/NACK selection” scheme is considered in which an implicit PUCCH resource linked with a PDCCH for scheduling a specific DL CC or partial or all DL CCs (i.e., linked with a lowest CCE index  $n_{CCE}$  or linked with  $n_{CCE}$  and  $n_{CCE}+1$ ) is used or a combination of the implicit PUCCH resource and an explicit PUCCH resource prescheduled for each UE through RRC signal is used.

Meanwhile, a situation in which a plurality of CCs are aggregated (CA) may be considered also in an LTE-A TDD system. Accordingly, it is considered that a plurality of ACK/NACK information/signals for a plurality of PDSCHs transmitted through a plurality of DL subframes and a plurality of CCs are transmitted through a specific CC (i.e., A/N CC) in UL subframes corresponding to the plural of DL subframes. In this case, as opposed to LTE-A FDD, a scheme (i.e., full ACK/NACK) may be considered in which a plurality of ACK/NACKs corresponding to the maximum number of CWs which can be transmitted on all CCs allocated to the UE are transmitted in all of a plurality of DL subframes (i.e., SF), or, a scheme (i.e., bundled ACK/NACK) may be considered in which the number of ACK/NACKs for transmission is reduced by applying ACK/NACK bundling with respect to a CW and/or CC and/or SF domain. (Here, CW bundling represents that ACK/NACK bundling for a CW per CC is applied to each DL SF, and CC bundling represents that ACK/NACK bundling for all or partial CCs is applied to each DL SF, and, in addition, SF bundling

represents that ACK/NACK bundling for all or partial DL SFs is applied to each CC. In particular, as the SF bundling method, an “ACK-counter” scheme indicating the total number of ACKs (or a partial number of ACKs) per CC with respect to all PDSCHs or DL grant PDCCHs received on each of CCs may be considered. Here, a “multi-bit ACK/NACK coding” or “ACK/NACK selection” based ACK/NACK transmission scheme may be configurably applied according to an ACK/NACK payload per UE, i.e., an ACK/NACK payload size for full or bundled ACK/NACK transmission configured per 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

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

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

$$n_{PUCCH}^{(1,p=p_0)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{CCE} + N_{PUCCH}^{(1)} \quad \text{for antenna port } p = p_0, \text{ where}$$

$$N_{PUCCH}^{(1)} \text{ is configured by higher layers, } N_c = \max \left\{ 0, \left\lfloor \frac{N_{RB}^{DL} \cdot (N_{sc}^{RB} \cdot c - 4)}{36} \right\rfloor \right\}, \text{ and } n_{CCE} \text{ is the}$$

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

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

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  $n_{\text{PUCCH}}^{(1,p)}$  with the value of  $n_{\text{PUCCH}}^{(1,p)}$  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  $n_{\text{PUCCH}}^{(1,p=p_0)}$  for antenna port  $p_0$  and the second PUCCH resource  $n_{\text{PUCCH}}^{(1,p=p_1)}$  for antenna port  $p_1$ , otherwise, the PUCCH resource value maps to a single PUCCH resource  $n_{\text{PUCCH}}^{(1,p=p_0)}$  for antenna port  $p_0$ .

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

| UL-DL 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

$$N_c \leq n_{\text{CCE},i} < N_{c+1}, \quad N_c = \max \left\{ 0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor \right\}, \quad n_{\text{CCE},i} \text{ is the number}$$

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 layers 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

$n_{\text{PUCCH},i}^{(1)}$  in sub-frame  $n$  using PUCCH format 1b. The value of  $b(0), b(1)$  and the PUCCH resource

$n_{\text{PUCCH},i}^{(1)}$  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                 | $n_{\text{PUCCH},0}^{(1)}$ | 1,0          |
| ACK, NACK/DTX            | $n_{\text{PUCCH},1}^{(1)}$ | 1,1          |
| NACK/DTX, ACK            | $n_{\text{PUCCH},0}^{(1)}$ | 0,1          |
| NACK, NACK/DTX           | $n_{\text{PUCCH},1}^{(1)}$ | 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,  $n_{\text{PUCCH},j}^{(1)}$  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,  $n_{\text{PUCCH},j}^{(1)}$  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  $n_{\text{PUCCH},j}^{(1)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$ , where  $c$  is selected from  $\{0, 1, 2, 3\}$

such that  $N_c \leq n_{\text{CCE},m} < N_{c+1}$ ,  $N_c = \max\left\{0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor\right\}$ , 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  $n_{\text{PUCCH},j}^{(1)}$  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  $n_{\text{PUCCH},j}^{(1)}$ , 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  $(n_{\text{PUCCH},j}^{(1)}, n_{\text{PUCCH},j+1}^{(1)})$ , otherwise, the PUCCH resource value maps to a single PUCCH resource  $n_{\text{PUCCH},j}^{(1)}$ . 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                       | $n_{\text{PUCCH},3}^{(1)}$ | 0,1          |
| ACK, NACK/DTX, NACK/DTX, NACK/DTX                  | $n_{\text{PUCCH},0}^{(1)}$ | 1,1          |
| NACK/DTX, ACK, ACK, ACK                            | $n_{\text{PUCCH},0}^{(1)}$ | 0,0          |
| NACK/DTX, ACK, ACK, NACK/DTX                       | $n_{\text{PUCCH},1}^{(1)}$ | 0,1          |
| NACK/DTX, ACK, NACK/DTX, ACK                       | $n_{\text{PUCCH},2}^{(1)}$ | 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(j)                        |                                     |                                      |                                       |
|---|------------------------------------|-------------------------------------|--------------------------------------|---------------------------------------|
|   | 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
 
$$n_{\text{PUCCH},i}^{(1)} = (M-m-1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$$
 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  $n-k_m$  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,  $i=0$  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'.

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

|                                                              |                            |                            |     |         |
|--------------------------------------------------------------|----------------------------|----------------------------|-----|---------|
| (ACK NACK/DTX, any, any),<br>except for (ACK, DTX, DTX, DTX) | ACK, ACX, NACK/DTX,<br>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, DTK, 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, DTK, 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),<br>except for (ACK, DTX, DTX, DTX) | ACK, DTK, DTK, DTX                                              | $n_{\text{PUCCH},2}^{(1)}$ | 0,0 | 0,0,0,1 |
| (ACK, NACK/DTX, any, any),<br>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,<br>any                                      | $n_{\text{PUCCH},1}^{(1)}$ | 1,0 | 1,1,0,0 |
| ACK, ACK, ACK, NACK/DTX                                       | (ACK, NACK/DTX any,<br>any), except for (ACK,<br>DTX, DTX, DTX) | $n_{\text{PUCCH},1}^{(1)}$ | 1,0 | 1,1,0,0 |
| ACK, ACK, NACK/DTX, any                                       | NACK/DTX, any, any,<br>any                                      | $n_{\text{PUCCH},1}^{(1)}$ | 0,1 | 1,0,0,0 |
| ACK, ACK, NACK/DTX, any                                       | (ACK, NACK/DTX any,<br>any), except for (ACK,<br>DTX, DTX, DTX) | $n_{\text{PUCCH},1}^{(1)}$ | 0,1 | 1,0,0,0 |
| ACK, DTX, DTX, DTX                                            | NACK/DTX, any, any,<br>any                                      | $n_{\text{PUCCH},0}^{(1)}$ | 1,1 | 0,1,0,0 |
| ACK, DTX, DTX, DTX                                            | (ACK, NACK/DTX any,<br>any), except for (ACK,<br>DTX, DTX, DTX) | $n_{\text{PUCCH},0}^{(1)}$ | 1,1 | 0,1,0,0 |
| ACK, ACK, ACK, ACK                                            | NACK/DTX any, any,<br>any                                       | $n_{\text{PUCCH},0}^{(1)}$ | 1,1 | 0,1,0,0 |
| ACK, ACK, ACK, ACK                                            | (ACK, NACK/DTX any,<br>any), except for (ACK,<br>DTX, DTX, DTX) | $n_{\text{PUCCH},0}^{(1)}$ | 1,1 | 0,1,0,0 |
| NACK, any, any, any                                           | NACK/DTX, any, any,<br>any                                      | $n_{\text{PUCCH},0}^{(1)}$ | 0,0 | 0,0,0,0 |

|                                                            |                                                            |                            |     |         |
|------------------------------------------------------------|------------------------------------------------------------|----------------------------|-----|---------|
| NACK, Any, any, any                                        | (ACK, NACK/DTK any, any), except for (ACK, DTK 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/DTK any, any), 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), 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

$$n_{\text{PUCCH}}^{(1,p=p_0)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)} \text{ for antenna port } p = p_0, \text{ where}$$

$$N_{\text{PUCCH}}^{(1)} \text{ is configured by higher layers, } c \text{ is selected from } \{0, 1, 2, 3\} \text{ such that } N_c \leq n_{\text{CCE},m} < N_{c+1},$$

$$N_c = \max \left\{ 0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor \right\}, \text{ and } n_{\text{CCE},m} \text{ is the number of the first CCE used for transmission of the}$$

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

$$\text{given by } n_{\text{PUCCH}}^{(1,p=p_1)} = n_{\text{PUCCH}}^{(1,p=p_0)} + 1$$

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  $n_{\text{PUCCH}}^{(1,p)}$  with the value of  $n_{\text{PUCCH}}^{(1,p)}$  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

$n_{\text{PUCCH}}^{(1,p=p_0)}$  for antenna port  $p_0$  and the second PUCCH resource  $n_{\text{PUCCH}}^{(1,p=p_1)}$  for antenna port  $p_1$ , otherwise, the PUCCH resource value

maps to a single PUCCH resource  $n_{\text{PUCCH}}^{(1,p=p_0)}$  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  $n_{\text{PUCCH}}^{(1)}$  selected from  $A$  PUCCH resources  $n_{\text{PUCCH},i}^{(1)}$  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  $n_{\text{PUCCH},0}^{(1)}$  is determined according to higher layer configuration. The PUCCH resource  $n_{\text{PUCCH},1}^{(1)}$  is determined as  $n_{\text{PUCCH},1}^{(1)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$ , where

$$N_{\text{PUCCH}}^{(1)} \text{ is configured by higher layers, } c \text{ is selected from } \{0, 1, 2, 3\} \text{ such that}$$

$$N_c \leq n_{\text{CCE},m} < N_{c+1}, N_c = \max \left\{ 0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor \right\}, \text{ and } n_{\text{CCE},m} \text{ is the number of the}$$

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

$n_{\text{PUCCH},2}^{(1)}$  is determined as  $n_{\text{PUCCH},2}^{(1)} = n_{\text{PUCCH},1}^{(1)} + 1 \cdot \text{HARQ-ACK}(0)$  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 DC 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  $n_{\text{PUCCH},j+1}^{(1)}$  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 $(n_{\text{PUCCH},j}^{(1)}, n_{\text{PUCCH},j+1}^{(1)})$ |
|----------------------------------|----------------------------------------------------------------------------------------|
| '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               |

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.

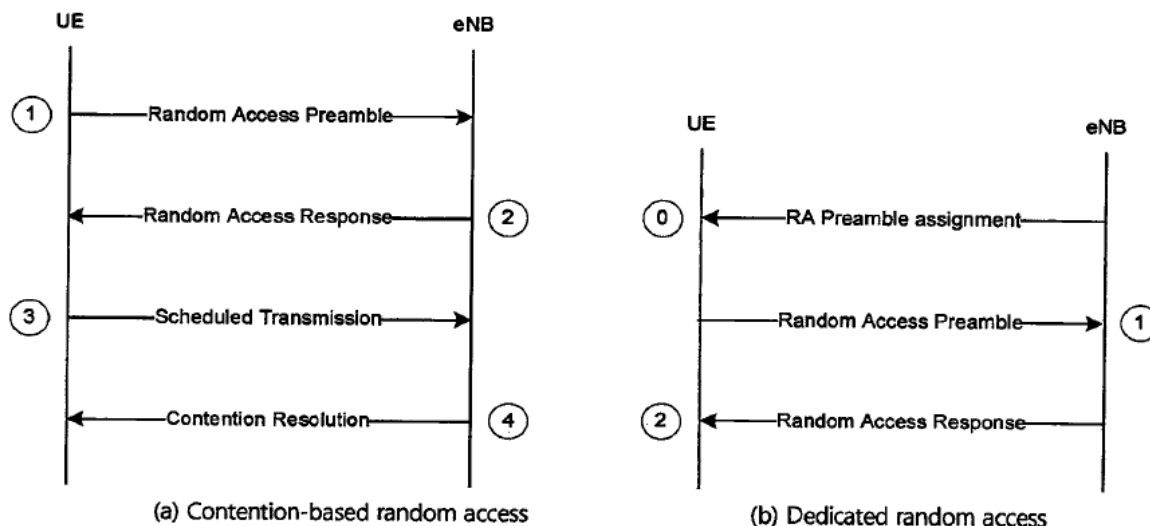


Figure 11. Random access procedures of 3GPP LTE Release-8 system

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 as below: "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 may be modified into an expression for a channel as below:

*"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*

In the present invention, the above QC-related definitions are not differentiated. That is, the QC concept may comply with one of the above definitions. Alternatively, the QC concept definition may be changed into another similar form in which antenna ports having an established QC assumption may be assumed to be transmitted at the co-location (e.g., UE may assume antenna ports to be antenna ports transmitted at the same transmission point). The spirit of the present invention includes such similar modifications. In the present invention, the QC-related definitions are interchangeably used for convenience of description.

In accordance with the above definitions, the UE cannot assume the same large-scale channel properties between corresponding antenna ports (APs) with respect to "non-quasi-co-located (NQC) antenna ports". That is, in this case, a typical UE receiver should perform independent processing for timing acquisition and tracking, frequency offset estimation and compensation, delay estimation, and Doppler estimation for each configured non-quasi-co-located (NQC) AP.

There are advantages in that UE can perform the following operations between APs capable of assuming QC:

With respect to the *Delay spread & Doppler spread*, the UE may identically apply the results of power-delay profile, delay spread and Doppler spectrum, and Doppler spread estimation for any one antenna port to a Wiener filter which is used upon channel estimation for another port.

With respect to the *Frequency shift & received timing*, the UE may perform time and frequency synchronization on any one antenna port and then apply the same synchronization to the demodulation of other antenna ports.

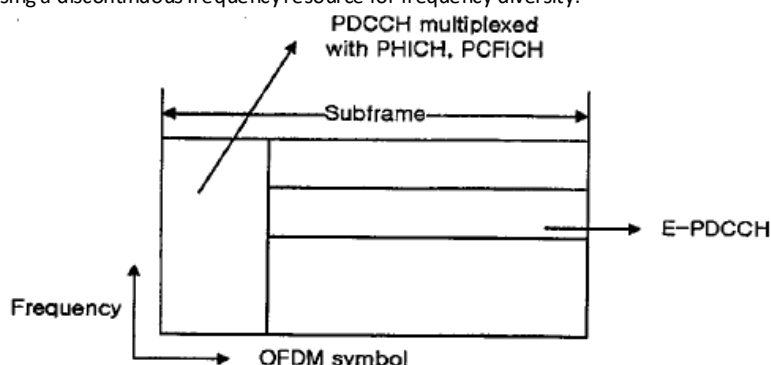
With respect to the *Average received power*, the UE may average RSRP measurements for two or more antenna ports.

If the UE receives a specific DMRS-based DL-related DCI format (e.g., DCI 2C) over a PDCCH (or ePDCCH), the UE performs data demodulation after performing channel estimation for the scheduled PDSCH through a configured DMRS sequence. If the UE can make an assumption that a DMRS ports configuration received through the DL scheduling grant allows QC with specific RS (e.g., a specific CSI-RS, a specific CRS, a DL serving cell CRS of the UE, etc.) ports, then the UE may apply the estimates of the large-scale channel

properties estimated through the specific RS (e.g., a specific CSI-RS, a specific CRS, a DL serving cell CRS of the UE, etc.) ports to channel estimation through the DMRS ports, thereby improving the processing performance of the DMRS-based receiver.

## ePDCCH

In an LTE-A system, an enhanced PDCCH (E-PDCCH) for transmitting a DL control signal has been introduced as an additional resource in addition to an existing PDCCH. Here, as shown in the figure, it is assumed that the E-PDCCH is transmitted after PDCCH is transmitted in an existing PDSCH domain, i.e., when viewed from the time axis. Although the figure illustrates that the E-PDCCH is transmitted using a continuous frequency resource, this is merely an example, and the E-PDCCH also can be transmitted using a discontinuous frequency resource for frequency diversity.



For each serving cell, higher layer signalling can configure a UE with one or two EPDCCH-PRB-sets for EPDCCH monitoring. The PRB-pairs corresponding to an EPDCCH-PRB-set are indicated by higher layers as described in section 9.1.4.4. Each EPDCCH-PRB-set consists of set of ECCEs numbered from 0 to  $N_{\text{ECCE},p,k}-1$  where  $N_{\text{ECCE},p,k}$  is the number of ECCEs in EPDCCH-PRB-set  $p$  of subframe  $k$ . Each EPDCCH-PRB-set can be configured for either localized EPDCCH transmission or distributed EPDCCH transmission.

The UE shall monitor a set of EPDCCH candidates on one or more activated serving cells as configured by higher layer signalling for control information, where monitoring implies attempting to decode each of the EPDCCHs in the set according to the monitored DCI formats.

The set of EPDCCH candidates to monitor are defined in terms of EPDCCH UE-specific search spaces.

For each serving cell, the subframes in which the UE monitors EPDCCH UE-specific search spaces are configured by higher layers.

The UE shall not monitor EPDCCH

For TDD and normal downlink CP, in special subframes for the special subframe configurations 0 and 5

For TDD and extended downlink CP, in special subframes for the special subframe configurations 0, 4 and 7

In subframes indicated by higher layers to decode PMCH

An EPDCCH UE-specific search space  $ES_k^{(L)}$  at aggregation level  $L \in \{1, 2, 4, 8, 16, 32\}$  is defined by a set of EPDCCH candidates.

For an EPDCCH-PRB-set  $p$  configured for distributed transmission, the ECCEs corresponding to EPDCCH candidate  $m$  of the search space

$ES_k^{(L)}$  are given by

$$\left\lceil \frac{L}{N_{\text{ECCE},p,k}} \left( (Y_{p,k} + m) \bmod \left\lfloor \frac{N_{\text{ECCE},p,k}}{L} \right\rfloor \right) + i \right\rceil$$

For an EPDCCH-PRB-set  $p$  configured for localised transmission, the ECCEs corresponding to EPDCCH candidate  $m$  of the search space

$ES_k^{(L)}$  are given by

$$\left[ \left\{ \left( Y_{p,k} + \left\lfloor \frac{m' \cdot N_{ECCE,p,k}}{L \cdot M_p^{(L)}} \right\rfloor \right) \bmod \left\lfloor N_{ECCE,p,k} / L \right\rfloor \right\} + i \right]$$

where

$Y_{p,k}$  is defined below,

$i=0, \dots, L-1$

$m' = m + M_p^{(L)} \cdot n_{CI}$  if the UE is configured with a carrier indicator field for the serving cell on which EPDCCH is monitored,  
otherwise  $m' = m$

$n_{CI}$  is the carrier indicator field value,

$$m = 0, 1, \dots, M_p^{(L)} - 1,$$

$M_p^{(L)}$  is the number of EPDCCH candidates to monitor at aggregation level  $L$  in EPDCCH-PRB-set  $p$ .

A UE is not expected to monitor an EPDCCH candidate, if an ECCE corresponding to that EPDCCH candidate is mapped to a PRB pair that overlaps in frequency with a transmission of either PBCH or primary or secondary synchronisation signals in the same subframe.

The variable  $Y_{p,k}$  is defined by

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

where  $Y_{p,-1} = n_{RNTI} \neq 0$ ,  $A = 39827$ ,  $D = 65537$  and  $k = \lceil n_s/2 \rceil$ ,  $n_s$ , the slot number within a radio frame. The RNTI value used for  $n_{RNTI}$  is defined in section 7.1 in downlink and section 8 in uplink.

EPDCCH formats

The enhanced physical downlink control channel (EPDCCH) carries scheduling assignments. An enhanced physical downlink control channel is transmitted using an aggregation of one or several consecutive enhanced control channel elements (ECCEs) where each ECCE consists of multiple enhanced resource element groups (EREGs), defined in Section 6.2.4A. The number of ECCEs used for one EPDCCH depends on the EPDCCH format as given by Table

6.8A.1-2 and the number of EREGs per ECCE is given by Table 6.8A.1-1. Both localized and distributed transmission is supported.

An EPDCCH can use either localized or distributed transmission, differing in the mapping of ECCEs to EREGs and PRB pairs.

A UE shall monitor multiple EPDCCHs as defined in [4]. One or two sets of physical resource-block pairs which a UE shall monitor for EPDCCH transmissions can be configured. All EPDCCH candidates in EPDCCH set  $S_m$  use either only localized or only distributed transmission as configured by higher layers. Within EPDCCH set  $S_m$  in subframe  $i$ , the ECCEs available for transmission of EPDCCHs are numbered from 0 to  $N_{ECCE,m,i} - 1$  and ECCE number  $n$  corresponds to

- EREGs numbered  $(n \bmod N_{RB}^{ECCE}) + j N_{RB}^{ECCE}$  in PRB index  $\left\lfloor n / N_{RB}^{ECCE} \right\rfloor$  for localized mapping, and

- EREGs numbered  $\lfloor n/N_{RB}^{S_m} \rfloor + jN_{RB}^{ECCE}$  in PRB indices  $(n + j \max(1, N_{RB}^{S_m}/N_{ECCE}^{EREG})) \bmod N_{RB}^{S_m}$  for distributed mapping,

where  $j = 0, 1, \dots, N_{ECCE}^{EREG} - 1$ ,  $N_{ECCE}^{EREG}$  is the number of EREGs per ECCE, and  $N_{RB}^{ECCE} = 16/N_{ECCE}^{EREG}$  is the number of ECCEs per resource-block pair. The physical resource-block pairs constituting EPDCCH set  $S_m$  are in this paragraph assumed to be numbered in ascending order from 0 to  $N_{RB}^{S_m} - 1$ .

Table 6.8A.1-1: Number of EREGs per ECCE,  $N_{ECCE}^{EREG}$ .

| Normal subframe | Normal cyclic prefix                    |                                               | Normal subframe | Extended cyclic prefix                        |  |
|-----------------|-----------------------------------------|-----------------------------------------------|-----------------|-----------------------------------------------|--|
|                 | Special, subframe configuration 3, 4, 8 | Special subframe, configuration 1, 2, 6, 7, 9 |                 | Special, subframe configuration 1, 2, 3, 5, 6 |  |
|                 | 4                                       |                                               | 8               |                                               |  |

Table 6.8A.1-2: Supported EPDCCH formats.

| EPDCCH format | Number of ECCEs for one EPDCCH, $N_{EPDCCH}^{ECCE}$ |                          |                        |                          |
|---------------|-----------------------------------------------------|--------------------------|------------------------|--------------------------|
|               | Case 1                                              |                          | Case 2                 |                          |
|               | Localized transmission                              | Distributed transmission | Localized transmission | Distributed transmission |
| 0             | 2                                                   | 2                        | 1                      | 1                        |
| 1             | 4                                                   | 4                        | 2                      | 2                        |
| 2             | 8                                                   | 8                        | 4                      | 4                        |
| 3             | 16                                                  | 16                       | 8                      | 8                        |
| 4             | -                                                   | 32                       | -                      | 16                       |

Case 1 in Table 6.8A.1-2 applies when

- DCI formats 2, 2A, 2B, 2C or 2D is used and  $N_{RB}^{DL} \geq 25$ , or
- any DCI format when  $n_{EPDCCH} < 104$  normal cyclic prefix is used in normal subframes or special subframes with configuration 3, 4, 8,

otherwise case 2 is used. The quantity  $n_{EPDCCH}$  for a particular UE is defined as the number of downlink resource elements  $(k, l)$  in a physical resource-block pair configured for possible EPDCCH transmission of EPDCCH set  $S_0$  and fulfilling all of the following criteria:

- they are part of any one of the 16 EREGs in the physical resource-block pair, and
- they are assumed by the UE not to be used for cell-specific reference signals or CSI reference signals
- the index  $l$  in the first slot in a subframe fulfils  $l \geq l_{EPDCCHstart}$  where  $l_{EPDCCHstart}$  is given by Section 9.1.4.1 of 3GPP TS 36.213.

The mapping to resource elements  $(k, l)$  on antenna port  $p$  meeting the criteria above shall be in increasing order of first the index  $k$  and then the index  $l$ , starting with the first slot and ending with the second slot in a subframe.

For localized transmission, the single antenna port  $p$  to use is given by Table 6.8A.5-1 with

$$n' = n_{ECCE,low} \bmod N_{RB}^{ECCE} + n_{RNTI} \bmod \min(N_{EPDCCH}^{ECCE}, N_{RB}^{ECCE})$$

where  $n_{ECCE,low}$  is the lowest ECCE index used by this EPDCCH transmission in the EPDCCH set  $n_{RNTI}$  corresponds to the RNTI associated

with the EPDCCH transmission, and  $N_{EPDCCH}^{ECCE}$  is the number of ECCEs used for this EPDCCH.

Table 6.8A.5-1: Antenna port to use for localized EPDCCH transmission.

| $n'$ | Normal cyclic prefix                   |                                             | Extended cyclic prefix |
|------|----------------------------------------|---------------------------------------------|------------------------|
|      | Normal subframes, configurations 3,4,8 | Special subframes, configurations 1,2,6,7,9 | Any subframe           |
| 0    | 107                                    | 107                                         | 107                    |
| 1    | 108                                    | 109                                         | 108                    |
| 2    | 109                                    |                                             | -                      |
| 3    | 110                                    | -                                           | -                      |

For distributed transmission, each resource element in an EREG is associated with one out of two antenna ports in an alternating manner where  $p \in \{107, 109\}$  for normal cyclic prefix and  $p \in \{107, 108\}$  for extended cyclic prefix.

### 3. Motivation of the Invention

In a next-generation system of LTE-A, it is considered to configure a low cost/low specification terminal which primarily aims at data communication, such as meter reading, water level measurement, monitoring camera utilization, inventory reporting of a vending machine, etc. For convenience, such a terminal is referred to as a Machine Type Communication (MTC) terminal. In the case of the MTC terminal, a data transmission amount is low and uplink/downlink data transmission/reception occurs occasionally. Therefore, it is efficient to reduce the price and battery power consumption of the terminal in consideration of such a low data transfer rate. This MTC terminal is characterized by low mobility, and thus a channel environment little changes. In the current LTE-A, providing the MTC terminal with wider coverage is being considered, and, to this end, various coverage enhancement techniques for the MTC terminal are being discussed.

Meanwhile, when the UE performs initial access to a specific cell, the UE receives, from eNodeB that operates/controls the cell, master information block (MIB), system information block (SIB) information, and radio resource control (RRC) parameters for the cell. Here, there occurs a problem that a MTC UE requires wider coverage than a legacy UE. Therefore, if eNodeB transmits SIB in the same manner as for a legacy UE, the MTC UE experiences difficulty in receiving the SIB. In order to resolve this problem, when transmitting SIB for the MTC UE having coverage issue through PDSCH, eNodeB may apply coverage enhancement techniques such as subframe repetition, subframe bundling, or the like.

The maximum bandwidth supported by normal LTE UEs is 20MHz. One potential technique to reduce the UE cost is to reduce the maximum bandwidth that the UE supports from 20MHz to a lower bandwidth (e.g., 1.4MHz, 3MHz or 5MHz). The reduction of the maximum bandwidth can be applied to the downlink and/or uplink, the RF and/or baseband components, the data and/or control channels. To be more specific, the following options have been considered and evaluated, which allow the bandwidth reduction on the DL and UL to be considered separately.

- DL
  - Option DL-1: Reduced bandwidth for both RF and baseband
  - Option DL-2: Reduced bandwidth for baseband only for both data channel and control channels
  - Option DL-3: Reduced bandwidth for data channel in baseband only, while the control channels are still

allowed to use the carrier bandwidth

- UL
  - Option UL-1: Reduced bandwidth for both RF and baseband
  - Option UL-2: No bandwidth reduction

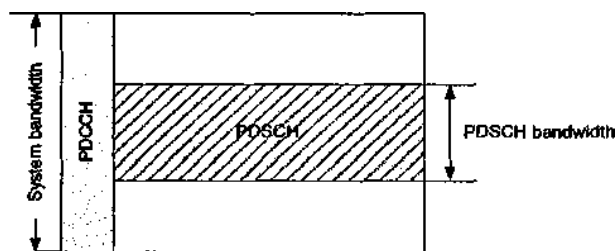
This option does not have any impact on coverage, power consumption, specifications, performance, and UE cost.

For all these options, the reduced bandwidth is assumed to be no less than 1.4MHz, and the frequency location of the reduced bandwidth is assumed to be fixed at the center of the carrier bandwidth. Technically, any combination of the DL and UL options is possible. However, some of the combinations may make more practical sense. For example, DL-2 would be a more natural choice than DL-1 when combined with UL-2.

Note that this is not intended to be an exhaustive list of the possible options. Some interesting variations of these options could allow the frequency location of the reduced bandwidth to be changed semi-statically, dynamically, or in a pre-defined pattern for each UE. Some of these variations could potentially allow more MTC UEs to be supported in the system.

When a bandwidth for a downlink data channel is reduced since the above method of Option DL-2 or DL-3 is used for the low-cost characteristic of the MTC UE, the MTC UE may be unable to operate smoothly only with techniques of an existing LTE-A system. Therefore, the present invention proposes operation techniques for the low-cost MTC UE which operates with a reduced bandwidth of a downlink data channel.

#### 4. Invention Summary



< Figure 1>

##### A. PDCCH transmission

As shown in <Figure 1>, a control channel (i.e., PDCCH) can be transmitted through an entire band region of a carrier bandwidth for a low-cost MTC UE in a downlink environment, whereas a bandwidth of a data channel may be reduced to a smaller value than the system bandwidth. In this case, the following operation may be performed for PDCCH transmission for the low-cost MTC UE.

A next LTA-A system considers a technique of repetitively transmitting a channel such as a PDSCH, a PDCCH, or the like for coverage enhancement of the MTC UE. Here, it is considered that a channel such as a PCFICH, a PHICH, or the like is not be transmitted for the MTC UE. Therefore, in order for the MTC UE not to necessarily receive PCFICH, the number of OFDM symbols on which the PDCCH is transmitted may be assumed to be always 3 symbols. Alternatively, the number of

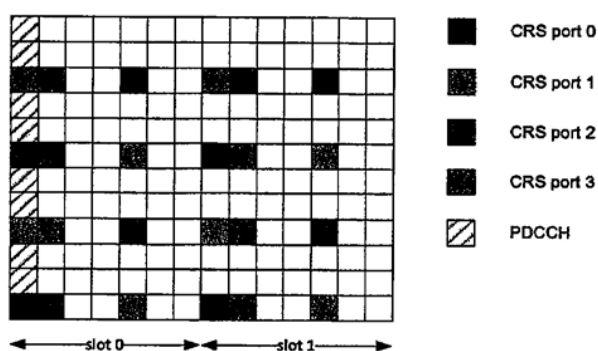
OFDM symbols may be notified to the terminal through PSS/SSS or PBCH transmission. In addition, also in the case of an MTC UE for which coverage enhancement is not applied, it is assumed that an entire system bandwidth to be assumed for buffering is used to store resource elements across an entire band on first three OFDM symbols in a normal CP case, and other OFDM symbols are restricted to 6 PRB or reduced data bandwidth. In addition, when the entire band is assumed for first several OFDM symbols, the number of OFDM symbols may be signaled through a higher layer, or may be designated in association with a cell ID, or may be transferred to PBCH or the like. In addition, when the terminal performs a cell search, it may be unconditionally assumed that the number of OFDM symbols received over the entire band is 0. Therefore, only data of a resource element for 6 PRBs can be stored.

Meanwhile, similarly to a legacy LTE-A system, the number of OFDM symbols on which the PDCCH is transmitted may be dynamically changed through indication via PCFICH or the like. In this case, the UE may attempt to receive a channel/signal through an entire bandwidth in an OFDM symbol region in which the PDCCH is transmitted, and may attempt to receive a channel/signal only through a band region for a data channel in an OFDM symbol region after the transmission of the PDCCH is ended.

The MTC UE may need to receive up to 4 ports CRS in the entire band in order to receive the PDCCH. In this case, in order for the UE to receive a CRS of up to 4 ports, at least first two OFDM symbols (i.e., OFDM symbol #0, OFDM symbol #1) must be received as shown in <Figure 2>. However, for example, if the PDCCH is received only on one OFDM symbol as shown in <Figure 2>, when the UE operates with a reduced bandwidth at which a data channel is transmitted from OFDM symbol #2 on which transmission of a PDSCH starts, the UE cannot receive the 4 ports CRS in an entire system bandwidth region for receiving the PDCCH.

Therefore, the present invention proposes to regulate a reception bandwidth as follows when the MTC UE receives a control channel through an entire region of a carrier bandwidth but a bandwidth for transmitting a data channel is reduced.

- The UE receives a channel/signal through an entire system bandwidth regardless of the number of PDCCH symbols on first two OFDM symbols (i.e., OFDM symbol #0, OFDM symbol #1).
- The UE operates at an entire system bandwidth on an OFDM symbol after OFDM symbol #2 when a PDCCH is transmitted on the corresponding symbol, and receives a channel/signal at a reduced bandwidth for a data channel when a PDSCH is transmitted.



<Figure 2>

- DCI format 1A

When the UE transmits DCI format 1A on a PDCCH, the number of bits of a Resource block assignment field of DCI format 1A is determined as  $\lceil \log_2 (N_{RB}^{DL} (N_{RB}^{DL} + 1) / 2) \rceil$ . Here,  $N_{RB}^{DL}$  represents a downlink bandwidth configuration and expressed in number of resource blocks. Meanwhile, for the low-cost MTC UE, a bandwidth for transmitting a data channel may be reduced to a smaller value than a system bandwidth in a downlink environment.

When  $N_{RB}^{DL}$  denotes the number of RBs in DCI format 1A, the number of bits of DCI format 1A may be always equal to the number of bits of DCI format 0. In this case, in order to equalize the number of bits of the DCI format 1A and the number of bits of the DCI format 0, zero padding may be performed on a DCI format having a smaller number of bits. In the present invention, when zero padding is performed on a DCI format having a smaller number of bits in order to equalize the number of bits of the DCI format 1A and the number of bits of the DCI format 0, the number of bits of the DCI format 1A is referred to as  $N_{1A\_long}$  and the number of bits of the DCI format 0 is referred to as  $N_{0\_long}$ . In this case,  $N_{1A\_long}$  and  $N_{0\_long}$  have the same value.

On the contrary, when  $N_{RB}^{DL}$  denotes the number of RBs of a bandwidth at which a data channel can be transmitted in the DCI format 1A, the number of bits of the DCI format 1A and the number of bits of the DCI format 0 may not be equalized.

If a bandwidth for transmitting a PDSCH is limited and  $N_{RB}^{DL}$  indicates the number of RBs of a bandwidth at which a data channel can be transmitted in an MTC environment, the size of a field for resource allocation of the DCI format 1A decreases, and thus the difference in length between the DCI format 1A for the low-cost MTC UE and the DCI format 0 increases. In this case, zero padding that is performed to equalize the number of bits of the DCI format 1A and the number of bits of the DCI format 0 may cause an overhead. In the present invention, when  $N_{RB}^{DL}$  indicates the number of RBs of a bandwidth at which a data channel can be transmitted in the DCI format 1A and zero-padding is not performed for equalizing the number of bits of the DCI format 1A and the number of bits of the DCI format 0, the number of bits of the DCI format 1A is referred to as  $N_{1A\_short}$  and the number of bits of the DCI format 0 is referred to as  $N_{0\_short}$ .

In this case, the present invention proposes to apply the value of  $N_{RB}^{DL}$  for transmitting the Resource block assignment field when the UE transmits DCI format 1A as the number of RBs of a downlink system bandwidth rather than the number of bandwidth for transmitting a data channel. That is, the present invention proposes that the UE assumes that the number of bits of the DCI format 1A is always equal to  $N_{1A\_long}$ . Furthermore, the present invention proposes that the UE assumes that the number of bits of the DCI format 0 is always equal to  $N_{0\_long}$ .

Alternatively, in order to receive a PDCCH transmitted on a CSS, the UE may interpret  $N_{RB}^{DL}$  as the number of RBs of the downlink system bandwidth rather than the number of RBs of the bandwidth at which a data channel can be transmitted, and as to a PDCCH transmitted on a USS, may interpret  $N_{RB}^{DL}$  as the number of RBs of the bandwidth at which a data channel can be transmitted in a downlink environment. Alternatively, the UE may interpret  $N_{RB}^{DL}$  as the number of RBs of the downlink system bandwidth rather than the number of RBs of the bandwidth at which a data channel can be transmitted in a PDCCH received using SI-RNTI (or another cell-specific RNTI), and may interpret  $N_{RB}^{DL}$  as the number of RBs of the bandwidth at which a data channel can be transmitted in a downlink environment in a PDCCH transmitted on C-RNTI (or another UE-specific RNTI). That is, the present invention proposes that the MTC UE for which a bandwidth for transmitting a data channel is reduced to a smaller value than the system bandwidth assumes that the number of bits of the DCI format 1A is equal to  $N_{1A\_long}$  in a PDCCH transmitted on CSS and the number of bits of the DCI format 1A is equal to  $N_{1A\_short}$  in a PDCCH transmitted on USS. (Furthermore, the present invention proposes that the MTC UE for which a bandwidth for transmitting a data channel reduced to a smaller value than the system bandwidth assumes that the number of bits of the DCI format 0 is equal to  $N_{0\_long}$  in a PDCCH transmitted on CSS and the number of bits of the DCI format 0 equal to  $N_{0\_short}$  in a PDCCH transmitted on USS.) In other words, when eNodeB transmits the DCI format 1A on the CSS to a UE which requires coverage enhancement among MTC UEs,  $N_{RB}^{DL}$  may indicate the number of RBs of the downlink system bandwidth, and in order to equalize the number of bits of the DCI format 1A and the number of bits of the DCI format 0, zero padding may be performed on a DCI format having a smaller number of bits so that the number of

bits of the DCI format 1A becomes  $N_{1A\_long}$ . (Furthermore, when eNodeB transmits the DCI format 0 on the CSS to a UE which requires coverage enhancement among MTC UEs, in order to equalize the number of bits of the DCI format 1A and the number of bits of the DCI format 0, zero padding may be performed on a DCI format having a smaller number of bits so that the number of bits of the DCI format 0 becomes  $N_{0\_long}$ .) When eNodeB transmits the DCI format 1A on the USS to the UE which requires coverage enhancement,  $N_{RB}^{DL}$  may indicate the number of RBs of the bandwidth at which a data channel can be transmitted, and the number of bits may be set to  $N_{1A\_short}$  without having to perform zero padding on the DCI format 1A. (Furthermore, when eNodeB transmits the DCI format 0 on the USS to the UE which requires coverage enhancement, the number of bits may be set to  $N_{0\_short}$  without having to perform zero padding on the DCI format 0.)

Alternatively, when transmitting DCI format 1A or another DCI format through a PDCCH, an MTC UE which requires coverage enhancement may interpret  $N_{RB}^{DL}$  as the number of RBs of the bandwidth at which a data channel can be transmitted in a downlink environment, and other UEs may interpret  $N_{RB}^{DL}$  as the number of RBs of the downlink system bandwidth rather than the number of RBs of the bandwidth at which a data channel can be transmitted. That is, a UE which requires coverage enhancement among MTC UEs may assume that the number of bits of the DCI format 1A is equal to  $N_{1A\_short}$ , and other UEs may assume that the number of bits of the DCI format 1A is equal to  $N_{1A\_long}$ .

(Furthermore, a UE which requires coverage enhancement among MTC UEs may assume that the number of bits of the DCI format 0 is equal to  $N_{0\_short}$ , and other UEs may assume that the number of bits of the DCI format 0 is equal to  $N_{0\_long}$ .) In the case of transmitting DCI format 1A/0 on the USS (or CSS),  $N_{RB}^{DL}$  may indicate the number of RBs of the bandwidth at which a data channel can be transmitted, and the number of bits may be maintained in different states without having to perform zero-padding to equalize the bit lengths of the DCI format 0 and the DCI format 1A. In this case, since the DCI format 0 and the DCI format 1A do not have the same bit length, the "Flag for format1/format1A differentiation" field included in the existing DCI formats 0 and 1A can be removed. In this case, in a particular environment, the DCI format 0 and the DCI format 1A have the same bit length. If the DCI format 0 and the DCI format 1A have the same bit length in a state in which the "Flag for format1/format1A differentiation" field is removed, the UE cannot differentiate the two DCI formats, and thus a technique for avoiding this situation is necessary. Therefore, to this end, the present invention proposes to add a "Flag for format1/format1A differentiation" field to the DCI format 0 and the DCI format 1A to differentiate the two DCI formats when the DCI format 0 and the DCI format 1A have the same bit length. Alternatively, the present invention proposes to perform 1-bit zero-padding on the DCI format 1A (or DCI format 0) to allow the two DCI formats to always have different lengths in order to differentiate the two DCI formats when the DCI format 0 and the DCI format 1A have the same bit length.

In the case of transmitting DCI format 1A/0 on the USS (or CSS),  $N_{RB}^{DL}$  may indicate the number of RBs of the bandwidth at which a data channel can be transmitted, and the number of bits may be maintained in different states without having to perform zero-padding to equalize the bit lengths of the DCI format 0 and the DCI format 1A. In this case, if the downlink system bandwidth is the same as a downlink data transmission bandwidth of the UE, for example, if the downlink data transmission bandwidth of the UE is 1.4 MHz and the downlink system bandwidth is also 1.4 MHz, eNodeB may transmit the DCI format 0 and the DCI format 1A by using the same method as a legacy method. That is, if the downlink system bandwidth is the same as the downlink data transmission bandwidth of the UE, for example, if the downlink data transmission bandwidth of the UE is 1.4 MHz and the downlink system bandwidth is also 1.4 MHz, eNodeB may perform zero padding on the DCI format having a shorter length so that the DCI format 0 and the DCI format 1A have the same bit length, and may perform transmission by adding the "Flag for format1/format1A differentiation" field to the DCI format 0 and the DCI format 1A to differentiate the two DCI formats.

## **B. Transmission of Cell-specific PDSCH**

When the MTC UE must receive a cell-specific PDSCH, the UE first searches for a DL grant for receiving a PDSCH through a common search space (CSS) region of a PDCCH. In this case, the contents of cell-specific data (e.g., SIB) to be transmitted to the MTC UE may be configured to be different from the contents of cell-specific data to be transmitted to a legacy UE. In addition, even for MTC UEs of the same type, the contents of cell-specific data to be transmitted to an MTC UE for which a coverage enhancement technique is required may be different from the contents of cell-specific data to be transmitted to another MTC UE for which a coverage enhancement technique is not required.

To this end, the present invention proposes to differently configure a CSS region of an MTC UE and a CSS region of a legacy UE. Here, the CSS region may be an RE resource, PRB region, and/or subframe region, or the like of the CSS. Furthermore, the present invention proposes to differently configure the CSS region of an MTC UE for which a coverage enhancement technique is required and the CSS region of an MTC UE for which a coverage enhancement technique is not required.

In this case, system information RNTI (SI-RNTI) for MTC UEs may be created additionally, so as to be used as RNTI for transmitting an SIB of the MTC or a cell-specific higher-layer signal. Additionally, SI-RNTI for an MTC UE having a coverage issue may be separately used as RNTI for transmitting an SIB of the MTC UE having a coverage issue or a cell-specific higher-layer signal.

The MTC UE may receive a configuration of a CSS region to be used by the MTC UE from eNodeB through a master information block (MIB) or SIB. Alternatively, since a region in which a cell-specific PDSCH for the MTC UE is transmitted is predetermined, the MTC UE may not expect to receive a PDCCH on CSS.

Unlike the case where legacy UEs acquire information on a PRB region in which a cell-specific PDSCH is transmitted through a DL grant transmitted on a CSS, a PRB region capable of transmitting a cell-specific PDSCH for an MTC UE in which only a bandwidth capable of transmitting a data channel is reduced may be fixed to center 6 RBs. Alternatively, the UE may receive, from eNodeB, a configuration of an RB region capable of transmitting a cell-specific PDSCH for the MTC UE through the MIB, SIB, or the like.

Further, as another method, it may be considered that a cell-specific PDSCH is shared between a normal UE, a low-cost MTC UE, and a UE that requires coverage enhancement. In this case, for the low-cost MTC UE, it may be assumed that a PDSCH is received on determined 6 PRBs, and an SIB may be unable to be decoded with a PDSCH transmitted at one time. Therefore, one SIB can be received by performing bundling by repeatedly reading a PDSCH a predetermined number (may be assumed to be transmitted through MIB or preset for UE) of times. For example, when it is assumed that SIB1 is transmitted on subframes #5/#25 (every 50 msec), a low-cost MTC UE must read a PDSCH four times on subframes #5/#25/#45/#65 to decode the SIB1 if the repetition number is configured to be 4. If the SIB is not transmitted on a subframe, decoding is attempted by reading the SIB the predetermined number of times on next frames. Alternatively, the SIB may be read by continuously performing decoding as in the case of retransmission. If a PDSCH to be transmitted exceeds 6 PRBs allocated to an MTC UE, a network eNB may assume that the PDSCH is punctured on a PRB other than the 6 PRBs, and may consider this assumption to allocate a resource of a next SIB PDSCH. Since a PDCCH may not be successfully decoded for a UE that requires coverage enhancement, a CSS PDSCH may be transmitted to a predetermined location on a predetermined subframe.

Furthermore, as another method, a CSS PDSCH may be configured through a higher layer configuration or through MIB or may be configured in advance so that an MTC UE may not monitor the CSS PDSCH. In this case, the MIB may include a

necessary configuration for reading information such as SIB, and it is assumed that RNTI which has to read the SIB may be set in the MIB. Furthermore, a method of signaling an SIB without a PDCCH similarly to a PBCH including an MIB is not excluded. Furthermore, an RNTI may be differently configured for an MTC UE which requires coverage enhancement and an MTC UE which does not require coverage enhancement, and if each RNTI is configured in MIB or each PBCH is transmitted separately, it may be assumed that the RNTI is configured in accordance with characteristics of the PBCH to be read. For example, when the PBCH is transmitted for the low-cost MTC UE, an included RNTI may be used to read a CSS PDSCH or SIB of the low-cost MTC UE, and when the PBCH is transmitted for coverage enhancement, the included RNTI may be used in SIB transmission of the UE which requires coverage enhancement. In this case, the RNTI may be regarded as a USS. In this case, in order to decrease the number of RNTIs on which each UE must perform blind decoding, the RNTI which must be read for each subframe for each UE may be higher-layer signaled or may be preconfigured. For example, RNTI for SIB or CSS PDSCH may be decoded on subframes subframe #0/#5, and decoding may be performed with UE RNTI on other subframes. Such a configuration may notify a subframe in which a CSS PDSCH or SIB is to be read in the form of a bitmap or a period/offset, or, on the contrary, may notify a subframe in which a USS PDSCH is to be read.

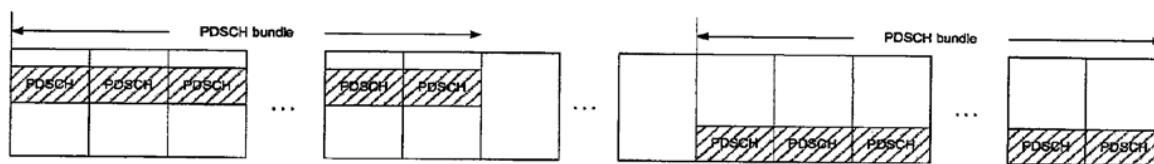
### C. Transmission of UE-specific PDSCH

- PDSCH transmission with coverage enhancement

When there is an MTC UE with a reduced bandwidth for receiving a data channel for low cost, a frequency location for the data channel of the MTC UE may be: 1) fixed; 2) changed depending on a predetermined pattern; 3) semi-statically configured; or 4) dynamically configured.

Meanwhile, since a coverage issue occurs for such an MTC UE, techniques of PDSCH repetition/bundling or the like may be used for coverage enhancement of a PDSCH. In this case, when a frequency location (or RB region) at which a PDSCH is transmitted is changed during subframe duration in which the PDSCH is repeated, the performance improvement effect may be decreased due to cross-subframes channel estimation.

Therefore, the present invention proposes that the RB region in which a PDSCH is transmitted is the same during PDSCH bundling in which reception of the same data is attempted, as shown in <Figure 3>. In this case, during PDSCH bundling in which reception of data is attempted, the RB region in which a PDSCH is transmitted may be the same as a PDSCH RB region transmitted through the first subframe of the PDSCH bundle. Alternatively, the present invention proposes that during PDSCH bundling in which reception of the same data is attempted, a band region (frequency location for receiving PDSCH) in which a PDSCH can be transmitted is the same. In this case, during PDSCH bundling in which reception of data is attempted, the band region (frequency location for receiving PDSCH) in which a PDSCH can be transmitted may be the same as a band region (frequency location for receiving PDSCH) in which a PDSCH applied in the first subframe of the PDSCH bundle can be transmitted.



<Figure 3>

#### - CSI report

The UE performs CSI report periodically or aperiodically in order to report a downlink channel state to eNodeB. CSI is classified into three types of information: Rank Indicator (RI), Precoding Matrix Index (PMI), and CHannel Quality Indication (CQI), and the UE transmits a portion or all of the information to eNodeB according to a situation.

The present invention assumes that, when the low-cost MTC UE uses a reduced bandwidth to receive a data channel, not only the data channel but also other channels and reference signals are also received only in the data bandwidth region during the corresponding period.

#### Periodic CSI report

When the MTC UE with a reduced bandwidth for receiving a data channel for low cost performs periodic CSI report on eNodeB, the UE must know which type of CQI feedback (e.g., wideband CQI, sub-band CQI) should be performed for the CQI report.

In this case, the followings may be considered as a CQI feedback method that can be used by the UE. Although the following description is about the CQI, the same may also be applied not only to the CQI but also to feedback for other information such as RI, PMI, etc.

##### ▪ Wideband (for system bandwidth) CQI

The UE, in order to perform periodic CQI feedback, may report wideband CQI for a system bandwidth rather than a bandwidth for data. When performing the CQI feedback, the UE device may measure the CQI for the entire system bandwidth by using CSI-RS, CRS, or the like received by the UE, and may perform feedback about the measurement. Even if the MTC UE with a reduced bandwidth for receiving a data channel fails to receive CSI-RS on all system RBs before performing the CQI feedback and has received CSI-RS only on some RBs, the MTC UE may estimate the CQI by using only the received CSI-RS.

As another method for performing wideband CQI, the UE may measure the CQI for the entire bandwidth by using CRS received during a period (e.g., period for receiving a PDCCH) in which the UE operates at the entire system bandwidth, and may perform feedback for the measurement.

Alternatively, the UE may perform wideband CQI feedback for the bandwidth at which data is transmitted. That is, when performing wideband CQI feedback, the UE may measure the CQI for the entire band region in which the UE can receive data, and may perform feedback about the measurement.

##### ▪ Subband CQI

In the case of the MTC UE with a reduced bandwidth for receiving a data channel, a band region for receiving data during the duration for CQI feedback may be composed of only a partial sub-band of the entire system bandwidth as shown in the example of <Figure 4>.

In this case, sub-band CQI for the band region for receiving data during the duration for CQI feedback may be fed back. For example, when CQI feedback is performed on subframe K, the sub-band CQI for band regions for receiving data on N previous subframes from the subframe K may be fed back. In this case, the value of N may be the same as the subframe duration for CQI feedback.

In this case, when the MTC UE performs sub-band CQI feedback for CQI feedback, the UE may feed back information about CQI values for best M sub-bands in the band region for receiving data during the duration for CQI feedback and index values of the corresponding sub-bands.

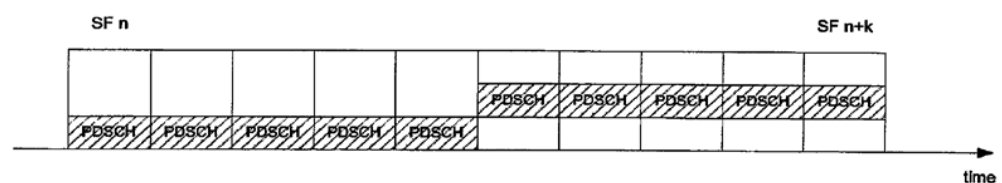
In this case, one sub-band may be composed of 6 RBs.

Alternatively, the UE may measure the CQI for the sub-band by using CRS received during a period (e.g., period for receiving a PDCCH) in which the UE operates at the entire system bandwidth, and may perform feedback for the measurement.

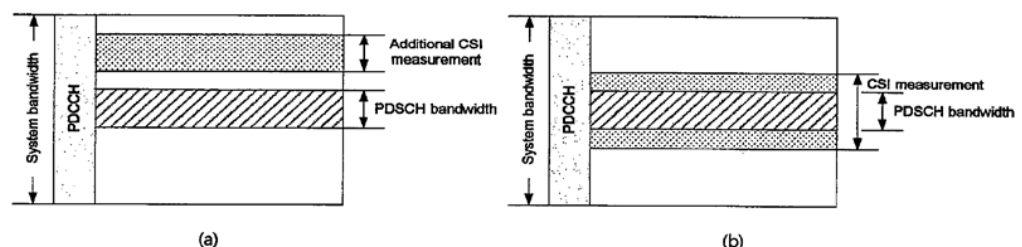
Alternatively, the UE may receive RSs (e.g., CRS, CSI-RS) for an additional band region in addition to the band region for receiving data and may measure CQI for the corresponding sub-band region, and may feed the CQI measurements back to eNodeB additionally or independently. For example, as shown in (a) of <Figure 5>, when the UE receives a configuration of a specific sub-band region from eNodeB through RRC, PDCCH, or the like, the UE may receive an RS for the corresponding sub-band region and may feed CQI information about the corresponding sub-band back to eNodeB additionally or independently. In this case, in order to notify information about the sub-band region for which the UE additionally measures CQI, eNodeB may notify the value of a gap between the band region for receiving data and the sub-band region for CQI measurement.

Alternatively, a sub-band in which the UE will additionally perform CQI measurement may be determined randomly or determined autonomously by the UE. In this case, when feeding back CQI for an additionally measured sub-band region to eNodeB, the UE should also notify sub-band index information about the sub-band region in which CQI has been measured.

A region in which the UE measures CQI by receiving an RS for an additional sub-band region in addition to the band region for receiving data may be composed of M additional RBs for one side or both sides of the band region for transmitting data as shown in (b) of <Figure 5>. That is, for example, when the UE is assigned RB #x to RB #x+a as a data band, the UE may always measure CQI for a region of RB #x-M to RB #x+a+M and may feed back the CQI to eNodeB.



<Figure 4>



<Figure 5>

#### Aperiodic CSI report

In order for the MTC UE with a reduced bandwidth for receiving a data channel for low cost to perform aperiodic CSI report on eNodeB, the UE must receive an indication for reporting an aperiodic CSI through a CSI request field of a PDCCH (UL grant). At present, the CSI request field is configured with 1 bit or 2 bits. Here, the CSI request field for the MTC UE may be always configured with 1 bit.

Here, the UL grant that has instructed the MTC UE with a reduced bandwidth for receiving a data channel to perform aperiodic CSI report may be transmitted through "subframe a". In this case, for the CSI report for the request for the CSI report, the MTC UE may report CSI, RI, and PMI values for a band region for receiving a data channel on the "subframe a". More specifically, when the aperiodic

CSI report request is received, a sub-band in which CSI report is to be performed may be configured through a higher layer in advance, may be pre-designated, or may be transferred through the request. In this case, the UE may measure the CSI by using CRS or CSI-RS received in the corresponding sub-band. In consideration of the case where the UE does not listen to the corresponding sub-band, a valid downlink subframe may be configured to be downlink subframe index, in which the request is received, + k ( $k \geq 1$ ).

The UE may measure CSI for the sub-band by using CRS received during a period (e.g., period for receiving a PDCCH) in which the UE operates at the entire system bandwidth, and may perform feedback for the measurement.

Alternatively, the UE may receive RSs (e.g., CRS, CSI-RS) for an additional band region in addition to the band region for receiving data and may measure CSI for the corresponding sub-band region, and may feed the CSI measurements back to eNodeB additionally or independently.

For example, as shown in (a) of <Figure 5>, when the UE receives a configuration of a specific sub-band region from eNodeB through RRC, PDCCH (e.g., aperiodic CSI report request field) or the like, the UE may receive an RS for the corresponding sub-band region and may feed CSI information about the corresponding sub-band back to eNodeB additionally or independently. In this case, in order to notify information about the sub-band region for which the UE additionally measures CQI, eNodeB may notify the value of a gap between the band region for receiving data and the sub-band region for CQI measurement.

Alternatively, a sub-band in which the UE will additionally perform CSI measurement may be determined randomly or determined autonomously by the UE. In this case, when feeding back CSI for an additionally measured sub-band region to eNodeB, the UE should also notify sub-band index information about the sub-band region in which CSI has been measured.

A region in which the UE measures CSI by receiving an RS for an additional sub-band region in addition to the band region for receiving data may be composed of M additional RBs for one side or both sides of the band region for transmitting data as shown in (b) of <Figure 5>. That is, for example, when the UE is assigned RB #x to RB #x+a as a data band, the UE may always measure CSI for a region of RB #x-M to RB #x+a+M and may feed back the CSI to eNodeB.

#### **D. Transmission of PMCH**

The MTC UE, which has a delay tolerant characteristic and is optimized for receiving occasionally transmitted data, may not need to receive a PMCH. Furthermore, the MTC UE with a reduced bandwidth of a downlink data channel compared to a system bandwidth for the low-cost characteristic may be unable to smoothly receive a PMCH.

Therefore, the present invention proposes that the MTC UE does not expect to receive data (PMCH) in an MBSFN subframe. Specifically, the present invention proposes that the MTC UE does not expect to receive all data and control channels except for an UL grant in an MBSFN subframe. Alternatively, the present invention proposes that the MTC UE does not expect to receive all of the data and control channels in an MBSFN subframe. More specifically, when the MTC UE cannot support TM9 and/or TM10, reception of all of the data and control channels may not be expected in an MBSFN subframe, or reception of the control/data channels except for the uplink grant may not be expected. To this end, capability signaling may be performed to indicate whether the MTC UE supports the TM9 and/or TM10. More specifically, when the MTC UE cannot support TM9 and/or TM10, capability signaling may be additionally performed to indicate whether the UE can receive CSI-RS. Alternatively, even if the MTC UE cannot support TM9 and/or TM10, the MTC UE may be mandated to receive CSI-RS.

#### **E. Operation in special subframe**

The number of downlink OFDM symbols to be received by the UE on a special subframe varies depending on a special subframe configuration. In the case of the UE which has a reduced buffer size compared to a legacy UE due to a reduced data bandwidth, although data for all REs cannot be stored in a normal downlink subframe, there may be a case where the data for all REs can be stored in a special subframe.

Therefore, the present invention proposes that the MTC UE with a reduced bandwidth of a downlink data channel compared to a system bandwidth operates at the full bandwidth for all downlink OFDM symbols during DwPTS in special subframes with special subframe configurations 0, 5.

In this case, eNodeB may transmit CSI-RS or the like at the full bandwidth during DwPTS so that the UE with a reduced bandwidth of a downlink data channel can perform CSI measurement for the full bandwidth.

## **DESCRIPTION OF THE RELATED ART**

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.

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.

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.

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.

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.

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.

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.

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 or 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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

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.

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.

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

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

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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

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

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.

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.

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.

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.

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.

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.

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.

#### Brief Description of the Drawings

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

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

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

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

FIG. 4 illustrates a Structure of the physical channel.

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

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

DRAWINGS

Fig. 1

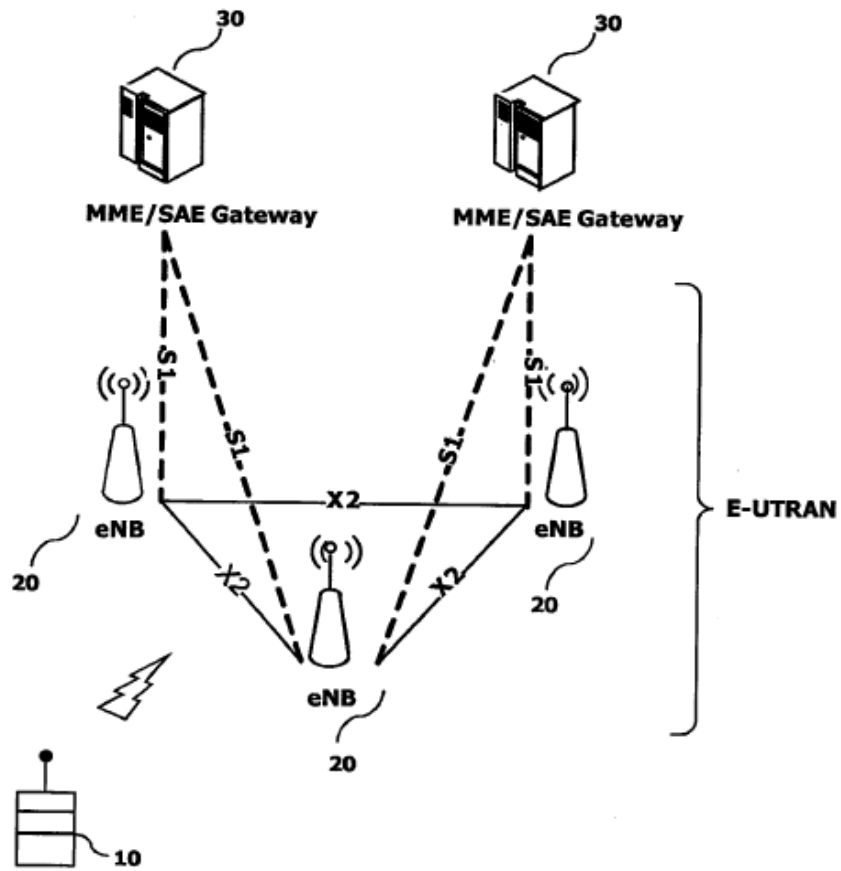


Fig. 2

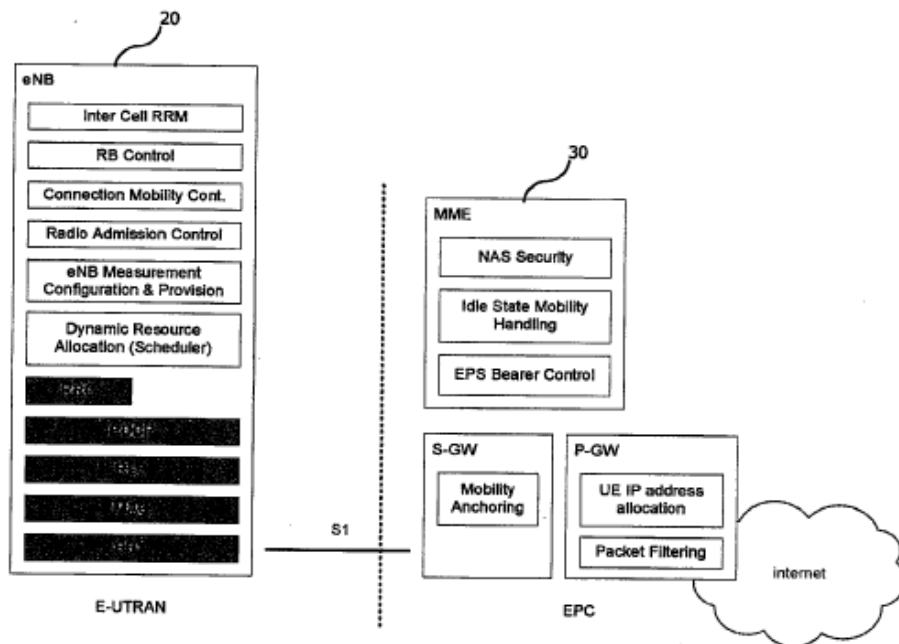


Fig. 3a

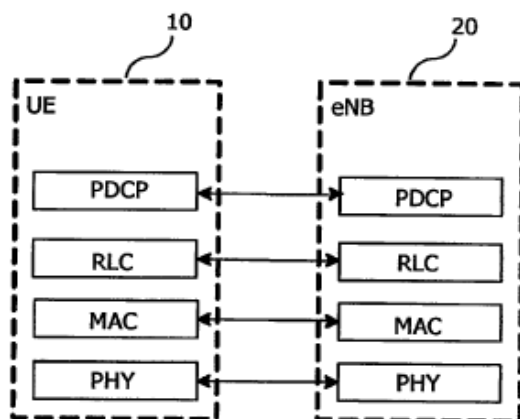


Fig. 3b

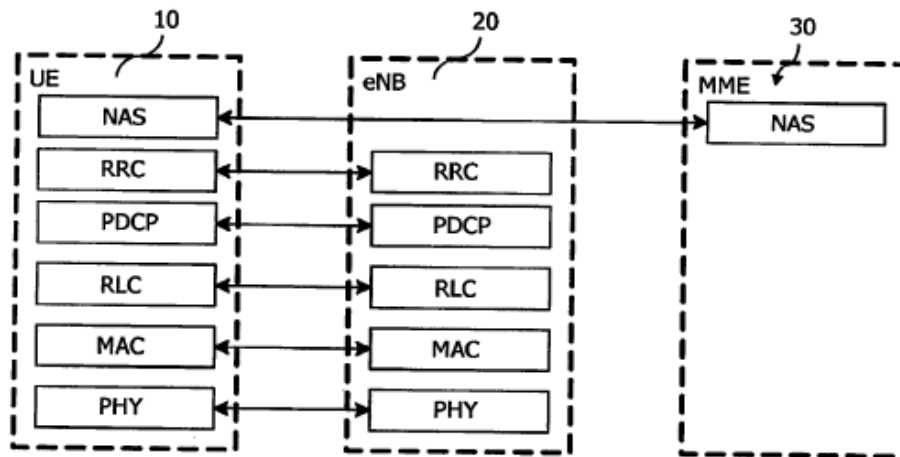


Fig. 4

### Structure of the physical channel

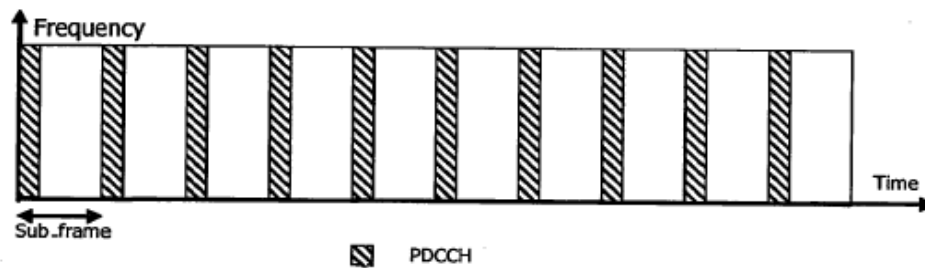


Fig. 5

### Random Access procedure for E-UTRAN initial access

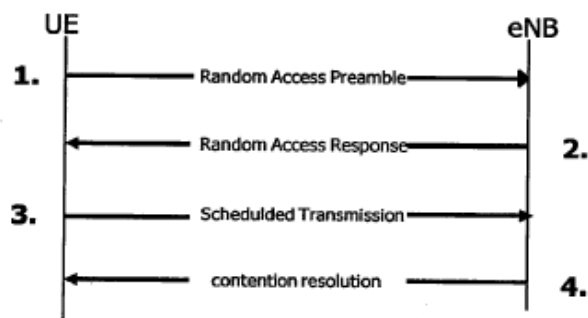
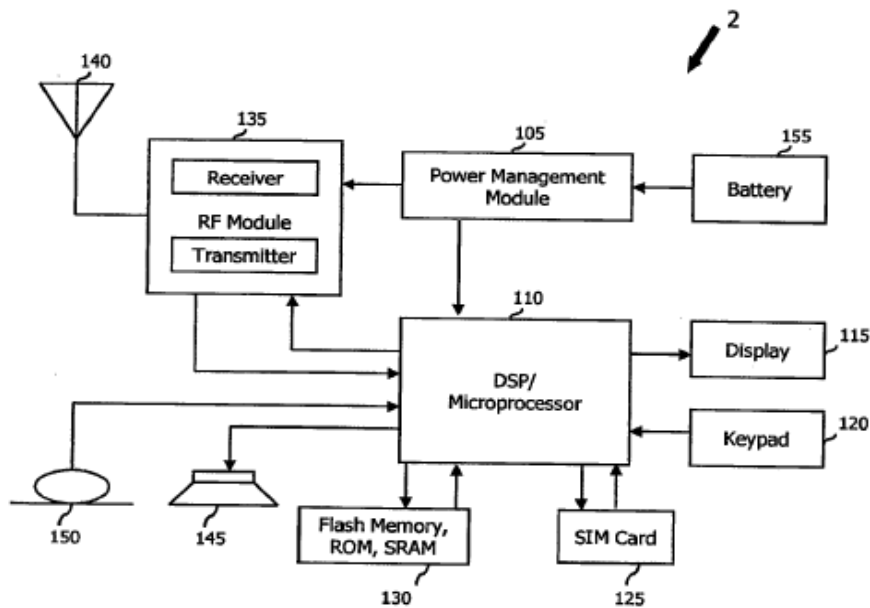


Fig. 6

### MOBILE STATION/ACCESS TERMINAL





## TRANSLATOR'S CERTIFICATE OF TRANSLATION

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Date: *Aug 8, 2024*

To whom it may concern:

I, *Kang, Eui Keun*, a translator fluent in the Korean and English languages, on behalf of Questel, do solemnly and sincerely declare that the following is, to the best of my knowledge and belief, a true and correct translation of the document(s) listed below in a form that best reflects the intention and meaning of the original text.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true. I further declare that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

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Signed this *8th* day of *Aug*, 2024

Signature

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