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Electronic Acknowledgement Receipt

EFS ID:	16245747
Application Number:	61843456
International Application Number:	
Confirmation Number:	6204
Title of Invention:	DOWNLINK DATA TRANSMISSION FOR LOW-COST MTC UE
First Named Inventor/Applicant Name:	Hyangsun YOU
Customer Number:	67487
Filer:	Andrew S. Park
Filer Authorized By:	
Attorney Docket Number:	UT13-0772-US
Receipt Date:	08-JUL-2013
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1	Provisional Cover Sheet (SB16)	UT13-0772_CoverSheet.pdf	1477320 <div>0a533bddf7dc872f5231c7d7965d90c667f4277</div>	no	3
Warnings:					
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2	Specification - Not in English	UT13772_SPEC.pdf	8153051 <div>1566b879eba8f2777d5fda19d509c5bde1bca29</div>	no	69
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3	Fee Worksheet (SB06)	fee-info.pdf	29588 <div>2221355251d534e9a158fda4b6c07abd715580d</div>	no	2
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Electronic Acknowledgement Receipt

EFS ID:	16245751
Application Number:	61843456
International Application Number:	
Confirmation Number:	6204
Title of Invention:	DOWNLINK DATA TRANSMISSION FOR LOW-COST MTC UE
First Named Inventor/Applicant Name:	Hyangsun YOU
Customer Number:	67487
Filer:	Andrew S. Park
Filer Authorized By:	
Attorney Docket Number:	UT13-0772-US
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1	Authorization to access Appl. by Trilateral Office	UT13-0772_sb0039.pdf	223197	no	2
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National Stage of an International Application under 35 U.S.C. 371

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PTO/SB/16 (11-08)

Approved for use through 05/31/2015. OMB 0651-0032

U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

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Provisional Application for Patent Cover Sheet

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c)

Inventor(s)

Inventor 1

Remove

Given Name	Middle Name	Family Name	City	State	Country i
Hyangsun		YOU	Anyang		KR

Inventor 2

Remove

Given Name	Middle Name	Family Name	City	State	Country i
Yunjung		YI	Anyang		KR

Inventor 3

Remove

Given Name	Middle Name	Family Name	City	State	Country i
Suckchel		YANG	Anyang		KR

All Inventors Must Be Listed – Additional Inventor Information blocks may be generated within this form by selecting the Add button.

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Title of Invention

DOWNLINK DATA TRANSMISSION FOR LOW-COST MTC UE

Attorney Docket Number (if applicable)

UT13-0772-US

Correspondence Address

Direct all correspondence to (select one):

☒ The address corresponding to Customer Number ☐ Firm or Individual Name

Customer Number

67487

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☒ No.

☐ Yes, the invention was made by an agency of the United States Government. The U.S. Government agency name is:

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Entity Status

Applicant asserts small entity status under 37 CFR 1.27 or applicant certifies micro entity status under 37 CFR 1.29

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Signature

Please see 37 CFR 1.4(d) for the form of the signature.

Signature	/Andrew S. Park/			Date (YYYY-MM-DD)	2013-07-08
First Name	Andrew	Last Name	Park	Registration Number (If appropriate)	47841

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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

본 발명에서는 low-cost 특성을 위해 PDSCH 전송 BW를 줄인 MTC UE들의 downlink data 전송 기법들을 제안한다.

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

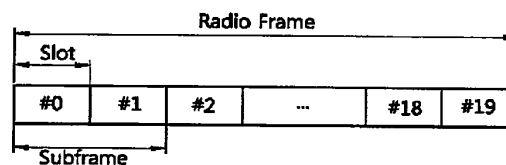


Figure 1. Structure of a radio frame of 3GPP LTE

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,

Section 1

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.

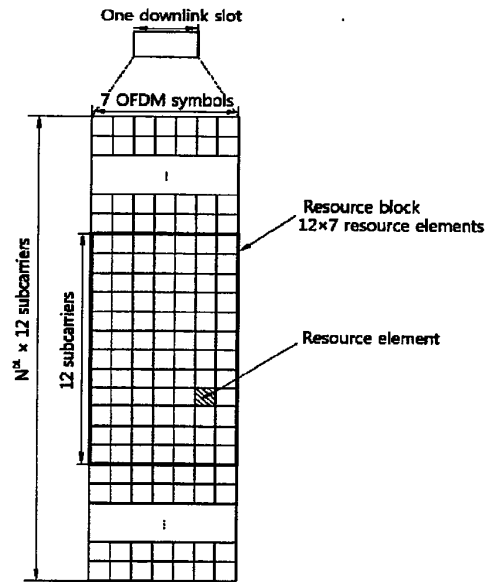


Figure 2. Resource grid for one downlink slot

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.

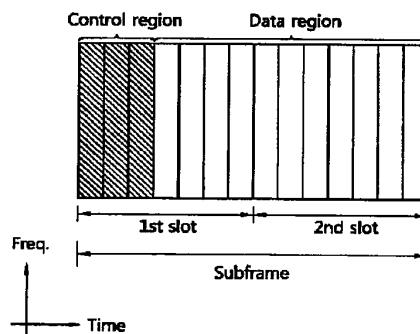


Figure 3. Structure of downlink subframe

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.

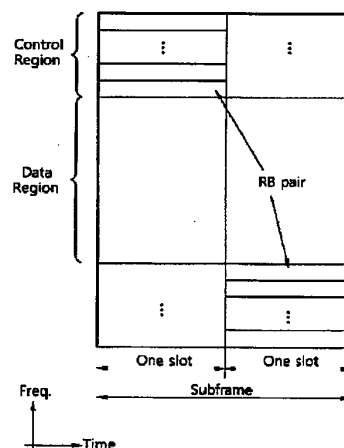


Figure 4. Structure of uplink subframe

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.

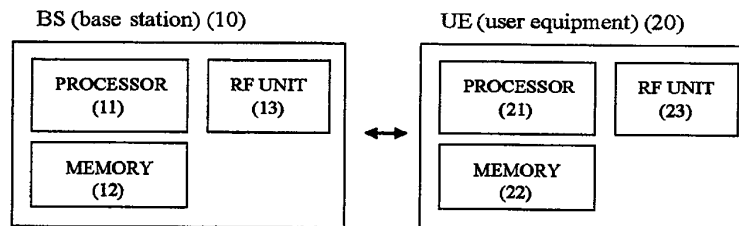


Figure 5. System for implementing present invention

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 $L \leq M \leq N$.

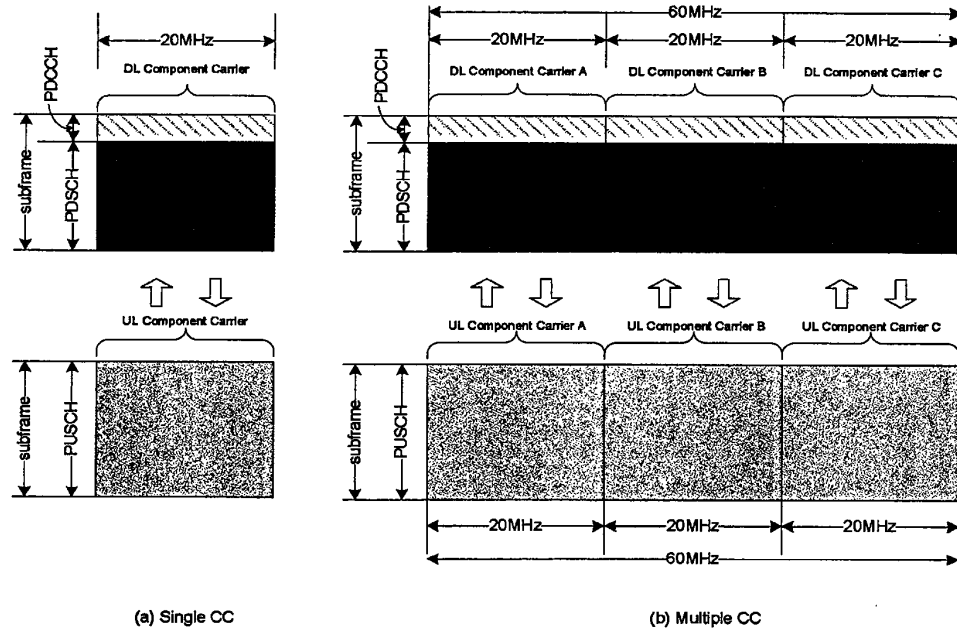


Figure 6. Subframe structure of 3GPP LTE Release-8 system and LTE-A system with CC aggregation

Carrier aggregation을 지원하는 시스템에서 cell은 다음 Figure 7과 같이 구분할 수 있다.

Configured cell은 Figure 7에서와 같이 기지국의 cell 중에서 measurement report를 근거로 carrier aggregation할 수 있도록 한 cell로서 UE별로 설정된다. Configured cell은 PDSCH 전송에 대한 ACK/NACK 전송을 위한 resource를 미리 예약해 놓게 된다. Activated cell은 configured cell 중에서 실제로 PDSCH/PUSCH를 전송하도록 설정된 cell로서 PDSCH/PUSCH 전송을 위한 CSI report와 SRS transmission을 수행하게 된다. De-activated cell은 기지국의 명령 또는 timer 동작에 의해서 PDSCH/PUSCH 전송을 하지 않도록 하는 cell로서 CSI report 및 SRS 전송도 중단된다.

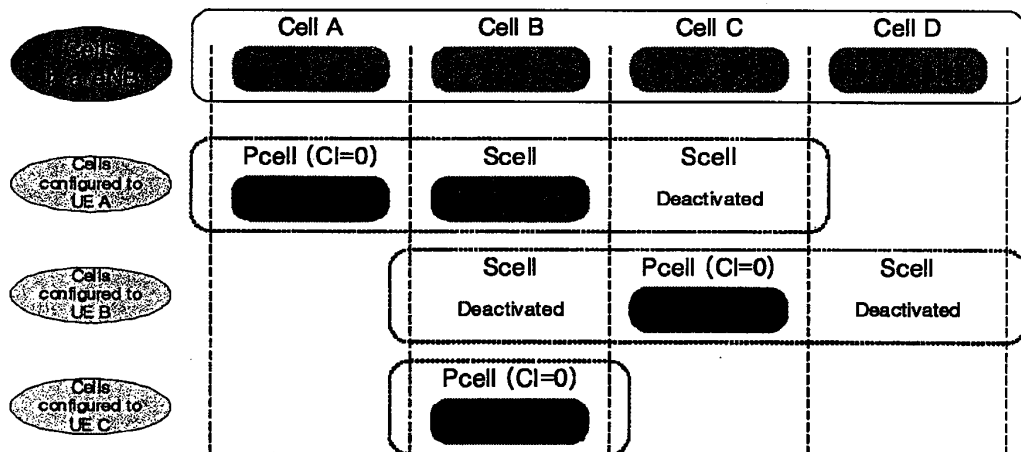


Figure 7. Configured cell, activated cell, de-activated cell

Synchronization signal (SS) in LTE-A FDD

SS는 P-SS와 S-SS로 구성되며, 셀 탐색을 수행할 때 사용되는 신호이다.

그림 7 (a)와 (b)는 각각 기본 CP와 확장 CP를 사용하는 시스템의 경우 SS의 전송을 위한 프레임 구조를 도시한 것이다. SS는 inter-RAT measurement의 용이함을 위해 GSM 프레임 길이인 4.6ms를 고려하여 부프레임 0번과 부프레임5번의 두 번째 슬롯에서 각각 전송되고, 해당 라디오 프레임에 대한 경계는 S-SS를 통해 검출 가능하다. P-SS는 해당 슬롯의 맨 마지막 OFDM 심볼에서 전송되고, S-SS는 P-SS 바로 앞 OFDM 심볼에서 전송된다. SS는 3개의 P-SS와 168개의 S-SS의 조합을 통해 총 504개의 물리계층 셀 식별자(physical cell ID)를 전송할 수가 있다. 또한, SS 및 PBCH는 시스템 대역폭 내의 가운데 6RB 내에서 전송되어, 전송 대역폭에 관계없이 UE가 검출 혹은 복호할 수 있도록 한다.

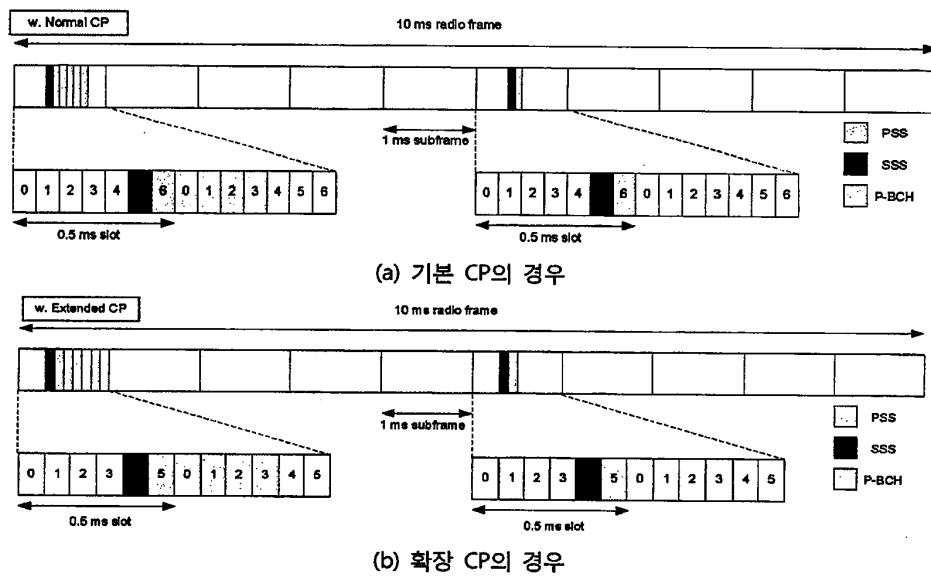


그림 7. SS 전송을 위한 프레임 구조

SS의 전송 다이버시티 방식은 단일 안테나 포트 (single antenna port)만을 사용하고, 표준에서는 따로 정의하지 않는다. 즉, 단일 안테나 전송 혹은 UE에 투명한(transparent) 전송 방식 (예를 들어 PVS, TSTD, CDD) 을 사용할 수가 있다.

a. P-SS 부호

길이 63의 ZC (Zadoff-Chu) 시퀀스를 주파수 영역에서 정의하여 P-SS의 시퀀스로 사용한다. ZC 시퀀스는 식 (1)에 의해 정의되며, DC 부반송파에 해당되는 시퀀스 요소(element), $n=31$ 은 천공 (puncturing)한다. 식 (1)에서 $N_{zc}=63$ 이다.

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

가운데 부분의 6RB (=72 부반송파) 중 9개의 남은 부반송파는 항상 0의 값으로 전송하며, 동기 수행을 위한 필터 설계에 용이함을 가져다 준다. 총 3개의 P-SS를 정의하기 위해 식 (1)에서 $u=25, 29$, 그리고 34의 값을 사용한다. 이 때, 29와 34는 켈레대칭(conjugate symmetry) 관계를 가지고 있어서, 2개의 상관 (correlation)을 동시에 수행할

수가 있다. 여기서, 켈레대칭은 다음 식 (2)의 관계를 의미하며 이 특성을 이용하여 $u=29$ 와 34에 대한 원상 상관기 (one-shot correlator)의 구현이 가능하여, 전체적인 연산량을 약 33.3% 감소시킬 수 있다.

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

b. S-SS 부호

S-SS를 위해 사용되는 시퀀스는 길이 31의 두 개 m-시퀀스를 인터리빙된 접합을 하고 두 개의 시퀀스를 조합하여 168 셀 그룹 식별자 (cell group ID)를 전송한다. S-SS의 시퀀스로서 m-시퀀스는 주파수 선택적 환경에서 강건하고, 고속 하다마드 변환 (Fast Hadamard Transform)을 이용한 고속 m-시퀀스 변환으로 연산량을 줄일 수가 있다. 또한, 두 개의 짧은 부호 (short code)로 S-SS를 구성하는 것은 단말의 연산량을 줄이기 위해 제안되었다.

그림 8은 논리 영역에서의 두 개의 시퀀스가 물리 영역에서 인터리빙되어 매핑되는 것을 보여주는 그림이다. S-SS부호 생성을 위해 사용되는 두 개의 m-시퀀스를 각각 S1, S2라고 정의할 때, 부프레임 0의 S-SS가 (S1, S2) 두 조합으로 셀 그룹 식별자를 전송한다면, 부프레임 5의 S-SS는 (S2, S1)으로 교환(swapping)하여 전송함으로써, 10ms 프레임 경계를 구분할 수 있게 된다. 이 때, 사용되는 S-SS 부호는 $x^5 + x^2 + 1$ 의 생성다항식을 사용하며, 서로 다른 순환 전이 (circular shift)를 통해 총 31개의 부호를 생성할 수가 있다.

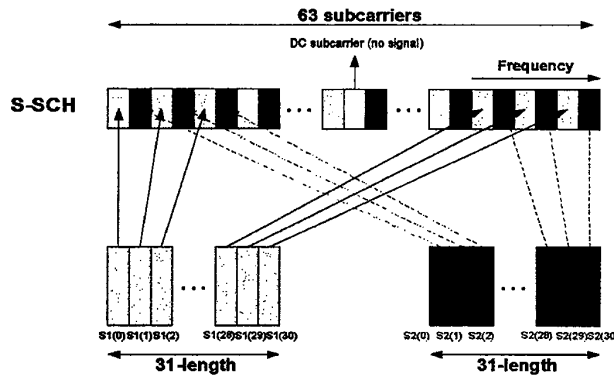


그림 8. S-SS 부호 생성 방식

수신 성능을 향상시키기 위하여, P-SS 기반 (P-SS-based)의 서로 다른 두 개의 시퀀스를 정의하여, S-SS에 스크램블링 하되 S1과 S2에 서로 다른 시퀀스로 스크램블링 한다. 그 후, S1 기반 (S1-based)의 스크램블링 부호를 정의하여, S2에 스크램블링을 수행한다. 이 때, S-SS의 부호는 5ms 단위로 교환되지만 P-SS 기반의 스크램블링 부호는 교환되지 않는다. P-SS 기반의 스크램블링 부호는 $x^5 + x^3 + 1$ 의 생성 다항식으로부터 생성된 m-시퀀스에서 P-SS 인덱스에 따라 6개의 순환 전이 버전으로 정의하고, S1 기반의 스크램블링 부호는 $x^5 + x^4 + x^2 + x^1 + 1$ 의 다항식으로부터 생성된 m-시퀀스에서 S1의 인덱스에 따라 8개의 순환 전이 버전으로 정의한다.

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.

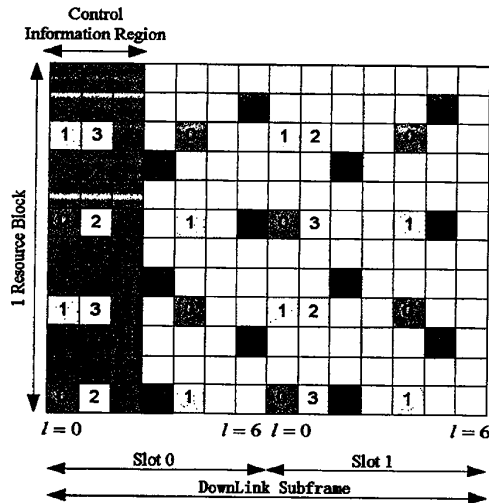


그림 9

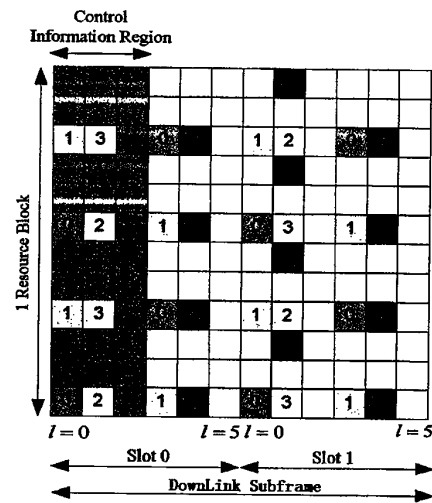


그림 10

그림 9 and 그림 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, 1, 2, 3 mean cell specific common RS to be transmitted for channel measurement and data demodulation commonly for each antenna port 0-3. In addition, UE-specific RS, , 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

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

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

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

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

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

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

DRS

Normal CP

Extend CP

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

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

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

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

Reference signal (RS) in LTE-A

The SRS, which are not associated with uplink data and/or control transmission, are primarily used for channel quality estimation to enable frequency-selective scheduling on the uplink. However, they can be used for other purposes such as to enhance power control or to support various start-up functions for UEs not recently scheduled. Some examples include initial Modulation and Coding Scheme (MCS) selection, initial power control for data transmissions, timing advance, and so-called frequency semi-selective scheduling in which the frequency resource is assigned selectively for the first slot of a subframe and hops pseudorandomly to a different frequency in the second slot. In addition, SRS can be used for downlink channel quality estimation under the assumption that the wireless channel is reciprocal between the uplink and downlink. This assumption is 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 그림 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%.

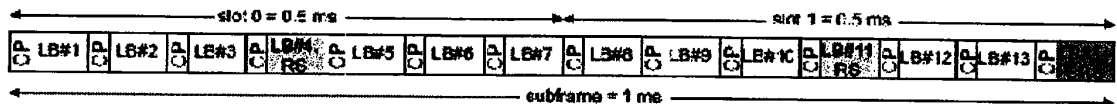


그림 11. Uplink subframe configuration with SRS symbol

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

현 LTE 표준에서는 채널 정보 없이 운용되는 open-loop MIMO와, closed-loop MIMO 두 가지 송신 방식이 존재하며 closed-loop MIMO에서는 MIMO 안테나의 multiplexing gain을 얻기 위해 송 수신 단은 각각 채널 정보

즉 CSI를 바탕으로 beamforming 을 수행한다. 기지국은 CSI를 얻기 위해 UE에게 PUCCH(Physical Uplink Control Channel) 또는 PUSCH(Physical Uplink Shared CHannel)를 할당하여 downlink CSI를 피드백 하도록 명령한다.

CSI는 RI(Rank Indicator), PMI(Precoding Matrix Index), CQI(Channel Quality Indication) 세가지 정보로 크게 분류된다. RI는 채널의 rank 정보를 나타내며, UE가 동일 주파수 시간 자원을 통해 수신 하는 stream의 개수를 의미한다. 이 값은 채널의 long term fading에 의해 dominant 하게 결정되므로 PMI, CQI 값 보다 통상 더 긴 주기를 가지고 UE에서 기지국으로 피드백 된다. 두 번째로, PMI는 채널의 공간 특성을 반영한 값으로 SINR 등의 metric을 기준으로 UE가 선호하는 기지국의 precoding index를 나타낸다. CQI는 채널의 세기를 나타내는 값으로 통상 기지국이 PMI를 이용했을 때 얻을 수 있는 수신 SINR을 의미한다.

LTE-A와 같은 보다 진보된 통신 시스템에서는 MU-MIMO (multi-user MIMO)를 이용한 추가적인 multi-user diversity를 얻는 것이 추가되었다. 이를 위해 채널 피드백 관점에서는 보다 높은 accuracy가 요구된다. 그 이유는 MU-MIMO에서는 안테나 domain에서 multiplexing 되는 UE간의 간섭 채널 존재하기 때문에 피드백 채널 accuracy가 피드백을 올린 UE 뿐 아니라 multiplexing 되는 다른 UE의 간섭에도 큰 영향을 미치기 때문이다. 따라서 LTE-A에서는 피드백 채널 accuracy를 높이기 위해 최종 PMI를 long term and/or wideband PMI인 W1와 short term and/or sub-band PMI인 W2 둘로 나누어 설계하는 것이 결정되었다.

두 채널 정보로부터 하나의 최종 PMI를 구성하는 hierarchical codebook transformation 방식의 예시로 아래와 같이 채널의 long-term covariance matrix를 이용하여 codebook을 transform하는 것이 있다.

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

위 수식에서 $\mathbf{W2}$ (=short term PMI)는 short-term 채널 정보를 반영하기 위해 만들어진 codebook의 codeword이며, $\mathbf{W}$ 은 transform된 최종 codebook의 codeword, $\text{norm}(\mathbf{A})$ 은 행렬 $\mathbf{A}$ 의 각 column 별 norm이 1로 normalization된 행렬을 의미한다.

기존 W1과 W2의 구체적인 구조는 다음과 같다.

(수식 0)

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

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

상기 codeword 구조는 cross polarized antenna를 사용하는 하고 안테나 간 간격이 조밀한 경우 (통상 인접 안테나 간 거리가 신호 파장의 반 이하인 경우 해당) 발생하는 채널의 correlation 특성을 반영하여 설계한 구조이다. Cross polarized 안테나의 경우 안테나를 horizontal antenna group과 vertical antenna group 으로 구분 할 수 있는데, 각 안테나 그룹은 ULA(uniform linear array) 안테나의 특성을 가지며, 두 안테나 그룹은 co-

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located되어 있다. 따라서 각 그룹의 안테나 간 correlation은 동일한 linear phase increment 특성을 가지며, 안테나 그룹 간 correlation은 phase rotation된 특성을 갖는다. Codebook은 결국 채널을 quantization 한 값이기 때문에 source에 해당하는 채널의 특성을 그대로 반영하여 codebook을 설계하는 것이 필요하다. 설명의 편의를 위해 상기 구조로 만든 rank 1 codeword를 예로 들면 이러한 채널 특성이 수식 0를 만족하는 codeword에 반영되었음을 확인할 수 있다.

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

위 식에서 codeword는 N_t (Tx 안테나 수) by 1 의 vector로 표현되며 상위 vector $X_i(k)$ 와 하위 vector $\alpha_j X_i(k)$ 들로 구조화 되어있고, 각각은 horizontal antenna group과 vertical antenna group의 correlation 특성을 보여준다. $X_i(k)$ 는 각 안테나 그룹의 안테나 간 correlation 특성을 반영하여 linear phase increment를 갖는 벡터로 표현하는 것이 유리하며, 대표적인 예로 DFT 행렬을 이용할 수 있다.

또한 CoMP를 위해서도 보다 높은 채널 accuracy가 필요하다. CoMP JT의 경우 여러 기지국이 특정 UE에게 동일한 데이터를 협력 전송하므로 이론적으로 안테나가 지리적으로 분산되어 있는 MIMO 시스템으로 간주 할 수 있다. 즉, JT에서 MU-MIMO를 하는 경우도 single 셀 MU-MIMO와 마찬가지로 co scheduling 되는 UE간 간섭을 피하기 위해 높은 수준의 채널 accuracy가 요구 된다. CoMP CB의 경우 역시 인접 셀이 서빙 셀에게 주는 간섭을 회피하기 위해서 정교한 채널 정보가 요구된다.

Restricted RLM and RRM/CSI measurement

Interference coordination의 한 방법으로 aggressor 셀이 일부 physical channel의 transmission power/activity를 줄이는 (zero power로 설정하는 동작까지 포함) silent subframe(almost blank subframe; ABS라고 불릴 수도 있음)을 사용하고 victim 셀이 이를 고려하여 UE를 scheduling하는 time domain inter-셀 interference coordination이 가능하다. 이 경우 victim 셀 UE의 입장에서 interference level이 subframe에 따라서 크게 변화하게 되는데, 이런 상황에서 각 subframe에서의 보다 정확한 radio link monitoring(RLM)이나 RSRP/RSRQ 등을 measure하는 radio resource management (RRM) 동작을 수행하거나 link adaptation을 위해서 channel state information(CSI)를 측정하기 위해서, 상기 monitoring/measurement는 균일한 interference 특성을 지니는 subframe의 set들로 제한되어야 한다. 3GPP LTE system에서는 아래와 같이 restricted RLM and RRM/CSI measurement가 정의되었다.

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.

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

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

CSI reporting is periodic or aperiodic.

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

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

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

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

Aperiodic CSI reporting using PUSCH

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

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

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

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

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

Value of CSI request field	Description
'00'	No aperiodic CSI report is triggered
'01'	Aperiodic CSI report is triggered for serving cell c
'10'	Aperiodic CSI report is triggered for a 1 st set of serving cells configured by higher layers
'11'	Aperiodic CSI report is triggered for a 2 nd set of serving cells configured by higher layers

PDCCH assignment procedure in LTE-A

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

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

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

where Y_k is defined below, $i = 0, \dots, L - 1$. For the common search space $m' = m$. For the UE specific search space, for the serving cell on which PDCCH is monitored, if the monitoring UE is configured with carrier indicator field then $m' = m + M^{(L)} \cdot n_{\text{CI}}$ where n_{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 $Y_{-1} = n_{\text{RNTI}} \neq 0$, $A = 39827$, $D = 65537$ and $k = \lfloor n_s/2 \rfloor$, n_s is the slot number within a radio frame. The RNTI value used for n_{RNTI} is defined in [3] as a kind of UE's ID.

Table 12: PDCCH candidates monitored by a UE

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

ACK/NACK transmission for LTE-A

LTE-A 시스템에서는 복수의 DL CC를 통해 전송된 복수의 PDSCH에 대한 복수의 ACK/NACK 정보/신호를 특정 UL CC를 통해 전송하는 것을 고려하고 있다. 이를 위해 기존 Rel-8 LTE에서의 PUCCH format 1a/1b를 이용한 ACK/NACK 전송과는 달리, 복수의 ACK/NACK 정보를 채널 코딩 (e.g. Reed-Muller code, Tail-biting convolutional code, etc.)한 후 PUCCH format 2, 또는 아래와 같은 Block-spreading 기반의 변형된 형태의 새로운 PUCCH format (i.e. E-PUCCH format)을 이용하여 복수의 ACK/NACK 정보/신호를 전송하는 것을 고려할 수 있다.

- Block-spreading

Block-spreading 기법은 제어 정보/신호 (e.g. ACK/NACK, etc.) 전송을 기존 LTE에서의 PUCCH format 1 또는 2 계열과는 다르게 SC-FDMA 방식을 이용하여 변조하는 방법이다. 이 방식에서는 Figure 10에서와 같이 심볼 sequence가 OCC (Orthogonal Cover Code)에 의해 time-domain spreading되어 전송되는 형태이며, OCC를 이용하여 동일한 RB에 여러 UE들의 제어 신호들을 multiplexing시킬 수 있다. 앞서의 PUCCH format 2에서는 하나의 심볼 sequence가 시간 영역에 걸쳐 전송되고 CAZAC sequence의 cyclic shift (i.e. CCS)를 이용하여 UE multiplexing을 수행하는 반면, Block-spreading 기반의 E-PUCCH format의 경우 하나의 심볼 sequence가 주파수 영역에 걸쳐 전송되고 OCC 기반의 time-domain spreading을 이용하여 UE multiplexing을 수행한다. 하나의 예로 Figure 10과 같이 하나의 심볼 sequence를 length-5 (SF = 5)의 OCC를 이용하여 5개의 SC-FDMA 심볼을 생성시켜 전송하는 방법을 나타낸다. 그림의 예제에서는 1 slot 동안 총 2개의 RS 심볼을 사용하였지만, 3개의 RS 심볼을 사용하고 SF = 4의 OCC를 이용하는 방식 등 다양한 응용도 고려할 수 있다. 여기서, RS 심볼은 특정 cyclic shift를 갖는 CAZAC sequence로부터 생성될 수 있으며, 시간 영역의 복수 RS 심볼에 특정 OCC가 적용된 (곱해진) 형태로 전송될 수 있다.

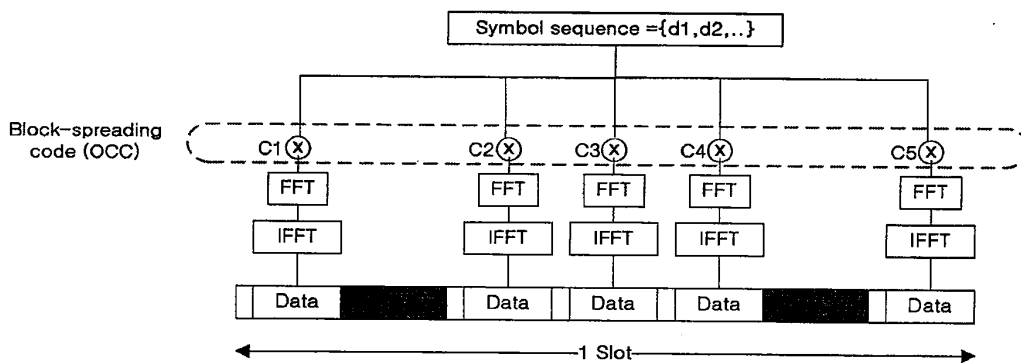


Figure 10. Block-spreading 기반의 E-PUCCH format 예시 (i.e. PUCCH format 3)

설명의 편의를 위해, PUCCH format 2 또는 E-PUCCH format을 사용하는 이러한 채널 코딩 기반의 복수 ACK/NACK 전송 방식을 "multi-bit ACK/NACK coding" 전송 방법이라 칭한다. 이 방법은 복수 DL CC의 PDSCH에 대한 ACK/NACK 또는 DTX 정보 (PDCCH를 수신/검출하지 못함을 의미)들을 채널 코딩하여 생성된 ACK/NACK coded block을 전송하는 방법을 나타낸다. 예를 들어 단말이 어떤 DL CC에서 SU-MIMO mode로 동작하여 2개의 codeword (CW)를 수신한다면 그 CC에 대해 CW 별로 ACK/ACK, ACK/NACK, NACK/ACK, NACK/NACK의 총 4개의 feedback state를 전송하거나, DTX까지 포함하여 최대 5개의 feedback state를 가질 수 있다. 또한 만약 단말이 single CW 수신을 한다면 ACK, NACK, DTX의 최대 3개 state를 가질 수 있다 (만약, NACK을 DTX와 동일하게 처리한다면 ACK, NACK/DTX의 총 2개 state를 가질 수 있다). 따라서 만약 단말이 최대 5개의 DL CC를 aggregation하고 모든 CC에서 SU-MIMO mode로 동작한다면 최대 5⁵개의 전송 가능한 feedback state를 가질 수 있고 이를 표현하기 위한 ACK/NACK payload 사이즈는 총 12 bits가 된다 (만약, DTX를 NACK과 동일하게 처리한다면 feedback state 수는 4⁵개가 되고 이를 표현하기 위한 ACK/NACK payload 사이즈는 총 10 bits가 된다).

기존 Rel-8 TDD 시스템에 적용되는 앞서의 ACK/NACK multiplexing (i.e. ACK/NACK selection) 방법에서는, 기본적으로 각 UE의 PUCCH 자원 확보를 위해 해당 UE의 각 PDSCH를 스케줄링하는 PDCCH에 대응되는 (i.e. lowest CCE 인덱스와 링크되어있는) implicit PUCCH 자원을 사용하는 implicit ACK/NACK selection 방식을 고려하고 있다. 한편, LTE-A FDD 시스템에서는 기본적으로 UE-specific하게 설정되는 하나의 특정 UL CC를 통하여 복수의 DL CC를 통해 전송된 복수의 PDSCH에 대한 복수 ACK/NACK 전송을 고려하고 있으며, 이를 위해 특정 혹은 일부

혹은 모든 DL CC를 스케줄링하는 PDCCH에 링크되어 있는 (i.e. lowest CCE 인덱스 nCCE에 링크되어있는, 혹은 nCCE와 nCCE+1에 링크되어있는) implicit PUCCH 자원 혹은 해당 implicit PUCCH 자원과 RRC signal을 통해 각 UE에게 미리 예약된 explicit PUCCH 자원의 조합을 사용하는 "ACK/NACK selection" 방식을 고려하고 있다.

한편, LTE-A TDD 시스템에서도 복수의 CC가 aggregation (CA)된 상황을 고려할 수 있으며, 이에 따라 복수의 DL subframe과 복수의 CC를 통해 전송된 복수의 PDSCH에 대한 복수 ACK/NACK 정보/신호를, 해당 복수 DL subframe에 대응되는 UL subframe에서 특정 CC (i.e. A/N CC)를 통해 전송하는 것을 고려하고 있다. 여기서는 앞서 LTE-A FDD에서와는 달리, UE에게 할당된 모든 CC를 통해 전송될 수 있는 최대 CW 수에 대응되는 복수 ACK/NACK을, 복수 DL subframe (i.e. SF) 모두에 대하여 전송하는 방식 (i.e. full ACK/NACK)을 고려하거나, 또는 CW and/or CC and/or SF domain에 대해 ACK/NACK bundling을 적용하여 전체 전송 ACK/NACK 수를 줄여서 전송하는 방식 (i.e. bundled ACK/NACK)을 고려할 수 있다 (여기서, CW bundling의 경우 각 DL SF에 대해 CC별로 CW에 대한 ACK/NACK bundling을 적용하는 것을 의미하고, CC bundling의 경우 각 DL SF에 대해 모든 혹은 일부 CC에 대한 ACK/NACK bundling을 적용하는 것을 의미하며, SF bundling의 경우 각 CC에 대해 모든 혹은 일부 DL SF에 대한 ACK/NACK bundling을 적용하는 것을 의미한다. 특징적으로 SF bundling 방법으로써, CC 각각에 대해 수신된 모든 PDSCH or DL grant PDCCH에 대하여 CC별 총 ACK 개수 (혹은, 일부 ACK 개수)를 알려주는 "ACK-counter" 방식을 고려할 수 있다). 이때, UE별 ACK/NACK payload, 즉 각 UE별로 설정된 full or bundled ACK/NACK 전송을 위한 ACK/NACK payload의 사이즈에 따라 "multi-bit ACK/NACK coding" 혹은 "ACK/NACK selection" 기반의 ACK/NACK 전송 기법을 configurable하게 적용할 수 있다.

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.

Section 1

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

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

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

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

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

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

TDD HARQ-ACK procedure for one configured serving cell

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

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

For TDD HARQ-ACK bundling or TDD HARQ-ACK multiplexing for one configured serving cell and a subframe n with $M = 1$ where M is the number of elements in the set K defined in Table 12, the UE shall use PUCCH

resource $n_{\text{PUCCH}}^{(1,p)}$ 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 $N_c \leq n_{\text{CCE}} < N_{c+1}$ and shall use

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

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

If there is only a PDSCH transmission where there is not a corresponding PDCCH detected within subframe(s) $n-k$, where $k \in K$ and K is defined in Table 12, the UE shall use PUCCH format 1a/1b and PUCCH resource $n_{\text{PUCCH}}^{(1,p)}$ 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 $N_c \leq n_{\text{CCE},i} < N_{c+1}$, $N_c = \max\left\{0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor \right\}$, $n_{\text{CCE},i}$ is the number of the first CCE used for transmission of the corresponding PDCCH in subframe $n-k_i$, and $N_{\text{PUCCH}}^{(1)}$ is configured by higher layers.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

HARQ-ACK transmission on two antenna ports ($p \in [p_0, p_1]$) is supported for PUCCH format 3 and TDD with more than one configured serving cell. TDD UL-DL configuration 5 with PUCCH format 3 is only supported for up to

two configured serving cells. TDD UL-DL configuration 5 with channel selection for two configured serving cells is not supported.

PUCCH format 1b with channel selection HARQ-ACK procedure

For TDD HARQ-ACK multiplexing with PUCCH format 1b with channel selection and two configured serving cells and a subframe n with $M \leq 2$ where M is the number of elements in the set K defined in Table 12, the UE shall transmit $b(0)b(1)$ on PUCCH resource $n_{\text{PUCCH}}^{(1)}$ selected from A PUCCH resources, $n_{\text{PUCCH},j}^{(1)}$ 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 $n_{\text{PUCCH},i}^{(1)} = (M-m-1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$, where c is selected from $\{0, 1, 2, 3\}$ such that $N_c \leq n_{\text{CCE},m} < N_{c+1}$, $N_c = \max\left\{0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor\right\}$, 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	$n_{\text{PUCCH},0}^{(1)}$	0, 1
ACK, NACK/DTX, NACK/DTX, NACK/DTX	$n_{\text{PUCCH},0}^{(1)}$	1, 1
NACK/DTX, ACK, ACK, ACK	$n_{\text{PUCCH},1}^{(1)}$	0, 0
NACK/DTX, ACK, ACK, NACK/DTX	$n_{\text{PUCCH},2}^{(1)}$	0, 1

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

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

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

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

For Primary cell:

- If for a PDSCH transmission on the primary cell where there is not a corresponding PDCCH detected within the subframe(s) $n - k$, where $k \in K$,
 - the value of $n_{\text{PUCCH},0}^{(1)}$ is determined according to higher layer configuration.
 - for a PDSCH transmission on the primary cell indicated by the detection of a corresponding PDCCH within the subframe(s) $n - k_m$, where $k_m \in K$ with the DAI value in the PDCCH equal to '1' (defined in Table 9) or a PDCCH indicating downlink SPS release within the subframe(s) $n - k_m$, where $k_m \in K$ with the DAI value in the PDCCH equal to '1', the PUCCH resource $n_{\text{PUCCH},1}^{(1)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$ where c is selected from {0, 1, 2, 3} such that $N_c \leq n_{\text{CCE},m} < N_{c+1}$, $N_c = \max\left\{0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor\right\}$, where $n_{\text{CCE},m}$ is the number of the first CCE used for transmission of the corresponding PDCCH in subframe $n - k_m$ and $N_{\text{PUCCH}}^{(1)}$ is configured by higher layers.
 - HARQ-ACK(0) is the ACK/NACK/DTX response for the PDSCH transmission without a corresponding PDCCH. HARQ-ACK(*j*), $1 \leq j \leq M - 1$, is the ACK/NACK/DTX response for the PDSCH transmission with corresponding PDCCH and DAI value in the PDCCH equal to '*j*'.
- Otherwise,

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- for a PDSCH transmission on the primary cell indicated by the detection of a corresponding PDCCH within the subframe(s) $n - k_m$, where $k_m \in K$ with the DAI value in the PDCCH equal to either '1' or '2' or a PDCCH indicating downlink SPS release within the subframe(s) $n - k_m$, where $k_m \in K$ with the DAI value in the PDCCH equal to either '1' or '2', the PUCCH resource $n_{\text{PUCCH},i}^{(1)} = (M - m - 1) \cdot N_c + m \cdot N_{c+1} + n_{\text{CCE},m} + N_{\text{PUCCH}}^{(1)}$, where c is selected from $\{0, 1, 2, 3\}$ such that $N_c \leq n_{\text{CCE},m} < N_{c+1}$, $N_c = \max\left\{0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor\right\}$, where $n_{\text{CCE},m}$ is the number of the first CCE used for transmission of the corresponding PDCCH in subframe $n - k_m$, $N_{\text{PUCCH}}^{(1)}$ is configured by higher layers, $i = 0$ for the corresponding PDCCH with the DAI value equal to '1' and $i = 1$ for the corresponding PDCCH with the DAI value equal to '2'.
- HARQ-ACK(j), $0 \leq j \leq M - 1$, is the ACK/NACK/DTX response for the PDSCH transmission with corresponding PDCCH and DAI value in the PDCCH equal to ' $j + 1$ '.

For Secondary cell:

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

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

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

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

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

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

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

DTX)				
ACK, ACK, ACK, NACK/DTX	ACK, DTX, DTX, DTX	$n_{PUCCH,2}^{(1)}$	1, 1	1, 1, 0, 1
ACK, ACK, ACK, NACK/DTX	ACK, ACK, ACK, ACK	$n_{PUCCH,2}^{(1)}$	1, 1	1, 1, 0, 1
ACK, ACK, NACK/DTX, any	ACK, DTX, DTX, DTX	$n_{PUCCH,2}^{(1)}$	0, 1	1, 0, 0, 1
ACK, ACK, NACK/DTX, any	ACK, ACK, ACK, ACK	$n_{PUCCH,2}^{(1)}$	0, 1	1, 0, 0, 1
ACK, DTX, DTX, DTX	ACK, DTX, DTX, DTX	$n_{PUCCH,2}^{(1)}$	1, 0	0, 1, 0, 1
ACK, DTX, DTX, DTX	ACK, ACK, ACK, ACK	$n_{PUCCH,2}^{(1)}$	1, 0	0, 1, 0, 1
ACK, ACK, ACK, ACK	ACK, DTX, DTX, DTX	$n_{PUCCH,2}^{(1)}$	1, 0	0, 1, 0, 1
ACK, ACK, ACK, ACK	ACK, ACK, ACK, ACK	$n_{PUCCH,2}^{(1)}$	1, 0	0, 1, 0, 1
NACK/DTX, any, any, any	ACK, DTX, DTX, DTX	$n_{PUCCH,2}^{(1)}$	0, 0	0, 0, 0, 1
NACK/DTX, any, any, any	ACK, ACK, ACK, ACK	$n_{PUCCH,2}^{(1)}$	0, 0	0, 0, 0, 1
(ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX)	ACK, DTX, DTX, DTX	$n_{PUCCH,2}^{(1)}$	0, 0	0, 0, 0, 1
(ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX)	ACK, ACK, ACK, ACK	$n_{PUCCH,2}^{(1)}$	0, 0	0, 0, 0, 1
ACK, ACK, ACK, NACK/DTX	NACK/DTX, any, any, any	$n_{PUCCH,1}^{(1)}$	1, 0	1, 1, 0, 0
ACK, ACK, ACK, NACK/DTX	(ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX)	$n_{PUCCH,1}^{(1)}$	1, 0	1, 1, 0, 0
ACK, ACK, NACK/DTX, any	NACK/DTX, any, any, any	$n_{PUCCH,1}^{(1)}$	0, 1	1, 0, 0, 0
ACK, ACK, NACK/DTX, any	(ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX)	$n_{PUCCH,1}^{(1)}$	0, 1	1, 0, 0, 0
ACK, DTX, DTX, DTX	NACK/DTX, any, any, any	$n_{PUCCH,0}^{(1)}$	1, 1	0, 1, 0, 0
ACK, DTX, DTX, DTX	(ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX)	$n_{PUCCH,0}^{(1)}$	1, 1	0, 1, 0, 0
ACK, ACK, ACK, ACK	NACK/DTX, any, any, any	$n_{PUCCH,0}^{(1)}$	1, 1	0, 1, 0, 0
ACK, ACK, ACK, ACK	(ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX)	$n_{PUCCH,0}^{(1)}$	1, 1	0, 1, 0, 0
NACK, any, any, any	NACK/DTX, any, any, any	$n_{PUCCH,0}^{(1)}$	0, 0	0, 0, 0, 0
NACK, any, any, any	(ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX)	$n_{PUCCH,0}^{(1)}$	0, 0	0, 0, 0, 0
(ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX)	NACK/DTX, any, any, any	$n_{PUCCH,0}^{(1)}$	0, 0	0, 0, 0, 0
(ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX)	(ACK, NACK/DTX, any, any), except for (ACK, DTX, DTX, DTX)	$n_{PUCCH,0}^{(1)}$	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),	No Transmission		0, 0, 0, 0

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

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

PUCCH format 3 HARQ-ACK procedure

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

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

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

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 $N_{\text{PUCCH}}^{(1)}$ is configured by higher layers, c is selected from $\{0, 1, 2, 3\}$ such that $N_c \leq n_{\text{CCE},m} < N_{c+1}$, $N_c = \max\left\{0, \left\lfloor \frac{N_{\text{RB}}^{\text{DL}} \cdot (N_{\text{sc}}^{\text{RB}} \cdot c - 4)}{36} \right\rfloor\right\}$, and $n_{\text{CCE},m}$ is the number of the first CCE used for transmission of the corresponding PDCCH in subframe $n-k_m$ where $k_m \in K$. For a UE configured with a transmission mode that supports up to two transport blocks on the primary cell, the PUCCH resource $n_{\text{PUCCH},2}^{(1)}$ is determined as $n_{\text{PUCCH},2}^{(1)} = n_{\text{PUCCH},1}^{(1)} + 1$. HARQ-ACK(0) is the ACK/NACK/DTX response for the PDSCH without a corresponding PDCCH detected. HARQ-ACK(1) is the ACK/NACK/DTX response for the first transport block of the PDSCH indicated by the detection of a corresponding PDCCH for which the value of the DAI field in the corresponding DCI format is equal to '1' or for the PDCCH indicating downlink SPS release for which the value of the DAI field in the corresponding DCI format is equal to '1'. HARQ-ACK(2) is the ACK/NACK/DTX response for the second transport block of the PDSCH indicated by the detection of a corresponding PDCCH for which the value of the DAI field in the corresponding DCI format is equal to '1'.
- for $M > 1$ and a PDSCH transmission only on the primary cell indicated by the detection of a corresponding PDCCH within subframe(s) $n-k_m$, where $k_m \in K$ with the DAI value in the PDCCH greater than '1' (defined in Table 9) or a PDCCH indicating downlink SPS release within the subframe(s) $n-k_m$, where $k_m \in K$ with the DAI value in the PDCCH greater than '1', the UE shall use PUCCH format 3 and PUCCH resource $n_{\text{PUCCH}}^{(3,p)}$ where the value of $n_{\text{PUCCH}}^{(3,p)}$ is determined according to higher layer configuration and the TPC field in a PDCCH assignment with DAI value greater than '1' shall be used to determine the PUCCH resource value from one of the four PUCCH resource values configured by higher layers. A UE shall assume that the same HARQ-ACK PUCCH resource value is transmitted on all PDCCH assignments used to determine the PUCCH resource values within the subframe(s) $n-k_m$, where $k_m \in K$.
- for a PDSCH transmission on the secondary cell indicated by the detection of a corresponding PDCCH within subframe(s) $n-k_m$, where $k_m \in K$, the UE shall use PUCCH format 3 and PUCCH resource $n_{\text{PUCCH}}^{(3,p)}$ where the value of $n_{\text{PUCCH}}^{(3,p)}$ is determined according to higher layer configuration and the TPC field in the corresponding PDCCH shall be used to determine the PUCCH resource value from one of the four resource values configured by higher layers. If a PDCCH corresponding to a PDSCH on the primary cell within subframe(s) $n-k_m$, where $k_m \in K$, or a PDCCH indicating downlink SPS release within subframe(s) $n-k_m$, where $k_m \in K$, is detected, the TPC field in the PDCCH with the DAI value greater than '1' shall be used to determine the PUCCH resource value from one of the four resource values configured by higher layers. A UE shall assume that the same HARQ-ACK PUCCH resource value is transmitted on all PDCCH assignments in the primary cell and in each secondary cell that are used to determine the PUCCH resource value within the subframe(s) $n-k_m$, where $k_m \in K$.

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

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

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

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

PUCCH format 1b with channel selection HARQ-ACK procedure

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

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

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

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

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

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

resource $n_{\text{PUCCH},j+1}^{(1)}$ is given by $n_{\text{PUCCH},j+1}^{(1)} = n_{\text{CCE}} + 1 + N_{\text{PUCCH}}^{(1)}$ where n_{CCE} is the number of the first CCE used for transmission of the corresponding PDCCH and $N_{\text{PUCCH}}^{(1)}$ is configured by higher layers.

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

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

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

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

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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 1 st PUCCH resource value configured by the higher layers
'01'	The 2 nd PUCCH resource value configured by the higher layers
'10'	The 3 rd PUCCH resource value configured by the higher layers
'11'	The 4 th 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.

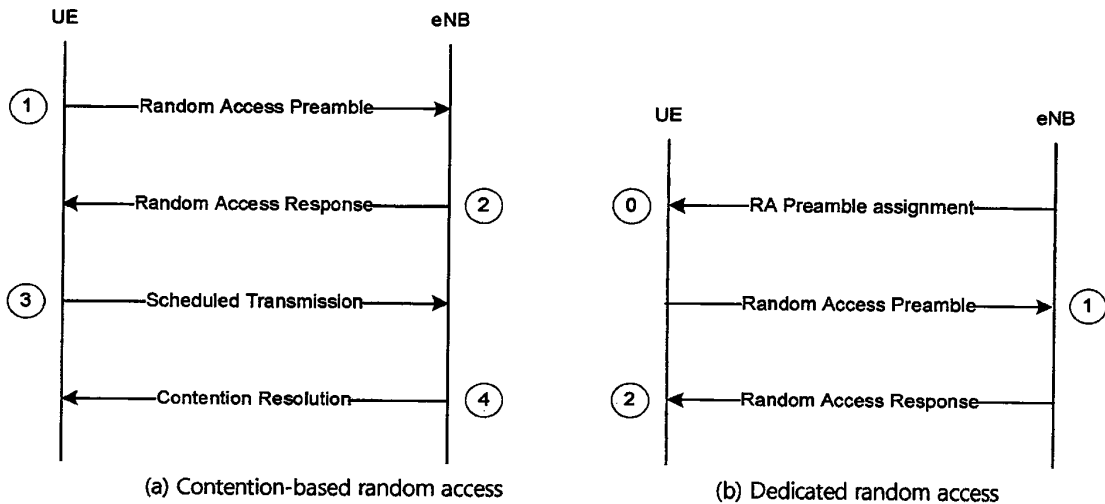


Figure 11. Random access procedures of 3GPP LTE Release-8 system

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

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"quasi co-located (QC)" (혹은 "quasi co-location (QC)")이라는 용어에 대하여 다음과 같이 정의하여 사용한다:

"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

혹은 위 정의는 유사하게 다음과 같이 channel에 대한 표현으로 변형되어 사용될 수도 있다:

"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

본 발명에서는 위 QC관련 정의들을 구분하지 않는다. 즉, QC개념은 위 정의들 중에 하나를 따를 수 있다. 혹은 유사한 다른 형태로, QC가정이 성립하는 antenna ports간에는 마치 co-location에서 전송하는 것처럼 가정할 수 있다는 형태 (e.g., 동일 전송point에서 전송하는 antenna ports이다라고 UE가 가정할 수 있다는 등)으로 QC개념 정의가 변형될 수도 있으며, 본 발명의 사상은 이와 같은 유사 변형 예들을 포함한다. 본 발명에서는 설명의 편의상 위 QC관련 정의들을 혼용하여 사용한다.

위 정의에 의하여, UE는 "non-quasi-co-located (NQC) antenna ports"에 대해서는 해당 antenna ports (APs)간에 동일한 상기 large-scale channel properties를 가정할 수 없다. 즉, 이 경우 통상적인 UE receiver는, timing acquisition and tracking, frequency offset estimation and compensation, delay estimation, and Doppler estimation 등에 대하여 각각의 설정된 non-quasi-co-located(NQC) AP별로 독립적인 processing을 수행하여야 한다.

QC를 가정할 수 있는 AP간에 대해서는, UE는 다음과 같은 동작을 수행할 수 있다는 장점이 있다:

Delay spread & Doppler spread 에 대하여, UE는 어떤 하나의 port에 대한 power-delay-profile, delay spread 및 Doppler spectrum, Doppler spread 추정 결과를, 다른 port에 대한 채널 추정 시 사용되는 Wiener filter 등에 동일하게 적용할 수 있다.

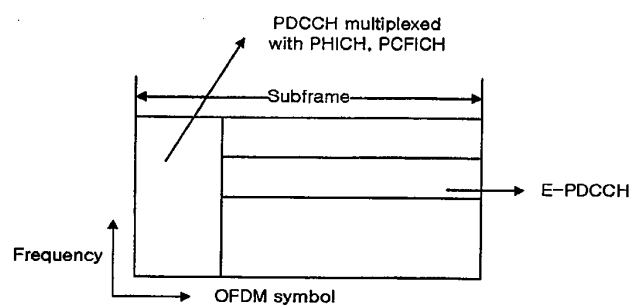
Frequency shift & Received Timing 에 대하여, UE는 어떤 하나의 port에 대한 time and frequency synchronization 수행한 후, 동일한 synchronization을 다른 port의 demodulation에 적용할 수 있다.

Average received power 에 대하여, UE는 over two or more antenna ports에 대하여 RSRP measurements를 averaging할 수 있다.

UE가 PDCCH (혹은 ePDCCH)를 통해 특정 DMRS-based DL-related DCI format (e.g., DCI 2C)을 수신하면, UE는 configured DMRS sequence를 통해 해당 scheduled PDSCH에 대한 채널 추정을 수행한 후 data demodulation을 하게 된다. 예를 들어, 만일 UE가 이러한 DL scheduling grant로부터 받은 DMRS ports configuration이 특정 RS(e.g., 특정 CSI-RS or 특정 CRS or 자신의 DL serving-cell CRS, etc.) ports와 QC가정을 할 수 있다면, UE는 해당 DMRS ports를 통한 채널 추정시 특정 RS(e.g., 특정 CSI-RS or 특정 CRS or 자신의 DL serving-cell CRS, etc.) ports로부터 추정했던 delay spread 등의 상기 large-scale channel properties 추정치를 그대로 적용하여 DMRS-based receiver processing 성능을 향상시킬 수가 있다.

ePDCCH

LTE-A 시스템에서는 기존의 PDCCH에 더하여 추가적인 자원으로 DL control signal을 전송하는 enhanced PDCCH(E-PDCCH)를 도입하기로 하였다. 여기서 E-PDCCH는 그림에서와 같이 기존의 PDSCH 영역에, 즉 시간 축에서 보았을 때 PDCCH가 전송된 이후에 전송되는 것으로 가정한다. 그림에서 E-PDCCH가 연속하는 주파수 자원을 사용하여 전송되는 것으로 나타났으나 이것은 일례에 불과하며 주파수 다이버시티를 위해서 불연속적인 주파수 자원을 이용하여 전송하는 것도 가능하다.



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 $N_{ECCE,p,k} - 1$ where

$N_{ECCE,p,k}$ 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

$$\lfloor L \{ (Y_{p,k} + m') \bmod \lfloor N_{ECCE,p,k} / L \rfloor \} + i \rfloor$$

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

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

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

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

where $Y_{p,-1} = n_{RNTI} \neq 0$, $A = 39827$, $D = 65537$ 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 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

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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 $(n \bmod N_{RB}^{ECCE}) + jN_{RB}^{ECCE}$ in PRB index $\lfloor n/N_{RB}^{ECCE} \rfloor$ 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 $n_{EPDCCH} < 104$ and 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 $l \geq l_{\text{EPDCCHStart}}$ where $l_{\text{EPDCCHStart}}$ 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

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

where $n_{\text{ECCE,low}}$ 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 $N_{\text{EPDCCH}}^{\text{ECCE}}$ 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, Special 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

LTE-A의 차기 시스템은 계량기 검침, 수위측정, 감시 카메라의 활용, 자판기의 재고보고 등의 데이터 통신을 위주로 하는 저가/저사양의 단말을 구성하는 것을 고려하고 있다. 이러한 단말을 편의상 MTC (Machine Type Communication) 단말이라고 통칭한다. MTC 단말의 경우 전송 데이터량이 적고 상/하향 링크 데이터 송수신이가끔씩 발생하기 때문에 이러한 낮은 데이터 전송률에 맞춰서 단말기의 단가를 낮추고 배터리 소모를 줄이는 것이 효율적이다. 이러한 MTC 단말은 이동성이 적은 것을 특징으로 하며, 따라서 채널 환경이 거의 변하지 않는 특성을 지니고 있다. 현재 LTE-A에서는 이러한 MTC 단말이 기존에 비해 넓은 coverage를 지닐 수 있도록 할 것을 고려하고 있으며, 이를 위해 MTC 단말을 위한 다양한 coverage enhancement 기법들이 논의되고 있다.

한편, UE가 특정 cell에 초기 접속을 수행할 경우, UE는 해당 cell을 운용/제어하는 eNodeB로부터 해당 cell에 대한 MID (master information block), SIB (system information block) 정보와 RRC (radio resource control) parameter들을 수신하게 된다. 이 때, MTC UE는 legacy UE에 비해 coverage가 더 넓어야 한다는 문제가 존재한다. 때문에 eNodeB가 legacy UE와 동일하게 SIB를 전송하면, MTC UE는 이를 수신하는데 어려움을 겪게 된다. 이를 해결하기 위해 eNodeB는 coverage issue가 존재하는 MTC UE의 SIB를 PDSCH를 통해 전송하는 경우, subframe repetition, subframe bundling 등과 같은 coverage enhancement를 위한 기법들을 적용되어 전송 될 수 있다.

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.

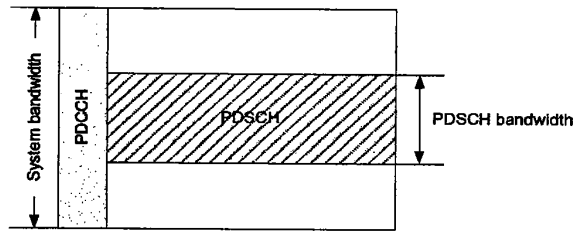
- DL
 - Option DL-1: Reduced bandwidth for both RF and baseband
 - Option DL-2: Reduced bandwidth for baseband only for both data channel and control channels
 - Option DL-3: Reduced bandwidth for data channel in baseband only, while the control channels are still allowed to use the carrier bandwidth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

MTC UE의 low-cost 특성을 위해, 상기 Option DL-2 또는 DL-3의 방법이 사용되어, downlink data channel을 위한 bandwidth가 줄어들게 될 경우, MTC UE는 기존의 LTE-A 시스템의 기법만으로는 원활하게 동작을 하지 못할 수 있다. 따라서 본 발명에서는 특히 downlink data channel의 bandwidth를 줄여 동작하는 low-cost MTC UE를 위한 동작 기법들을 제안한다.

4. Invention Summary



<도 1>

A. PDCCH의 전송

<도 1>에 도시된 것과 같이 Low-cost MTC UE를 위해 downlink 환경에서 control channel (i.e. PDCCH)은 carrier bandwidth의 전체 band 영역으로 전송될 수 있는 반면, data channel이 전송될 수 있는 bandwidth 만이 system bandwidth 보다 작은 값으로 감소될 수 있다. 이 때, low-cost MTC UE를 위한 PDCCH 전송을 위해 아래와 같은 동작이 수행될 수 있다.

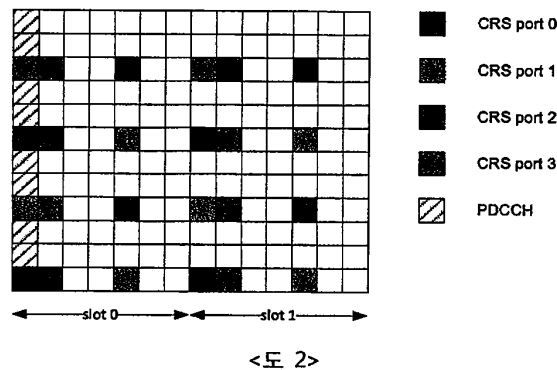
향후 LTE-A 시스템에서는 MTC UE의 coverage enhancement를 위해 PDSCH, PDCCH 등의 channel을 repetition 하여 전송하는 기법을 고려하고 있다. 이 때, MTC UE를 위해서는 PCFICH, PHICH 등의 channel이 전송되지 않을 것을 고려하고 있다. 따라서 MTC UE가 PCFICH를 수신할 필요가 없도록 하기 위해, PDCCH가 전송되는 OFDM symbol의 수는 항상 3 symbol이라고 가정할 수 있다. 혹은 몇 개의 symbol인지 PSS/SSS에 전송되거나 PBCH에 전송되어 단말에게 알려질 수 있다. 또한 coverage enhancement가 적용되지 않은 MTC UE의 경우에도 buffering을 위해 가정해야 하는 전체 system bandwidth가 normal CP의 경우, 첫 3개의 OFDM symbol에 대해서는 전 대역에 걸친 resource element를 저장한다고 가정하며, 그 이외에 OFDM symbol들은 6PRB 혹은 reduction 된 data bandwidth로 한정할 수 있다고 가정한다. 또한 첫 몇 개의 OFDM symbol에 대해 전 대역을 가정할 때 몇 개의 OFDM symbol인지는 higher layer 로 signaling되거나 cell ID와 연계되어 지정되거나, PBCH등에 전달될 수 있다. 더불어 단말이 cell search의 단계에서는 무조건 전 대역으로 오는 OFDM symbol이 0이라고 가정할 수 있다. 따라서 6PRB에 대한 resource element의 data만 store할 수 있다.

한편, 기존과 LTE-A system에서와 같이 PDCCH가 전송되는 OFDM symbol의 수가 PCFICH를 통한 indication 등을 통해 dynamic하게 변경될 수도 있다. 이 경우, UE는 PDCCH가 전송되는 OFDM symbol 영역에서는 전 대역을 통해 channel/signal의 수신을 시도하고, PDCCH의 전송이 끝난 후의 OFDM symbol 영역에서는 data channel을 위한 band 영역만을 통해 channel/signal의 수신을 시도할 수 있다.

MTC UE는 PDCCH의 수신을 위해 전 대역으로부터 최대 4 ports CRS를 수신해야 할 필요가 있다. 이 때, UE가 4 ports까지의 CRS를 수신하기 위해서는 <도 2>에 도시된 것과 같이 최소 앞에서부터 2개의 OFDM symbol (i.e. OFDM symbol #0, OFDM symbol #1)을 수신해야 한다. 하지만 예를 들어 <도 2>에서와 같이 한 개의 OFDM symbol 상으로만 PDCCH가 전송되는 경우, UE가 PDSCH의 전송이 시작되는 OFDM symbol #2부터 data channel이 전송되는 bandwidth로 동작 bandwidth를 감소하여 동작하게 되면, UE는 PDCCH를 수신할 위한 전 system bandwidth 영역에서의 4 ports CRS를 수신할 수 없게 된다.

따라서 본 발명에서는 MTC UE가 control channel은 carrier bandwidth의 전 영역을 통해 수신하는 반면, data channel이 전송될 수 있는 bandwidth는 reduction이 되는 경우, 다음과 같이 수신 bandwidth를 조절할 것을 제안한다.

- UE는 처음 2개의 OFDM symbol (i.e. OFDM symbol #0, OFDM symbol #1)에서는 PDCCH symbol의 개수에 상관없이 전체 system bandwidth로 channel/signal을 수신한다.
- UE는 OFDM symbol #2 이후의 OFDM symbol에서는 해당 symbol에 PDCCH가 전송되는 경우에는 전체 system bandwidth로 동작하고, PDSCH가 전송되는 경우에는 data channel을 위해 reduction 된 bandwidth로 channel/signal을 수신한다.



<도 2>

- DCI format 1A

UE가 PDCCH 상으로 DCI format 1A를 전송하는 경우, DCI format 1A의 Resource block assignment field의 bit 수는 $\lceil \log_2(N_{RB}^{DL}(N_{RB}^{DL} + 1)/2) \rceil$ 와 같이 정해진다. 이 때, N_{RB}^{DL} 은 Downlink bandwidth configuration, expressed in number of resource blocks를 의미한다. 한편, low-cost MTC UE를 위해 downlink 환경에서 data channel이 전송될 수 있는 bandwidth는 system bandwidth 보다 작은 값으로 감소될 수 있다.

DCI format 1A에서 N_{RB}^{DL} 가 downlink system bandwidth의 RB 개수를 의미할 경우, DCI format 1A의 bit 수는 DCI format 0의 bit 수와 항상 동일할 수 있다. 이 때, DCI format 1A의 bit 수와 DCI format 0의 bit 수를 동일하게 만들기 위해, bit 수가 더 적은 DCI format에 zero padding을 수행할 수 있다. 본 발명에서는 이와 같이 DCI format 1A의 bit 수와 DCI format 0의 bit 수를 동일하게 만들기 위해, bit 수가 더 적은 DCI format에 zero padding을 수행하였을 경우의 DCI format 1A의 bit 수를 N_{1A_long} 이라고 하고, DCI format 0의 bit 수를 N_{0_long} 이라고 하겠다. 이 때, N_{1A_long} 와 N_{0_long} 는 동일한 값을 지니게 된다.

반면, DCI format 1A에서 N_{RB}^{DL} 가 data channel이 전송될 수 있는 bandwidth의 RB 개수를 의미할 경우, DCI format 1A의 bit 수와 DCI format 0의 bit 수를 동일하게 맞추지 않을 수 있다. MTC 환경에서 PDSCH가 전송되는

bandwidth를 제한하고, N_{RB}^{DL} 가 data channel이 전송될 수 있는 bandwidth의 RB 개수를 의미하게 되면, 이러한 환경에서 필요한 DCI format 1A의 resource allocation을 위한 field의 크기는 작아지게 되고, 이로 인해 low-cost MTC UE를 위한 DCI format 1A의 길이와 DCI format 0의 길이의 차이가 커지게 된다. 이 경우, DCI format 1A의 bit 수와 DCI format 0의 bit 수를 동일하게 만들기 위해 zero padding을 수행하는 것은 오히려 overhead를 초래할 수 있다. 이 경우 본 발명에서는 DCI format 1A에서 N_{RB}^{DL} 가 data channel이 전송될 수 있는 bandwidth의 RB 개수를 의미하고, DCI format 1A의 bit 수와 DCI format 0의 bit 수를 동일하게 맞추기 위해 zero-padding을 수행하지 않았을 때의 DCI format 1A의 bit 수를 N_{1A_short} 라고 하고, DCI format 0의 bit 수를 N_{0_short} 라고 하겠다.

이 경우, 본 발명에서는 UE가 DCI format 1A를 전송할 때에 Resource block assignment field를 전송하기 위한 N_{RB}^{DL} 의 값을 data channel이 전송될 수 있는 bandwidth의 RB 개수가 아닌 downlink system bandwidth의 RB 개수로 적용할 것을 제안한다. 즉, 본 발명에서는 UE는 DCI format 1A의 bit 수가 항상 N_{1A_long} 과 같다고 가정할 것을 제안한다. 또한 본 발명에서는 UE는 DCI format 0의 bit 수가 항상 N_{0_long} 과 같다고 가정할 것을 제안한다.

또는 UE는 CSS 상으로 전송되는 PDCCH를 수신하기 위해서는 N_{RB}^{DL} 를 data channel이 전송될 수 있는 bandwidth의 RB 개수가 아닌 downlink system bandwidth의 RB 개수로 해석하고, USS 상으로 전송되는 PDCCH에서는 N_{RB}^{DL} 를 downlink 환경에서 data channel이 전송될 수 있는 bandwidth의 RB 개수로 해석할 수 있다.

또는 UE는 SI-RNTI (또는 다른 cell-specific RNTI)를 이용하여 수신하는 PDCCH에서는 N_{RB}^{DL} 를 data channel이 전송될 수 있는 bandwidth의 RB 개수가 아닌 downlink system bandwidth의 RB 개수로 해석하고, C-RNTI (또는 다른 UE-specific RNTI) 상으로 전송되는 PDCCH에서는 N_{RB}^{DL} 를 downlink 환경에서 data channel이 전송될 수 있는 bandwidth의 RB 개수로 해석할 수 있다. 즉, 본 발명에서는 data channel이 전송될 수 있는 bandwidth가 system bandwidth 보다 작은 값으로 감소된 MTC UE가 CSS 상으로 전송되는 PDCCH에서는 DCI format 1A의 bit 수가 N_{1A_long} 과 같고, USS 상으로 전송되는 PDCCH에서는 DCI format 1A의 bit 수가 N_{1A_short} 과 같다고 가정할 것을 제안한다. (또한 data channel이 전송될 수 있는 bandwidth가 system bandwidth 보다 작은 값으로 감소된 MTC UE가 CSS 상으로 전송되는 PDCCH에서는 DCI format 0의 bit 수가 N_{0_long} 과 같고, USS 상으로 전송되는 PDCCH에서는 DCI format 0의 bit 수가 N_{0_short} 과 같다고 가정할 것을 제안한다.) 다른 말로 eNodeB는 MTC UE 중 coverage enhancement가 필요 한 UE에게는 CSS 상으로 DCI format 1A를 전송할 경우, N_{RB}^{DL} 는 downlink system bandwidth의 RB 개수를 의미하며, DCI format 1A의 bit 수와 DCI format 0의 bit 수를 동일하게 만들기 위해, bit 수가 더 적은 DCI format에 zero padding을 수행하여 DCI format 1A의 bit 수가 N_{1A_long} 이 되도록 전송할 수 있다. (또한 eNodeB는 MTC UE 중 coverage enhancement가 필요 한 UE에게는 CSS 상으로 DCI format 0를 전송할 경우, DCI format 1A의 bit 수와 DCI format 0의 bit 수를 동일하게 만들기 위해, bit 수가 더 적은 DCI format에 zero padding을 수행하여 DCI format 0의 bit 수가 N_{0_long} 이 되도록 전송할 수 있다.) eNodeB가 coverage enhancement가 필요 한 UE에게 USS 상으로 DCI format 1A를 전송할 경우, N_{RB}^{DL} 는 data channel이 전송될 수 있는 bandwidth의 RB 개수를 의미하며, DCI format 1A에 zero-padding을 수행하지 않고 bit 수가 N_{1A_short} 가 되도록 전송한다. (또한 eNodeB가 coverage enhancement가 필요 한 UE에게 USS 상으로 DCI format 0를 전송할 경우, DCI format 0에 zero-padding을 수행하지 않고 bit 수가 N_{0_short} 가 되도록 전송한다.)

또는 MTC UE 중 coverage enhancement가 필요 한 UE는 PDCCH를 통해 DCI format 1A 또는 다른 DCI format을 전송할 경우, N_{RB}^{DL} 를 downlink 환경에서 data channel이 전송될 수 있는 bandwidth의 RB 개수로 해석하고, 이외의 다른 UE들은 N_{RB}^{DL} 를 data channel이 전송될 수 있는 bandwidth의 RB 개수가 아닌 downlink system bandwidth의 RB 개수로 해석할 수 있다. 즉, MTC UE 중 coverage enhancement가 필요 한 UE는 DCI format 1A의 bit 수를 N_{1A_short} 과 같다고 가정하고, 이외의 다른 UE들은 DCI format 1A의 bit 수가 N_{1A_long} 과 같다고

가정할 수 있다. (또한 MTC UE 중 coverage enhancement가 필요 한 UE는 DCI format 0의 bit 수를 N_{0_short} 과 같다고 가정하고, 이 외의 다른 UE들은 DCI format 0의 bit 수가 N_{0_long} 과 같다고 가정할 수 있다.)

USS (또는 CSS) 상으로 전송하는 DCI format 1A/0를 전송할 경우, N_{RB}^{DL} 는 data channel이 전송될 수 있는 bandwidth의 RB 개수를 의미하며, DCI format 0와 DCI format 1A를 bit length를 동일하게 맞추기 위해 zero-padding을 수행하지 않고 bit 수가 서로 다른 상태를 유지하도록 할 수 있다. 이 경우, DCI format 0와 DCI format 1A의 bit length가 동일하지 않기 때문에 기존에 DCI format 0와 1A에 포함되어 있던 'Flag for format1/format1A differentiation' field를 제거할 수 있다. 이 경우, 특정 환경에서 DCI format 0와 DCI format 1A의 bit length가 동일해지는 상황이 발생할 수 있다. 'Flag for format1/format1A differentiation' field를 제거한 상태에서 DCI format 0와 DCI format 1A의 bit length가 동일해지면 UE가 두 DCI format을 구별할 수 없기 때문에, 이를 방지하기 위한 기법이 필요하다. 따라서 본 발명에서는 이를 위해 DCI format 0와 DCI format 1A의 bit length가 동일해질 경우, 두 DCI format을 구별하기 위해 DCI format 0와 DCI format 1A에 'Flag for format1/format1A differentiation' field를 추가하여 전송할 것을 제안한다. 또는 DCI format 0와 DCI format 1A의 bit length가 동일해질 경우, 두 DCI format을 구별하기 위해 DCI format 1A (또는 DCI format 0)에 1 bit의 zero-padding을 수행하여 항상 두 DCI format의 length가 다르게 만들어 줄 것을 제안한다.

USS (또는 CSS) 상으로 전송하는 DCI format 1A/0를 전송할 경우, N_{RB}^{DL} 는 data channel이 전송될 수 있는 bandwidth의 RB 개수를 의미하며, DCI format 0와 DCI format 1A를 bit length를 동일하게 맞추기 위해 zero-padding을 수행하지 않고 bit 수가 서로 다른 상태를 유지하도록 할 수 있다. 이 때, 특징적으로 downlink system bandwidth가 UE의 downlink data 전송 bandwidth와 동일 할 경우, 예를 들어 UE의 downlink data 전송 bandwidth가 1.4MHz이고 downlink system bandwidth도 1.4MHz일 경우, eNodeB는 legacy와 같은 방법으로 DCI format 0와 DCI format 1A를 전송할 수 있다. 즉, eNodeB는 특징적으로 Downlink system bandwidth가 UE의 downlink data 전송 bandwidth와 동일 할 경우, 예를 들어 UE의 downlink data 전송 bandwidth가 1.4MHz이고 downlink system bandwidth도 1.4MHz일 경우, DCI format 0와 DCI format 1A의 bits length가 동일하도록 더 짧은 길이를 지닌 DCI format에 zero padding을 수행하고, 두 DCI format을 구별하기 위해 DCI format 0와 DCI format 1A에 'Flag for format1/format1A differentiation' field를 추가하여 전송할 수 있다.

B. Cell-specific PDSCH의 전송

MTC UE가 cell-specific한 PDSCH를 수신해야 할 경우, UE는 PDCCH의 CSS (common search space) 영역을 통해 PDSCH 수신을 위한 DL grant를 search하게 된다. 이 때, MTC UE에게 전송해야 할 cell-specific 한 data (e.g. SIB)의 내용은 legacy UE에게 전송해야 할 cell-specific 한 data의 내용과 다르게 구성될 수 있다. 또한 같은 MTC UE 일지라도 coverage enhancement를 위한 기법의 사용이 필요한 MTC UE와 그렇지 않은 MTC UE에게 전송해야 할 cell-specific data의 내용이 다를 수 있다.

이를 위해 본 발명에서는 MTC UE의 CSS 영역과 legacy UE의 CSS 영역이 서로 다르게 구성될 것을 제안한다. 여기서 CSS 영역이라 함은 CSS의 RE 자원, PRB 영역 and/or subframe 영역 등이 될 수 있다. 또한 본 발명에서는 coverage enhancement를 위한 기법의 사용이 필요한 MTC UE와 그렇지 않은 MTC UE에 대한 CSS 영역이 서로 다르게 구성될 것을 제안한다.

이 때, 특징적으로 MTC UE들을 위한 SI-RNTI (system information RNTI)를 별도로 만들어, MTC의 SIB 혹은 cell-specific higher-layer signal을 전송하기 위한 RNTI로 사용할 수 있다. 추가적으로 coverage issue가 존재하는 MTC UE를 위한 SI-RNTI를 별도로 사용하여, coverage issue가 존재하는 MTC UE의 SIB 혹은 cell-specific higher-layer signal을 전송하기 위한 RNTI로 사용할 수 있다.

MTC UE는 자신이 사용할 CSS 영역을 MIB (master information block) 또는 SIB 상으로 eNodeB로부터 configure 받을 수 있다. 또는 MTC UE를 위한 cell-specific PDSCH가 전송되는 영역은 사전에 정해져 있어, MTC UE는 CSS 상으로 PDCCH를 수신하는 것을 기대하지 않을 수 있다.

기존에 UE들이 cell-specific PDSCH가 전송되는 PRB 영역에 대한 정보를 CSS 상으로 전송되는 DL grant를 통해 얻은 것과는 달리, data channel이 전송될 수 있는 bandwidth 만이 감소되어 있는 MTC UE를 위한 cell-specific PDSCH가 전송될 수 있는 PRB 영역은 center 6RB로 고정될 수 있다. 또는 UE는 MTC UE를 위한 cell-specific PDSCH가 전송될 수 있는 RB 영역은 MIB 또는 SIB 등을 통해 eNodeB로부터 configure 받을 수 있다.

또한 다른 방법으로는 cell-specific PDSCH가 normal UE와 low cost MTC UE 와 coverage enhancement가 필요한 UE사이에 공유되는 방법도 생각해 볼 수 있다. 이 경우, low cost MTC UE의 경우는 정해진 6PRB 에 PDSCH가 온다고 가정할 수 있으며, 한번에 전송된 PDSCH로 SIB를 decoding하지 못할 수도 있다. 따라서, 정해진 repetition의 숫자 (MIB로 전송되거나 UE에게 미리 설정되어있다고 가정할 수 있다) 만큼, PDSCH를 읽어서 bundling을 수행하여 하나의 SIB를 전송 받을 수 있다. 예를 들어, SIB1을 subframe #5/#25 (every 50msec)에서 전송한다고 가정할 경우, repetition이 4로 configure된 경우, a low cost MTC UE는 subframe #5/#25/#45/#65에서 네 번의 PDSCH를 읽어야 SIB1을 decoding할 수 있게 된다. 만약 subframe에 SIB가 전송되지 않는다면, 다음 subframe에서 읽어서 설정된 횟수만큼 읽어서 decoding을 시도하게 된다. 혹은 retransmission처럼 decoding을 연속적으로 수행하여 읽을 수도 있다. Network eNB의 입장에서는 전송되는 PDSCH가 MTC UE에게 할당된 6PRB를 넘어서는 경우, 해당 MTC UE에게는 PDSCH가 6PRB이외에서 puncturing된다고 가정할 수 있으며, 그러한 것을 고려하여 다음 SIB PDSCH의 resource를 할당할 수 있다. Coverage enhancement가 필요한 UE를 위해서는 PDCCH가 성공적으로 decoding되지 않을 수 있기 때문에, 정해진 subframe에서 CSS PDSCH를 정해진 위치에 전송할 수 있다.

또한 다른 방법으로는 MTC UE가 CSS PDSCH를 monitoring하지 않도록 higher layer configuration을 통하여 설정하거나 MIB등으로 configure해주거나 미리 설정되어 있을 수 있다. 이 경우, SIB등의 정보를 읽기 위하여 MIB는 필요한 설정을 포함할 수 있으며, SIB를 읽어야 하는 RNTI등이 MIB에 설정이 될 수 있음을 가정한다. 또한 SIB가 MIB를 포함하는 PBCH처럼 PDCCH 없이 signaling될 수 있는 방법을 배제하지 않는다. 좀 더 나아가서, RNTI는 MTC UE와 coverage enhancement를 필요로 하는 UE와 MTC UE중에서 coverage enhancement를 필요로 하는 UE별로 다르게 설정될 수 있으며, 각 RNTI가 MIB에 설정되거나 각각 PBCH가 따로 전송되는 경우, 읽는 PBCH의 특성에 맞추어 RNTI가 설정된다고 가정할 수 있다. 예를 들어, PBCH가 low cost MTC UE를 위해서 전송되는 경우, 포함된 RNTI는 low cost MTC UE의 CSS PDSCH나 SIB를 읽는 것에 사용될 수 있고, PBCH가 coverage enhancement를 위해서 전송되는 경우, 포함된 RNTI는 coverage enhancement 가 필요한 UE의 SIB전송에 사용될 수 있다. 이 경우, 해당 RNTI는 USS로 간주될 수 있다. 이 경우, 각 UE가 blind decoding을 해야 하는 RNTI의 숫자를 줄이기 위해서 각 UE별로 subframe별로 읽어야 하는 RNTI를 higher layer signaling 해주거나, 미리 설정되어 있을 수 있다. 예를 들어, subframe #0/#5는 SIB or CSS PDSCH를 위한 RNTI를 디코딩하고, 다른 subframe에서는 UE RNTI로 디코딩하도록 할 수 있다. 이러한 설정은 CSS PDSCH or SIB를 읽을 subframe을 bitmap의 형태나, period/offset의 형태로 알려줄 수 있거나, 반대로 USS PDSCH를 읽을 subframe을 알려줄 수도 있다.

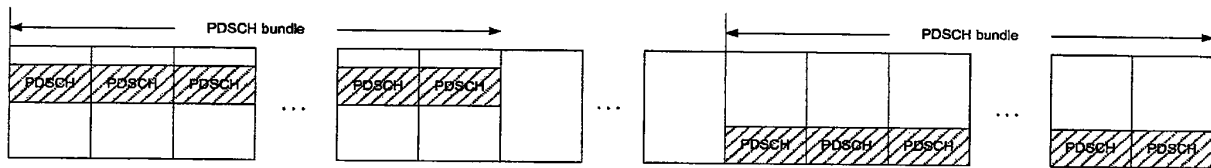
C. UE-specific PDSCH의 전송

- PDSCH transmission with coverage enhancement

Low-cost를 위해 data channel을 수신할 수 있는 bandwidth가 감소된 MTC UE가 존재할 때, MTC UE의 data channel을 위한 frequency location은 1) 고정되거나, 2) pre-determined pattern에 의해 달라지거나, 3) semi-static하게 configure되거나 또는 4) dynamic하게 configure 될 수 있다.

한편, 이러한 MTC UE에게 coverage issue가 존재하여, PDSCH의 coverage enhancement를 위해 PDSCH repetition/bundling 등의 기법을 사용할 수 있다. 이 때, PDSCH의 repetition 하는 subframe duration 동안 PDSCH가 전송되는 frequency location (or RB 영역)이 바뀌게 되면, cross-subframes channel estimation으로 인한 성능 향상의 효과가 줄어들 수 있다.

따라서 본 발명에서는 <도 3>에 도시된 것과 같이, 동일 data에 대한 수신을 시도하는 PDSCH bundle 동안에는 PDSCH가 전송되는 RB 영역이 동일할 것을 제안한다. 이 때, 특징적으로 data에 대한 수신을 시도하는 PDSCH bundle 동안에는 PDSCH가 전송되는 RB 영역은 PDSCH bundle의 첫 번째 subframe을 통해 전송되는 PDSCH RB 영역과 동일할 수 있다. 또는 본 발명에서는 동일 data에 대한 수신을 시도하는 PDSCH bundle 동안에는 PDSCH가 전송될 수 있는 band 영역 (PDSCH 수신을 위한 frequency location)이 동일할 것을 제안한다. 이 때, 특징적으로 data에 대한 수신을 시도하는 PDSCH bundle 동안에는 PDSCH가 전송될 수 있는 band 영역 (PDSCH 수신을 위한 frequency location)은 PDSCH bundle의 첫 번째 subframe에서 적용하는 PDSCH가 전송될 수 있는 band 영역 (PDSCH 수신을 위한 frequency location)과 동일할 수 있다.



<도 3>

- CSI report

UE는 eNodeB에게 downlink channel의 상태를 report 하기 위해 periodic하게 또는 aperiodic하게 CSI report를 수행하게 된다. CSI는 RI (Rank Indicator), PMI (Precoding Matrix Index), CQI (Channel Quality Indication) 세가지 정보로 크게 분류되며, UE는 상황에 따라 이들 중 전체 또는 일부 정보를 eNodeB에게 전송하게 된다.

본 발명에서는 low-cost MTC UE가 data channel의 수신을 위해 reduction 된 bandwidth를 사용할 경우, 해당 기간 동안은 data channel 뿐만 아니라 다른 channel 및 reference signal 역시 data bandwidth 영역에서만 수신 하는 것을 가정한다.

Periodic CSI report

Low-cost를 위해 data channel을 수신할 수 있는 bandwidth가 감소된 MTC UE가 eNodeB에게 periodic CSI report를 수행할 경우, UE는 CQI report를 위해 어떠한 방식의 CQI feedback (e.g. wideband CQI, sub-band CQI)을 수행할지를 알아야 한다.

이 때, UE가 사용할 수 있는 CQI feedback 방법으로는 다음과 같은 것들을 고려할 수 있다. 아래 내용은 CQI에 대해 설명하고 있지만 CQI 뿐 아니라 RI, PMI 등 다른 CSI 정보에 대한 feedback에도 동일하게 적용될 수 있다.

- Wideband (for system bandwidth) CQI

UE는 periodic CQI feedback을 수행하기 위해, data를 위한 bandwidth가 아닌 system bandwidth에 대한 wideband CQI를 report할 수 있다. UE는 CQI feedback을 수행할 때에 자신이 전송 받은 CSI-RS, CRS 등을 이용하여 전체 system bandwidth에 대한 CQI를 측정하고, 이에 대한 feedback을 수행할 수 있다. 이 때, data channel을 수신할 수 있는 bandwidth가 감소된 MTC UE가 UE는 CQI feedback을 수행하기 이전에 전체 system RB 상으로 CSI-RS를 수신하지 못하고, 일부 RB 상으로만 CSI-RS를 수신하였더라도 수신한 CSI-RS 만을 사용하여 CQI를 추정할 수 있다.

Wideband CQI를 수행하는 다른 방법으로 UE는 전 system bandwidth로 동작하는 기간 (e.g. PDCCH를 수신하는 기간) 동안 수신한 CRS를 이용하여 전 bandwidth에 대한 CQI를 측정하고, 이에 대한 feedback을 수행할 수 있다.

또는 UE는 data가 전송되는 bandwidth에 대해 wideband CQI feedback을 수행할 수 있다. 즉, UE는 wideband CQI feedback을 수행하는 경우, 자신이 data를 수신할 수 있는 전체 band 영역에 대한 CQI를 측정하고, 이에 대한 feedback을 수행할 수 있다.

- Subband CQI

Data channel을 수신할 수 있는 bandwidth가 감소된 MTC UE의 경우, <도 4>에 도시된 예제와 같이 CQI feedback을 위한 duration 동안 data를 수신할 수 있는 band 영역이 전체 system bandwidth 중 일부 sub-band 만으로 구성될 수 있다.

이 경우, CQI feedback을 위한 duration 동안 data를 수신할 수 있는 band 영역에 대한 sub-band CQI를 feedback 할 수 있다. 예를 들어 subframe K에서 CQI feedback을 수행하는 경우, subframe K로부터 이전 N개의 subframe의 subframe에서의 data를 수신할 수 있는 band 영역들에 대한 sub-band CQI를 feedback 할 수 있다. 이 때, 특징적으로 N의 값은 CQI feedback을 위한 subframe duration과 같은 값일 수 있다.

이 때, 특징적으로 MTC UE이 CQI feedback을 위해 sub-band CQI feedback을 수행할 경우, UE는 CQI feedback을 위한 duration 동안 data를 수신할 수 있는 band 영역 중 best-M 개의 sub-band에 대한 CQI 값과 해당 sub-band의 index 값에 대한 정보를 feedback 할 수 있다.

이 때, 특징적으로 하나의 sub-band는 6RB로 구성될 수 있다.

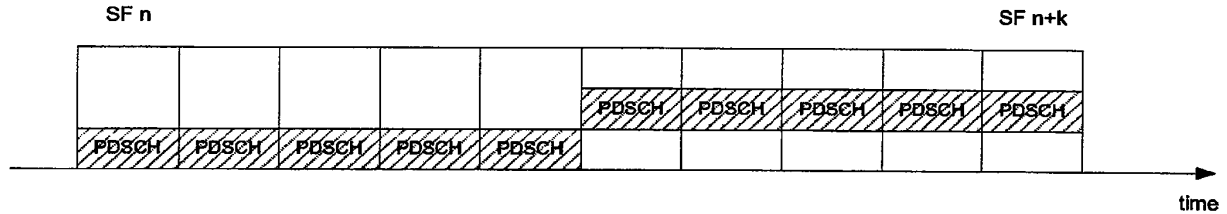
또는 UE는 전 system bandwidth로 동작하는 기간 (e.g. PDCCH를 수신하는 기간) 동안 수신한 CRS를 이용하여 sub-band에 대한 CQI를 측정하고, 이에 대한 feedback을 수행할 수 있다.

또는 UE는 data 수신을 위한 band 영역 이외에 추가적인 band 영역에 대한 RS (e.g. CRS, CSI-RS)들을 수신하여 해당 sub-band 영역에 대한 CQI를 측정하고, 이를 eNodeB에게 추가적으로 또는 독립적으로 feedback 할 수 있다. 예를 들어 UE는 <도 5>의 (a)에 도시된 것과 같이 eNodeB로부터 특정 sub-band 영역을 RRC, PDCCH 등을 통해 configure 받으면, UE는 해당 sub-band 영역에 대한 RS를 수신하여 해당 sub-band에 대한 CQI 정보를 추가적으로 또는 독립적으로 eNodeB에게 feedback 할 수 있다. 이 때, UE가 추가적으로 CQI를 측정한 sub-band 영역에 대한 정보를 eNodeB가 UE가 알려주기 위해, UE의 data 수신 band 영역과 CQI 측정을 위한 sub-band 영역간의 gap의 값을 알려줄 수 있다.

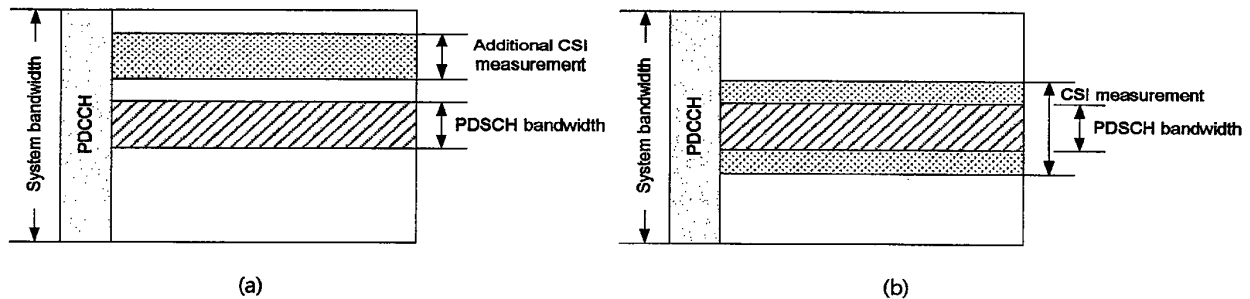
또는 UE가 추가적으로 CQI 측정을 수행 할 sub-band는 random하게 또는 UE의 맘대로 정해질 수 있다. 이 경우, UE는 eNodeB에게 추가적으로 측정한 sub-band 영역에 대한 CQI를 feedback 할 때에, CQI를 측정한 sub-band 영역에 대한 sub-band index 정보를 함께 알려주어야 한다.

UE가 data 수신을 위한 band 영역 이외에 추가적인 sub-band 영역에 대한 RS를 수신하여 CQI를 측정하는 영역은 <도 5>의 (b)에 도시된 것과 같이 data가 전송될 수 있는 band 영역의 한 쪽에 대한 추가적인 M개의 RB 또는 양 쪽에 대한 추가적인 M개의 RB로 구성될 수 있다. 즉, 예를 들어 UE는 x번

RB부터 $x+a$ 번 RB까지를 data band로 할당 받았을 때, 항상 $x-M$ 번 RB부터 $x+a+M$ 번 RB의 영역에 대한 CQI를 측정하여 eNodeB에게 feedback을 수행할 수 있다.



<도 4>



<도 5>

Aperiodic CSI report

Low-cost를 위해 data channel을 수신할 수 있는 bandwidth가 감소된 MTC UE가 eNodeB에게 aperiodic CSI report를 수행하기 위해, UE는 PDCCH (UL grant)의 CSI request field를 통해 aperiodic CSI를 report 하라는 indication을 받아야 한다. 현재 CSI request field는 1 bit 또는 2 bits로 구성되어 있다. 이 때, MTC UE를 위한 CSI request field는 항상 1 bit로 구성될 수 있다.

이 때, data channel을 수신할 수 있는 bandwidth가 감소된 MTC UE에게 aperiodic CSI report의 수행을 지시한 UL grant가 'subframe a'를 통해 전송될 수 있다. 이 경우, 해당 CSI report의 요청에 대한 CSI report를 위해, MTC UE는 'subframe a'에서의 data channel 수신을 위한 band 영역에 대한 CQI, RI, PMI 값의 report를 수행할 수 있다. 좀 더 특징적으로 aperiodic CSI report request를 받았을 경우, CSI report를 하게 될 sub-band를 미리 higher layer로 설정 받거나 미리 지정되어 있거나 request에 지정되어 전달될 수 있다. 이 경우, UE는 해당 sub-band에서 내려오는 CRS나 CSI-RS를 이용하여 CSI를 measure할 수 있다. UE가 해당 sub-band를 듣고 있지 않을 경우를 고려하여, valid downlink subframe은 기존과 다르게 해당 request가 내려오는 downlink subframe index + k ($k \geq 1$)로 설정될 수 있다.

UE는 전 system bandwidth로 동작하는 기간 (e.g. PDCCH를 수신하는 기간) 동안 수신한 CRS를 이용하여 sub-band에 대한 CSI를 측정하고, 이에 대한 feedback을 수행할 수 있다.

또는 UE는 data 수신을 위한 band 영역 이외에 추가적인 band 영역에 대한 RS (e.g. CRS, CSI-RS)들을 수신하여 해당 sub-band 영역에 대한 CSI를 측정하고, 이를 eNodeB에게 추가적으로 또는 독립적으로 feedback 할 수 있다. 예를 들어 UE는 <도 5>의 (a)에 도시된 것과 같이 eNodeB로부터 특정 sub-band 영역을 RRC, PDCCH (e.g.

aperiodic CSI report request field) 등을 통해 configure 받으면, UE는 해당 sub-band 영역에 대한 RS를 수신하여 해당 sub-band에 대한 CSI 정보를 추가적으로 또는 독립적으로 eNodeB에게 feedback 할 수 있다. 이 때, UE가 추가적으로 CQI를 측정한 sub-band 영역에 대한 정보를 eNodeB가 UE가 알려주기 위해, UE의 data 수신 band 영역과 CQI 측정을 위한 sub-band 영역간의 gap의 값을 알려줄 수 있다.

또는 UE가 추가적으로 CSI 측정을 수행 할 sub-band는 random하게 또는 UE의 맘대로 정해질 수 있다. 이 경우, UE는 eNodeB에게 추가적으로 측정한 sub-band 영역에 대한 CSI 를 feedback 할 때에, CSI 를 측정한 sub-band 영역에 대한 sub-band index 정보를 함께 알려주어야 한다.

UE가 data 수신을 위한 band 영역 이외에 추가적인 sub-band 영역에 대한 RS를 수신하여 CSI 를 측정하는 영역은 <도 5>의 (b)에 도시된 것과 같이 data가 전송될 수 있는 band 영역의 한 쪽에 대한 추가적인 M개의 RB 또는 양 쪽에 대한 추가적인 M개의 RB로 구성될 수 있다. 즉, 예를 들어 UE는 x번 RB부터 x+a번 RB까지를 data band로 할당 받았을 때, 항상 x-M번 RB부터 x+a+M번 RB의 영역에 대한 CSI 를 측정하여 eNodeB에게 feedback을 수행할 수 있다.

D. PMCH의 전송

Delay tolerant한 특성을 지니며, 가끔씩 전송되는 data 수신에 최적화 되어 있는 MTC UE는 PMCH를 수신할 필요가 없을 수 있다. 또한 low-cost 특성을 위해 system bandwidth에 비해 downlink data channel의 bandwidth가 감소 된 MTC UE는 원활하게 PMCH를 수신하지 못할 수 있다.

이에 본 발명에서는 MTC UE는 MBSFN subframe에서 data (PMCH)의 수신을 기대하지 않을 것을 제안한다. 특징적으로 MTC UE는 MBSFN subframe에서 UL grant를 제외 한 모든 data, control channel의 수신을 기대하지 않을 것을 제안한다. 또는 MTC UE는 MBSFN subframe에서 모든 data, control channel의 수신을 기대하지 않을 것을 제안한다. 좀 더 특징적으로 MTC UE가 TM9 and/or TM10 을 support하지 못하는 경우 MBSFN subframe에서 모든 data, control channel의 수신을 기대하지 않거나, uplink grant를 제외한 control/data channel 을 기대하지 않을 수 있다. 이를 위해서 MTC UE가 TM9 and/or TM10 을 support하는지 capability signaling을 해줄 수 있다. 좀 더 특징적으로 MTC UE가 TM9 and/or TM10을 support하지 못하는 경우, UE는 CSI-RS를 받을 수 있는지 없는지에 대한 capability signaling을 별도로 해줄 수 있다. 혹은 TM9 and/or TM10을 support하지 못하더라도 MTC UE는 CSI-RS를 받을 수 있도록 mandate 시킬 수 있다.

E. Special subframe에서의 동작

Special subframe에서는 special subframe configuration에 따라 UE가 수신해야 할 downlink OFDM symbol의 개수가 달라지게 된다. 이 때, data bandwidth가 줄어들어 기존의 UE에 비해 UE가 저장할 수 있는 buffer의 size가 감소 된 UE의 경우, normal downlink subframe에서는 모든 RE에 대한 data를 저장할 수 없지만, special subframe에서는 모든 downlink RE에 대한 data를 저장할 수 있는 경우가 생길 수 있다.

따라서 본 발명에서는 system bandwidth에 비해 downlink data channel의 bandwidth가 감소 된 MTC UE가 special subframe configuration 0, 5를 지닌 special subframe에서는 DwPTS 동안 모든 downlink OFDM symbol에 대해 full bandwidth로 동작할 것을 제안한다.

이 경우, eNodeB는 DwPTS 동안 full bandwidth로 CSI-RS 등을 전송함으로써 downlink data channel의 bandwidth가 감소 된 UE가 DwPTS 동안 full bandwidth에 대한 CSI measurement를 수행하도록 할 수 있다.

DESCRIPTION OF THE RELATED ART

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[0031]

[0032]

[0033] Brief Description of the Drawings

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

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

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

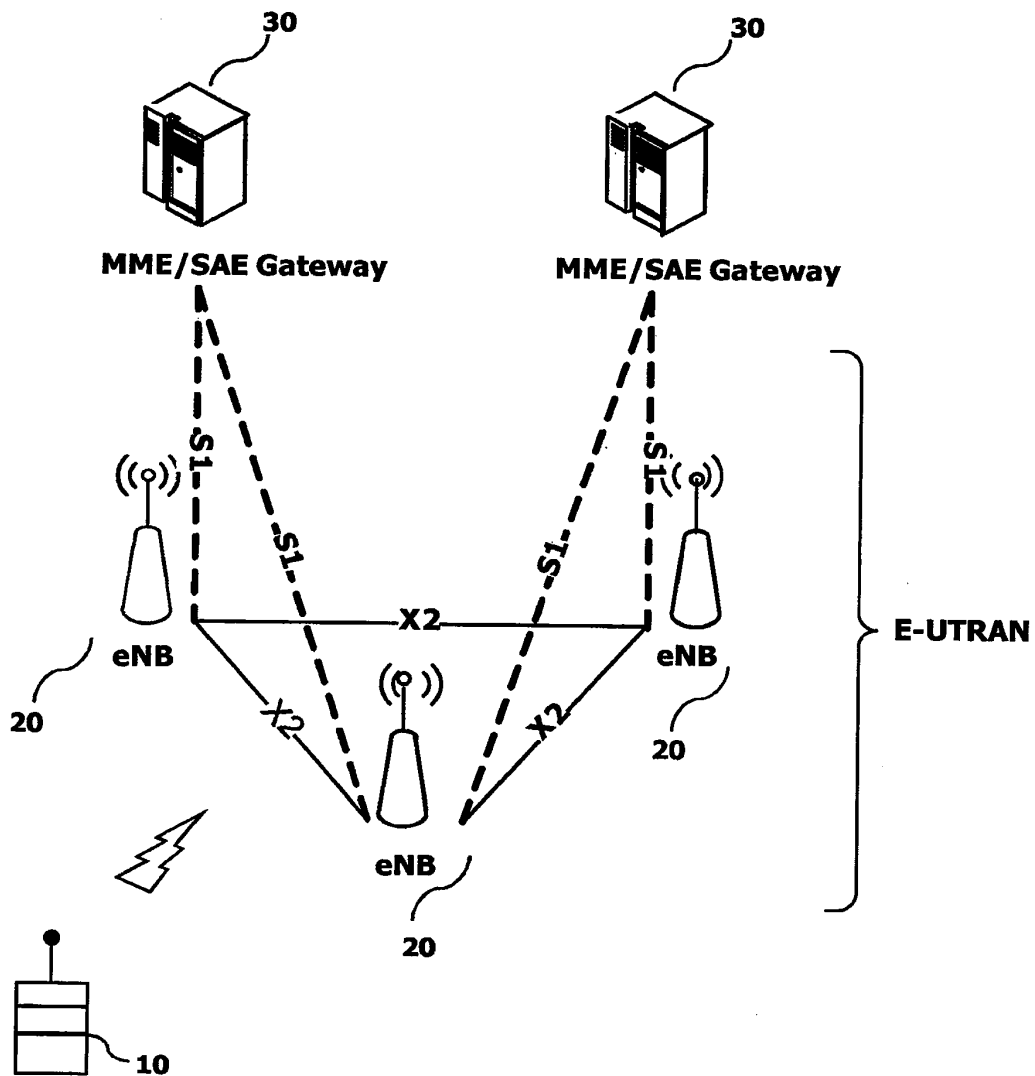
[0037] FIG. 3(b) illustrates the control-plane protocol stack for the E-UMTS

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

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

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

Fig. 1



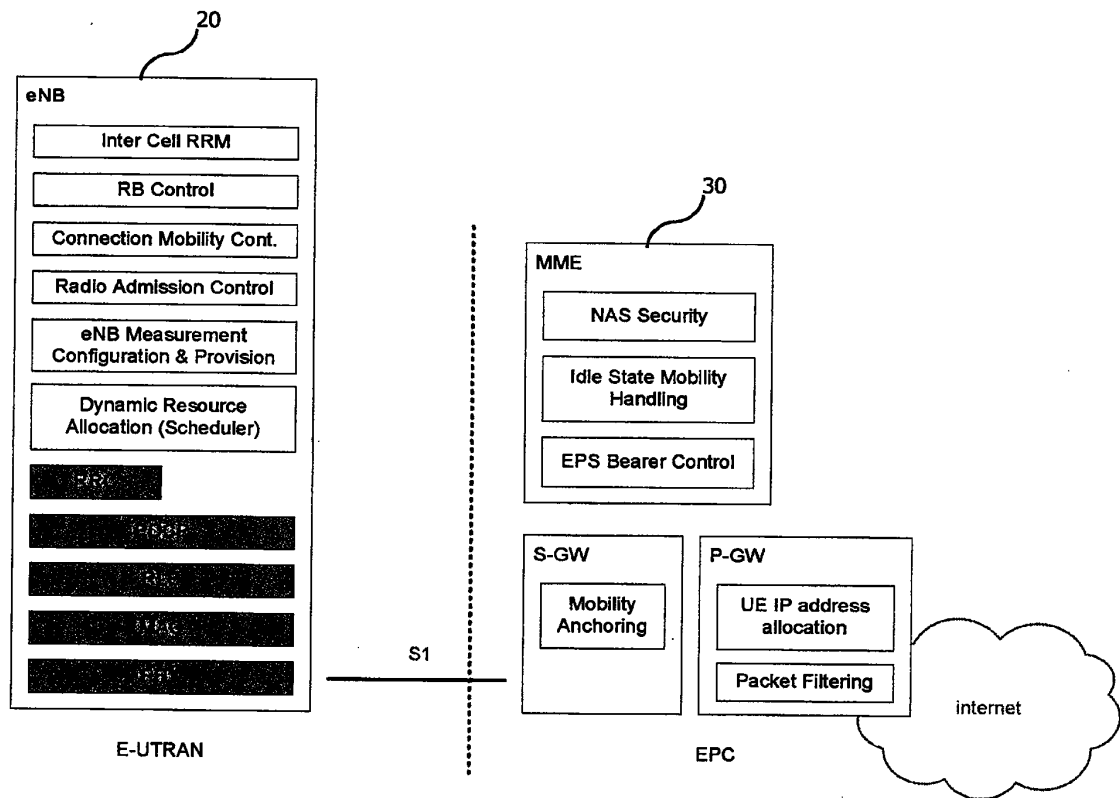


Fig. 3(a)

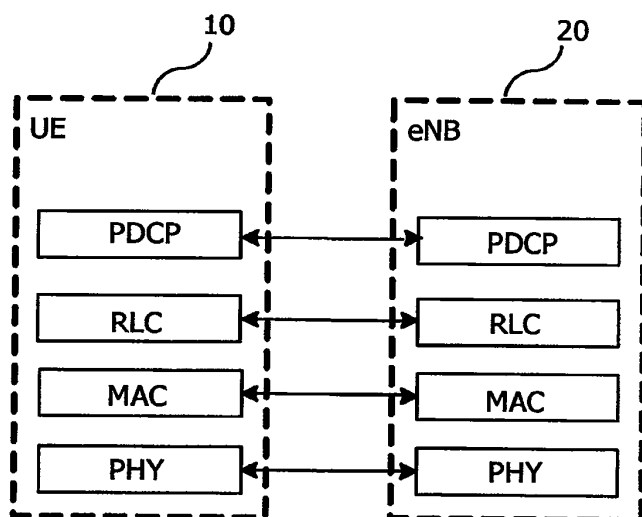


Fig. 3(b)

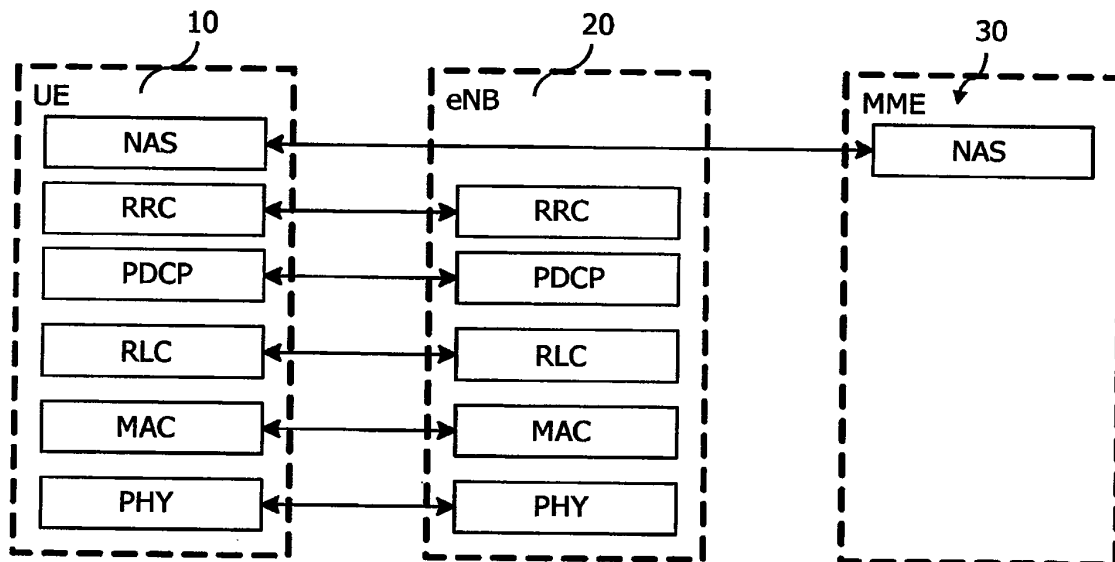


Fig. 4
Structure of the physical channel

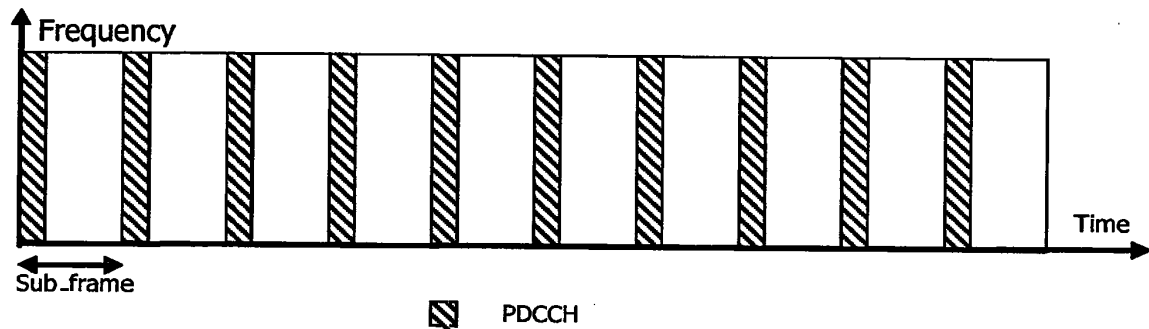


Fig. 5
Random Access procedure for E-UTRAN initial access

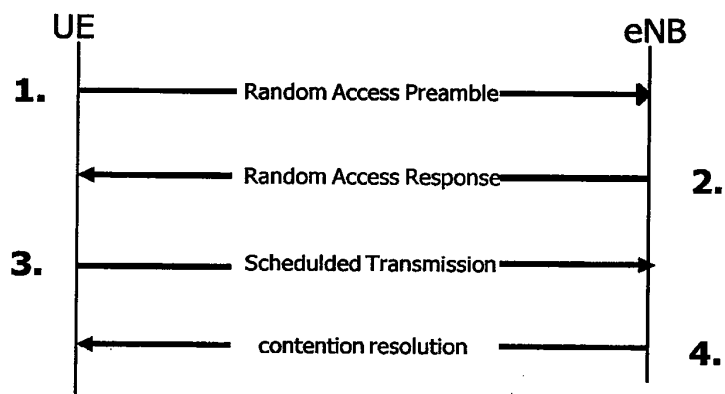


Fig. 6
MOBILE STATION/ACCESS TERMINAL

