Going into the future, there will be a number of new applications that will be more and more delay critical. Examples include remote control/driving of vehicles, augmented reality applications in e.g. smart glasses, or specific machine communications requiring low latency as well as critical communications.

Various pre-scheduling strategies can be used to lower the latency to some extent, but similarly to shorter Scheduling Request (SR) interval introduced in Rel-9, they do not necessarily address all efficiency aspects.

It should also be noted that reduced latency of user plane data may also indirectly give shorter call set-up/bearer set-up times, due to faster transport of control signalling.

To ensure LTE evolution and competitiveness it appears therefore necessary to study and improve the packet data latencies.

4 Objective

4.1 Objective of SI or Core part WI or Testing part WI

The objective of this study item is:

- Study enhancements to the E-UTRAN radio system in order to:
  - Significantly reduce the packet data latency over the LTE Uu air interface for an active UE
  - Significantly reduce the packet data transport round trip latency for UEs that have been inactive for a longer period (in connected state).

The study area includes resource efficiency, including air interface capacity, battery lifetime, control channel resources, specification impact and technical feasibility. Both FDD and TDD duplex modes are considered.

As first aspect, potential gains like reduced response time and improved TCP throughput due to latency improvements on typical applications and use cases are identified and documented. In this evaluation RAN2 may assume latency reductions due to protocol enhancements as well as shortened TTIs. In conclusion, this aspect of the study is supposed to show what latency reductions would be desirable [RAN2].

As second aspect, the following areas should be studied and documented:

- Fast uplink access solutions [RAN2]:
  - for active UEs and UEs that have been inactive a longer time, but are kept in RRC Connected, focus should be on reducing user plane latency for the scheduled UL transmission and getting a more resource efficient solution with protocol and signaling enhancements, compared to the pre-scheduling solutions allowed by the standard today, both with and without preserving the current TTI length and processing times;
- From RAN1#83: TTI shortening and reduced processing times [RAN1]:
  - Assess specification impact and study feasibility and performance of TTI lengths between 0.5ms and one OFDM symbol, taking into account impact on reference signals and physical layer control signaling
  - backwards compatibility shall be preserved (thus allowing normal operation of pre-Rel 13 UEs on the same carrier);

4.2 Objective of Performance part WI

NOTE: Leave empty if the WI proposal does not contain a RAN performance part.

RAN time budget proposal

NOTE: For WIs/SIs under RAN WG5 leadership this section is not filled out. Otherwise:
For a not yet approved WI/SI the rapporteur has to fill out the last row of the table(s) below up to the target date of the WI/SI (if necessary add further tables): Indicate the number of time units (1 TU ~ 2h), i.e. one value for each session/field. If no time unit is needed, leave the field empty.
For WI/SI already approved in the past, the tables below will no longer be updated in the WI/SI description (i.e. the tables reflect the status of the initial approval). But changes can be proposed in the status report of the WI/SI.

Processor **230** then determines which pre-coding matrix to use for determining the beamforming weights then processes the extracted message.

Turning to FIG. **3**, this figure shows an alternative simplified functional block diagram of a communication device according to one embodiment of the invention. As shown in FIG. **3**, the communication device **300** in a wireless communication system can be utilized for realizing the UEs (or ATs) **116** and **122** in FIG. **1** or the base station (or AN) **100** in FIG. **1**, and the wireless communications system is preferably the LTE system. The communication device **300** may include an input device **302**, an output device **304**, a control circuit **306**, a central processing unit (CPU) **308**, a memory **310**, a program code **312**, and a transceiver **314**. The control circuit **306** executes the program code **312** in the memory **310** through the CPU **308**, thereby controlling an operation of the communications device **300**. The communications device **300** can receive signals input by a user through the input device **302**, such as a keyboard or keypad, and can output images and sounds through the output device **304**, such as a monitor or speakers. The transceiver **314** is used to receive and transmit wireless signals, delivering received signals to the control circuit **306**, and outputting signals generated by the control circuit **306** wirelessly. The communication device **300** in a wireless communication system can also be utilized for realizing the AN **100** in FIG. **1**.

FIG. **4** is a simplified block diagram of the program code **312** shown in FIG. **3** in accordance with one embodiment of the invention. In this embodiment, the program code **312** includes an application layer **400**, a Layer 3 portion **402**, and a Layer 2 portion **404**, and is coupled to a Layer 1 portion **406**. The Layer 3 portion **402** generally performs radio resource control. The Layer 2 portion **404** generally performs link control. The Layer 1 portion **406** generally performs physical connections.

Packet data latency is one of the important metrics for performance evaluation. Reducing packet data latency improves the system performance. In 3GPP RP-150465, the study item "Study on latency reduction techniques for LTE" generally aims to investigate and standardize some techniques of latency reduction.

According to 3GPP RP-150465, the objective of the study item is generally to study enhancements to the E-UTRAN radio system in order to significantly reduce the packet data latency over the LTE Uu air interface for an active UE and significantly reduce the packet data transport round trip latency for UEs that have been inactive for a longer period (in connected state). The study area includes resource efficiency, including air interface capacity, battery lifetime, control channel resources, specification impact and technical feasibility. Both FDD (Frequency Division Duplex) and TDD (Time Division Duplex) duplex modes are considered.

According to 3GPP RP-150465, two following areas should be studies and documented:

1. Fast Uplink Access Solutions—

For active UEs and UEs that have been inactive a longer time, but are kept in RRC Connected, the focus should be (i) on reducing user plane latency for the scheduled UL transmission, and (ii) on getting a more resource efficient solution with protocol and signaling enhancements, compared to the pre-scheduling solutions allowed by the standard today, both with and without preserving the current TTI (Transmission Time Interval) length and processing times.

2. TTI Shortening and Reduced Processing Times—

Assess specification impact and study feasibility and performance of TTI lengths between 0.5 ms and one OFDM (Orthogonal Frequency Division Multiplexing) symbol, taking into account impact on reference signals and physical layer control signaling.

FIG. **5** is a reproduction of Figure 1 of 3GPP RP-150310. FIG. **5** generally illustrates the improvement corresponding to the areas.

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- Pre-grant→fast uplink access but with limited throughput
- Resources can be allocated with (modified) SPS
- Remove the requirement to send padding when no data is in buffer→saves battery resources when inactive
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- Switch to dynamic scheduling when entering active phase→optimizing throughput when having lot of data in send buffer

Detailed result of the study can be found in 3GPP TR 36.881 v0.6.0 as quoted below, which confirmed that it would be beneficial to skip the configured grant if there is no data or regular MAC (Medium Access Control) CE (Control Element) to be sent:

8.1 Semi-Persistent Scheduling

With current Semi-Persistent Scheduling (SPS), the eNodeB may configure SPS periodicity via dedicated RRC signalling. Current minimum SPS periodicity is 10 ms. Supporting a SPS periodicity of 1 TTI is beneficial as this may reduce the latency of initial UL transmissions. This would allow UL transmission in consecutive subframes.

8.2 UL Grant Reception

In current specifications, the UE sends a MAC PDU containing a MAC CE for padding BSR and optionally padding bits in response to an allocated UL dynamic or configured grant even if no data is available for transmission in the UE buffer and no other regular MAC CE is needed to be sent. It is beneficial to allow UEs to skip (most) dynamic and configured uplink grants if no data is available for transmission. With frequent UL grants, allowing skipping UL grants may decrease UL interference and improve UE battery efficiency. The UE will continue to send one or more regular MAC CE(s), if any. The eNB may enable skipping UL grants by RRC dedicated signalling.

8.2.1 Configured SPS Activation and Deactivation

The SPS resources are UE specific and may be reserved (configured and active) for a longer period in time. As such, it is in some cases considered useful for the eNB to be timely aligned with the UE state on activated or deactivated SPS resource(s), and if UL transmissions might occur in the granted SPS resource allocation instances.

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L2 PROTOCOL SOLUTION EXAMPLE



- Pre-grant → fast uplink access but with limited throughput
  - Resources can be allocated with (modified) SPS
- Remove the requirement to send padding when no data is in buffer → saves battery resources when inactive
  - Good throughput per watt statistics
- Switch to dynamic scheduling when entering active phase → optimizing throughput when having lot of data in send buffer

Processor **230** then determines which pre-coding matrix to use for determining the beamforming weights then processes the extracted message.

Turning to FIG. **3**, this figure shows an alternative simplified functional block diagram of a communication device according to one embodiment of the invention. As shown in FIG. **3**, the communication device **300** in a wireless communication system can be utilized for realizing the UEs (or ATs) **116** and **122** in FIG. **1** or the base station (or AN) **100** in FIG. **1**, and the wireless communications system is preferably the LTE system. The communication device **300** may include an input device **302**, an output device **304**, a control circuit **306**, a central processing unit (CPU) **308**, a memory **310**, a program code **312**, and a transceiver **314**. The control circuit **306** executes the program code **312** in the memory **310** through the CPU **308**, thereby controlling an operation of the communications device **300**. The communications device **300** can receive signals input by a user through the input device **302**, such as a keyboard or keypad, and can output images and sounds through the output device **304**, such as a monitor or speakers. The transceiver **314** is used to receive and transmit wireless signals, delivering received signals to the control circuit **306**, and outputting signals generated by the control circuit **306** wirelessly. The communication device **300** in a wireless communication system can also be utilized for realizing the AN **100** in FIG. **1**.

FIG. **4** is a simplified block diagram of the program code **312** shown in FIG. **3** in accordance with one embodiment of the invention. In this embodiment, the program code **312** includes an application layer **400**, a Layer 3 portion **402**, and a Layer 2 portion **404**, and is coupled to a Layer 1 portion **406**. The Layer 3 portion **402** generally performs radio resource control. The Layer 2 portion **404** generally performs link control. The Layer 1 portion **406** generally performs physical connections.

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According to 3GPP RP-150465, the objective of the study item is generally to study enhancements to the E-UTRAN radio system in order to significantly reduce the packet data latency over the LTE Uu air interface for an active UE and significantly reduce the packet data transport round trip latency for UEs that have been inactive for a longer period (in connected state). The study area includes resource efficiency, including air interface capacity, battery lifetime, control channel resources, specification impact and technical feasibility. Both FDD (Frequency Division Duplex) and TDD (Time Division Duplex) duplex modes are considered.

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8.2.1 Configured SPS Activation and Deactivation

The SPS resources are UE specific and may be reserved (configured and active) for a longer period in time. As such, it is in some cases considered useful for the eNB to be timely aligned with the UE state on activated or deactivated SPS resource(s), and if UL transmissions might occur in the granted SPS resource allocation instances.

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7 Evaluation Structure and Assumptions

8 Solutions for latency reduction

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4 An acknowledged activation/deactivation of the SPS grant resources may reduce DRX misalignment.

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2 With a higher degree of robustness of the activation/deactivation mechanism, the eNB may not have to repeat unnecessarily the SPS grant.

3 A activation and deactivation acknowledgement mechanism may allow for less conservative use of preconfigured SPS resources and may allow decreased PDCCH load as lower aggregation level can be used.

4 An acknowledged activation/deactivation of the SPS grant resources may reduce DRX misalignment.

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2 DRX impacted by the additional UL transmission including the HARQ wait time (handling of inactivity timer /short cycle timer)

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Acknowledgement Based Con's

1 Unnecessary UE battery consumption in instances of empty UE buffer at activation/deactivation;

2 DRX impacted by the additional UL transmission including the HARQ wait time (handling of inactivity timer/short cycle timer)

3 Increased uplink interference in instances where the SPS allocation is changed due to e.g. PDCCH activation/deactivation and where the UE buffer is empty.

4 New UE behaviour needed for deactivation/release acknowledgment.

5 DRX misalignment probability may be increased due to loss of ACK compared to if ACK is received correctly

6 SPS resources may be unused for a duration as a result of a missing ACK after successful PDCCH reception.

Acknowledgement Free Pro's

1 Relies on the legacy behaviour that the UE in the rare cases of PDCCH loss (e.g. 1%) and non-empty buffer may initiate a SR procedure (alt. RACH procedure). The eNB may then re-initialise SPS or allocate a dynamic grant for the UE to compensate the PDCCH loss.

2 No additional UL transmissions that may cause interference in instances where the SPS allocation is changed due to e.g. PDCCH activation/deactivation and the UE buffer is empty.

3 UE may go earlier to DRX

4 UE behaviour simplified and no new behaviour at deactivation is needed.

Acknowledgement Free Con's

1 Increased PDCCH aggregation level may need to be used which increases the PDCCH resource usage

2 SPS resources may be unused until a SR procedure has been initiated by the UE missing the PDCCH

3 SPS deactivation on PDCCH may need repetition to have robust SPS resource release

4 SPS resources are not released after release indication and are only detected at first periodic grant allocation opportunity after the release signalling time instance.

In the current 3GPP E-UTRA MAC specification (3GPP TS 36.321 v12.5.0), semi-persistent scheduling operates as follows:

5.10 Semi-Persistent Scheduling

When Semi-Persistent Scheduling is enabled by RRC, the following information is provided [8]:

Semi-Persistent Scheduling C-RNTI;

Uplink Semi-Persistent Scheduling interval semiPersistSchedIntervalUL and number of empty transmissions before implicit release implicitReleaseAfter, if Semi-Persistent Scheduling is enabled for the uplink;

Whether twointervalsConfig is enabled or disabled for uplink, only for TDD;

Downlink Semi-Persistent Scheduling interval semiPersistSchedIntervalDL and number of configured HARQ processes for Semi-Persistent Scheduling numberOfConfSPS-Processes, if Semi-Persistent Scheduling is enabled for the downlink;

When Semi-Persistent Scheduling for uplink or downlink is disabled by RRC, the corresponding configured grant or configured assignment shall be discarded.

Semi-Persistent Scheduling is supported on the SpCell only. Semi-Persistent Scheduling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.

NOTE: When eIMTA is configured for the SpCell, if a configured uplink grant or a configured downlink assignment occurs on a subframe that can be reconfigured through eIMTA L1 signalling, then the UE behaviour is left unspecified.

5.10.1 Downlink

After a Semi-Persistent downlink assignment is configured, the MAC entity shall consider sequentially that the N^{th} assignment occurs in the subframe for which:

$$(10*SFN+\text{subframe})=[(10*SFN_{start\ time}+\text{subframe}_{start\ time})+N*\text{semiPersistSchedIntervalDL}]\text{modulo } 10240.$$

Where $SFN_{start\ time}$ and $\text{subframe}_{start\ time}$ are the SFN and subframe, respectively, at the time the configured downlink assignment were (re-)initialised.

5.10.2 Uplink

After a Semi-Persistent Scheduling uplink grant is configured, the MAC entity shall:

if twointervalsConfig is enabled by upper layer:

set the Subframe_Offset according to Table 7.4-1.

else:

set Subframe_Offset to 0.

consider sequentially that the N^{th} grant occurs in the subframe for which:

$$(10*SFN+\text{subframe})=[(10*SFN_{start\ time}+\text{subframe}_{start\ time})+N*\text{semiPersistSchedIntervalUL}+\text{Subframe_Offset}*(N \text{ modulo } 2)]\text{modulo } 10240.$$

Where $SFN_{start\ time}$ and $\text{subframe}_{start\ time}$ are the SFN and subframe, respectively, at the time the configured uplink grant were (re-)initialised.

The MAC entity shall clear the configured uplink grant immediately after implicitReleaseAfter [8] number of consecutive new MAC PDUs each containing zero MAC SDUs have been provided by the Multiplexing and Assembly entity, on the Semi-Persistent Scheduling resource.

NOTE: Retransmissions for Semi-Persistent Scheduling can continue after clearing the configured uplink grant.

[. . .]

5.4.1 UL Grant Reception

In order to transmit on the UL-SCH the MAC entity must have a valid uplink grant (except for non-adaptive HARQ retransmissions) which it may receive dynamically on the PDCCH or in a Random Access Response or which may be configured semi-persistently. To perform requested transmissions, the MAC layer receives HARQ information from lower layers. When the physical layer is configured for uplink spatial multiplexing, the MAC layer can receive up to two grants (one per HARQ process) for the same TTI from lower layers.

If the MAC entity has a C-RNTI, a Semi-Persistent Scheduling C-RNTI, or a Temporary C-RNTI, the MAC entity shall for each TTI and for each Serving Cell belonging to a TAG that has a running timeAlignmentTimer and for each grant received for this TTI:

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3 Increased uplink interference in instances where the SPS allocation is changed due to e.g. PDCCH activation/deactivation and where the UE buffer is empty.

4 New UE behaviour needed for deactivation/release acknowledgment.

5 DRX misalignment probability may be increased due to loss of ACK compared to if ACK is received correctly

6 SPS resources may be unused for a duration as a result of a missing ACK after successful PDCCH reception.

Acknowledgement free Pro's

1 Relies on the legacy behaviour that the UE in the rare cases of PDCCH loss (e.g. 1%) and non-empty buffer may initiate a SR procedure (alt. RACH procedure). The eNB may then re-initialise SPS or allocate a dynamic grant for the UE to compensate the PDCCH loss.

2 No additional UL transmissions that may cause interference in instances where the SPS allocation is changed due to e.g. PDCCH activation/deactivation and the UE buffer is empty.

3 UE may go earlier to DRX

4 UE behaviour simplified and no new behaviour at deactivation is needed.

Acknowledgement free Con's

1 Increased PDCCH aggregation level may need to be used which increases the PDCCH resource usage

2 SPS resources may be unused until a SR procedure has been initiated by the UE missing the PDCCH

3 SPS deactivation on PDCCH may need repetition to have robust SPS resource release

4 SPS resources are not released after release indication and are only detected at first periodic grant allocation opportunity after the release signalling time instance.

8.3 Handover Latency

One possible area of improvement where several existing and new applications could benefit from is to minimize latency during handovers for a mobile UE. Although TCP based applications could recover from errors introduced by poor radio conditions during handovers, the delay introduced by handovers for real time applications is least desired. Two potential solutions to reduce latency during HO are provided below.

8.3.1 Solution 1: RACH-less handover

The solution of RACH-less handover can be introduced when the source cell, the target cell and the UE are synchronized. In a synchronized network, it is assumed that subframe boundary between the source cell and target cell are aligned. One option is that at a mutually agreed time (e.g. SFN), the UE switches from source cell to target cell, without requiring random access procedure. Another option is that the UE follows the legacy handover procedure but skips the RACH related steps. A RACH attempt procedure during handovers typically takes ~10~12 ms. An average handover procedure takes ~40~50 ms to complete. Eliminating ~10~12 ms of RACH delay during a handover procedure can significantly reduce the data interruption during handovers and improve the user experience.

The synchronization may be achieved between the two eNB cells over X2 signalling and the UE via RRC signalling. Based on the fact that all three nodes are in sync, the source cell stops DL transmission to the UE, the target cell provides an uplink grant to the UE, and the UE acquires the target.

Target cell TA without RACH

One of the main purposes of RACH procedure during HO is to obtain target cell TA. In absence of RACH procedure, the UE may be able to obtain the target cell TA without explicit TA command when the source cell and the target cell are time synchronized. As illustrated in Figure 8.X.2-1, the UE first obtains the DL propagation delay difference between the source cell and the target cell (i.e., T1-T2). Assuming the UL propagation delay is the same as the DL propagation delay, the UE can derive the target cell TA from the source cell TA by:

$$TA_{target} = TA_{source} - 2\,(T_1 - T_2).$$

NOTE: The accuracy of the target cell TA obtained by this method needs to be further checked by RAN4.

Acknowledgment Based Pro's

1 With an acknowledgment on the PDCCH grant activating or deactivating the SPS allocation, the eNB may be able to distinguish from cases where the PDCCH is missed by the UE.

2 With a higher degree of robustness of the activation/deactivation mechanism, the eNB may not have to repeat unnecessarily the SPS grant.

3 A activation and deactivation acknowledgement mechanism may allow for less conservative use of preconfigured SPS resources and may allow decreased PDCCH load as lower aggregation level can be used.

4 An acknowledged activation/deactivation of the SPS grant resources may reduce DRX misalignment.

Acknowledgement Based Con's

1 Unnecessary UE battery consumption in instances of empty UE buffer at activation/deactivation;

2 DRX impacted by the additional UL transmission including the HARQ wait time (handling of inactivity timer/short cycle timer)

3 Increased uplink interference in instances where the SPS allocation is changed due to e.g. PDCCH activation/deactivation and where the UE buffer is empty.

4 New UE behaviour needed for deactivation/release acknowledgment.

5 DRX misalignment probability may be increased due to loss of ACK compared to if ACK is received correctly

6 SPS resources may be unused for a duration as a result of a missing ACK after successful PDCCH reception.

Acknowledgement Free Pro's

1 Relies on the legacy behaviour that the UE in the rare cases of PDCCH loss (e.g. 1%) and non-empty buffer may initiate a SR procedure (alt. RACH procedure). The eNB may then re-initialise SPS or allocate a dynamic grant for the UE to compensate the PDCCH loss.

2 No additional UL transmissions that may cause interference in instances where the SPS allocation is changed due to e.g. PDCCH activation/deactivation and the UE buffer is empty.

3 UE may go earlier to DRX

4 UE behaviour simplified and no new behaviour at deactivation is needed.

Acknowledgement Free Con's

1 Increased PDCCH aggregation level may need to be used which increases the PDCCH resource usage

2 SPS resources may be unused until a SR procedure has been initiated by the UE missing the PDCCH

3 SPS deactivation on PDCCH may need repetition to have robust SPS resource release

4 SPS resources are not released after release indication and are only detected at first periodic grant allocation opportunity after the release signalling time instance.

In the current 3GPP E-UTRA MAC specification (3GPP TS 36.321 v12.5.0), semi-persistent scheduling operates as follows:

5.10 Semi-Persistent Scheduling

When Semi-Persistent Scheduling is enabled by RRC, the following information is provided [8]:

Semi-Persistent Scheduling C-RNTI;

Uplink Semi-Persistent Scheduling interval semiPersistSchedIntervalUL and number of empty transmissions before implicit release implicitReleaseAfter, if Semi-Persistent Scheduling is enabled for the uplink;

Whether twointervalsConfig is enabled or disabled for uplink, only for TDD;

Downlink Semi-Persistent Scheduling interval semiPersistSchedIntervalDL and number of configured HARQ processes for Semi-Persistent Scheduling numberOfConfSPS-Processes, if Semi-Persistent Scheduling is enabled for the downlink;

When Semi-Persistent Scheduling for uplink or downlink is disabled by RRC, the corresponding configured grant or configured assignment shall be discarded.

Semi-Persistent Scheduling is supported on the SpCell only. Semi-Persistent Scheduling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.

NOTE: When eIMTA is configured for the SpCell, if a configured uplink grant or a configured downlink assignment occurs on a subframe that can be reconfigured through eIMTA L1 signalling, then the UE behaviour is left unspecified.

5.10.1 Downlink

After a Semi-Persistent downlink assignment is configured, the MAC entity shall consider sequentially that the N^{th} assignment occurs in the subframe for which:

$$(10*SFN+\text{subframe})=[(10*SFN_{start\ time}+\text{subframe}_{start\ time})+N*\text{semiPersistSchedIntervalDL}]\text{modulo } 10240.$$

Where $SFN_{start\ time}$ and $\text{subframe}_{start\ time}$ are the SFN and subframe, respectively, at the time the configured downlink assignment were (re-)initialised.

5.10.2 Uplink

After a Semi-Persistent Scheduling uplink grant is configured, the MAC entity shall:

if twointervalsConfig is enabled by upper layer:

set the Subframe_Offset according to Table 7.4-1.

else:

set Subframe_Offset to 0.

consider sequentially that the N^{th} grant occurs in the subframe for which:

$$(10*SFN+\text{subframe})=[(10*SFN_{start\ time}+\text{subframe}_{start\ time})+N*\text{semiPersistSchedIntervalUL}+\text{Subframe_Offset}*(N \text{ modulo } 2)]\text{modulo } 10240.$$

Where $SFN_{start\ time}$ and $\text{subframe}_{start\ time}$ are the SFN and subframe, respectively, at the time the configured uplink grant were (re-)initialised.

The MAC entity shall clear the configured uplink grant immediately after implicitReleaseAfter [8] number of consecutive new MAC PDUs each containing zero MAC SDUs have been provided by the Multiplexing and Assembly entity, on the Semi-Persistent Scheduling resource.

NOTE: Retransmissions for Semi-Persistent Scheduling can continue after clearing the configured uplink grant.

[. . .]

5.4.1 UL Grant Reception

In order to transmit on the UL-SCH the MAC entity must have a valid uplink grant (except for non-adaptive HARQ retransmissions) which it may receive dynamically on the PDCCH or in a Random Access Response or which may be configured semi-persistently. To perform requested transmissions, the MAC layer receives HARQ information from lower layers. When the physical layer is configured for uplink spatial multiplexing, the MAC layer can receive up to two grants (one per HARQ process) for the same TTI from lower layers.

If the MAC entity has a C-RNTI, a Semi-Persistent Scheduling C-RNTI, or a Temporary C-RNTI, the MAC entity shall for each TTI and for each Serving Cell belonging to a TAG that has a running timeAlignmentTimer and for each grant received for this TTI:

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5.10 Semi-Persistent Scheduling

When Semi-Persistent Scheduling is enabled by RRC, the following information is provided [8]:

- Semi-Persistent Scheduling C-RNTI;
- Uplink Semi-Persistent Scheduling interval *semiPersistSchedIntervalUL* and number of empty transmissions before implicit release *implicitReleaseAfter*, if Semi-Persistent Scheduling is enabled for the uplink;
- Whether *twoIntervalsConfig* is enabled or disabled for uplink, only for TDD;
- Downlink Semi-Persistent Scheduling interval *semiPersistSchedIntervalDL* and number of configured HARQ processes for Semi-Persistent Scheduling *numberOfConfSPS-Processes*, if Semi-Persistent Scheduling is enabled for the downlink;

When Semi-Persistent Scheduling for uplink or downlink is disabled by RRC, the corresponding configured grant or configured assignment shall be discarded.

Semi-Persistent Scheduling is supported on the SpCell only.

Semi-Persistent Scheduling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.

NOTE: When eIMTA is configured for the SpCell, if a configured uplink grant or a configured downlink assignment occurs on a subframe that can be reconfigured through eIMTA L1 signalling, then the UE behaviour is left unspecified.

5.10.1 Downlink

After a Semi-Persistent downlink assignment is configured, the MAC entity shall consider sequentially that the N^{th} assignment occurs in the subframe for which:

- (10 * SFN + subframe) = [(10 * $SFN_{start\ time}$ + $subframe_{start\ time}$) + N * *semiPersistSchedIntervalDL*] modulo 10240.

Where $SFN_{start\ time}$ and $subframe_{start\ time}$ are the SFN and subframe, respectively, at the time the configured downlink assignment were (re-)initialised.

5.10.2 Uplink

After a Semi-Persistent Scheduling uplink grant is configured, the MAC entity shall:

- if *twoIntervalsConfig* is enabled by upper layer:
  - set the Subframe_Offset according to Table 7.4-1.
- else:
  - set Subframe_Offset to 0.
- consider sequentially that the N^{th} grant occurs in the subframe for which:
  - (10 * SFN + subframe) = [(10 * $SFN_{start\ time}$ + $subframe_{start\ time}$) + N * *semiPersistSchedIntervalUL* + Subframe_Offset * (N modulo 2)] modulo 10240.

Where $SFN_{start\ time}$ and $subframe_{start\ time}$ are the SFN and subframe, respectively, at the time the configured uplink grant were (re-)initialised.

The MAC entity shall clear the configured uplink grant immediately after *implicitReleaseAfter* [8] number of consecutive new MAC PDUs each containing zero MAC SDUs have been provided by the Multiplexing and Assembly entity, on the Semi-Persistent Scheduling resource.

NOTE: Retransmissions for Semi-Persistent Scheduling can continue after clearing the configured uplink grant.

Acknowledgment Based Pro's
1 With an acknowledgment on the PDCCH grant activating or deactivating the SPS allocation, the eNB may be able to distinguish from cases where the PDCCH is missed by the UE.
2 With a higher degree of robustness of the activation/deactivation mechanism, the eNB may not have to repeat unnecessarily the SPS grant.
3 A activation and deactivation acknowledgement mechanism may allow for less conservative use of preconfigured SPS resources and may allow decreased PDCCH load as lower aggregation level can be used.
4 An acknowledged activation/deactivation of the SPS grant resources may reduce DRX misalignment.
Acknowledgement Based Con's
1 Unnecessary UE battery consumption in instances of empty UE buffer at activation/deactivation;
2 DRX impacted by the additional UL transmission including the HARQ wait time (handling of inactivity timer/short cycle timer)
3 Increased uplink interference in instances where the SPS allocation is changed due to e.g. PDCCH activation/deactivation and where the UE buffer is empty.
4 New UE behaviour needed for deactivation/release acknowledgment.
5 DRX misalignment probability may be increased due to loss of ACK compared to if ACK is received correctly
6 SPS resources may be unused for a duration as a result of a missing ACK after successful PDCCH reception.
Acknowledgement Free Pro's
1 Relies on the legacy behaviour that the UE in the rare cases of PDCCH loss (e.g. 1%) and non-empty buffer may initiate a SR procedure (alt. RACH procedure). The eNB may then re-initialise SPS or allocate a dynamic grant for the UE to compensate the PDCCH loss.
2 No additional UL transmissions that may cause interference in instances where the SPS allocation is changed due to e.g. PDCCH activation/deactivation and the UE buffer is empty.
3 UE may go earlier to DRX
4 UE behaviour simplified and no new behaviour at deactivation is needed.
Acknowledgement Free Con's
1 Increased PDCCH aggregation level may need to be used which increases the PDCCH resource usage
2 SPS resources may be unused until a SR procedure has been initiated by the UE missing the PDCCH
3 SPS deactivation on PDCCH may need repetition to have robust SPS resource release
4 SPS resources are not released after release indication and are only detected at first periodic grant allocation opportunity after the release signalling time instance.

In the current 3GPP E-UTRA MAC specification (3GPP TS 36.321 v12.5.0), semi-persistent scheduling operates as follows:

5.10 Semi-Persistent Scheduling
When Semi-Persistent Scheduling is enabled by RRC, the following information is provided [8]:
Semi-Persistent Scheduling C-RNTI;
Uplink Semi-Persistent Scheduling interval semiPersistSchedIntervalUL and number of empty transmissions before implicit release implicitReleaseAfter, if Semi-Persistent Scheduling is enabled for the uplink;
Whether twointervalsConfig is enabled or disabled for uplink, only for TDD;

Downlink Semi-Persistent Scheduling interval semiPersistSchedIntervalDL and number of configured HARQ processes for Semi-Persistent Scheduling numberOfConfSPS-Processes, if Semi-Persistent Scheduling is enabled for the downlink;
When Semi-Persistent Scheduling for uplink or downlink is disabled by RRC, the corresponding configured grant or configured assignment shall be discarded.
Semi-Persistent Scheduling is supported on the SpCell only.
Semi-Persistent Scheduling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.
NOTE: When eIMTA is configured for the SpCell, if a configured uplink grant or a configured downlink assignment occurs on a subframe that can be reconfigured through eIMTA L1 signalling, then the UE behaviour is left unspecified.
5.10.1 Downlink
After a Semi-Persistent downlink assignment is configured, the MAC entity shall consider sequentially that the N^{th} assignment occurs in the subframe for which:
$(10*SFN+subframe)=[(10*SFN_{start\ time}+subframe_{start\ time})+N*semiPersistSchedIntervalDL]\text{modulo } 10240.$
Where $SFN_{start\ time}$ and $subframe_{start\ time}$ are the SFN and subframe, respectively, at the time the configured downlink assignment were (re-)initialised.
5.10.2 Uplink
After a Semi-Persistent Scheduling uplink grant is configured, the MAC entity shall:
if twointervalsConfig is enabled by upper layer:
set the Subframe_Offset according to Table 7.4-1.
else:
set Subframe_Offset to 0.
consider sequentially that the N^{th} grant occurs in the subframe for which:
$(10*SFN+subframe)=[(10*SFN_{start\ time}+subframe_{start\ time})+N*semiPersistSchedIntervalUL+Subframe_Offset*(N \text{ modulo } 2)]\text{modulo } 10240.$
Where $SFN_{start\ time}$ and $subframe_{start\ time}$ are the SFN and subframe, respectively, at the time the configured uplink grant were (re-)initialised.
The MAC entity shall clear the configured uplink grant immediately after implicitReleaseAfter [8] number of consecutive new MAC PDUs each containing zero MAC SDUs have been provided by the Multiplexing and Assembly entity, on the Semi-Persistent Scheduling resource.
NOTE: Retransmissions for Semi-Persistent Scheduling can continue after clearing the configured uplink grant.
[. . .]
5.4.1 UL Grant Reception
In order to transmit on the UL-SCH the MAC entity must have a valid uplink grant (except for non-adaptive HARQ retransmissions) which it may receive dynamically on the PDCCH or in a Random Access Response or which may be configured semi-persistently. To perform requested transmissions, the MAC layer receives HARQ information from lower layers. When the physical layer is configured for uplink spatial multiplexing, the MAC layer can receive up to two grants (one per HARQ process) for the same TTI from lower layers.
If the MAC entity has a C-RNTI, a Semi-Persistent Scheduling C-RNTI, or a Temporary C-RNTI, the MAC entity shall for each TTI and for each Serving Cell belonging to a TAG that has a running timeAlignmentTimer and for each grant received for this TTI:

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The MAC entity shall ignore NDI received in all downlink assignments on PDCCH for its Temporary C-RNTI when determining if NDI on PDCCH for its C-RNTI has been toggled compared to the value in the previous transmission.

NOTE: When the MAC entity is configured with more than one serving cell, UE behaviors for storing data to the soft buffer is specified in [2].

NOTE: If the MAC entity receives a retransmission with a TB size different from the last valid TB size signalled for this TB, the UE behavior is left up to UE implementation.

5.3.3 Disassembly and demultiplexing

The MAC entity shall disassemble and demultiplex a MAC PDU as defined in subclause 6.1.2.

5.4 UL-SCH data transfer

5.4.1 UL Grant reception

In order to transmit on the UL-SCH the MAC entity must have a valid uplink grant (except for non-adaptive HARQ retransmissions) which it may receive dynamically on the PDCCH or in a Random Access Response or which may be configured semi-persistently. To perform requested transmissions, the MAC layer receives HARQ information from lower layers. When the physical layer is configured for uplink spatial multiplexing, the MAC layer can receive up to two grants (one per HARQ process) for the same TTI from lower layers.

If the MAC entity has a C-RNTI, a Semi-Persistent Scheduling C-RNTI, or a Temporary C-RNTI, the MAC entity shall for each TTI and for each Serving Cell belonging to a TAG that has a running *timeAlignmentTimer* and for each grant received for this TTI:

- if an uplink grant for this TTI and this Serving Cell has been received on the PDCCH for the MAC entity's C-RNTI or Temporary C-RNTI; or
- if an uplink grant for this TTI has been received in a Random Access Response:
  - if the uplink grant is for MAC entity's C-RNTI and if the previous uplink grant delivered to the HARQ entity for the same HARQ process was either an uplink grant received for the MAC entity's Semi-Persistent Scheduling C-RNTI or a configured uplink grant:
    - consider the NDI to have been toggled for the corresponding HARQ process regardless of the value of the NDI.
  - deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
- else, if this Serving Cell is the SpCell and if an uplink grant for this TTI has been received for the SpCell on the PDCCH of the SpCell for the MAC entity's Semi-Persistent Scheduling C-RNTI:
  - if the NDI in the received HARQ information is 1:
    - consider the NDI for the corresponding HARQ process not to have been toggled;
    - deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
  - else if the NDI in the received HARQ information is 0:
    - if PDCCH contents indicate SPS release:
      - clear the configured uplink grant (if any).
    - else:
      - store the uplink grant and the associated HARQ information as configured uplink grant;
      - initialise (if not active) or re-initialise (if already active) the configured uplink grant to start in this TTI and to recur according to rules in subclause 5.10.2;
      - consider the NDI bit for the corresponding HARQ process to have been toggled;

Acknowledgment Based Pro's
1 With an acknowledgment on the PDCCH grant activating or deactivating the SPS allocation, the eNB may be able to distinguish from cases where the PDCCH is missed by the UE.
2 With a higher degree of robustness of the activation/deactivation mechanism, the eNB may not have to repeat unnecessarily the SPS grant.
3 A activation and deactivation acknowledgement mechanism may allow for less conservative use of preconfigured SPS resources and may allow decreased PDCCH load as lower aggregation level can be used.
4 An acknowledged activation/deactivation of the SPS grant resources may reduce DRX misalignment.
Acknowledgement Based Con's
1 Unnecessary UE battery consumption in instances of empty UE buffer at activation/deactivation;
2 DRX impacted by the additional UL transmission including the HARQ wait time (handling of inactivity timer/short cycle timer)
3 Increased uplink interference in instances where the SPS allocation is changed due to e.g. PDCCH activation/deactivation and where the UE buffer is empty.
4 New UE behaviour needed for deactivation/release acknowledgment.
5 DRX misalignment probability may be increased due to loss of ACK compared to if ACK is received correctly
6 SPS resources may be unused for a duration as a result of a missing ACK after successful PDCCH reception.
Acknowledgement Free Pro's
1 Relies on the legacy behaviour that the UE in the rare cases of PDCCH loss (e.g. 1%) and non-empty buffer may initiate a SR procedure (alt. RACH procedure). The eNB may then re-initialise SPS or allocate a dynamic grant for the UE to compensate the PDCCH loss.
2 No additional UL transmissions that may cause interference in instances where the SPS allocation is changed due to e.g. PDCCH activation/deactivation and the UE buffer is empty.
3 UE may go earlier to DRX
4 UE behaviour simplified and no new behaviour at deactivation is needed
Acknowledgement Free Con's
1 Increased PDCCH aggregation level may need to be used which increases the PDCCH resource usage
2 SPS resources may be unused until a SR procedure has been initiated by the UE missing the PDCCH
3 SPS deactivation on PDCCH may need repetition to have robust SPS resource release
4 SPS resources are not released after release indication and are only detected at first periodic grant allocation opportunity after the release signalling time instance.

In the current 3GPP E-UTRA MAC specification (3GPP TS 36.321 v12.5.0), semi-persistent scheduling operates as follows:

5.10 Semi-Persistent Scheduling

When Semi-Persistent Scheduling is enabled by RRC, the following information is provided [8]:
Semi-Persistent Scheduling C-RNTI;
Uplink Semi-Persistent Scheduling interval semiPersistSchedIntervalUL and number of empty transmissions before implicit release implicitReleaseAfter, if Semi-Persistent Scheduling is enabled for the uplink;
Whether twointervalsConfig is enabled or disabled for uplink, only for TDD;

Downlink Semi-Persistent Scheduling interval semiPersistSchedIntervalDL and number of configured HARQ processes for Semi-Persistent Scheduling numberOfConfSPS-Processes, if Semi-Persistent Scheduling is enabled for the downlink;

When Semi-Persistent Scheduling for uplink or downlink is disabled by RRC, the corresponding configured grant or configured assignment shall be discarded.

Semi-Persistent Scheduling is supported on the SpCell only. Semi-Persistent Scheduling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.

NOTE: When eIMTA is configured for the SpCell, if a configured uplink grant or a configured downlink assignment occurs on a subframe that can be reconfigured through eIMTA L1 signalling, then the UE behaviour is left unspecified.

5.10.1 Downlink

After a Semi-Persistent downlink assignment is configured, the MAC entity shall consider sequentially that the N^{th} assignment occurs in the subframe for which:

$$(10*SFN+\text{subframe})=[(10*SFN_{start\ time}+\text{subframe}_{start\ time})+N*\text{semiPersistSchedIntervalDL}]\text{modulo } 10240.$$

Where $SFN_{start\ time}$ and $\text{subframe}_{start\ time}$ are the SFN and subframe, respectively, at the time the configured downlink assignment were (re-)initialised.

5.10.2 Uplink

After a Semi-Persistent Scheduling uplink grant is configured, the MAC entity shall:
if twointervalsConfig is enabled by upper layer:
set the Subframe_Offset according to Table 7.4-1.
else:
set Subframe_Offset to 0.
consider sequentially that the N^{th} grant occurs in the subframe for which:

$$(10*SFN+\text{subframe})=[(10*SFN_{start\ time}+\text{subframe}_{start\ time})+N*\text{semiPersistSchedIntervalUL}+\text{Subframe_Offset}*(N \text{ modulo } 2)]\text{modulo } 10240.$$

Where $SFN_{start\ time}$ and $\text{subframe}_{start\ time}$ are the SFN and subframe, respectively, at the time the configured uplink grant were (re-)initialised.

The MAC entity shall clear the configured uplink grant immediately after implicitReleaseAfter [8] number of consecutive new MAC PDUs each containing zero MAC SDUs have been provided by the Multiplexing and Assembly entity, on the Semi-Persistent Scheduling resource.

NOTE: Retransmissions for Semi-Persistent Scheduling can continue after clearing the configured uplink grant.

[ ]

5.4.1 UL Grant Reception

In order to transmit on the UL-SCH the MAC entity must have a valid uplink grant (except for non-adaptive HARQ retransmissions) which it may receive dynamically on the PDCCH or in a Random Access Response or which may be configured semi-persistently. To perform requested transmissions, the MAC layer receives HARQ information from lower layers. When the physical layer is configured for uplink spatial multiplexing, the MAC layer can receive up to two grants (one per HARQ process) for the same TTI from lower layers.

If the MAC entity has a C-RNTI, a Semi-Persistent Scheduling C-RNTI, or a Temporary C-RNTI, the MAC entity shall for each TTI and for each Serving Cell belonging to a TAG that has a running timeAlignmentTimer and for each grant received for this TTI:

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The MAC entity shall ignore NDI received in all downlink assignments on PDCCH for its Temporary C-RNTI when determining if NDI on PDCCH for its C-RNTI has been toggled compared to the value in the previous transmission.

NOTE: When the MAC entity is configured with more than one serving cell, UE behaviors for storing data to the soft buffer is specified in [2].

NOTE: If the MAC entity receives a retransmission with a TB size different from the last valid TB size signalled for this TB, the UE behavior is left up to UE implementation.

5.3.3 Disassembly and demultiplexing

The MAC entity shall disassemble and demultiplex a MAC PDU as defined in subclause 6.1.2.

5.4 UL-SCH data transfer

5.4.1 UL Grant reception

In order to transmit on the UL-SCH the MAC entity must have a valid uplink grant (except for non-adaptive HARQ retransmissions) which it may receive dynamically on the PDCCH or in a Random Access Response or which may be configured semi-persistently. To perform requested transmissions, the MAC layer receives HARQ information from lower layers. When the physical layer is configured for uplink spatial multiplexing, the MAC layer can receive up to two grants (one per HARQ process) for the same TTI from lower layers.

If the MAC entity has a C-RNTI, a Semi-Persistent Scheduling C-RNTI, or a Temporary C-RNTI, the MAC entity shall for each TTI and for each Serving Cell belonging to a TAG that has a running *timeAlignmentTimer* and for each grant received for this TTI:

- if an uplink grant for this TTI and this Serving Cell has been received on the PDCCH for the MAC entity's C-RNTI or Temporary C-RNTI; or
- if an uplink grant for this TTI has been received in a Random Access Response:
  - if the uplink grant is for MAC entity's C-RNTI and if the previous uplink grant delivered to the HARQ entity for the same HARQ process was either an uplink grant received for the MAC entity's Semi-Persistent Scheduling C-RNTI or a configured uplink grant:
    - consider the NDI to have been toggled for the corresponding HARQ process regardless of the value of the NDI.
  - deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
- else, if this Serving Cell is the SpCell and if an uplink grant for this TTI has been received for the SpCell on the PDCCH of the SpCell for the MAC entity's Semi-Persistent Scheduling C-RNTI:
  - if the NDI in the received HARQ information is 1:
    - consider the NDI for the corresponding HARQ process not to have been toggled;
    - deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
  - else if the NDI in the received HARQ information is 0:
    - if PDCCH contents indicate SPS release:
      - clear the configured uplink grant (if any).
    - else:
      - store the uplink grant and the associated HARQ information as configured uplink grant;
      - initialise (if not active) or re-initialise (if already active) the configured uplink grant to start in this TTI and to recur according to rules in subclause 5.10.2;
      - consider the NDI bit for the corresponding HARQ process to have been toggled;

if an uplink grant for this TTI and this Serving Cell has been received on the PDCCH for the MAC entity's C-RNTI or Temporary C-RNTI; or
if an uplink grant for this TTI has been received in a Random Access Response:
if the uplink grant is for MAC entity's C-RNTI and if the previous uplink grant delivered to the HARQ entity for the same HARQ process was either an uplink grant received for the MAC entity's Semi-Persistent Scheduling C-RNTI or a configured uplink grant:
consider the NDI to have been toggled for the corresponding HARQ process regardless of the value of the NDI.
deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else, if this Serving Cell is the SpCell and if an uplink grant for this TTI has been received for the SpCell on the PDCCH of the SpCell for the MAC entity's Semi-Persistent Scheduling C-RNTI:
if the NDI in the received HARQ information is 1:
consider the NDI for the corresponding HARQ process not to have been toggled;
deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else if the NDI in the received HARQ information is 0:
if PDCCH contents indicate SPS release:
clear the configured uplink grant (if any).
else:
store the uplink grant and the associated HARQ information as configured uplink grant;
initialise (if not active) or re-initialise (if already active) the configured uplink grant to start in this TTI and to recur according to rules in subclause 5.10.2;
consider the NDI bit for the corresponding HARQ process to have been toggled;
deliver the configured uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else, if this Serving Cell is the SpCell and an uplink grant for this TTI has been configured for the SpCell:
consider the NDI bit for the corresponding HARQ process to have been toggled;
deliver the configured uplink grant, and the associated HARQ information to the HARQ entity for this TTI.
NOTE: The period of configured uplink grants is expressed in TTIs.
NOTE: If the MAC entity receives both a grant in a Random Access Response and a grant for its C-RNTI or Semi persistent scheduling C-RNTI requiring transmissions on the SpCell in the same UL subframe, the MAC entity may choose to continue with either the grant for its RA-RNTI or the grant for its C-RNTI or Semi persistent scheduling C-RNTI.
NOTE: When a configured uplink grant is indicated during a measurement gap and indicates an UL-SCH transmission during a measurement gap, the MAC entity processes the grant but does not transmit on UL-SCH.

Details of UL HARQ operation can be found in 3GPP TS 36.321 v12.5.0 as follows:

5.4.2 HARQ Operation

5.4.2.1 HARQ Entity

There is one HARQ entity at the MAC entity for each Serving Cell with configured uplink, which maintains a number of parallel HARQ processes allowing transmissions

to take place continuously while waiting for the HARQ feedback on the successful or unsuccessful reception of previous transmissions.

The number of parallel HARQ processes per HARQ entity is specified in [2], clause 8.

When the physical layer is configured for uplink spatial multiplexing [2], there are two HARQ processes associated with a given TTI. Otherwise there is one HARQ process associated with a given TTI.

At a given TTI, if an uplink grant is indicated for the TTI, the HARQ entity identifies the HARQ process(es) for which a transmission should take place. It also routes the received HARQ feedback (ACK/NACK information), MCS and resource, relayed by the physical layer, to the appropriate HARQ process(es).

When TTI bundling is configured, the parameter TTI_BUNDLE_SIZE provides the number of TTIs of a TTI bundle. TTI bundling operation relies on the HARQ entity for invoking the same HARQ process for each transmission that is part of the same bundle. Within a bundle HARQ retransmissions are non-adaptive and triggered without waiting for feedback from previous transmissions according to TTI_BUNDLE_SIZE. The HARQ feedback of a bundle is only received for the last TTI of the bundle (i.e the TTI corresponding to TTI_BUNDLE_SIZE), regardless of whether a transmission in that TTI takes place or not (e.g. when a measurement gap occurs). A retransmission of a TTI bundle is also a TTI bundle. TTI bundling is not supported when the MAC entity is configured with one or more SCells with configured uplink.

TTI bundling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.

For transmission of Msg3 during Random Access (see subclause 5.1.5) TTI bundling does not apply.

For each TTI, the HARQ entity shall:
identify the HARQ process(es) associated with this TTI, and for each identified HARQ process:
if an uplink grant has been indicated for this process and this TTI:
if the received grant was not addressed to a Temporary C-RNTI on PDCCH and if the NDI provided in the associated HARQ information has been toggled compared to the value in the previous transmission of this HARQ process; or
if the uplink grant was received on PDCCH for the C-RNTI and the HARQ buffer of the identified process is empty; or
if the uplink grant was received in a Random Access Response:
if there is a MAC PDU in the Msg3 buffer and the uplink grant was received in a Random Access Response:
obtain the MAC PDU to transmit from the Msg3 buffer.
else:
obtain the MAC PDU to transmit from the "Multiplexing and assembly" entity;
deliver the MAC PDU and the uplink grant and the HARQ information to the identified HARQ process;
instruct the identified HARQ process to trigger a new transmission.
else:
deliver the uplink grant and the HARQ information (redundancy version) to the identified HARQ process;

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- deliver the configured uplink grant and the associated HARQ information to the HARQ entity for this TTI.

- else, if this Serving Cell is the SpCell and an uplink grant for this TTI has been configured for the SpCell:
  - consider the NDI bit for the corresponding HARQ process to have been toggled;
  - deliver the configured uplink grant, and the associated HARQ information to the HARQ entity for this TTI.

NOTE: The period of configured uplink grants is expressed in TTIs.

NOTE: If the MAC entity receives both a grant in a Random Access Response and a grant for its C-RNTI or Semi persistent scheduling C-RNTI requiring transmissions on the SpCell in the same UL subframe, the MAC entity may choose to continue with either the grant for its RA-RNTI or the grant for its C-RNTI or Semi persistent scheduling C-RNTI.

NOTE: When a configured uplink grant is indicated during a measurement gap and indicates an UL-SCH transmission during a measurement gap, the MAC entity processes the grant but does not transmit on UL-SCH.

5.4.2 HARQ operation

5.4.2.1 HARQ entity

There is one HARQ entity at the MAC entity for each Serving Cell with configured uplink, which maintains a number of parallel HARQ processes allowing transmissions to take place continuously while waiting for the HARQ feedback on the successful or unsuccessful reception of previous transmissions.

The number of parallel HARQ processes per HARQ entity is specified in [2], clause 8.

When the physical layer is configured for uplink spatial multiplexing [2], there are two HARQ processes associated with a given TTI. Otherwise there is one HARQ process associated with a given TTI.

At a given TTI, if an uplink grant is indicated for the TTI, the HARQ entity identifies the HARQ process(es) for which a transmission should take place. It also routes the received HARQ feedback (ACK/NACK information), MCS and resource, relayed by the physical layer, to the appropriate HARQ process(es).

When TTI bundling is configured, the parameter TTI_BUNDLE_SIZE provides the number of TTIs of a TTI bundle. TTI bundling operation relies on the HARQ entity for invoking the same HARQ process for each transmission that is part of the same bundle. Within a bundle HARQ retransmissions are non-adaptive and triggered without waiting for feedback from previous transmissions according to TTI_BUNDLE_SIZE. The HARQ feedback of a bundle is only received for the last TTI of the bundle (i.e the TTI corresponding to TTI_BUNDLE_SIZE), regardless of whether a transmission in that TTI takes place or not (e.g. when a measurement gap occurs). A retransmission of a TTI bundle is also a TTI bundle. TTI bundling is not supported when the MAC entity is configured with one or more SCells with configured uplink.

TTI bundling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.

For transmission of Msg3 during Random Access (see subclause 5.1.5) TTI bundling does not apply.

For each TTI, the HARQ entity shall:

- identify the HARQ process(es) associated with this TTI, and for each identified HARQ process:
  - if an uplink grant has been indicated for this process and this TTI:
    - if the received grant was not addressed to a Temporary C-RNTI on PDCCH and if the NDI provided in the associated HARQ information has been toggled compared to the value in the previous transmission of this HARQ process; or
    - if the uplink grant was received on PDCCH for the C-RNTI and the HARQ buffer of the identified process is empty; or
    - if the uplink grant was received in a Random Access Response:

if an uplink grant for this TTI and this Serving Cell has been received on the PDCCH for the MAC entity's C-RNTI or Temporary C-RNTI; or
if an uplink grant for this TTI has been received in a Random Access Response:
if the uplink grant is for MAC entity's C-RNTI and if the previous uplink grant delivered to the HARQ entity for the same HARQ process was either an uplink grant received for the MAC entity's Semi-Persistent Scheduling C-RNTI or a configured uplink grant:
consider the NDI to have been toggled for the corresponding HARQ process regardless of the value of the NDI.
deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else, if this Serving Cell is the SpCell and if an uplink grant for this TTI has been received for the SpCell on the PDCCH of the SpCell for the MAC entity's Semi-Persistent Scheduling C-RNTI:
if the NDI in the received HARQ information is 1:
consider the NDI for the corresponding HARQ process not to have been toggled;
deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else if the NDI in the received HARQ information is 0:
if PDCCH contents indicate SPS release:
clear the configured uplink grant (if any).
else:
store the uplink grant and the associated HARQ information as configured uplink grant;
initialise (if not active) or re-initialise (if already active) the configured uplink grant to start in this TTI and to recur according to rules in subclause 5.10.2;
consider the NDI bit for the corresponding HARQ process to have been toggled;
deliver the configured uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else, if this Serving Cell is the SpCell and an uplink grant for this TTI has been configured for the SpCell:
consider the NDI bit for the corresponding HARQ process to have been toggled;
deliver the configured uplink grant, and the associated HARQ information to the HARQ entity for this TTI.
NOTE: The period of configured uplink grants is expressed in TTIs.
NOTE: If the MAC entity receives both a grant in a Random Access Response and a grant for its C-RNTI or Semi persistent scheduling C-RNTI requiring transmissions on the SpCell in the same UL subframe, the MAC entity may choose to continue with either the grant for its RA-RNTI or the grant for its C-RNTI or Semi persistent scheduling C-RNTI.
NOTE: When a configured uplink grant is indicated during a measurement gap and indicates an UL-SCH transmission during a measurement gap, the MAC entity processes the grant but does not transmit on UL-SCH.

Details of UL HARQ operation can be found in 3GPP TS 36.321 v12.5.0 as follows:
5.4.2 HARQ Operation
5.4.2.1 HARQ Entity
There is one HARQ entity at the MAC entity for each Serving Cell with configured uplink, which maintains a number of parallel HARQ processes allowing transmissions to take place continuously while waiting for the HARQ feedback on the successful or unsuccessful reception of previous transmissions.
The number of parallel HARQ processes per HARQ entity is specified in [2], clause 8.
When the physical layer is configured for uplink spatial multiplexing [2], there are two HARQ processes associated with a given TTI. Otherwise there is one HARQ process associated with a given TTI.
At a given TTI, if an uplink grant is indicated for the TTI, the HARQ entity identifies the HARQ process(es) for which a transmission should take place. It also routes the received HARQ feedback (ACK/NACK information), MCS and resource, relayed by the physical layer, to the appropriate HARQ process(es).
When TTI bundling is configured, the parameter TTI_BUNDLE_SIZE provides the number of TTIs of a TTI bundle. TTI bundling operation relies on the HARQ entity for invoking the same HARQ process for each transmission that is part of the same bundle. Within a bundle HARQ retransmissions are non-adaptive and triggered without waiting for feedback from previous transmissions according to TTI_BUNDLE_SIZE. The HARQ feedback of a bundle is only received for the last TTI of the bundle (i.e the TTI corresponding to TTI_BUNDLE_SIZE), regardless of whether a transmission in that TTI takes place or not (e.g. when a measurement gap occurs). A retransmission of a TTI bundle is also a TTI bundle. TTI bundling is not supported when the MAC entity is configured with one or more SCells with configured uplink.
TTI bundling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.
For transmission of Msg3 during Random Access (see subclause 5.1.5) TTI bundling does not apply.
For each TTI, the HARQ entity shall:
identify the HARQ process(es) associated with this TTI, and for each identified HARQ process:
if an uplink grant has been indicated for this process and this TTI:
if the received grant was not addressed to a Temporary C-RNTI on PDCCH and if the NDI provided in the associated HARQ information has been toggled compared to the value in the previous transmission of this HARQ process; or
if the uplink grant was received on PDCCH for the C-RNTI and the HARQ buffer of the identified process is empty; or
if the uplink grant was received in a Random Access Response:
if there is a MAC PDU in the Msg3 buffer and the uplink grant was received in a Random Access Response:
obtain the MAC PDU to transmit from the Msg3 buffer.
else:
obtain the MAC PDU to transmit from the "Multiplexing and assembly" entity;
deliver the MAC PDU and the uplink grant and the HARQ information to the identified HARQ process;
instruct the identified HARQ process to trigger a new transmission.
else:
deliver the uplink grant and the HARQ information (redundancy version) to the identified HARQ process;

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- deliver the configured uplink grant and the associated HARQ information to the HARQ entity for this TTI.

- else, if this Serving Cell is the SpCell and an uplink grant for this TTI has been configured for the SpCell:
  - consider the NDI bit for the corresponding HARQ process to have been toggled;
  - deliver the configured uplink grant, and the associated HARQ information to the HARQ entity for this TTI.

NOTE: The period of configured uplink grants is expressed in TTIs.

NOTE: If the MAC entity receives both a grant in a Random Access Response and a grant for its C-RNTI or Semi persistent scheduling C-RNTI requiring transmissions on the SpCell in the same UL subframe, the MAC entity may choose to continue with either the grant for its RA-RNTI or the grant for its C-RNTI or Semi persistent scheduling C-RNTI.

NOTE: When a configured uplink grant is indicated during a measurement gap and indicates an UL-SCH transmission during a measurement gap, the MAC entity processes the grant but does not transmit on UL-SCH.

5.4.2 HARQ operation

5.4.2.1 HARQ entity

There is one HARQ entity at the MAC entity for each Serving Cell with configured uplink, which maintains a number of parallel HARQ processes allowing transmissions to take place continuously while waiting for the HARQ feedback on the successful or unsuccessful reception of previous transmissions.

The number of parallel HARQ processes per HARQ entity is specified in [2], clause 8.

When the physical layer is configured for uplink spatial multiplexing [2], there are two HARQ processes associated with a given TTI. Otherwise there is one HARQ process associated with a given TTI.

At a given TTI, if an uplink grant is indicated for the TTI, the HARQ entity identifies the HARQ process(es) for which a transmission should take place. It also routes the received HARQ feedback (ACK/NACK information), MCS and resource, relayed by the physical layer, to the appropriate HARQ process(es).

When TTI bundling is configured, the parameter TTI_BUNDLE_SIZE provides the number of TTIs of a TTI bundle. TTI bundling operation relies on the HARQ entity for invoking the same HARQ process for each transmission that is part of the same bundle. Within a bundle HARQ retransmissions are non-adaptive and triggered without waiting for feedback from previous transmissions according to TTI_BUNDLE_SIZE. The HARQ feedback of a bundle is only received for the last TTI of the bundle (i.e the TTI corresponding to TTI_BUNDLE_SIZE), regardless of whether a transmission in that TTI takes place or not (e.g. when a measurement gap occurs). A retransmission of a TTI bundle is also a TTI bundle. TTI bundling is not supported when the MAC entity is configured with one or more SCells with configured uplink.

TTI bundling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.

For transmission of Msg3 during Random Access (see subclause 5.1.5) TTI bundling does not apply.

For each TTI, the HARQ entity shall:

- identify the HARQ process(es) associated with this TTI, and for each identified HARQ process:
  - if an uplink grant has been indicated for this process and this TTI:
    - if the received grant was not addressed to a Temporary C-RNTI on PDCCH and if the NDI provided in the associated HARQ information has been toggled compared to the value in the previous transmission of this HARQ process; or
    - if the uplink grant was received on PDCCH for the C-RNTI and the HARQ buffer of the identified process is empty; or
    - if the uplink grant was received in a Random Access Response:

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if an uplink grant for this TTI and this Serving Cell has been received on the PDCCH for the MAC entity's C-RNTI or Temporary C-RNTI; or
if an uplink grant for this TTI has been received in a Random Access Response:
if the uplink grant is for MAC entity's C-RNTI and if the previous uplink grant delivered to the HARQ entity for the same HARQ process was either an uplink grant received for the MAC entity's Semi-Persistent Scheduling C-RNTI or a configured uplink grant:
consider the NDI to have been toggled for the corresponding HARQ process regardless of the value of the NDI.
deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else, if this Serving Cell is the SpCell and if an uplink grant for this TTI has been received for the SpCell on the PDCCH of the SpCell for the MAC entity's Semi-Persistent Scheduling C-RNTI:
if the NDI in the received HARQ information is 1:
consider the NDI for the corresponding HARQ process not to have been toggled;
deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else if the NDI in the received HARQ information is 0:
if PDCCH contents indicate SPS release:
clear the configured uplink grant (if any).
else:
store the uplink grant and the associated HARQ information as configured uplink grant;
initialise (if not active) or re-initialise (if already active) the configured uplink grant to start in this TTI and to recur according to rules in subclause 5.10.2;
consider the NDI bit for the corresponding HARQ process to have been toggled;
deliver the configured uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else, if this Serving Cell is the SpCell and an uplink grant for this TTI has been configured for the SpCell:
consider the NDI bit for the corresponding HARQ process to have been toggled;
deliver the configured uplink grant, and the associated HARQ information to the HARQ entity for this TTI.
NOTE: The period of configured uplink grants is expressed in TTIs.
NOTE: If the MAC entity receives both a grant in a Random Access Response and a grant for its C-RNTI or Semi persistent scheduling C-RNTI requiring transmissions on the SpCell in the same UL subframe, the MAC entity may choose to continue with either the grant for its RA-RNTI or the grant for its C-RNTI or Semi persistent scheduling C-RNTI.
NOTE: When a configured uplink grant is indicated during a measurement gap and indicates an UL-SCH transmission during a measurement gap, the MAC entity processes the grant but does not transmit on UL-SCH.

Details of UL HARQ operation can be found in 3GPP TS 36.321 v12.5.0 as follows:

5.4.2 HARQ Operation
5.4.2.1 HARQ Entity
There is one HARQ entity at the MAC entity for each Serving Cell with configured uplink, which maintains a number of parallel HARQ processes allowing transmissions

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to take place continuously while waiting for the HARQ feedback on the successful or unsuccessful reception of previous transmissions.
The number of parallel HARQ processes per HARQ entity is specified in [2], clause 8.
When the physical layer is configured for uplink spatial multiplexing [2], there are two HARQ processes associated with a given TTI. Otherwise there is one HARQ process associated with a given TTI.
At a given TTI, if an uplink grant is indicated for the TTI, the HARQ entity identifies the HARQ process(es) for which a transmission should take place. It also routes the received HARQ feedback (ACK/NACK information), MCS and resource, relayed by the physical layer, to the appropriate HARQ process(es).
When TTI bundling is configured, the parameter TTI_BUNDLE_SIZE provides the number of TTIs of a TTI bundle. TTI bundling operation relies on the HARQ entity for invoking the same HARQ process for each transmission that is part of the same bundle. Within a bundle HARQ retransmissions are non-adaptive and triggered without waiting for feedback from previous transmissions according to TTI_BUNDLE_SIZE. The HARQ feedback of a bundle is only received for the last TTI of the bundle (i.e the TTI corresponding to TTI_BUNDLE_SIZE), regardless of whether a transmission in that TTI takes place or not (e.g. when a measurement gap occurs). A retransmission of a TTI bundle is also a TTI bundle. TTI bundling is not supported when the MAC entity is configured with one or more SCells with configured uplink.
TTI bundling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.
For transmission of Msg3 during Random Access (see subclause 5.1.5) TTI bundling does not apply.
For each TTI, the HARQ entity shall:
identify the HARQ process(es) associated with this TTI, and for each identified HARQ process:
if an uplink grant has been indicated for this process and this TTI:
if the received grant was not addressed to a Temporary C-RNTI on PDCCH and if the NDI provided in the associated HARQ information has been toggled compared to the value in the previous transmission of this HARQ process; or
if the uplink grant was received on PDCCH for the C-RNTI and the HARQ buffer of the identified process is empty; or
if the uplink grant was received in a Random Access Response:
if there is a MAC PDU in the Msg3 buffer and the uplink grant was received in a Random Access Response:
obtain the MAC PDU to transmit from the Msg3 buffer.
else:
obtain the MAC PDU to transmit from the "Multiplexing and assembly" entity;
deliver the MAC PDU and the uplink grant and the HARQ information to the identified HARQ process;
instruct the identified HARQ process to trigger a new transmission.
else:
deliver the uplink grant and the HARQ information (redundancy version) to the identified HARQ process;

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- if there is a MAC PDU in the Msg3 buffer and the uplink grant was received in a Random Access Response:
  - obtain the MAC PDU to transmit from the Msg3 buffer.
- else:
  - obtain the MAC PDU to transmit from the "Multiplexing and assembly" entity;
- deliver the MAC PDU and the uplink grant and the HARQ information to the identified HARQ process;
- instruct the identified HARQ process to trigger a new transmission.

- else:
  - deliver the uplink grant and the HARQ information (redundancy version) to the identified HARQ process;
  - instruct the identified HARQ process to generate an adaptive retransmission.

- else, if the HARQ buffer of this HARQ process is not empty:
  - instruct the identified HARQ process to generate a non-adaptive retransmission.

When determining if NDI has been toggled compared to the value in the previous transmission the MAC entity shall ignore NDI received in all uplink grants on PDCCH for its Temporary C-RNTI.

5.4.2.2 HARQ process

Each HARQ process is associated with a HARQ buffer.

Each HARQ process shall maintain a state variable CURRENT_TX_NB, which indicates the number of transmissions that have taken place for the MAC PDU currently in the buffer, and a state variable HARQ_FEEDBACK, which indicates the HARQ feedback for the MAC PDU currently in the buffer. When the HARQ process is established, CURRENT_TX_NB shall be initialized to 0.

The sequence of redundancy versions is 0, 2, 3, 1. The variable CURRENT_IRV is an index into the sequence of redundancy versions. This variable is up-dated modulo 4.

New transmissions are performed on the resource and with the MCS indicated on PDCCH or Random Access Response. Adaptive retransmissions are performed on the resource and, if provided, with the MCS indicated on PDCCH. Non-adaptive retransmission is performed on the same resource and with the same MCS as was used for the last made transmission attempt.

The MAC entity is configured with a Maximum number of HARQ transmissions and a Maximum number of Msg3 HARQ transmissions by RRC: *maxHARQ-Tx* and *maxHARQ-Msg3Tx* respectively. For transmissions on all HARQ processes and all logical channels except for transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to *maxHARQ-Tx*. For transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to *maxHARQ-Msg3Tx*.

When the HARQ feedback is received for this TB, the HARQ process shall:

- set HARQ_FEEDBACK to the received value.

If the HARQ entity requests a new transmission, the HARQ process shall:

- set CURRENT_TX_NB to 0;
- set CURRENT_IRV to 0;
- store the MAC PDU in the associated HARQ buffer;

if an uplink grant for this TTI and this Serving Cell has been received on the PDCCH for the MAC entity's C-RNTI or Temporary C-RNTI; or
if an uplink grant for this TTI has been received in a Random Access Response:
if the uplink grant is for MAC entity's C-RNTI and if the previous uplink grant delivered to the HARQ entity for the same HARQ process was either an uplink grant received for the MAC entity's Semi-Persistent Scheduling C-RNTI or a configured uplink grant:
consider the NDI to have been toggled for the corresponding HARQ process regardless of the value of the NDI.
deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else, if this Serving Cell is the SpCell and if an uplink grant for this TTI has been received for the SpCell on the PDCCH of the SpCell for the MAC entity's Semi-Persistent Scheduling C-RNTI:
if the NDI in the received HARQ information is 1:
consider the NDI for the corresponding HARQ process not to have been toggled;
deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else if the NDI in the received HARQ information is 0:
if PDCCH contents indicate SPS release:
clear the configured uplink grant (if any).
else:
store the uplink grant and the associated HARQ information as configured uplink grant;
initialise (if not active) or re-initialise (if already active) the configured uplink grant to start in this TTI and to recur according to rules in subclause 5.10.2;
consider the NDI bit for the corresponding HARQ process to have been toggled;
deliver the configured uplink grant and the associated HARQ information to the HARQ entity for this TTI.
else, if this Serving Cell is the SpCell and an uplink grant for this TTI has been configured for the SpCell:
consider the NDI bit for the corresponding HARQ process to have been toggled;
deliver the configured uplink grant, and the associated HARQ information to the HARQ entity for this TTI.
NOTE: The period of configured uplink grants is expressed in TTIs.
NOTE: If the MAC entity receives both a grant in a Random Access Response and a grant for its C-RNTI or Semi persistent scheduling C-RNTI requiring transmissions on the SpCell in the same UL subframe, the MAC entity may choose to continue with either the grant for its RA-RNTI or the grant for its C-RNTI or Semi persistent scheduling C-RNTI.
NOTE: When a configured uplink grant is indicated during a measurement gap and indicates an UL-SCH transmission during a measurement gap, the MAC entity processes the grant but does not transmit on UL-SCH.

Details of UL HARQ operation can be found in 3GPP TS 36.321 v12.5.0 as follows:

5.4.2 HARQ Operation

5.4.2.1 HARQ Entity

There is one HARQ entity at the MAC entity for each Serving Cell with configured uplink, which maintains a number of parallel HARQ processes allowing transmissions to take place continuously while waiting for the HARQ feedback on the successful or unsuccessful reception of previous transmissions.

The number of parallel HARQ processes per HARQ entity is specified in [2], clause 8.

When the physical layer is configured for uplink spatial multiplexing [2], there are two HARQ processes associated with a given TTI. Otherwise there is one HARQ process associated with a given TTI.

At a given TTI, if an uplink grant is indicated for the TTI, the HARQ entity identifies the HARQ process(es) for which a transmission should take place. It also routes the received HARQ feedback (ACK/NACK information), MCS and resource, relayed by the physical layer, to the appropriate HARQ process(es).

When TTI bundling is configured, the parameter TTI_BUNDLE_SIZE provides the number of TTIs of a TTI bundle. TTI bundling operation relies on the HARQ entity for invoking the same HARQ process for each transmission that is part of the same bundle. Within a bundle HARQ retransmissions are non-adaptive and triggered without waiting for feedback from previous transmissions according to TTI_BUNDLE_SIZE. The HARQ feedback of a bundle is only received for the last TTI of the bundle (i.e the TTI corresponding to TTI_BUNDLE_SIZE), regardless of whether a transmission in that TTI takes place or not (e.g. when a measurement gap occurs). A retransmission of a TTI bundle is also a TTI bundle. TTI bundling is not supported when the MAC entity is configured with one or more SCells with configured uplink.

TTI bundling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.

For transmission of Msg3 during Random Access (see subclause 5.1.5) TTI bundling does not apply.

For each TTI, the HARQ entity shall:
identify the HARQ process(es) associated with this TTI, and for each identified HARQ process:
if an uplink grant has been indicated for this process and this TTI:
if the received grant was not addressed to a Temporary C-RNTI on PDCCH and if the NDI provided in the associated HARQ information has been toggled compared to the value in the previous transmission of this HARQ process; or
if the uplink grant was received on PDCCH for the C-RNTI and the HARQ buffer of the identified process is empty; or
if the uplink grant was received in a Random Access Response:
if there is a MAC PDU in the Msg3 buffer and the uplink grant was received in a Random Access Response:
obtain the MAC PDU to transmit from the Msg3 buffer.
else:
obtain the MAC PDU to transmit from the "Multiplexing and assembly" entity;
deliver the MAC PDU and the uplink grant and the HARQ information to the identified HARQ process;
instruct the identified HARQ process to trigger a new transmission.
else:
deliver the uplink grant and the HARQ information (redundancy version) to the identified HARQ process;

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- if there is a MAC PDU in the Msg3 buffer and the uplink grant was received in a Random Access Response:
  - obtain the MAC PDU to transmit from the Msg3 buffer.
- else:
  - obtain the MAC PDU to transmit from the "Multiplexing and assembly" entity;
- deliver the MAC PDU and the uplink grant and the HARQ information to the identified HARQ process;
- instruct the identified HARQ process to trigger a new transmission.

- else:
  - deliver the uplink grant and the HARQ information (redundancy version) to the identified HARQ process;
  - instruct the identified HARQ process to generate an adaptive retransmission.
- else, if the HARQ buffer of this HARQ process is not empty:
  - instruct the identified HARQ process to generate a non-adaptive retransmission.

When determining if NDI has been toggled compared to the value in the previous transmission the MAC entity shall ignore NDI received in all uplink grants on PDCCH for its Temporary C-RNTI.

5.4.2.2 HARQ process

Each HARQ process is associated with a HARQ buffer.

Each HARQ process shall maintain a state variable CURRENT_TX_NB, which indicates the number of transmissions that have taken place for the MAC PDU currently in the buffer, and a state variable HARQ_FEEDBACK, which indicates the HARQ feedback for the MAC PDU currently in the buffer. When the HARQ process is established, CURRENT_TX_NB shall be initialized to 0.

The sequence of redundancy versions is 0, 2, 3, 1. The variable CURRENT_IRV is an index into the sequence of redundancy versions. This variable is up-dated modulo 4.

New transmissions are performed on the resource and with the MCS indicated on PDCCH or Random Access Response. Adaptive retransmissions are performed on the resource and, if provided, with the MCS indicated on PDCCH. Non-adaptive retransmission is performed on the same resource and with the same MCS as was used for the last made transmission attempt.

The MAC entity is configured with a Maximum number of HARQ transmissions and a Maximum number of Msg3 HARQ transmissions by RRC: *maxHARQ-Tx* and *maxHARQ-Msg3Tx* respectively. For transmissions on all HARQ processes and all logical channels except for transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to *maxHARQ-Tx*. For transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to *maxHARQ-Msg3Tx*.

When the HARQ feedback is received for this TB, the HARQ process shall:

- set HARQ_FEEDBACK to the received value.

If the HARQ entity requests a new transmission, the HARQ process shall:

- set CURRENT_TX_NB to 0;
- set CURRENT_IRV to 0;
- store the MAC PDU in the associated HARQ buffer;

instruct the identified HARQ process to generate an adaptive retransmission.
else, if the HARQ buffer of this HARQ process is not empty:
instruct the identified HARQ process to generate a non-adaptive retransmission.
When determining if NDI has been toggled compared to the value in the previous transmission the MAC entity shall ignore NDI received in all uplink grants on PDCCH for its Temporary C-RNTI.
5.4.2.2 HARQ Process
Each HARQ process is associated with a HARQ buffer.
Each HARQ process shall maintain a state variable CURRENT_TX_NB, which indicates the number of transmissions that have taken place for the MAC PDU currently in the buffer, and a state variable HARQ_FEEDBACK, which indicates the HARQ feedback for the MAC PDU currently in the buffer. When the HARQ process is established, CURRENT_TX_NB shall be initialized to 0.
The sequence of redundancy versions is 0, 2, 3, 1. The variable CURRENT_IRV is an index into the sequence of redundancy versions. This variable is up-dated modulo 4.
New transmissions are performed on the resource and with the MCS indicated on PDCCH or Random Access Response. Adaptive retransmissions are performed on the resource and, if provided, with the MCS indicated on PDCCH. Non-adaptive retransmission is performed on the same resource and with the same MCS as was used for the last made transmission attempt.
The MAC entity is configured with a Maximum number of HARQ transmissions and a Maximum number of Msg3 HARQ transmissions by RRC: maxHARQ-Tx and maxHARQ-Msg3Tx respectively. For transmissions on all HARQ processes and all logical channels except for transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to maxHARQ-Tx. For transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to maxHARQ-Msg3Tx.
When the HARQ feedback is received for this TB, the HARQ process shall:
set HARQ_FEEDBACK to the received value.
If the HARQ entity requests a new transmission, the HARQ process shall:
set CURRENT_TX_NB to 0;
set CURRENT_IRV to 0;
store the MAC PDU in the associated HARQ buffer;
store the uplink grant received from the HARQ entity;
set HARQ_FEEDBACK to NACK;
generate a transmission as described below.
If the HARQ entity requests a retransmission, the HARQ process shall:
increment CURRENT_TX_NB by 1;
if the HARQ entity requests an adaptive retransmission:
store the uplink grant received from the HARQ entity;
set CURRENT_IRV to the index corresponding to the redundancy version value provided in the HARQ information;
set HARQ_FEEDBACK to NACK;
generate a transmission as described below.

else if the HARQ entity requests a non-adaptive retransmission:
if HARQ_FEEDBACK=NACK:
generate a transmission as described below.
NOTE: When receiving a HARQ ACK alone, the MAC entity keeps the data in the HARQ buffer.
NOTE: When no UL-SCH transmission can be made due to the occurrence of a measurement gap, no HARQ feedback can be received and a non-adaptive retransmission follows.
To generate a transmission, the HARQ process shall:
if the MAC PDU was obtained from the Msg3 buffer; or
if Sidelink Discovery Gaps for Transmission are not configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer in this TTI; or
if Sidelink Discovery Gaps for Transmission are configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer, and there is no Sidelink Discovery Gap for Transmission in this TTI; or
if Sidelink Discovery Gaps for Transmission are configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer, and there is a Sidelink Discovery Gap for Transmission, and there is no configured grant for transmission on SL-DCH in this TTI:
instruct the physical layer to generate a transmission according to the stored uplink grant with the redundancy version corresponding to the CURRENT_IRV value;
increment CURRENT_IRV by 1;
if there is a measurement gap or Sidelink Discovery Gap for Reception at the time of the HARQ feedback reception for this transmission and if the MAC PDU was not obtained from the Msg3 buffer:
set HARQ_FEEDBACK to ACK at the time of the HARQ feedback reception for this transmission.
After performing above actions, the HARQ process then shall:
if CURRENT_TX_NB=maximum number of transmissions−1:
flush the HARQ buffer;
In the current 3GPP E-UTRA RRC specification (3GPP TS 36.331 v12.5.0), semi-persistent scheduling is configured as follows:
SPS-Config
The IE SPS-Config is used to specify the semi-persistent scheduling configuration.

SPS-Config Information Element

```
-- ASN1START
SPS-Config ::= SEQUENCE {
   semiPersistSchedC-RNTI     C-RNTI          OPTIONAL,    -- Need OR
   sps-ConfigDL               SPS-ConfigDL    OPTIONAL,    -- Need ON
   sps-ConfigUL               SPS-ConfigUL    OPTIONAL     -- Need ON
}
```

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- store the uplink grant received from the HARQ entity;
- set HARQ_FEEDBACK to NACK;
- generate a transmission as described below.

If the HARQ entity requests a retransmission, the HARQ process shall:

- increment CURRENT_TX_NB by 1;
- if the HARQ entity requests an adaptive retransmission:
  - store the uplink grant received from the HARQ entity;
  - set CURRENT_IRV to the index corresponding to the redundancy version value provided in the HARQ information;
  - set HARQ_FEEDBACK to NACK;
  - generate a transmission as described below.
- else if the HARQ entity requests a non-adaptive retransmission:
  - if HARQ_FEEDBACK = NACK:
    - generate a transmission as described below.

NOTE: When receiving a HARQ ACK alone, the MAC entity keeps the data in the HARQ buffer.

NOTE: When no UL-SCH transmission can be made due to the occurrence of a measurement gap, no HARQ feedback can be received and a non-adaptive retransmission follows.

To generate a transmission, the HARQ process shall:

- if the MAC PDU was obtained from the Msg3 buffer; or
- if there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer in this TTI:
  - instruct the physical layer to generate a transmission according to the stored uplink grant with the redundancy version corresponding to the CURRENT_IRV value;
  - increment CURRENT_IRV by 1;
  - if there is a measurement gap at the time of the HARQ feedback reception for this transmission and if the MAC PDU was not obtained from the Msg3 buffer:
    - set HARQ_FEEDBACK to ACK at the time of the HARQ feedback reception for this transmission.

After performing above actions, the HARQ process then shall:

- if CURRENT_TX_NB = maximum number of transmissions – 1:
  - flush the HARQ buffer;

instruct the identified HARQ process to generate an adaptive retransmission.
else, if the HARQ buffer of this HARQ process is not empty:
instruct the identified HARQ process to generate a non-adaptive retransmission.
When determining if NDI has been toggled compared to the value in the previous transmission the MAC entity shall ignore NDI received in all uplink grants on PDCCH for its Temporary C-RNTI.
5.4.2.2 HARQ Process
Each HARQ process is associated with a HARQ buffer.
Each HARQ process shall maintain a state variable CURRENT_TX_NB, which indicates the number of transmissions that have taken place for the MAC PDU currently in the buffer, and a state variable HARQ_FEEDBACK, which indicates the HARQ feedback for the MAC PDU currently in the buffer. When the HARQ process is established, CURRENT_TX_NB shall be initialized to 0.
The sequence of redundancy versions is 0, 2, 3, 1. The variable CURRENT_IRV is an index into the sequence of redundancy versions. This variable is up-dated modulo 4.
New transmissions are performed on the resource and with the MCS indicated on PDCCH or Random Access Response. Adaptive retransmissions are performed on the resource and, if provided, with the MCS indicated on PDCCH. Non-adaptive retransmission is performed on the same resource and with the same MCS as was used for the last made transmission attempt.
The MAC entity is configured with a Maximum number of HARQ transmissions and a Maximum number of Msg3 HARQ transmissions by RRC: maxHARQ-Tx and maxHARQ-Msg3Tx respectively. For transmissions on all HARQ processes and all logical channels except for transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to maxHARQ-Tx. For transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to maxHARQ-Msg3Tx.
When the HARQ feedback is received for this TB, the HARQ process shall:
set HARQ_FEEDBACK to the received value.
If the HARQ entity requests a new transmission, the HARQ process shall:
set CURRENT_TX_NB to 0;
set CURRENT_IRV to 0;
store the MAC PDU in the associated HARQ buffer;
store the uplink grant received from the HARQ entity;
set HARQ_FEEDBACK to NACK;
generate a transmission as described below.
If the HARQ entity requests a retransmission, the HARQ process shall:
increment CURRENT_TX_NB by 1;
if the HARQ entity requests an adaptive retransmission:
store the uplink grant received from the HARQ entity;
set CURRENT_IRV to the index corresponding to the redundancy version value provided in the HARQ information;
set HARQ_FEEDBACK to NACK;
generate a transmission as described below.

else if the HARQ entity requests a non-adaptive retransmission:
if HARQ_FEEDBACK=NACK:
generate a transmission as described below.
NOTE: When receiving a HARQ ACK alone, the MAC entity keeps the data in the HARQ buffer.
NOTE: When no UL-SCH transmission can be made due to the occurrence of a measurement gap, no HARQ feedback can be received and a non-adaptive retransmission follows.
To generate a transmission, the HARQ process shall:
if the MAC PDU was obtained from the Msg3 buffer; or
if Sidelink Discovery Gaps for Transmission are not configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer in this TTI; or
if Sidelink Discovery Gaps for Transmission are configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer, and there is no Sidelink Discovery Gap for Transmission in this TTI; or
if Sidelink Discovery Gaps for Transmission are configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer, and there is a Sidelink Discovery Gap for Transmission, and there is no configured grant for transmission on SL-DCH in this TTI:
instruct the physical layer to generate a transmission according to the stored uplink grant with the redundancy version corresponding to the CURRENT_IRV value;
increment CURRENT_IRV by 1;
if there is a measurement gap or Sidelink Discovery Gap for Reception at the time of the HARQ feedback reception for this transmission and if the MAC PDU was not obtained from the Msg3 buffer:
set HARQ_FEEDBACK to ACK at the time of the HARQ feedback reception for this transmission.
After performing above actions, the HARQ process then shall:
if CURRENT_TX_NB=maximum number of transmissions−1:
flush the HARQ buffer;

In the current 3GPP E-UTRA RRC specification (3GPP TS 36.331 v12.5.0), semi-persistent scheduling is configured as follows:

SPS-Config

The IE SPS-Config is used to specify the semi-persistent scheduling configuration.

SPS-Config Information Element

```
-- ASN1START
SPS-Config ::= SEQUENCE {
   semiPersistSchedC-RNTI     C-RNTI          OPTIONAL,    -- Need OR
   sps-ConfigDL               SPS-ConfigDL    OPTIONAL,    -- Need ON
   sps-ConfigUL               SPS-ConfigUL    OPTIONAL     -- Need ON
}
```

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```
SRS-AntennaPort ::=                ENUMERATED {an1, an2, an4, spare1}

-- ASN1STOP
```

SoundingRS-UL-Config field descriptions
ackNackSRS-SimultaneousTransmission Parameter: *Simultaneous-AN-and-SRS*, see TS 36.213 [23, 8.2]. For SCells this field is not applicable and the UE shall ignore the value.
cyclicShift, cyclicShiftAp Parameter: n_SRS for periodic and aperiodic sounding reference signal transmission respectively. See TS 36.211 [21, 5.5.3.1], where cs0 corresponds to 0 etc.
duration Parameter: Duration for periodic sounding reference signal transmission. See TS 36.213 [21, 8.2]. FALSE corresponds to "single" and value TRUE to "indefinite".
freqDomainPosition, freqDomainPositionAp Parameter: n_{RRC} for periodic and aperiodic sounding reference signal transmission respectively, see TS 36.211 [21, 5.5.3.2].
srs-AntennaPort, srs-AntennaPortAp Indicates the number of antenna ports used for periodic and aperiodic sounding reference signal transmission respectively, see TS 36.211 [21, 5.5.3]. UE shall release *srs-AntennaPort* if *SoundingRS-UL-ConfigDedicated* is released.
srs-Bandwidth, srs-BandwidthAp Parameter: B_{SRS} for periodic and aperiodic sounding reference signal transmission respectively, see TS 36.211 [21, tables 5.5.3.2-1, 5.5.3.2-2, 5.5.3.2-3 and 5.5.3.2-4].
srs-BandwidthConfig Parameter: SRS Bandwidth Configuration. See TS 36.211, [21, table 5.5.3.2-1, 5.5.3.2-2, 5.5.3.2-3 and 5.5.3.2-4]. Actual configuration depends on UL bandwidth. bw0 corresponds to value 0, bw1 to value 1 and so on.
srs-ConfigApDCI-Format0 / srs-ConfigApDCI-Format1a2b2c / srs-ConfigApDCI-Format4 Parameters indicate the resource configurations for aperiodic sounding reference signal transmissions triggered by DCI formats 0, 1A, 2B, 2C, 4. See TS 36.213 [23, 8.2].
srs-ConfigIndex, srs-ConfigIndexAp Parameter: I_{SRS} for periodic and aperiodic sounding reference signal transmission respectively. See TS 36.213 [23, table 8.2-1 and table 8.2-2] for periodic and TS 36.213 [23, table 8.2-4 and table 8.2-5] for aperiodic SRS transmission.
srs-HoppingBandwidth Parameter: SRS hopping bandwidth $b_{hop} \in \{0,1,2,3\}$ for periodic sounding reference signal transmission, see TS 36.211 [21, 5.5.3.2] where hbw0 corresponds to value 0, hbw1 to value 1 and so on.
srs-MaxUpPts Parameter: srsMaxUpPts, see TS 36.211 [21, 5.5.3.2]. If this field is present, reconfiguration of $m_{\mathrm{SRS},0}^{\max}$ applies for UpPts, otherwise reconfiguration does not apply.
srs-SubframeConfig Parameter: SRS SubframeConfiguration. See TS 36.211, [21, table 5.5.3.3-1] applies for FDD whereas TS 36.211, [21, table 5.5.3.3-2] applies for TDD. sc0 corresponds to value 0, sc1 to value 1 and so on.
transmissionComb, transmissionCombAp Parameter: $\bar{k}_{\mathrm{TC}} \in \{0,1\}$ for periodic and aperiodic sounding reference signal transmission respectively, see TS 36.211 [21, 5.5.3.2].

Conditional presence	Explanation
TDD	This field is optional present for TDD, need OR; it is not present for FDD and the UE shall delete any existing value for this field.

– *SPS-Config*

The IE *SPS-Config* is used to specify the semi-persistent scheduling configuration.

***SPS-Config* information element**

```
-- ASN1START

SPS-Config ::=  SEQUENCE {
```


instruct the identified HARQ process to generate an adaptive retransmission.
else, if the HARQ buffer of this HARQ process is not empty:
instruct the identified HARQ process to generate a non-adaptive retransmission.

When determining if NDI has been toggled compared to the value in the previous transmission the MAC entity shall ignore NDI received in all uplink grants on PDCCH for its Temporary C-RNTI.

5.4.2.2 HARQ Process

Each HARQ process is associated with a HARQ buffer.

Each HARQ process shall maintain a state variable CURRENT_TX_NB, which indicates the number of transmissions that have taken place for the MAC PDU currently in the buffer, and a state variable HARQ_FEEDBACK, which indicates the HARQ feedback for the MAC PDU currently in the buffer. When the HARQ process is established, CURRENT_TX_NB shall be initialized to 0.

The sequence of redundancy versions is 0, 2, 3, 1. The variable CURRENT_IRV is an index into the sequence of redundancy versions. This variable is up-dated modulo 4.

New transmissions are performed on the resource and with the MCS indicated on PDCCH or Random Access Response. Adaptive retransmissions are performed on the resource and, if provided, with the MCS indicated on PDCCH. Non-adaptive retransmission is performed on the same resource and with the same MCS as was used for the last made transmission attempt.

The MAC entity is configured with a Maximum number of HARQ transmissions and a Maximum number of Msg3 HARQ transmissions by RRC: maxHARQ-Tx and maxHARQ-Msg3Tx respectively. For transmissions on all HARQ processes and all logical channels except for transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to maxHARQ-Tx. For transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to maxHARQ-Msg3Tx.

When the HARQ feedback is received for this TB, the HARQ process shall:
set HARQ_FEEDBACK to the received value.

If the HARQ entity requests a new transmission, the HARQ process shall:
set CURRENT_TX_NB to 0;
set CURRENT_IRV to 0;
store the MAC PDU in the associated HARQ buffer;
store the uplink grant received from the HARQ entity;
set HARQ_FEEDBACK to NACK;
generate a transmission as described below.

If the HARQ entity requests a retransmission, the HARQ process shall:
increment CURRENT_TX_NB by 1;
if the HARQ entity requests an adaptive retransmission:
store the uplink grant received from the HARQ entity;
set CURRENT_IRV to the index corresponding to the redundancy version value provided in the HARQ information;
set HARQ_FEEDBACK to NACK;
generate a transmission as described below.
else if the HARQ entity requests a non-adaptive retransmission:
if HARQ_FEEDBACK=NACK:
generate a transmission as described below.

NOTE: When receiving a HARQ ACK alone, the MAC entity keeps the data in the HARQ buffer.

NOTE: When no UL-SCH transmission can be made due to the occurrence of a measurement gap, no HARQ feedback can be received and a non-adaptive retransmission follows.

To generate a transmission, the HARQ process shall:
if the MAC PDU was obtained from the Msg3 buffer; or
if Sidelink Discovery Gaps for Transmission are not configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer in this TTI; or
if Sidelink Discovery Gaps for Transmission are configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer, and there is no Sidelink Discovery Gap for Transmission in this TTI; or
if Sidelink Discovery Gaps for Transmission are configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer, and there is a Sidelink Discovery Gap for Transmission, and there is no configured grant for transmission on SL-DCH in this TTI:
instruct the physical layer to generate a transmission according to the stored uplink grant with the redundancy version corresponding to the CURRENT_IRV value;
increment CURRENT_IRV by 1;
if there is a measurement gap or Sidelink Discovery Gap for Reception at the time of the HARQ feedback reception for this transmission and if the MAC PDU was not obtained from the Msg3 buffer:
set HARQ_FEEDBACK to ACK at the time of the HARQ feedback reception for this transmission.

After performing above actions, the HARQ process then shall:
if CURRENT_TX_NB=maximum number of transmissions−1:
flush the HARQ buffer;

In the current 3GPP E-UTRA RRC specification (3GPP TS 36.331 v12.5.0), semi-persistent scheduling is configured as follows:

SPS-Config

The IE SPS-Config is used to specify the semi-persistent scheduling configuration.

SPS-Config Information Element

```
-- ASN1START
SPS-Config ::= SEQUENCE {
   semiPersistSchedC-RNTI     C-RNTI              OPTIONAL,    -- Need OR
   sps-ConfigDL               SPS-ConfigDL        OPTIONAL,    -- Need ON
   sps-ConfigUL               SPS-ConfigUL        OPTIONAL     -- Need ON
}
```

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```
    semiPersistSchedC-RNTI          C-RNTI                  OPTIONAL,           -- Need OR
    sps-ConfigDL                    SPS-ConfigDL            OPTIONAL,           -- Need ON
    sps-ConfigUL                    SPS-ConfigUL            OPTIONAL            -- Need ON
}

SPS-ConfigDL ::=    CHOICE{
    release                         NULL,
    setup                           SEQUENCE {
        semiPersistSchedIntervalDL          ENUMERATED {
                                                sf10, sf20, sf32, sf40, sf64, sf80,
                                                sf128, sf160, sf320, sf640, spare6,
                                                spare5, spare4, spare3, spare2,
                                                spare1},
        numberOfConfSPS-Processes           INTEGER (1..8),
        n1PUCCH-AN-PersistentList           N1PUCCH-AN-PersistentList,
        ...,
        [[  twoAntennaPortActivated-r10     CHOICE {
                release                         NULL,
                setup                           SEQUENCE {
                    n1PUCCH-AN-PersistentListP1-r10 N1PUCCH-AN-PersistentList
                }
            }                                                           OPTIONAL    -- Need ON
        ]]
    }
}

SPS-ConfigUL ::=    CHOICE {
    release                         NULL,
    setup                           SEQUENCE {
        semiPersistSchedIntervalUL          ENUMERATED {
                                                sf10, sf20, sf32, sf40, sf64, sf80,
                                                sf128, sf160, sf320, sf640, spare6,
                                                spare5, spare4, spare3, spare2,
                                                spare1},
        implicitReleaseAfter                ENUMERATED {e2, e3, e4, e8},
        p0-Persistent                       SEQUENCE {
            p0-NominalPUSCH-Persistent          INTEGER (-126..24),
            p0-UE-PUSCH-Persistent              INTEGER (-8..7)
        }       OPTIONAL,                                               -- Need OP
        twoIntervalsConfig                  ENUMERATED {true}           OPTIONAL,   -- Cond TDD
        ...,
        [[  p0-PersistentSubframeSet2-r12       CHOICE {
                release                             NULL,
                setup                               SEQUENCE {
                    p0-NominalPUSCH-PersistentSubframeSet2-r12          INTEGER (-126..24),
                    p0-UE-PUSCH-PersistentSubframeSet2-r12              INTEGER (-8..7)
                }
            }                                                           OPTIONAL    -- Need ON
        ]]
    }
}

N1PUCCH-AN-PersistentList ::=       SEQUENCE (SIZE (1..4)) OF INTEGER (0..2047)

-- ASN1STOP
```


instruct the identified HARQ process to generate an adaptive retransmission.

else, if the HARQ buffer of this HARQ process is not empty:

instruct the identified HARQ process to generate a non-adaptive retransmission.

When determining if NDI has been toggled compared to the value in the previous transmission the MAC entity shall ignore NDI received in all uplink grants on PDCCH for its Temporary C-RNTI.

5.4.2.2 HARQ Process

Each HARQ process is associated with a HARQ buffer.

Each HARQ process shall maintain a state variable CURRENT_TX_NB, which indicates the number of transmissions that have taken place for the MAC PDU currently in the buffer, and a state variable HARQ_FEEDBACK, which indicates the HARQ feedback for the MAC PDU currently in the buffer. When the HARQ process is established, CURRENT_TX_NB shall be initialized to 0.

The sequence of redundancy versions is 0, 2, 3, 1. The variable CURRENT_IRV is an index into the sequence of redundancy versions. This variable is up-dated modulo 4.

New transmissions are performed on the resource and with the MCS indicated on PDCCH or Random Access Response. Adaptive retransmissions are performed on the resource and, if provided, with the MCS indicated on PDCCH. Non-adaptive retransmission is performed on the same resource and with the same MCS as was used for the last made transmission attempt.

The MAC entity is configured with a Maximum number of HARQ transmissions and a Maximum number of Msg3 HARQ transmissions by RRC: maxHARQ-Tx and max-HARQ-Msg3Tx respectively. For transmissions on all HARQ processes and all logical channels except for transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to max-HARQ-Tx. For transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to maxHARQ-Msg3Tx.

When the HARQ feedback is received for this TB, the HARQ process shall:

set HARQ_FEEDBACK to the received value.

If the HARQ entity requests a new transmission, the HARQ process shall:

set CURRENT_TX_NB to 0;

set CURRENT_IRV to 0;

store the MAC PDU in the associated HARQ buffer;

store the uplink grant received from the HARQ entity;

set HARQ_FEEDBACK to NACK;

generate a transmission as described below.

If the HARQ entity requests a retransmission, the HARQ process shall:

increment CURRENT_TX_NB by 1;

if the HARQ entity requests an adaptive retransmission:

store the uplink grant received from the HARQ entity;

set CURRENT_IRV to the index corresponding to the redundancy version value provided in the HARQ information;

set HARQ_FEEDBACK to NACK;

generate a transmission as described below.

else if the HARQ entity requests a non-adaptive retransmission:

if HARQ_FEEDBACK=NACK:

generate a transmission as described below.

NOTE: When receiving a HARQ ACK alone, the MAC entity keeps the data in the HARQ buffer.

NOTE: When no UL-SCH transmission can be made due to the occurrence of a measurement gap, no HARQ feedback can be received and a non-adaptive retransmission follows.

To generate a transmission, the HARQ process shall:

if the MAC PDU was obtained from the Msg3 buffer; or

if Sidelink Discovery Gaps for Transmission are not configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer in this TTI; or

if Sidelink Discovery Gaps for Transmission are configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer, and there is no Sidelink Discovery Gap for Transmission in this TTI; or

if Sidelink Discovery Gaps for Transmission are configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer, and there is a Sidelink Discovery Gap for Transmission, and there is no configured grant for transmission on SL-DCH in this TTI:

instruct the physical layer to generate a transmission according to the stored uplink grant with the redundancy version corresponding to the CURRENT_IRV value;

increment CURRENT_IRV by 1;

if there is a measurement gap or Sidelink Discovery Gap for Reception at the time of the HARQ feedback reception for this transmission and if the MAC PDU was not obtained from the Msg3 buffer:

set HARQ_FEEDBACK to ACK at the time of the HARQ feedback reception for this transmission.

After performing above actions, the HARQ process then shall:

if CURRENT_TX_NB=maximum number of transmissions−1:

flush the HARQ buffer;

In the current 3GPP E-UTRA RRC specification (3GPP TS 36.331 v12.5.0), semi-persistent scheduling is configured as follows:

SPS-Config

The IE SPS-Config is used to specify the semi-persistent scheduling configuration.

SPS-Config Information Element

```
-- ASN1START
SPS-Config ::= SEQUENCE {
    semiPersistSchedC-RNTI      C-RNTI                  OPTIONAL,           -- Need OR
    sps-ConfigDL                SPS-ConfigDL            OPTIONAL,           -- Need ON
    sps-ConfigUL                SPS-ConfigUL            OPTIONAL            -- Need ON
}
```

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```
    semiPersistSchedC-RNTI          C-RNTI                  OPTIONAL,           -- Need OR
    sps-ConfigDL                    SPS-ConfigDL            OPTIONAL,           -- Need ON
    sps-ConfigUL                    SPS-ConfigUL            OPTIONAL            -- Need ON
}

SPS-ConfigDL ::=    CHOICE{
    release                         NULL,
    setup                           SEQUENCE {
        semiPersistSchedIntervalDL          ENUMERATED {
                                                sf10, sf20, sf32, sf40, sf64, sf80,
                                                sf128, sf160, sf320, sf640, spare6,
                                                spare5, spare4, spare3, spare2,
                                                spare1},
        numberOfConfSPS-Processes           INTEGER (1..8),
        n1PUCCH-AN-PersistentList           N1PUCCH-AN-PersistentList,
        ...,
        [[  twoAntennaPortActivated-r10     CHOICE {
                release                         NULL,
                setup                           SEQUENCE {
                    n1PUCCH-AN-PersistentListP1-r10 N1PUCCH-AN-PersistentList
                }
            }                                                               OPTIONAL    -- Need ON
        ]]
    }
}

SPS-ConfigUL ::=    CHOICE {
    release                         NULL,
    setup                           SEQUENCE {
        semiPersistSchedIntervalUL          ENUMERATED {
                                                sf10, sf20, sf32, sf40, sf64, sf80,
                                                sf128, sf160, sf320, sf640, spare6,
                                                spare5, spare4, spare3, spare2,
                                                spare1},
        implicitReleaseAfter                ENUMERATED {e2, e3, e4, e8},
        p0-Persistent                       SEQUENCE {
            p0-NominalPUSCH-Persistent          INTEGER (-126..24),
            p0-UE-PUSCH-Persistent              INTEGER (-8..7)
        }       OPTIONAL,                                           -- Need OP
        twoIntervalsConfig                  ENUMERATED {true}       OPTIONAL,   -- Cond TDD
        ...,
        [[  p0-PersistentSubframeSet2-r12       CHOICE {
                release                             NULL,
                setup                               SEQUENCE {
                    p0-NominalPUSCH-PersistentSubframeSet2-r12      INTEGER (-126..24),
                    p0-UE-PUSCH-PersistentSubframeSet2-r12          INTEGER (-8..7)
                }
            }                                                       OPTIONAL    -- Need ON
        ]]
    }
}

N1PUCCH-AN-PersistentList ::=       SEQUENCE (SIZE (1..4)) OF INTEGER (0..2047)

-- ASN1STOP
```


-continued

```
SDS-ConfigDL ::= CHOICE{
  release                         NULL,
  setup                           SEQUENCE {
    semiPersistSchedIntervalDL          ENUMERATED {
                                            sf10, sf20, sf32, sf40, sf64, sf80,
                                            sf128, sf160, sf320, sf640, spare6,
                                            spare5, spare4, spare3, spare2,
                                            spare1},
    numberofConfSPS-Processes           INTEGER (1..8),
    n1PUCCH-AN-PersistentList           N1PUCCH-AN-PersistentList,
    . . .,
    [[ twoAntennaPortActivated-r10      CHOICE {
        release                             NULL,
        setup                               SEQUENCE {
          n1PUCCH-AN-PersistentListP1-r10 N1PUCCH-AN-PersistentList
        }
      }                                                         OPTIONAL        -- Need
ON
    ]]
  }
}
SPS-ConfigUL ::= CHOICE {
  release                         NULL,
  setup                           SEQUENCE {
    semiPersistSchedIntervalUL          ENUMERATED {
                                            sf10, sf20, sf32, sf40, sf64, sf80,
                                            sf128, sf160, sf320, sf640, spare6,
                                            spare5, spare4, spare3, spare2,
                                            spare1},
    implicitReleaseAfter                ENUMERATED {e2, e3, e4, e8},
    p0-Persistent                       SEQUENCE {
      p0-NominalPUSCH-Persistent          INTEGER (-126..24),
      p0-UE-PUSCH-Persistent              INTEGER (-8..7)
  }   OPTIONAL,                                         -- Need OP
    twoIntervalsConfig                  ENUMERATED {true}   OPTIONAL,       -- Cond TDD
    . . .,
    [[ p0-PersistentSubframeSet2-r12    CHOICE {
        release                             NULL,
        setup                               SEQUENCE {
          p0-NominalPUSCH-PersistentSubframeSet2-r12    INTEGER (-126..24),
          p0-UE-PUSCH-PersistentSubframeSet2-r12        INTEGER (-8..7)
        }
      }                                                         OPTIONAL        -- Need ON
    ]]
  }
}
N1PUCCH-AN-PersistentList ::= SEQUENCE (SIZE (1..4)) OF INTEGER (0..2047)
-- ASN1STOP
```

SPS-Config field descriptions
implicitReleaseAfter
Number of empty transmissions before implicit release, see TS 36.321 [6, 5.10.2]. Value e2 corresponds to 2 transmissions, e3 corresponds to 3 transmissions and so on. n1PUCCH-AN-PersistentList, n1PUCCH-AN-PersistentListP1
List of parameter: $n_{PUCCH}^{(1,p)}$ for antenna port P0 and for antenna port P1 respectively, see TS 36.213 [23, 10.1]. Field n1-PUCCH-AN-PersistentListP1 is applicable only if the twoAntennaPortActivatedPUCCH-Format1a1b in PUCCH-ConfigDedicated-v1020 is set to true. Otherwise the field is not configured.
numberOfConfSPS-Processes
The number of configured HARQ processes for Semi-Persistent Scheduling, see TS 36.321 [6].
p0-NominalPUSCH-Persistent
Parameter: $P_{O_NOMINAL_PUSCH}$ (0). See TS 36.213 [23, 5.1.1.1], unit dBm step 1. This field is applicable for persistent scheduling, only. If choice setup is used and p0-Persistent is absent, apply the value of p0-NominalPUSCH for

-continued

SPS-Config field descriptions
p0-NominalPUSCH-Persistent. If uplink power control subframe sets are configured by tpc-SubframeSet, this field applies for uplink power control subframe set 1.
p0-NominalPUSCH-PersistentSubframeSet2
Parameter: $P_{O_NOMINAL_PUSCH}$ (0). See TS 36.213 [23, 5.1.1.1], unit dBm step 1. This field is applicable for persistent scheduling, only. If p0-PersistentSubframeSet2-r12 is not configured, apply the value of p0-NominalPUSCH-SubframeSet2-r12 for p0-NominalPUSCH-PersistentSubframeSet2. E-UTRAN configures this field only if uplink power control subframe sets are configured by tpc-SubframeSet, in which case this field applies for uplink power control subframe set 2.
p0-UE-PUSCH-Persistent
Parameter: $P_{O_UE_PUSCH}$ (0). See TS 36.213 [23, 5.1.1.1], unit dB. This field is applicable for persistent scheduling, only. If choice setup is used and p0-Persistent is absent, apply the value of p0-UE-PUSCH for p0-UE-PUSCH-Persistent. If uplink power control subframe sets are configured by tpc-SubframeSet, this field applies for uplink power control subframe set 1.

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SPS-Config field descriptions
implicitReleaseAfter Number of empty transmissions before implicit release, see TS 36.321 [6, 5.10.2]. Value e2 corresponds to 2 transmissions, e3 corresponds to 3 transmissions and so on.
n1PUCCH-AN-PersistentList , n1PUCCH-AN-PersistentListP1 List of parameter: $n_{\mathrm{PUCCH}}^{(1,p)}$ for antenna port P0 and for antenna port P1 respectively, see TS 36.213 [23, 10.1]. Field *n1-PUCCH-AN-PersistentListP1* is applicable only if the *twoAntennaPortActivatedPUCCH-Format1a1b* in *PUCCH-ConfigDedicated-v1020* is set to *true*. Otherwise the field is not configured.
numberOfConfSPS-Processes The number of configured HARQ processes for Semi-Persistent Scheduling, see TS 36.321 [6].
p0-NominalPUSCH-Persistent Parameter: $P_{\mathrm{O_NOMINAL_PUSCH}}(0)$. See TS 36.213 [23, 5.1.1.1], unit dBm step 1. This field is applicable for persistent scheduling, only. If choice setup is used and *p0-Persistent* is absent, apply the value of *p0-NominalPUSCH* for *p0-NominalPUSCH-Persistent*. If uplink power control subframe sets are configured by *tpc-SubframeSet*, this field applies for uplink power control subframe set 1.
p0-NominalPUSCH-PersistentSubframeSet2 Parameter: $P_{\mathrm{O_NOMINAL_PUSCH}}(0)$. See TS 36.213 [23, 5.1.1.1], unit dBm step 1. This field is applicable for persistent scheduling, only. If *p0-PersistentSubframeSet2-r12* is not configured, apply the value of *p0-NominalPUSCH-SubframeSet2-r12* for *p0-NominalPUSCH-PersistentSubframeSet2*. E-UTRAN configures this field only if uplink power control subframe sets are configured by *tpc-SubframeSet*, in which case this field applies for uplink power control subframe set 2.
p0-UE-PUSCH-Persistent Parameter: $P_{\mathrm{O_UE_PUSCH}}(0)$. See TS 36.213 [23, 5.1.1.1], unit dB. This field is applicable for persistent scheduling, only. If choice setup is used and *p0-Persistent* is absent, apply the value of p0-UE-PUSCH for *p0-UE-PUSCH-Persistent*. If uplink power control subframe sets are configured by *tpc-SubframeSet*, this field applies for uplink power control subframe set 1.
p0-UE-PUSCH-PersistentSubframeSet2 Parameter: $P_{\mathrm{O_UE_PUSCH}}(0)$. See TS 36.213 [23, 5.1.1.1], unit dB. This field is applicable for persistent scheduling, only. If *p0-PersistentSubframeSet2-r12* is not configured, apply the value of *p0-UE-PUSCH-SubframeSet2* for *p0-UE-PUSCH-PersistentSubframeSet2*. E-UTRAN configures this field only if uplink power control subframe sets are configured by *tpc-SubframeSet*, in which case this field applies for uplink power control subframe set 2.
semiPersistSchedC-RNTI Semi-persistent Scheduling C-RNTI, see TS 36.321 [6].
semiPersistSchedIntervalDL Semi-persistent scheduling interval in downlink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames.
semiPersistSchedIntervalUL Semi-persistent scheduling interval in uplink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames.
twoIntervalsConfig Trigger of two-intervals-Semi-Persistent Scheduling in uplink. See TS 36.321 [6, 5.10]. If this field is present, two-intervals-SPS is enabled for uplink. Otherwise, two-intervals-SPS is disabled.

Conditional presence	Explanation
TDD	This field is optional present for TDD, need OR; it is not present for FDD and the UE shall delete any existing value for this field.

– *TDD-Config*

The IE *TDD-Config* is used to specify the TDD specific physical channel configuration.

***TDD-Config* information element**

```
-- ASN1START

TDD-Config ::=                      SEQUENCE {
    subframeAssignment                  ENUMERATED {
                                            sa0, sa1, sa2, sa3, sa4, sa5, sa6},
    specialSubframePatterns             ENUMERATED {
```


-continued

```
SDS-ConfigDL ::= CHOICE{
  release                           NULL,
  setup                             SEQUENCE {
    semiPersistSchedIntervalDL          ENUMERATED {
                                            sf10, sf20, sf32, sf40, sf64, sf80,
                                            sf128, sf160, sf320, sf640, spare6,
                                            spare5, spare4, spare3, spare2,
                                            spare1},
    numberofConfSPS-Processes           INTEGER (1..8),
    n1PUCCH-AN-PersistentList           N1PUCCH-AN-PersistentList,
    . . .,
    [[ twoAntennaPortActivated-r10      CHOICE {
         release                            NULL,
         setup                              SEQUENCE {
           n1PUCCH-AN-PersistentListP1-r10 N1PUCCH-AN-PersistentList
         }
      }                                                     OPTIONAL        -- Need
ON
    ]]
  }
}
SPS-ConfigUL ::= CHOICE {
  release                           NULL,
  setup                             SEQUENCE {
    semiPersistSchedIntervalUL          ENUMERATED {
                                            sf10, sf20, sf32, sf40, sf64, sf80,
                                            sf128, sf160, sf320, sf640, spare6,
                                            spare5, spare4, spare3, spare2,
                                            spare1},
    implicitReleaseAfter                ENUMERATED {e2, e3, e4, e8},
    p0-Persistent                       SEQUENCE {
      p0-NominalPUSCH-Persistent        INTEGER (-126..24),
      p0-UE-PUSCH-Persistent            INTEGER (-8..7)
  }   OPTIONAL,                                         -- Need OP
    twoIntervalsConfig                  ENUMERATED {true}   OPTIONAL,       -- Cond TDD
    . . . ,
    [[ p0-PersistentSubframeSet2-r12    CHOICE {
         release                            NULL,
         setup                              SEQUENCE {
           p0-NominalPUSCH-PersistentSubframeSet2-r12       INTEGER (-126..24),
           p0-UE-PUSCH-PersistentSubframeSet2-r12           INTEGER (-8..7)
         }
      }                                                     OPTIONAL        -- Need ON
    ]]
  }
}
N1PUCCH-AN-PersistentList ::= SEQUENCE (SIZE (1..4)) OF INTEGER (0..2047)
-- ASN1STOP
```

-continued

SPS-Config field descriptions
implicitReleaseAfter Number of empty transmissions before implicit release, see TS 36.321 [6, 5.10.2]. Value e2 corresponds to 2 transmissions, e3 corresponds to 3 transmissions and so on. n1PUCCH-AN-PersistentList, n1PUCCH-AN-PersistentListP1 List of parameter: $n_{PUCCH}^{(1,p)}$ for antenna port P0 and for antenna port P1 respectively, see TS 36.213 [23, 10.1]. Field n1-PUCCH-AN-PersistentListP1 is applicable only if the twoAntennaPortActivatedPUCCH-Format1a1b in PUCCH-ConfigDedicated-v1020 is set to true. Otherwise the field is not configured. numberOfConfSPS-Processes The number of configured HARQ processes for Semi-Persistent Scheduling, see TS 36.321 [6]. p0-NominalPUSCH-Persistent Parameter: $P_{O_NOMINAL_PUSCH}(0)$. See TS 36.213 [23, 5.1.1.1], unit dBm step 1. This field is applicable for persistent scheduling, only. If choice setup is used and p0-Persistent is absent, apply the value of p0-NominalPUSCH for

-continued

SPS-Config field descriptions
p0-NominalPUSCH-Persistent. If uplink power control subframe sets are configured by tpc-SubframeSet, this field applies for uplink power control subframe set 1. p0-NominalPUSCH-PersistentSubframeSet2 Parameter: $P_{O_NOMINAL_PUSCH}(0)$. See TS 36.213 [23, 5.1.1.1], unit dBm step 1. This field is applicable for persistent scheduling, only. If p0-PersistentSubframeSet2-r12 is not configured, apply the value of p0-NominalPUSCH-SubframeSet2-r12 for p0-NominalPUSCH-PersistentSubframeSet2. E-UTRAN configures this field only if uplink power control subframe sets are configured by tpc-SubframeSet, in which case this field applies for uplink power control subframe set 2. p0-UE-PUSCH-Persistent Parameter: $P_{O_UE_PUSCH}(0)$. See TS 36.213 [23, 5.1.1.1], unit dB. This field is applicable for persistent scheduling, only. If choice setup is used and p0-Persistent is absent, apply the value of p0-UE-PUSCH for p0-UE-PUSCH-Persistent. If uplink power control subframe sets are configured by tpc-SubframeSet, this field applies for uplink power control subframe set 1.

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SPS-Config field descriptions
implicitReleaseAfter Number of empty transmissions before implicit release, see TS 36.321 [6, 5.10.2]. Value e2 corresponds to 2 transmissions, e3 corresponds to 3 transmissions and so on.
n1PUCCH-AN-PersistentList* , *n1PUCCH-AN-PersistentListP1 List of parameter: $n_{\mathrm{PUCCH}}^{(1,p)}$ for antenna port P0 and for antenna port P1 respectively, see TS 36.213 [23, 10.1]. Field *n1-PUCCH-AN-PersistentListP1* is applicable only if the *twoAntennaPortActivatedPUCCH-Format1a1b* in *PUCCH-ConfigDedicated-v1020* is set to *true*. Otherwise the field is not configured.
numberOfConfSPS-Processes The number of configured HARQ processes for Semi-Persistent Scheduling, see TS 36.321 [6].
p0-NominalPUSCH-Persistent Parameter: $P_{\mathrm{O_NOMINAL_PUSCH}}(0)$. See TS 36.213 [23, 5.1.1.1], unit dBm step 1. This field is applicable for persistent scheduling, only. If choice setup is used and *p0-Persistent* is absent, apply the value of *p0-NominalPUSCH* for *p0-NominalPUSCH-Persistent*. If uplink power control subframe sets are configured by *tpc-SubframeSet*, this field applies for uplink power control subframe set 1.
p0-NominalPUSCH-PersistentSubframeSet2 Parameter: $P_{\mathrm{O_NOMINAL_PUSCH}}(0)$. See TS 36.213 [23, 5.1.1.1], unit dBm step 1. This field is applicable for persistent scheduling, only. If *p0-PersistentSubframeSet2-r12* is not configured, apply the value of *p0-NominalPUSCH-SubframeSet2-r12* for *p0-NominalPUSCH-PersistentSubframeSet2*. E-UTRAN configures this field only if uplink power control subframe sets are configured by *tpc-SubframeSet*, in which case this field applies for uplink power control subframe set 2.
p0-UE-PUSCH-Persistent Parameter: $P_{\mathrm{O_UE_PUSCH}}(0)$. See TS 36.213 [23, 5.1.1.1], unit dB. This field is applicable for persistent scheduling, only. If choice setup is used and *p0-Persistent* is absent, apply the value of p0-UE-PUSCH for *p0-UE-PUSCH-Persistent*. If uplink power control subframe sets are configured by *tpc-SubframeSet*, this field applies for uplink power control subframe set 1.
p0-UE-PUSCH-PersistentSubframeSet2 Parameter: $P_{\mathrm{O_UE_PUSCH}}(0)$. See TS 36.213 [23, 5.1.1.1], unit dB. This field is applicable for persistent scheduling, only. If *p0-PersistentSubframeSet2-r12* is not configured, apply the value of *p0-UE-PUSCH-SubframeSet2* for *p0-UE-PUSCH-PersistentSubframeSet2*. E-UTRAN configures this field only if uplink power control subframe sets are configured by *tpc-SubframeSet*, in which case this field applies for uplink power control subframe set 2.
semiPersistSchedC-RNTI Semi-persistent Scheduling C-RNTI, see TS 36.321 [6].
semiPersistSchedIntervalDL Semi-persistent scheduling interval in downlink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames.
semiPersistSchedIntervalUL Semi-persistent scheduling interval in uplink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames.
twoIntervalsConfig Trigger of two-intervals-Semi-Persistent Scheduling in uplink. See TS 36.321 [6, 5.10]. If this field is present, two-intervals-SPS is enabled for uplink. Otherwise, two-intervals-SPS is disabled.

Conditional presence	Explanation
TDD	This field is optional present for TDD, need OR; it is not present for FDD and the UE shall delete any existing value for this field.

– *TDD-Config*

The IE *TDD-Config* is used to specify the TDD specific physical channel configuration.

***TDD-Config* information element**

```
-- ASN1START

TDD-Config ::=                    SEQUENCE {
    subframeAssignment                ENUMERATED {
                                          sa0, sa1, sa2, sa3, sa4, sa5, sa6},
    specialSubframePatterns           ENUMERATED {
```


-continued

SPS-Config field descriptions	
p0-UE-PUSCH-PersistentSubframeSet2 Parameter: $P_{O_UE_PUSCH}(0)$. See TS 36.213 [23, 5.1.1.1], unit dB. This field is applicable for persistent scheduling, only. If p0-PersistentSubframeSet2-r12 is not configured, apply the value of p0-UE-PUSCH-SubframeSet2 for p0-UE-PUSCH-PersistentSubframeSet2. E-UTRAN configures this field only if uplink power control subframe sets are configured by tpc-SubframeSet, in which case this field applies for uplink power control subframe set 2. semiPersistSchedC-RNTI Semi-persistent Scheduling C-RNTI, see TS 36.321 [6]. semiPersistSchedIntervalDL Semi-persistent scheduling interval in downlink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames. semiPersistSchedIntervalUL Semi-persistent scheduling interval in uplink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames. twoIntervalsConfig Trigger of two-intervals-Semi-Persistent Scheduling in uplink. See TS 36.321 [6, 5.10]. If this field is present, two-intervals-SPS is enabled for uplink. Otherwise, two-intervals-SPS is disabled.	
Conditional presence	Explanation
TDD	This field is optional present for TDD, need OR; it is not present for FDD and the UE shall delete any existing value for this field.

Some UEs are capable of transmitting PUSCH (Physical Uplink Shared Channel) and PUCCH (Physical Uplink Control Channel) simultaneously, and some UEs are not capable of transmitting PUSCH and PUCCH simultaneously. Such capability would be reported to eNB (evolved Node B) so that eNB could decide whether to configure this functionality or not. Even if UE support this feature, eNB may decide not to configure this function if the channel condition of the UE is poor, as to transmit both channel simultaneously is more power consuming. In such case, the UE maximum transmission power may not guarantee proper power level for each channel. UE may decide which channel to transmit UCI (Uplink Control Information) with depending on whether PUSCH and PUCCH simultaneously is configured or not.

Section 10.1 of 3GPP 36.213 v12.5.0 states:

10.1 UE Procedure for Determining Physical Uplink Control Channel Assignment

If the UE is configured for a single serving cell and is not configured for simultaneous PUSCH and PUCCH transmissions, then in subframe n uplink control information (UCI) shall be transmitted

- on PUCCH using format 1/1a/1b/3 or 2/2a/2b if the UE is not transmitting PUSCH
- on PUSCH if the UE is transmitting PUSCH in subframe n unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, in which case UCI is not transmitted

If the UE is configured for a single serving cell and simultaneous PUSCH and PUCCH transmission, then in subframe n UCI shall be transmitted

- on PUCCH using format 1/1a/1b/3 if the UCI consists only of HARQ-ACK and/or SR
- on PUCCH using format 2 if the UCI consists only of periodic CSI
- on PUCCH using format 2/2a/2b/3 if the UCI consists of periodic CSI and HARQ-ACK and if the UE is not transmitting PUSCH
- on PUCCH and PUSCH if the UCI consists of HARQ-ACK/HARQ-ACK+SR/positive SR and periodic/aperiodic CSI and if the UE is transmitting PUSCH in subframe n, in which case the HARQ-ACK/HARQ-ACK+SR/positive SR is transmitted on PUCCH using format 1/1a/1b/3 and the periodic/aperiodic CSI transmitted on PUSCH unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, in which case periodic/aperiodic CSI is not transmitted

For a UE with poor channel condition, such as in cell edge, it is possible to configure HARQ-ACK (Hybrid Automatic Repeat Request Acknowledgement) repetition to improve the HARQ-ACK feedback reliability by repeating the transmission of ACK/NACK (Acknowledgement/Negative Acknowledgement) multiple times. Under such situation, the HARQ-ACK would be transmitted on PUCCH without multiplexed onto other channel, e.g., PUSCH, to enjoy the combining gain of repetition across subframes, as some of the repetitions would occur on the same resource and joint demodulation/channel estimation is possible.

Section 10.2 of 3GPP 36.213 v12.5.0 states:

10.2 Uplink HARQ-ACK Timing

For TDD or for FDD-TDD and primary cell frame structure type 2 or for FDD-TDD and primary cell frame structure type 1, if a UE configured with EIMTA-MainConfigServCell-r12 for a serving cell, "UL/DL configuration" of the serving cell in subclause 10.2 refers to the UL/DL configuration given by the parameter eimta-HARQ-ReferenceConfig-r12 for the serving cell unless specified otherwise.

For FDD or for FDD-TDD and primary cell frame structure type 1, the UE shall upon detection of a PDSCH transmission in subframe n−4 intended for the UE and for which an HARQ-ACK shall be provided, transmit the HARQ-ACK response in subframe n. If HARQ-ACK repetition is enabled, upon detection of a PDSCH transmission in subframe n−4 intended for the UE and for which HARQ-ACK response shall be provided, and if the UE is not repeating the transmission of any HARQ-ACK in subframe n corresponding to a PDSCH transmission in subframes $n-N_{ANRep}-3, \ldots, n-5$, the UE:

- shall transmit only the HARQ-ACK response (corresponding to the detected PDSCH transmission in subframe n−4) on PUCCH in subframes n, n+1, . . . , $n+N_{ANRep}-1$;
- shall not transmit any other signal/channel in subframes n, n+1, . . . , $n+N_{ANRep}-1$; and
- shall not transmit any HARQ-ACK response repetitions corresponding to any detected PDSCH transmission in subframes $n-3, \ldots, n+N_{ANRep}-5$.

< . . . >

For TDD, if HARQ-ACK repetition is enabled, upon detection of a PDSCH transmission within subframe(s) n−k,

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Table 9.2-2: PUCCH resource value for downlink semi-persistent scheduling

Value of 'TPC command for PUCCH'	$n_{PUCCH}^{(i,p)}$
'00'	The first PUCCH resource value configured by the higher layers
'01'	The second PUCCH resource value configured by the higher layers
'10'	The third PUCCH resource value configured by the higher layers
'11'	The fourth PUCCH resource value configured by the higher layers

9.3 PDCCH/EPDCCH control information procedure

A UE shall discard the PDCCH/EPDCCH if consistent control information is not detected.

10 Physical uplink control channel procedures

If the UE is configured with a SCG, the UE shall apply the procedures described in this clause for both MCG and SCG

- When the procedures are applied for MCG, the terms 'secondary cell', 'secondary cells' , 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells, serving cell, serving cells belonging to the MCG respectively.
- When the procedures are applied for SCG, the terms 'secondary cell', 'secondary cells', 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells (not including PSCell), serving cell, serving cells belonging to the SCG respectively. The term 'primary cell' in this clause refers to the PSCell of the SCG.

10.1 UE procedure for determining physical uplink control channel assignment

If the UE is configured for a single serving cell and is not configured for simultaneous PUSCH and PUCCH transmissions, then in subframe n uplink control information (UCI) shall be transmitted

- on PUCCH using format 1/1a/1b/3 or 2/2a/2b if the UE is not transmitting PUSCH
- on PUSCH if the UE is transmitting PUSCH in subframe n unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, in which case UCI is not transmitted

If the UE is configured for a single serving cell and simultaneous PUSCH and PUCCH transmission, then in subframe n UCI shall be transmitted

- on PUCCH using format 1/1a/1b/3 if the UCI consists only of HARQ-ACK and/or SR
- on PUCCH using format 2 if the UCI consists only of periodic CSI
- on PUCCH using format 2/2a/2b/3 if the UCI consists of periodic CSI and HARQ-ACK and if the UE is not transmitting PUSCH
- on PUCCH and PUSCH if the UCI consists of HARQ-ACK/HARQ-ACK+SR/positive SR and periodic/aperiodic CSI and if the UE is transmitting PUSCH in subframe n, in which case the HARQ-ACK/HARQ-ACK+SR/positive SR is transmitted on PUCCH using format 1/1a/1b/3 and the periodic/aperiodic CSI transmitted on PUSCH unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, in which case periodic/aperiodic CSI is not transmitted

If the UE is configured with more than one serving cell and is not configured for simultaneous PUSCH and PUCCH transmission, then in subframe n UCI shall be transmitted

- on PUCCH using format 1/1a/1b/3 or 2/2a/2b if the UE is not transmitting PUSCH

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SPS-Config field descriptions
p0-UE-PUSCH-PersistentSubframeSet2 Parameter: $P_{O_UE_PUSCH}(0)$. See TS 36.213 [23, 5.1.1.1], unit dB. This field is applicable for persistent scheduling, only. If p0-PersistentSubframeSet2-r12 is not configured, apply the value of p0-UE-PUSCH-SubframeSet2 for p0-UE-PUSCH-PersistentSubframeSet2. E-UTRAN configures this field only if uplink power control subframe sets are configured by tpc-SubframeSet, in which case this field applies for uplink power control subframe set 2.
semiPersistSchedC-RNTI Semi-persistent Scheduling C-RNTI, see TS 36.321 [6].
semiPersistSchedIntervalDL Semi-persistent scheduling interval in downlink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames.
semiPersistSchedIntervalUL Semi-persistent scheduling interval in uplink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames.
twoIntervalsConfig Trigger of two-intervals-Semi-Persistent Scheduling in uplink. See TS 36.321 [6, 5.10]. If this field is present, two-intervals-SPS is enabled for uplink. Otherwise, two-intervals-SPS is disabled.

Conditional presence	Explanation
TDD	This field is optional present for TDD, need OR; it is not present for FDD and the UE shall delete any existing value for this field.

Some UEs are capable of transmitting PUSCH (Physical Uplink Shared Channel) and PUCCH (Physical Uplink Control Channel) simultaneously, and some UEs are not capable of transmitting PUSCH and PUCCH simultaneously. Such capability would be reported to eNB (evolved Node B) so that eNB could decide whether to configure this functionality or not. Even if UE support this feature, eNB may decide not to configure this function if the channel condition of the UE is poor, as to transmit both channel simultaneously is more power consuming. In such case, the UE maximum transmission power may not guarantee proper power level for each channel. UE may decide which channel to transmit UCI (Uplink Control Information) with depending on whether PUSCH and PUCCH simultaneously is configured or not.

Section 10.1 of 3GPP 36.213 v12.5.0 states:

10.1 UE Procedure for Determining Physical Uplink Control Channel Assignment

If the UE is configured for a single serving cell and is not configured for simultaneous PUSCH and PUCCH transmissions, then in subframe n uplink control information (UCI) shall be transmitted

on PUCCH using format 1/1a/1b/3 or 2/2a/2b if the UE is not transmitting PUSCH

on PUSCH if the UE is transmitting PUSCH in subframe n unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, in which case UCI is not transmitted

If the UE is configured for a single serving cell and simultaneous PUSCH and PUCCH transmission, then in subframe n UCI shall be transmitted

on PUCCH using format 1/1a/1b/3 if the UCI consists only of HARQ-ACK and/or SR

on PUCCH using format 2 if the UCI consists only of periodic CSI

on PUCCH using format 2/2a/2b/3 if the UCI consists of periodic CSI and HARQ-ACK and if the UE is not transmitting PUSCH

on PUCCH and PUSCH if the UCI consists of HARQ-ACK/HARQ-ACK+SR/positive SR and periodic/aperiodic CSI and if the UE is transmitting PUSCH in subframe n, in which case the HARQ-ACK/HARQ-ACK+SR/positive SR is transmitted on PUCCH using format 1/1a/1b/3 and the periodic/aperiodic CSI transmitted on PUSCH unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, in which case periodic/aperiodic CS

10.2 Uplink HARQ-ACK timing

For TDD or for FDD-TDD and primary cell frame structure type 2 or for FDD-TDD and primary cell frame structure type 1, if a UE configured with *EIMTA-MainConfigServCell-r12* for a serving cell, "UL/DL configuration" of the serving cell in subclause 10.2 refers to the UL/DL configuration given by the parameter *eimta-HarqReferenceConfig-r12* for the serving cell unless specified otherwise.

For FDD or for FDD-TDD and primary cell frame structure type 1, the UE shall upon detection of a PDSCH transmission in subframe *n-4* intended for the UE and for which an HARQ-ACK shall be provided, transmit the HARQ-ACK response in subframe *n*. If HARQ-ACK repetition is enabled, upon detection of a PDSCH transmission in subframe *n-4* intended for the UE and for which HARQ-ACK response shall be provided, and if the UE is not repeating the transmission of any HARQ-ACK in subframe n corresponding to a PDSCH transmission in subframes $n-N_{ANRep}-3, \ldots, n-5$, the UE:

- shall transmit only the HARQ-ACK response (corresponding to the detected PDSCH transmission in subframe $n-4$) on PUCCH in subframes $n, n+1, \ldots, n+N_{ANRep}-1$;
- shall not transmit any other signal in subframes $n, n+1, \ldots, n+N_{ANRep}-1$; and
- shall not transmit any HARQ-ACK response repetitions corresponding to any detected PDSCH transmission in subframes $n-3, \ldots, n+N_{ANRep}-5$.

For TDD and a UE configured with *EIMTA-MainConfigServCell-r12* for at least one serving cell, if the UE is configured with one serving cell or if the UE is configured with more than one serving cell and the TDD UL/DL configuration of all the configured serving cells is the same, the DL-reference UL/DL configuration for a serving cell is the UL/DL configuration of the serving cell.

For FDD-TDD and primary cell frame structure type 1, if a serving cell is a secondary serving cell with frame structure type 2, the DL-reference UL/DL configuration for the serving cell is the UL/DL configuration of the serving cell.

For TDD, if the UE is configured with more than one serving cell and if at least two serving cells have different UL/DL configurations and if a serving cell is a primary cell, then the primary cell UL/DL configuration is the DL-reference UL/DL configuration for the serving cell.

For FDD-TDD and primary cell frame structure type 2, if a serving cell is a primary cell or if a serving cell is a secondary cell with frame structure type 1, then the primary cell UL/DL configuration is the DL-reference UL/DL configuration for the serving cell.

For TDD and if the UE is configured with more than one serving cell and if at least two serving cells have different UL/DL configurations and if a serving cell is a secondary cell, or for FDD-TDD and primary cell frame structure type 2 and if a serving cell is a secondary cell with frame structure type 2

- if the pair formed by (primary cell UL/DL configuration, serving cell UL/DL configuration) belongs to Set 1 in Table 10.2-1 or
- if the UE is not configured to monitor PDCCH/EPDCCH in another serving cell for scheduling the serving cell, and if the pair formed by (primary cell UL/DL configuration, serving cell UL/DL configuration) belongs to Set 2 or Set 3 in Table 10.2-1 or
- if the UE is configured to monitor PDCCH/EPDCCH in another serving cell for scheduling the serving cell, and if the pair formed by (primary cell UL/DL configuration, serving cell UL/DL configuration) belongs to Set 4 or Set 5 in Table 10.2-1

then the DL-reference UL/DL configuration for the serving cell is defined in the corresponding Set in Table 10.2-1.

For TDD and if a UE is configured with more than one serving cell and if at least two serving cells have different UL/DL configurations or for FDD-TDD and primary cell frame structure type 2, if the DL-reference UL/DL configuration for at least one serving cell is TDD UL/DL Configuration 5, then the UE is not expected to be configured with more than two serving cells.

For TDD and a UE not configured with *EIMTA-MainConfigServCell-r12* for any serving cell, if the UE is configured with one serving cell, or the UE is configured with more than one serving cell and the UL/DL configurations of all serving cells is same, then the UE shall upon detection of a PDSCH transmission within subframe(s) $n-k$, where

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SPS-Config field descriptions	
p0-UE-PUSCH-PersistentSubframeSet2	Parameter: $P_{O_UE_PUSCH}(0)$. See TS 36.213 [23, 5.1.1.1], unit dB. This field is applicable for persistent scheduling, only. If p0-PersistentSubframeSet2-r12 is not configured, apply the value of p0-UE-PUSCH-SubframeSet2 for p0-UE-PUSCH-PersistentSubframeSet2. E-UTRAN configures this field only if uplink power control subframe sets are configured by tpc-SubframeSet, in which case this field applies for uplink power control subframe set 2.
semiPersistSchedC-RNTI	Semi-persistent Scheduling C-RNTI, see TS 36.321 [6].
semiPersistSchedIntervalDL	Semi-persistent scheduling interval in downlink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames.
semiPersistSchedIntervalUL	Semi-persistent scheduling interval in uplink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames.
twoIntervalsConfig	Trigger of two-intervals Semi-Persistent Scheduling in uplink. See TS 36.321 [6, 5.10]. If this field is present, two-intervals-SPS is enabled for uplink. Otherwise, two-intervals-SPS is disabled.

Conditional presence	Explanation
TDD	This field is optional present for TDD, need OR; it is not present for FDD and the UE shall delete any existing value for this field.

Some UEs are capable of transmitting PUSCH (Physical Uplink Shared Channel) and PUCCH (Physical Uplink Control Channel) simultaneously, and some UEs are not capable of transmitting PUSCH and PUCCH simultaneously. Such capability would be reported to eNB (evolved Node B) so that eNB could decide whether to configure this functionality or not. Even if UE support this feature, eNB may decide not to configure this function if the channel condition of the UE is poor, as to transmit both channel simultaneously is more power consuming. In such case, the UE maximum transmission power may not guarantee proper power level for each channel. UE may decide which channel to transmit UCI (Uplink Control Information) with depending on whether PUSCH and PUCCH simultaneously is configured or not.

Section 10.1 of 3GPP 36.213 v12.5.0 states:

10.1 UE Procedure for Determining Physical Uplink Control Channel Assignment

If the UE is configured for a single serving cell and is not configured for simultaneous PUSCH and PUCCH transmissions, then in subframe n uplink control information (UCI) shall be transmitted

- on PUCCH using format 1/1a/1b/3 or 2/2a/2b if the UE is not transmitting PUSCH
- on PUSCH if the UE is transmitting PUSCH in subframe n unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, in which case UCI is not transmitted

If the UE is configured for a single serving cell and simultaneous PUSCH and PUCCH transmission, then in subframe n UCI shall be transmitted

- on PUCCH using format 1/1a/1b/3 if the UCI consists only of HARQ-ACK and/or SR
- on PUCCH using format 2 if the UCI consists only of periodic CSI
- on PUCCH using format 2/2a/2b/3 if the UCI consists of periodic CSI and HARQ-ACK and if the UE is not transmitting PUSCH
- on PUCCH and PUSCH if the UCI consists of HARQ-ACK/HARQ-ACK+SR/positive SR and periodic/aperiodic CSI and if the UE is transmitting PUSCH in subframe n, in which case the HARQ-ACK/HARQ-ACK+SR/positive SR is transmitted on PUCCH using format 1/1a/1b/3 and the periodic/aperiodic CSI transmitted on PUSCH unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, in which case periodic/aperiodic CSI is not transmitted

For a UE with poor channel condition, such as in cell edge, it is possible to configure HARQ-ACK (Hybrid Automatic Repeat Request Acknowledgement) repetition to improve the HARQ-ACK feedback reliability by repeating the transmission of ACK/NACK (Acknowledgement/Negative Acknowledgement) multiple times. Under such situation, the HARQ-ACK would be transmitted on PUCCH without multiplexed onto other channel, e.g., PUSCH, to enjoy the combining gain of repetition across subframes, as some of the repetitions would occur on the same resource and joint demodulation/channel estimation is possible.

Section 10.2 of 3GPP 36.213 v12.5.0 states:

10.2 Uplink HARQ-ACK Timing

For TDD or for FDD-TDD and primary cell frame structure type 2 or for FDD-TDD and primary cell frame structure type 1, if a UE configured with EIMTA-MainConfigServCell-r12 for a serving cell, "UL/DL configuration" of the serving cell in subclause 10.2 refers to the UL/DL configuration given by the parameter eimta-HARQ-ReferenceConfig-r12 for the serving cell unless specified otherwise.

For FDD or for FDD-TDD and primary cell frame structure type 1, the UE shall upon detection of a PDSCH transmission in subframe n−4 intended for the UE and for which an HARQ-ACK shall be provided, transmit the HARQ-ACK response in subframe n. If HARQ-ACK repetition is enabled, upon detection of a PDSCH transmission in subframe n−4 intended for the UE and for which HARQ-ACK response shall be provided, and if the UE is not repeating the transmission of any HARQ-ACK in subframe n corresponding to a PDSCH transmission in subframes $n-N_{ANRep}-3, \ldots, n-5$, the UE:

- shall transmit only the HARQ-ACK response (corresponding to the detected PDSCH transmission in subframe n−4) on PUCCH in subframes $n, n+1, \ldots, n+N_{ANRep}-1$;
- shall not transmit any other signal/channel in subframes $n, n+1, \ldots, n+N_{ANRep}-1$; and
- shall not transmit any HARQ-ACK response repetitions corresponding to any detected PDSCH transmission in subframes $n-3, \ldots, n+N_{ANRep}-5$.

< . . . >

For TDD, if HARQ-ACK repetition is enabled, upon detection of a PDSCH transmission within subframe(s) n−k,

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$k \in K$ and K is defined in Table 10.1.3.1-1 intended for the UE and for which HARQ-ACK response shall be provided, transmit the HARQ-ACK response in UL subframe *n*.

For TDD and if a UE is configured with more than one serving cell and if at least two serving cells have different UL/DL configurations, or if a UE is configured with *EIMTA-MainConfigServCell-r12* for at least one serving cell. or for FDD-TDD and primary cell frame structure type 2 and if a serving cell *c* is frame structure type 2, then the UE shall upon detection of a PDSCH transmission within subframe(s) $n-k$ for serving cell c, where $k \in K_c$ intended for the UE and for which HARQ-ACK response shall be provided, transmit the HARQ-ACK response in UL subframe *n*, wherein set K_c contains values of $k \in K$ such that subframe *n-k* corresponds to a DL subframe or a special subframe for serving cell c, where DL subframe or special subframe of serving cell c is according to the higher layer parameter *eimta-HarqReferenceConfig-r12* if the UE is configured with the higher layer parameter *EIMTA-MainConfigServCell-r12* for serving cell c; K defined in Table 10.1.3.1-1 (where "UL/DL configuration" in Table 10.1.3.1-1 refers to the "DL-reference UL/DL configuration") is associated with subframe *n*.

For FDD-TDD and primary cell frame structure type 2, if a serving cell c is frame structure type 1 and a UE is not configured to monitor PDCCH/EPDCCH in another serving cell for scheduling the serving cell c, then the UE shall upon detection of a PDSCH transmission within subframe(s) $n-k$ for serving cell c, where $k \in K_c$, $K_c = K$ and K is defined in Table 10.1.3A-1 intended for the UE and for which HARQ-ACK response shall be provided, transmit the HARQ-ACK response in subframe *n*.

For FDD-TDD and primary cell frame structure type 2, if a serving cell c is frame structure type 1 and a UE is configured to monitor PDCCH/EPDCCH in another serving cell for scheduling serving cell c, then the UE shall upon detection of a PDSCH transmission within subframe(s) $n-k$ for serving cell c, where $k \in K_c$, $K_c = K$ and K is defined in Table 10.1.3.1-1, intended for the UE and for which HARQ-ACK response shall be provided, transmit the HARQ-ACK response in subframe *n*, where "UL/DL configuration" in Table 10.1.3.1-1 refers to the "DL-reference UL/DL configuration" of serving cell c.

For TDD, if HARQ-ACK repetition is enabled, upon detection of a PDSCH transmission within subframe(s) $n-k$, where $k \in K$ and K is defined in Table 10.1.3.1-1 intended for the UE and for which HARQ-ACK response shall be provided, and if the UE is not repeating the transmission of any HARQ-ACK in subframe n corresponding to a PDSCH transmission in a downlink or special subframe earlier than subframe $n-k$, the UE:

- shall transmit only the HARQ-ACK response (corresponding to the detected PDSCH transmission in subframe $n-k$) on PUCCH in UL subframe n and the next $N_{\text{ANRep}}-1$ UL subframes denoted as n_1, …, $n_{N_{\text{ANRep}}-1}$;
- shall not transmit any other signal in UL subframe n, n_1, …, $n_{N_{\text{ANRep}}-1}$; and
- shall not transmit any HARQ-ACK response repetitions corresponding to any detected PDSCH transmission in subframes n_i-k, where $k \in K_i$, K_i is the set defined in Table 10.1.3.1-1 corresponding to UL subframe n_i, and $1 \le i \le N_{\text{ANRep}}-1$.

For TDD, HARQ-ACK bundling, if the UE detects that at least one downlink assignment has been missed as described in subclause 7.3, the UE shall not transmit HARQ-ACK on PUCCH if HARQ-ACK is the only UCI present in a given subframe.

The uplink timing for the ACK corresponding to a detected PDCCH/EPDCCH indicating downlink SPS release shall be the same as the uplink timing for the HARQ-ACK corresponding to a detected PDSCH, as defined above.

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SPS-Config field descriptions	
p0-UE-PUSCH-PersistentSubframeSet2	Parameter: $P_{O_UE_PUSCH}(0)$. See TS 36.213 [23, 5.1.1.1], unit dB. This field is applicable for persistent scheduling, only. If p0-PersistentSubframeSet2-r12 is not configured, apply the value of p0-UE-PUSCH-SubframeSet2 for p0-UE-PUSCH-PersistentSubframeSet2. E-UTRAN configures this field only if uplink power control subframe sets are configured by tpc-SubframeSet, in which case this field applies for uplink power control subframe set 2.
semiPersistSchedC-RNTI	Semi-persistent Scheduling C-RNTI, see TS 36.321 [6].
semiPersistSchedIntervalDL	Semi-persistent scheduling interval in downlink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames.
semiPersistSchedIntervalUL	Semi-persistent scheduling interval in uplink, see TS 36.321 [6]. Value in number of sub-frames. Value sf10 corresponds to 10 sub-frames, sf20 corresponds to 20 sub-frames and so on. For TDD, the UE shall round this parameter down to the nearest integer (of 10 sub-frames), e.g. sf10 corresponds to 10 sub-frames, sf32 corresponds to 30 sub-frames, sf128 corresponds to 120 sub-frames.
twoIntervalsConfig	Trigger of two-intervals-Semi-Persistent Scheduling in uplink. See TS 36.321 [6, 5.10]. If this field is present, two-intervals-SPS is enabled for uplink. Otherwise, two-intervals-SPS is disabled.

Conditional presence	Explanation
TDD	This field is optional present for TDD, need OR; it is not present for FDD and the UE shall delete any existing value for this field.

Some UEs are capable of transmitting PUSCH (Physical Uplink Shared Channel) and PUCCH (Physical Uplink Control Channel) simultaneously, and some UEs are not capable of transmitting PUSCH and PUCCH simultaneously. Such capability would be reported to eNB (evolved Node B) so that eNB could decide whether to configure this functionality or not. Even if UE support this feature, eNB may decide not to configure this function if the channel condition of the UE is poor, as to transmit both channel simultaneously is more power consuming. In such case, the UE maximum transmission power may not guarantee proper power level for each channel. UE may decide which channel to transmit UCI (Uplink Control Information) with depending on whether PUSCH and PUCCH simultaneously is configured or not.

Section 10.1 of 3GPP 36.213 v12.5.0 states:

10.1 UE Procedure for Determining Physical Uplink Control Channel Assignment

If the UE is configured for a single serving cell and is not configured for simultaneous PUSCH and PUCCH transmissions, then in subframe n uplink control information (UCI) shall be transmitted

on PUCCH using format 1/1a/1b/3 or 2/2a/2b if the UE is not transmitting PUSCH

on PUSCH if the UE is transmitting PUSCH in subframe n unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, in which case UCI is not transmitted

If the UE is configured for a single serving cell and simultaneous PUSCH and PUCCH transmission, then in subframe n UCI shall be transmitted

on PUCCH using format 1/1a/1b/3 if the UCI consists only of HARQ-ACK and/or SR

on PUCCH using format 2 if the UCI consists only of periodic CSI

on PUCCH using format 2/2a/2b/3 if the UCI consists of periodic CSI and HARQ-ACK and if the UE is not transmitting PUSCH

on PUCCH and PUSCH if the UCI consists of HARQ-ACK/HARQ-ACK+SR/positive SR and periodic/aperiodic CSI and if the UE is transmitting PUSCH in subframe n, in which case the HARQ-ACK/HARQ-ACK+SR/positive SR is transmitted on PUCCH using format 1/1a/1b/3 and the periodic/aperiodic CSI transmitted on PUSCH unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, in which case periodic/aperiodic CSI is not transmitted

For a UE with poor channel condition, such as in cell edge, it is possible to configure HARQ-ACK (Hybrid Automatic Repeat Request Acknowledgement) repetition to improve the HARQ-ACK feedback reliability by repeating the transmission of ACK/NACK (Acknowledgement/Negative Acknowledgement) multiple times. Under such situation, the HARQ-ACK would be transmitted on PUCCH without multiplexed onto other channel, e.g., PUSCH, to enjoy the combining gain of repetition across subframes, as some of the repetitions would occur on the same resource and joint demodulation/channel estimation is possible.

Section 10.2 of 3GPP 36.213 v12.5.0 states:

10.2 Uplink HARQ-ACK Timing

For TDD or for FDD-TDD and primary cell frame structure type 2 or for FDD-TDD and primary cell frame structure type 1, if a UE configured with EIMTA-MainConfigServCell-r12 for a serving cell, "UL/DL configuration" of the serving cell in subclause 10.2 refers to the UL/DL configuration given by the parameter eimta-HARQ-ReferenceConfig-r12 for the serving cell unless specified otherwise.

For FDD or for FDD-TDD and primary cell frame structure type 1, the UE shall upon detection of a PDSCH transmission in subframe n−4 intended for the UE and for which an HARQ-ACK shall be provided, transmit the HARQ-ACK response in subframe n. If HARQ-ACK repetition is enabled, upon detection of a PDSCH transmission in subframe n−4 intended for the UE and for which HARQ-ACK response shall be provided, and if the UE is not repeating the transmission of any HARQ-ACK in subframe n corresponding to a PDSCH transmission in subframes $n-N_{ANRep}-3, \ldots, n-5$, the UE:

shall transmit only the HARQ-ACK response (corresponding to the detected PDSCH transmission in subframe n−4) on PUCCH in subframes n, $n+1, \ldots, n+N_{ANRep}-1$;

shall not transmit any other signal/channel in subframes n, $n+1, \ldots, n+N_{ANRep}-1$; and

shall not transmit any HARQ-ACK response repetitions corresponding to any detected PDSCH transmission in subframes $n-3, \ldots, n+N_{ANRep}-5$.

< >

For TDD, if HARQ-ACK repetition is enabled, upon detection of a PDSCH transmission within subframe(s) n−k,

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$k \in K$ and K is defined in Table 10.1.3.1-1 intended for the UE and for which HARQ-ACK response shall be provided, transmit the HARQ-ACK response in UL subframe *n*.

For TDD and if a UE is configured with more than one serving cell and if at least two serving cells have different UL/DL configurations, or if a UE is configured with *EIMTA-MainConfigServCell-r12* for at least one serving cell. or for FDD-TDD and primary cell frame structure type 2 and if a serving cell *c* is frame structure type 2, then the UE shall upon detection of a PDSCH transmission within subframe(s) $n-k$ for serving cell c, where $k \in K_c$ intended for the UE and for which HARQ-ACK response shall be provided, transmit the HARQ-ACK response in UL subframe *n*, wherein set K_c contains values of $k \in K$ such that subframe *n-k* corresponds to a DL subframe or a special subframe for serving cell c, where DL subframe or special subframe of serving cell c is according to the higher layer parameter *eimta-HarqReferenceConfig-r12* if the UE is configured with the higher layer parameter *EIMTA-MainConfigServCell-r12* for serving cell c; K defined in Table 10.1.3.1-1 (where "UL/DL configuration" in Table 10.1.3.1-1 refers to the "DL-reference UL/DL configuration") is associated with subframe *n*.

For FDD-TDD and primary cell frame structure type 2, if a serving cell c is frame structure type 1 and a UE is not configured to monitor PDCCH/EPDCCH in another serving cell for scheduling the serving cell c, then the UE shall upon detection of a PDSCH transmission within subframe(s) $n-k$ for serving cell c, where $k \in K_c$, $K_c = K$ and K is defined in Table 10.1.3A-1 intended for the UE and for which HARQ-ACK response shall be provided, transmit the HARQ-ACK response in subframe *n*.

For FDD-TDD and primary cell frame structure type 2, if a serving cell c is frame structure type 1 and a UE is configured to monitor PDCCH/EPDCCH in another serving cell for scheduling serving cell c, then the UE shall upon detection of a PDSCH transmission within subframe(s) $n-k$ for serving cell c, where $k \in K_c$, $K_c = K$ and K is defined in Table 10.1.3.1-1, intended for the UE and for which HARQ-ACK response shall be provided, transmit the HARQ-ACK response in subframe *n*, where "UL/DL configuration" in Table 10.1.3.1-1 refers to the "DL-reference UL/DL configuration" of serving cell c.

For TDD, if HARQ-ACK repetition is enabled, upon detection of a PDSCH transmission within subframe(s) $n-k$, where $k \in K$ and K is defined in Table 10.1.3.1-1 intended for the UE and for which HARQ-ACK response shall be provided, and if the UE is not repeating the transmission of any HARQ-ACK in subframe n corresponding to a PDSCH transmission in a downlink or special subframe earlier than subframe $n-k$, the UE:

- shall transmit only the HARQ-ACK response (corresponding to the detected PDSCH transmission in subframe $n-k$) on PUCCH in UL subframe n and the next $N_{\text{ANRep}}-1$ UL subframes denoted as n_1, …, $n_{N_{\text{ANRep}}-1}$;
- shall not transmit any other signal in UL subframe n, n_1, …, $n_{N_{\text{ANRep}}-1}$; and
- shall not transmit any HARQ-ACK response repetitions corresponding to any detected PDSCH transmission in subframes n_i-k, where $k \in K_i$, K_i is the set defined in Table 10.1.3.1-1 corresponding to UL subframe n_i, and $1 \le i \le N_{\text{ANRep}}-1$.

For TDD, HARQ-ACK bundling, if the UE detects that at least one downlink assignment has been missed as described in subclause 7.3, the UE shall not transmit HARQ-ACK on PUCCH if HARQ-ACK is the only UCI present in a given subframe.

The uplink timing for the ACK corresponding to a detected PDCCH/EPDCCH indicating downlink SPS release shall be the same as the uplink timing for the HARQ-ACK corresponding to a detected PDSCH, as defined above.

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where Ice K and K is defined in Table 10.1.3.1-1 intended for the UE and for which HARQ-ACK response shall be provided, and if the UE is not repeating the transmission of any HARQ-ACK in subframe n corresponding to a PDSCH transmission in a downlink or special subframe earlier than subframe n−k, the UE:

- shall transmit only the HARQ-ACK response (corresponding to the detected PDSCH transmission in subframe n−k) on PUCCH in UL subframe n and the next $N_{ANRep}-1$ UL subframes denoted as $n_1, \ldots, n_{N_{ANRep}-1}$;
- shall not transmit any other signal/channel in UL subframe n, $n_1, \ldots, n_{N_{ANRep}-1}$; and
- shall not transmit any HARQ-ACK response repetitions corresponding to any detected PDSCH transmission in subframes n_i-k, where $k \in K_i$, K_i is the set defined in Table 10.1.3.1-1 corresponding to UL subframe n_i and $1 \le i \le N_{ANRep}-1$.

3GPP TS 36.212 v13.0.0 describes how physical layer process a transport block from MAC layer and how to multiplex uplink control information as follows:

5.2 Uplink Transport Channels and Control Information

If the UE is configured with a Master Cell Group (MCG) and Secondary Cell Group (SCG) [6], the procedures described in this clause are applied to the MCG and SCG, respectively. When the procedures are applied to a SCG, the term primary cell refers to the primary SCell (PSCell) of the SCG.

If the UE is configured with a PUCCH SCell [6], the procedures described in this clause are applied to the group of DL cells associated with the primary cell and the group of DL cells associated with the PUCCH SCell, respectively. When the procedures are applied to the group of DL cells associated with the PUCCH SCell, the term primary cell refers to the PUCCH SCell.

If the UE is configured with a LAA SCell, the procedures described in this clause are applied assuming the LAA SCell is an FDD SCell.

5.2.1 Random Access Channel

The sequence index for the random access channel is received from higher layers and is processed according to [2].

5.2.2 Uplink Shared Channel

Figure 5.2.2-1 shows the processing structure for the UL-SCH transport channel on one UL cell. Data arrives to the coding unit in the form of a maximum of two transport blocks every transmission time interval (TTI) per UL cell. The following coding steps can be identified for each transport block of an UL cell:

- Add CRC to the transport block
- Code block segmentation and code block CRC attachment
- Channel coding of data and control information
- Rate matching
- Code block concatenation
- Multiplexing of data and control information
- Channel interleaver

The coding steps for one UL-SCH transport block are shown in the figure below. The same general processing applies for each UL-SCH transport block on each UL cell with restrictions as specified in [3].

[Figure 5.2.2-1 of 3GPP TS 36.212 v13.0.0, Entitled "Transport Block Processing for UL-SCH" is Reproduced as FIG. 6]

5.2.2.1 Transport Block CRC Attachment

Error detection is provided on each UL-SCH transport block through a Cyclic Redundancy Check (CRC).

The entire transport block is used to calculate the CRC parity bits. Denote the bits in a transport block delivered to layer

1 by $a_0, a_1, a_2, a_3, \ldots, a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3, \ldots, p_{L-1}$, A is the size of the transport block and L is the number of parity bits. The lowest order information bit a_0 is mapped to the most significant bit of the transport block as defined in section 6.1.1 of [5].

The parity bits are computed and attached to the UL-SCH transport block according to section 5.1.1 setting L to 24 bits and using the generator polynomial $g_{CRC24A}(D)$.

5.2.2.2 Code Block Segmentation and Code Block CRC Attachment

The bits input to the code block segmentation are denoted by $b_0, b_1, b_2, b_3, \ldots, b_{B-1}$ where B is the number of bits in the transport block (including CRC).

Code block segmentation and code block CRC attachment are performed according to section 5.1.2.

The bits after code block segmentation are denoted by $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \ldots, c_{r(K_r-1)}$, where r is the code block number and K_r is the number of bits for code block number r.

5.2.2.3 Channel Coding of UL-SCH

Code blocks are delivered to the channel coding block. The bits in a code block are denoted by $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \ldots, c_{r(K_r-1)}$, where r is the code block number, and K_r is the number of bits in code block number r. The total number of code blocks is denoted by C and each code block is individually turbo encoded according to section 5.1.3.2.

After encoding the bits are denoted by $d_{r0}^{(i)}, d_{r1}^{(i)}, d_{r2}^{(i)}, d_{r3}^{(i)}, \ldots, d_{r(D_r-1)}^{(i)}$, with i=0, 1, and 2 and where D_r is the number of bits on the i-th coded stream for code block number r, i.e. $D_r=K_r+4$.

5.2.2.4 Rate Matching

Turbo coded blocks are delivered to the rate matching block. They are denoted by $d_{r0}^{(i)}, d_{r1}^{(i)}, d_{r2}^{(i)}, d_{r3}^{(i)}, \ldots, d_{r(D_r-1)}^{(i)}$, with i=0, 1, and 2, and where r is the code block number, i is the coded stream index, and D_r is the number of bits in each coded stream of code block number r. The total number of code blocks is denoted by C and each coded block is individually rate matched according to section 5.1.4.1.

After rate matching, the bits are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, \ldots, e_{r(E_r-1)}$, where r is the coded block number, and where E_r is the number of rate matched bits for code block number r.

5.2.2.5 Code Block Concatenation

The bits input to the code block concatenation block are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, \ldots, e_{r(E_r-1)}$ for r=0, …, C−1 and where E_r is the number of rate matched bits for the r-th code block.

Code block concatenation is performed according to section 5.1.5.

The bits after code block concatenation are denoted by $f_0, f_1, f_2, f_3, \ldots, f_{G-1}$, where G is the total number of coded bits for transmission of the given transport block over N_L transmission layers excluding the bits used for control transmission, when control information is multiplexed with the UL-SCH transmission.

5.2.2.6 Channel Coding of Control Information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI), HARQ-ACK and rank indication, and CSI-RS resource indication (CRI). Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When control data are transmitted in the PUSCH, the channel coding for HARQ-ACK, rank indication, CRI and channel quality information $o_0, o_1, o_2, \ldots, o_{O-1}$ is done independently.

For the cases with TDD primary cell, the number of HARQ-ACK bits is determined as described in section 7.3 of [3].

5.1.5 Code block concatenation

The input bit sequence for the code block concatenation block are the sequences e_{rk}, for $r = 0,...,C-1$ and $k = 0,...,E_r - 1$. The output bit sequence from the code block concatenation block is the sequence f_k for $k = 0,...,G-1$.

The code block concatenation consists of sequentially concatenating the rate matching outputs for the different code blocks. Therefore,

Set $k = 0$ and $r = 0$

while $r < C$

Set $j = 0$

while $j < E_r$

$f_k = e_{rj}$

$k = k + 1$

$j = j + 1$

end while

$r = r + 1$

end while

5.2 Uplink transport channels and control information

If the UE is configured with a Master Cell Group (MCG) and Secondary Cell Group (SCG) [6], the procedures described in this clause are applied to the MCG and SCG, respectively. When the procedures are applied to a SCG, the term primary cell refers to the primary SCell (PSCell) of the SCG.

If the UE is configured with a PUCCH SCell [6], the procedures described in this clause are applied to the group of DL cells associated with the primary cell and the group of DL cells associated with the PUCCH SCell, respectively. When the procedures are applied to the group of DL cells associated with the PUCCH SCell, the term primary cell refers to the PUCCH SCell.

If the UE is configured with a LAA SCell, the procedures described in this clause are applied assuming the LAA SCell is an FDD SCell.

5.2.1 Random access channel

The sequence index for the random access channel is received from higher layers and is processed according to [2].

5.2.2 Uplink shared channel

Figure 5.2.2-1 shows the processing structure for the UL-SCH transport channel on one UL cell. Data arrives to the coding unit in the form of a maximum of two transport blocks every transmission time interval (TTI) per UL cell. The following coding steps can be identified for each transport block of an UL cell:

- Add CRC to the transport block
- Code block segmentation and code block CRC attachment
- Channel coding of data and control information
- Rate matching

where Ice K and K is defined in Table 10.1.3.1-1 intended for the UE and for which HARQ-ACK response shall be provided, and if the UE is not repeating the transmission of any HARQ-ACK in subframe n corresponding to a PDSCH transmission in a downlink or special subframe earlier than subframe n−k, the UE:

- shall transmit only the HARQ-ACK response (corresponding to the detected PDSCH transmission in subframe n−k) on PUCCH in UL subframe n and the next $N_{ANRep}-1$ UL subframes denoted as $n_1, \ldots, n_{N_{ANRep}-1}$;
- shall not transmit any other signal/channel in UL subframe n, $n_1, \ldots, n_{N_{ANRep}-1}$; and
- shall not transmit any HARQ-ACK response repetitions corresponding to any detected PDSCH transmission in subframes n_i-k, where $k \in K_i$, K_i is the set defined in Table 10.1.3.1-1 corresponding to UL subframe n_i, and $1 \le i \le N_{ANRep}-1$.

3GPP TS 36.212 v13.0.0 describes how physical layer process a transport block from MAC layer and how to multiplex uplink control information as follows:

5.2 Uplink Transport Channels and Control Information

If the UE is configured with a Master Cell Group (MCG) and Secondary Cell Group (SCG) [6], the procedures described in this clause are applied to the MCG and SCG, respectively. When the procedures are applied to a SCG, the term primary cell refers to the primary SCell (PSCell) of the SCG.

If the UE is configured with a PUCCH SCell [6], the procedures described in this clause are applied to the group of DL cells associated with the primary cell and the group of DL cells associated with the PUCCH SCell, respectively. When the procedures are applied to the group of DL cells associated with the PUCCH SCell, the term primary cell refers to the PUCCH SCell.

If the UE is configured with a LAA SCell, the procedures described in this clause are applied assuming the LAA SCell is an FDD SCell.

5.2.1 Random Access Channel

The sequence index for the random access channel is received from higher layers and is processed according to [2].

5.2.2 Uplink Shared Channel

Figure 5.2.2-1 shows the processing structure for the UL-SCH transport channel on one UL cell. Data arrives to the coding unit in the form of a maximum of two transport blocks every transmission time interval (TTI) per UL cell. The following coding steps can be identified for each transport block of an UL cell:

- Add CRC to the transport block
- Code block segmentation and code block CRC attachment
- Channel coding of data and control information
- Rate matching
- Code block concatenation
- Multiplexing of data and control information
- Channel interleaver

The coding steps for one UL-SCH transport block are shown in the figure below. The same general processing applies for each UL-SCH transport block on each UL cell with restrictions as specified in [3].

[Figure 5.2.2-1 of 3GPP TS 36.212 v13.0.0, Entitled "Transport Block Processing for UL-SCH" is Reproduced as FIG. 6]

5.2.2.1 Transport Block CRC Attachment

Error detection is provided on each UL-SCH transport block through a Cyclic Redundancy Check (CRC).

The entire transport block is used to calculate the CRC parity bits. Denote the bits in a transport block delivered to layer 1 by $a_0, a_1, a_2, a_3, \ldots, a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3, \ldots, p_{L-1}$. A is the size of the transport block and L is the number of parity bits. The lowest order information bit a_0 is mapped to the most significant bit of the transport block as defined in section 6.1.1 of [5].

The parity bits are computed and attached to the UL-SCH transport block according to section 5.1.1 setting L to 24 bits and using the generator polynomial $g_{CRC24A}(D)$.

5.2.2.2 Code Block Segmentation and Code Block CRC Attachment

The bits input to the code block segmentation are denoted by $b_0, b_1, b_2, b_3, \ldots, b_{B-1}$ where B is the number of bits in the transport block (including CRC).

Code block segmentation and code block CRC attachment are performed according to section 5.1.2.

The bits after code block segmentation are denoted by $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \ldots, c_{r(K_r-1)}$, where r is the code block number and K_r is the number of bits for code block number r.

5.2.2.3 Channel Coding of UL-SCH

Code blocks are delivered to the channel coding block. The bits in a code block are denoted by $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \ldots, c_{r(K_r-1)}$, where r is the code block number, and K_r is the number of bits in code block number r. The total number of code blocks is denoted by C and each code block is individually turbo encoded according to section 5.1.3.2.

After encoding the bits are denoted by $d_{r0}^{(i)}, d_{r1}^{(i)}, d_{r2}^{(i)}, d_{r3}^{(i)}, \ldots, d_{r(D_r-1)}^{(i)}$, with i=0, 1, and 2 and where D_r is the number of bits on the i-th coded stream for code block number r, i.e. $D_r=K_r+4$.

5.2.2.4 Rate Matching

Turbo coded blocks are delivered to the rate matching block. They are denoted by $d_{r0}^{(i)}, d_{r1}^{(i)}, d_{r2}^{(i)}, d_{r3}^{(i)}, \ldots, d_{r(D_r-1)}^{(i)}$, with i=0, 1, and 2, and where r is the code block number, i is the coded stream index, and D_r is the number of bits in each coded stream of code block number r. The total number of code blocks is denoted by C and each coded block is individually rate matched according to section 5.1.4.1.

After rate matching, the bits are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, \ldots, e_{r(E_r-1)}$, where r is the coded block number, and where E_r is the number of rate matched bits for code block number r.

5.2.2.5 Code Block Concatenation

The bits input to the code block concatenation block are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, \ldots, e_{r(E_r-1)}$ for r=0, . . . , C−1 and where E_r is the number of rate matched bits for the r-th code block.

Code block concatenation is performed according to section 5.1.5.

The bits after code block concatenation are denoted by $f_0, f_1, f_2, f_3, \ldots, f_{G-1}$, where G is the total number of coded bits for transmission of the given transport block over N_L transmission layers excluding the bits used for control transmission, when control information is multiplexed with the UL-SCH transmission.

5.2.2.6 Channel Coding of Control Information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI), HARQ-ACK and rank indication, and CSI-RS resource indication (CRI). Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When control data are transmitted in the PUSCH, the channel coding for HARQ-ACK, rank indication, CRI and channel quality information $o_0, o_1, o_2, \ldots, o_{O-1}$ is done independently.

For the cases with TDD primary cell, the number of HARQ-ACK bits is determined as described in section 7.3 of [3].

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- Code block concatenation
- Multiplexing of data and control information
- Channel interleaver

The coding steps for one UL-SCH transport block are shown in the figure below. The same general processing applies for each UL-SCH transport block on each UL cell with restrictions as specified in [3].

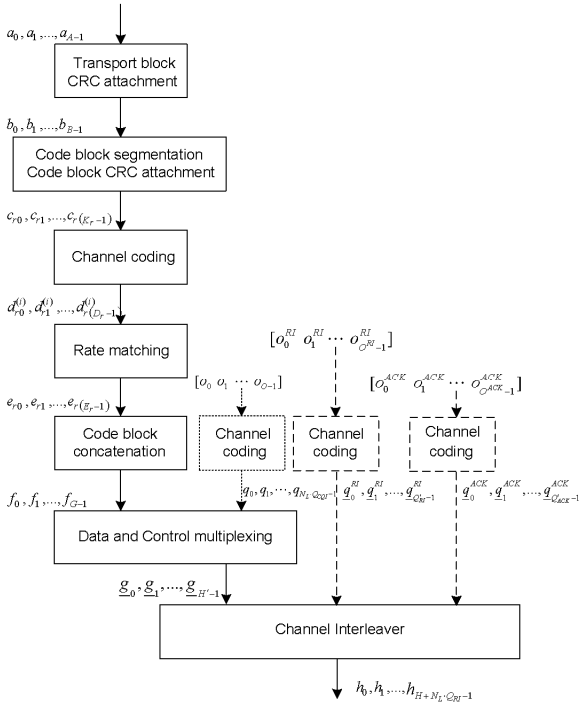


Figure 5.2.2-1: Transport block processing for UL-SCH.

5.2.2.1 Transport block CRC attachment

Error detection is provided on each UL-SCH transport block through a Cyclic Redundancy Check (CRC).

The entire transport block is used to calculate the CRC parity bits. Denote the bits in a transport block delivered to layer 1 by $a_0, a_1, a_2, a_3, ..., a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3, ..., p_{L-1}$. A is the size of the transport block and L is the number of parity bits. The lowest order information bit a_0 is mapped to the most significant bit of the transport block as defined in section 6.1.1 of [5].

where Ice K and K is defined in Table 10.1.3.1-1 intended
for the UE and for which HARQ-ACK response shall be
provided, and if the UE is not repeating the transmission of
any HARQ-ACK in subframe n corresponding to a PDSCH
transmission in a downlink or special subframe earlier than
subframe n−k, the UE:
- shall transmit only the HARQ-ACK response (corresponding to the detected PDSCH
frame n−k) on PUCCH in UL su
N_{ANRep}−1 UL subframes denoted
- shall not transmit any other signa
frame n, $n_1, \ldots, n_{N_{ANRep}-1}$; and
- shall not transmit any HARQ-ACK
corresponding to any detected PI
subframes n_i−k, where k∈K_i, K_i
Table 10.1.3.1-1 corresponding to
$1 \le i \le N_{ANRep}$−1.

3GPP TS 36.212 v13.0.0 describe
process a transport block from MA
multiplex uplink control information
5.2 Uplink Transport Channels and C
If the UE is configured with a Master C
Secondary Cell Group (SCG) [6], the
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refers to the PUCCH SCell.
If the UE is configured with a LAA
described in this clause are applied ass
is an FDD SCell.
5.2.1 Random Access Channel
The sequence index for the randon
received from higher layers and is p
[2].
5.2.2 Uplink Shared Channel
Figure 5.2.2-1 shows the processing
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coding unit in the form of a maxim
blocks every transmission time inter
The following coding steps can be
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Add CRC to the transport block
Code block segmentation and cod
ment
Channel coding of data and control information
Rate matching
Code block concatenation
Multiplexing of data and control information
Channel interleaver
The coding steps for one UL-SCH transport block are shown in the figure below. The same general processing applies for each UL-SCH transport block on each UL cell with restrictions as specified in [3].
[Figure 5.2.2-1 of 3GPP TS 36.212 v13.0.0, Entitled "Transport Block Processing for UL-SCH" is Reproduced as FIG. 6]
5.2.2.1 Transport Block CRC Attachment
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1 by $a_0, a_1, a_2, a_3, \ldots, a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3, \ldots, p_{L-1}$. A is the size of the transport block and L is the number of parity bits. The lowest order information bit a_0 is mapped to the most significant bit of the transport block as defined in section 6.1.1 of [5].

The parity bits are computed and attached to the UL-SCH

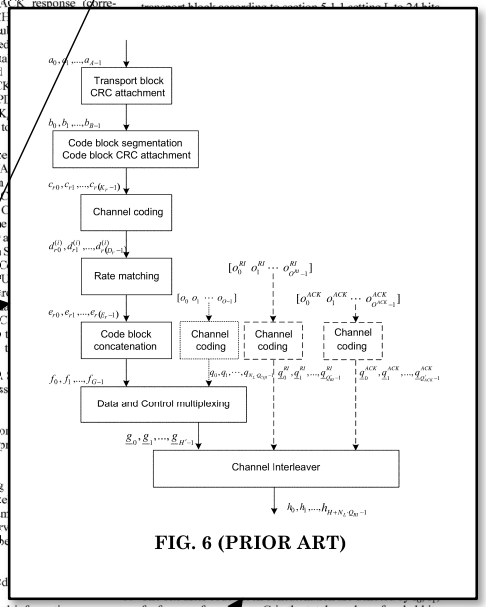


FIG. 6 (PRIOR ART)

$f_2, f_3, \ldots, f_{G-1}$. Where G is the total number of coded bits for transmission of the given transport block over N_L transmission layers excluding the bits used for control transmission, when control information is multiplexed with the UL-SCH transmission.

5.2.2.6 Channel Coding of Control Information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI), HARQ-ACK and rank indication, and CSI-RS resource indication (CRI). Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When control data are transmitted in the PUSCH, the channel coding for HARQ-ACK, rank indication, CRI and channel quality information $o_0, o_1, o_2, \ldots, o_{O-1}$ is done independently.

For the cases with TDD primary cell, the number of HARQ-ACK bits is determined as described in section 7.3 of [3].

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The parity bits are computed and attached to the UL-SCH transport block according to section 5.1.1 setting L to 24 bits and using the generator polynomial $g_{CRC24A}(D)$.

5.2.2.2 Code block segmentation and code block CRC attachment

The bits input to the code block segmentation are denoted by $b_0, b_1, b_2, b_3, ..., b_{B-1}$ where B is the number of bits in the transport block (including CRC).

Code block segmentation and code block CRC attachment are performed according to section 5.1.2.

The bits after code block segmentation are denoted by $c_{r0}, c_{r1}, c_{r2}, c_{r3}, ..., c_{r(K_r-1)}$, where r is the code block number and K_r is the number of bits for code block number r.

5.2.2.3 Channel coding of UL-SCH

Code blocks are delivered to the channel coding block. The bits in a code block are denoted by $c_{r0}, c_{r1}, c_{r2}, c_{r3}, ..., c_{r(K_r-1)}$, where r is the code block number, and K_r is the number of bits in code block number r. The total number of code blocks is denoted by C and each code block is individually turbo encoded according to section 5.1.3.2.

After encoding the bits are denoted by $d_{r0}^{(i)}, d_{r1}^{(i)}, d_{r2}^{(i)}, d_{r3}^{(i)}, ..., d_{r(D_r-1)}^{(i)}$, with $i = 0, 1,$ and 2 and where D_r is the number of bits on the i-th coded stream for code block number r, i.e. $D_r = K_r + 4$.

5.2.2.4 Rate matching

Turbo coded blocks are delivered to the rate matching block. They are denoted by $d_{r0}^{(i)}, d_{r1}^{(i)}, d_{r2}^{(i)}, d_{r3}^{(i)}, ..., d_{r(D_r-1)}^{(i)}$, with $i = 0, 1,$ and 2, and where r is the code block number, i is the coded stream index, and D_r is the number of bits in each coded stream of code block number r. The total number of code blocks is denoted by C and each coded block is individually rate matched according to section 5.1.4.1.

After rate matching, the bits are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, ..., e_{r(E_r-1)}$, where r is the coded block number, and where E_r is the number of rate matched bits for code block number r.

5.2.2.5 Code block concatenation

The bits input to the code block concatenation block are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, ..., e_{r(E_r-1)}$ for $r = 0, ..., C-1$ and where E_r is the number of rate matched bits for the r-th code block.

Code block concatenation is performed according to section 5.1.5.

The bits after code block concatenation are denoted by $f_0, f_1, f_2, f_3, ..., f_{G-1}$, where G is the total number of coded bits for transmission of the given transport block over N_L transmission layers excluding the bits used for control transmission, when control information is multiplexed with the UL-SCH transmission.

5.2.2.6 Channel coding of control information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI), HARQ-ACK and rank indication, and CSI-RS resource indication (CRI). Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When control data are transmitted in the PUSCH, the channel coding for HARQ-ACK, rank indication, CRI and channel quality information $o_0, o_1, o_2, ..., o_{O-1}$ is done independently.

For the cases with TDD primary cell, the number of HARQ-ACK bits is determined as described in section 7.3 of [3].

where Ice K and K is defined in Table 10.1.3.1-1 intended for the UE and for which HARQ-ACK response shall be provided, and if the UE is not repeating the transmission of any HARQ-ACK in subframe n corresponding to a PDSCH transmission in a downlink or special subframe earlier than subframe n−k, the UE:

- shall transmit only the HARQ-ACK response (corresponding to the detected PDSCH transmission in subframe n−k) on PUCCH in UL subframe n and the next $N_{SAKRep}-1$ UL subframes denoted as $n_1, \ldots, n_{N_{SAKRep}-1}$;
- shall not transmit any other signal/channel in UL subframe n, $n_1, \ldots, n_{N_{SAKRep}-1}$; and
- shall not transmit any HARQ-ACK response repetitions corresponding to any detected PDSCH transmission in subframes n_r-k, where $k \in K_r$, K_r is the set defined in Table 10.1.3.1-1 corresponding to UL subframe n_r and $1 \le i \le N_{SAKRep}-1$.

3GPP TS 36.212 v13.0.0 describes how physical layer process a transport block from MAC layer and how to multiplex uplink control information as follows:

5.2 Uplink Transport Channels and Control Information

If the UE is configured with a Master Cell Group (MCG) and Secondary Cell Group (SCG) [6], the procedures described in this clause are applied to the MCG and SCG, respectively. When the procedures are applied to a SCG, the term primary cell refers to the primary SCell (PSCell) of the SCG.

If the UE is configured with a PUCCH SCell [6], the procedures described in this clause are applied to the group of DL cells associated with the primary cell and the group of DL cells associated with the PUCCH SCell, respectively. When the procedures are applied to the group of DL cells associated with the PUCCH SCell, the term primary cell refers to the PUCCH SCell.

If the UE is configured with a LAA SCell, the procedures described in this clause are applied assuming the LAA SCell is an FDD SCell.

5.2.1 Random Access Channel

The sequence index for the random access channel is received from higher layers and is processed according to [2].

5.2.2 Uplink Shared Channel

Figure 5.2.2-1 shows the processing structure for the UL-SCH transport channel on one UL cell. Data arrives to the coding unit in the form of a maximum of two transport blocks every transmission time interval (TTI) per UL cell. The following coding steps can be identified for each transport block of an UL cell:

- Add CRC to the transport block
- Code block segmentation and code block CRC attachment
- Channel coding of data and control information
- Rate matching
- Code block concatenation
- Multiplexing of data and control information
- Channel interleaver

The coding steps for one UL-SCH transport block are shown in the figure below. The same general processing applies for each UL-SCH transport block on each UL cell with restrictions as specified in [3].

[Figure 5.2.2-1 of 3GPP TS 36.212 v13.0.0, Entitled "Transport Block Processing for UL-SCH" is Reproduced as FIG. 6]

5.2.2.1 Transport Block CRC Attachment

Error detection is provided on each UL-SCH transport block through a Cyclic Redundancy Check (CRC).

The entire transport block is used to calculate the CRC parity bits. Denote the bits in a transport block delivered to layer 1 by $a_0, a_1, a_2, a_3, \ldots, a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3, \ldots, p_{L-1}$. A is the size of the transport block and L is the number of parity bits. The lowest order information bit a_0 is mapped to the most significant bit of the transport block as defined in section 6.1.1 of [5].

The parity bits are computed and attached to the UL-SCH transport block according to section 5.1.1 setting L to 24 bits and using the generator polynomial $g_{CRC24A}(D)$.

5.2.2.2 Code Block Segmentation and Code Block CRC Attachment

The bits input to the code block segmentation are denoted by $b_0, b_1, b_2, b_3, \ldots, b_{B-1}$ where B is the number of bits in the transport block (including CRC).

Code block segmentation and code block CRC attachment are performed according to section 5.1.2.

The bits after code block segmentation are denoted by $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \ldots, c_{r(K_r-1)}$, where r is the code block number and K_r is the number of bits for code block number r.

5.2.2.3 Channel Coding of UL-SCH

Code blocks are delivered to the channel coding block. The bits in a code block are denoted by $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \ldots, c_{r(K_r-1)}$, where r is the code block number, and K_r is the number of bits in code block number r. The total number of code blocks is denoted by C and each code block is individually turbo encoded according to section 5.1.3.2.

After encoding the bits are denoted by $d_{r0}^{(i)}, d_{r1}^{(i)}, d_{r2}^{(i)}, d_{r3}^{(i)}, \ldots, d_{r(D_r-1)}^{(i)}$, with i=0, 1, and 2 and where D_r is the number of bits on the i-th coded stream for code block number r, i.e. $D_r=K_r+4$.

5.2.2.4 Rate Matching

Turbo coded blocks are delivered to the rate matching block. They are denoted by $d_{r0}^{(i)}, d_{r1}^{(i)}, d_{r2}^{(i)}, d_{r3}^{(i)}, \ldots, d_{r(D_r-1)}^{(i)}$, with i=0, 1, and 2, and where r is the code block number, i is the coded stream index, and D_r is the number of bits in each coded stream of code block number r. The total number of code blocks is denoted by C and each coded block is individually rate matched according to section 5.1.4.1.

After rate matching, the bits are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, \ldots, e_{r(E_r-1)}$, where r is the coded block number, and where E_r is the number of rate matched bits for code block number r.

5.2.2.5 Code Block Concatenation

The bits input to the code block concatenation block are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, \ldots, e_{r(E_r-1)}$ for r=0, . . . , C−1 and where E_r is the number of rate matched bits for the r-th code block.

Code block concatenation is performed according to section 5.1.5.

The bits after code block concatenation are denoted by $f_0, f_1, f_2, f_3, \ldots, f_{G-1}$, where G is the total number of coded bits for transmission of the given transport block over N_L transmission layers excluding the bits used for control transmission, when control information is multiplexed with the UL-SCH transmission.

5.2.2.6 Channel Coding of Control Information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI), HARQ-ACK and rank indication, and CSI-RS resource indication (CRI). Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When control data are transmitted in the PUSCH, the channel coding for HARQ-ACK, rank indication, CRI and channel quality information $o_0, o_1, o_2, \ldots, o_{O-1}$ is done independently.

For the cases with TDD primary cell, the number of HARQ-ACK bits is determined as described in section 7.3 of [3].

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When the UE transmits HARQ-ACK bits, rank indicator bits or CRI bits, it shall determine the number of coded modulation symbols per layer Q' for HARQ-ACK, rank indicator or CRI bits as follows.

For the case when only one transport block is transmitted in the PUSCH conveying the HARQ-ACK bits, rank indicator bits or CRI bits:

$$Q' = \min\left(\left\lceil \frac{O \cdot M_{sc}^{PUSCH-initial} \cdot N_{symb}^{PUSCH-initial} \cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C-1} K_r} \right\rceil, 4 \cdot M_{sc}^{PUSCH}\right)$$

where

- O is the number of HARQ-ACK bits, rank indicator bits or CRI bits, and
- M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current sub-frame for the transport block, expressed as a number of subcarriers in [2], and
- $N_{\text{symb}}^{\text{PUSCH-initial}}$ is the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the same transport block, respectively, given by $N_{\text{symb}}^{PUSCH\text{-}initial} = \left(2 \cdot \left(N_{\text{symb}}^{\text{UL}} - 1\right) - N_{\text{SRS}}\right)$, where
  - N_{SRS} is equal to 1
    - if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or
    - if UE transmits PUSCH and SRS in the same subframe in the same serving cell for initial transmission, or
    - if the PUSCH resource allocation for initial transmission even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or
    - if the subframe for initial transmission in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or
    - if the subframe for initial transmission in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.
  - Otherwise N_{SRS} is equal to 0.
- $M_{sc}^{PUSCH-initial}$, C, and K_r are obtained from the initial PDCCH or EPDCCH for the same transport block. If there is no initial PDCCH or EPDCCH with DCI format 0 for the same transport block, $M_{sc}^{PUSCH-initial}$, C, and K_r shall be determined from:
  - the most recent semi-persistent scheduling assignment PDCCH or EPDCCH, when the initial PUSCH for the same transport block is semi-persistently scheduled, or,
  - the random access response grant for the same transport block, when the PUSCH is initiated by the random access response grant.

For the case when two transport blocks are transmitted in the PUSCH conveying the HARQ-ACK bits, rank indicator bits or CRI bits:

$$Q' = \max\left[\min\left(Q'_{temp}, 4 \cdot M_{sc}^{PUSCH}\right) Q'_{\min}\right] \text{ with}$$

When the UE transmits HARQ-ACK bits, rank indicator bits or CRI bits, it shall determine the number of coded modulation symbols per layer Q′ for HARQ-ACK, rank indicator or CRI bits as follows.

For the case when only one transport block is transmitted in the PUSCH conveying the HARQ-ACK bits, rank indicator bits or CRI bits:

$$Q' = \min\left(\left\lceil \frac{O \cdot M_{sc}^{PUSCH\text{-}initial} \cdot N_{symb}^{PUSCH\text{-}initial} \cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C-1} K_r} \right\rceil, 4 \cdot M_{sc}^{PUSCH}\right)$$

where

O is the number of HARQ-ACK bits, rank indicator bits or CRI bits, and

M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current sub-frame for the transport block, expressed as a number of subcarriers in [2], and

$N_{symb}^{PUSCH\text{-}initial}$ is the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the same transport block, respectively, given by $N_{symb}^{PUSCH\text{-}Initial}=(2\cdot(N_{symb}^{UL}-1)-N_{SRS})$, where

N_{SRS} is equal to 1

- if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or
- if UE transmits PUSCH and SRS in the same subframe in the same serving cell for initial transmission, or
- if the PUSCH resource allocation for initial transmission even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or
- if the subframe for initial transmission in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or
- if the subframe for initial transmission in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.

Otherwise N_{SRS} is equal to 0.

$M_{sc}^{PUSCH\text{-}initial}$, C, and K_r are obtained from the initial PDCCH or EPDCCH for the same transport block. If there is no initial PDCCH or EPDCCH with DCI format 0 for the same transport block, $M_{sc}^{PUSCH\text{-}initial}$, C, and K_r shall be determined from:

- the most recent semi-persistent scheduling assignment PDCCH or EPDCCH, when the initial PUSCH for the same transport block is semi-persistently scheduled, or,
- the random access response grant for the same transport block, when the PUSCH is initiated by the random access response grant.

For the case when two transport blocks are transmitted in the PUSCH conveying the HARQ-ACK bits, rank indicator bits or CRI bits:

$Q' = \max[\min(Q'_{temp}, 4 \cdot M_{sc}^{PUSCH}), Q'_{min}]$ with

$$Q'_{temp} = \left\lceil \frac{O \cdot M_{sc}^{PUSCH\text{-}initial(1)} \cdot N_{symb}^{PUSCH\text{-}initial(1)} \cdot M_{sc}^{PUSCH\text{-}initial(2)} \cdot N_{symb}^{PUSCH\text{-}initial(2)} \cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C(1)-1} K_r^{(1)} \cdot M_{sc}^{PUSCH\text{-}initial(2)} \cdot N_{symb}^{PUSCH\text{-}initial(2)} + \sum_{r=0}^{C(2)-1} K_r^{(2)} \cdot M_{sc}^{PUSCH\text{-}initial(1)} \cdot N_{symb}^{PUSCH\text{-}initial(1)}} \right\rceil$$

where

O is the number of HARQ-ACK bits, rank indicator bits or CRI bits, and

Q'_{min}=O if O≤2, Q'_{min}=$\lceil 2O/Q'_m \rceil$ if 3≤O≤11 with Q'_{min} (Q_m^1, Q_m^2) where Q_m^x, x={1,2} is the modulation order of transport block "x", and $Q'_{min}=\lceil 2O_1/Q'_m \rceil + \lceil 2O_2/Q'_m \rceil$ if O>11 with $O_1=\lceil O/2 \rceil$ and $O_2=O-\lceil O/2 \rceil$.

$M_{sc}^{PUSCH\text{-}initial(x)}$,x={1,2} are the scheduled bandwidths for PUSCH transmission in the initial sub-frame for the first and second transport block, respectively, expressed as a number of subcarriers in [2], and

$N_{symb}^{PUSCH\text{-}initial(x)}$,x={1,2} are the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the first and second transport block given by $N_{symb}^{PUSCH\text{-}initial(x)}=(2\cdot(N_{symb}^{UL}-1)-N_{SRS}^{(x)})$,x={1,2}, where

$N_{SRS}^{(x)}$, x={1,2} is equal to 1

- if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or
- if UE transmits PUSCH and SRS in the same subframe in the same serving cell for initial transmission of transport block "x", or
- if the PUSCH resource allocation for initial transmission of transport bock "x" even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or
- if the subframe for initial transmission of transport block "x" in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or
- if the subframe for initial transmission of transport block "x" in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.

Otherwise $N_{SRS}^{(x)}$, x={1,2} is equal to 0.

$M_{sc}^{PUSCH\text{-}initial(x)}$, x={1,2}, $C^{(x)}$, x={1,2}, and $K_r^{(x)}$, x={1,2} are obtained from the initial PDCCH or EPDCCH for the corresponding transport block.

For HARQ-ACK, $Q_{ACK}=Q_m Q'$ and $\beta_{offset}^{PUSCH}=\beta_{offset}^{HARQ\text{-}ACK}$, where Q_m is the modulation order of a given transport block. For UEs configured with no more than five DL cells, $\beta_{offset}^{HARQ\text{-}ACK}$ shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH. For UEs configured with more than five DL cells, $\beta_{offset}^{HARQ\text{-}ACK}$ shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH and the number of HARQ-ACK feedback bits.

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$$Q'_{temp}=\left\lceil \frac{O\cdot M_{sc}^{PUSCH-initial(1)}\cdot N_{symb}^{PUSCH-initial(1)}\cdot M_{sc}^{PUSCH-initial(2)}\cdot N_{symb}^{PUSCH-initial(2)}\cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C^{(1)}-1} K_r^{(1)}\cdot M_{sc}^{PUSCH-initial(2)}\cdot N_{symb}^{PUSCH-initial(2)}+\sum_{r=0}^{C^{(2)}-1} K_r^{(2)}\cdot M_{sc}^{PUSCH-initial(1)}\cdot N_{symb}^{PUSCH-initial(1)}} \right\rceil$$

where

- O is the number of HARQ-ACK bits, rank indicator bits or CRI bits, and
- $Q'_{\min}=O$ if $O\le 2$, $Q'_{\min}=\lceil 2O/Q'_m\rceil$ if $3\le O\le 11$ with $Q'_m=\min\left(Q_m^1,Q_m^2\right)$ where $Q_m^x, x=\{1,2\}$ is the modulation order of transport block "x", and $Q'_{\min}=\lceil 2O_1/Q'_m\rceil+\lceil 2O_2/Q'_m\rceil$ if $O>11$ with $O_1=\lceil O/2\rceil$ and $O_2=O-\lceil O/2\rceil$.
- $M_{sc}^{PUSCH\text{-}initial(x)}, x=\{1,2\}$ are the scheduled bandwidths for PUSCH transmission in the initial sub-frame for the first and second transport block, respectively, expressed as a number of subcarriers in [2], and
- $N_{symb}^{PUSCH\text{-}initial(x)}, x=\{1,2\}$ are the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the first and second transport block given by $N_{symb}^{PUSCH\text{-}initial(x)}=\left(2\cdot\left(N_{symb}^{UL}-1\right)-N_{SRS}^{(x)}\right), x=\{1,2\}$, where
  - $N_{SRS}^{(x)}, x=\{1,2\}$ is equal to 1
    - if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or
    - if UE transmits PUSCH and SRS in the same subframe in the same serving cell for initial transmission of transport block "x", or
    - if the PUSCH resource allocation for initial transmission of transport bock "x" even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2] , or
    - if the subframe for initial transmission of transport block "x" in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or
    - if the subframe for initial transmission of transport block "x" in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.
  - Otherwise $N_{SRS}^{(x)}, x=\{1,2\}$ is equal to 0.
- $M_{sc}^{PUSCH\text{-}initial(x)}, x=\{1,2\}$, $C^{(x)}, x=\{1,2\}$, and $K_r^{(x)}, x=\{1,2\}$ are obtained from the initial PDCCH or EPDCCH for the corresponding transport block.

For HARQ-ACK, $Q_{ACK}=Q_m\cdot Q'$ and $\beta_{offset}^{PUSCH}=\beta_{offset}^{HARQ-ACK}$, where Q_m is the modulation order of a given transport block. For UEs configured with no more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH. For UEs configured with more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH and and the number of HARQ-ACK feedback bits.

For rank indication or CRI, $Q_{RI}=Q_m\cdot Q'$, $Q_{CRI}=Q_m\cdot Q'$ and $\beta_{offset}^{PUSCH}=\beta_{offset}^{RI}$, where Q_m is the modulation order of a given transport block, and β_{offset}^{RI} shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH, and on the uplink power control subframe set for the corresponding PUSCH when two uplink power control subframe sets are configured by higher layers for the cell.

For HARQ-ACK

When the UE transmits HARQ-ACK bits, rank indicator bits or CRI bits, it shall determine the number of coded modulation symbols per layer Q' for HARQ-ACK, rank indicator or CRI bits as follows.

For the case when only one transport block is transmitted in the PUSCH conveying the HARQ-ACK bits, rank indicator bits or CRI bits:

$$Q'=\min\left(\left\lceil \frac{O\cdot M_{sc}^{PUSCH\text{-}initial}\cdot N_{symb}^{PUSCH\text{-}initial}\cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C-1} K_r}\right\rceil, 4\cdot M_{sc}^{PUSCH}\right)$$

where

O is the number of HARQ-ACK bits, rank indicator bits or CRI bits, and

M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current sub-frame for the transport block, expressed as a number of subcarriers in [2], and

$N_{symb}^{PUSCH\text{-}initial}$ is the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the same transport block, respectively, given by $N_{symb}^{PUSCH\text{-}Initial}=(2\cdot(N_{symb}^{UL}-1)-N_{SRS})$, where

N_{SRS} is equal to 1

if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or

if UE transmits PUSCH and SRS in the same subframe in the same serving cell for initial transmission, or

if the PUSCH resource allocation for initial transmission even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or

if the subframe for initial transmission in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or

if the subframe for initial transmission in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.

Otherwise N_{SRS} is equal to 0.

$M_{sc}^{PUSCH\text{-}initial}$, C, and K_r are obtained from the initial PDCCH or EPDCCH for the same transport block. If there is no initial PDCCH or EPDCCH with DCI format 0 for the same transport block, $M_{sc}^{PUSCH\text{-}initial}$, C, and K_r shall be determined from:

the most recent semi-persistent scheduling assignment PDCCH or EPDCCH, when the initial PUSCH for the same transport block is semi-persistently scheduled, or,

the random access response grant for the same transport block, when the PUSCH is initiated by the random access response grant.

For the case when two transport blocks are transmitted in the PUSCH conveying the HARQ-ACK bits, rank indicator bits or CRI bits:

$Q'=\max[\min(Q'_{temp}, 4\cdot M_{sc}^{PUSCH}), Q'_{min}]$ with

$$Q'_{temp}=\left\lceil \frac{O\cdot M_{sc}^{PUSCH\text{-}initial(1)}\cdot N_{symb}^{PUSCH\text{-}initial(1)}\cdot M_{sc}^{PUSCH\text{-}initial(2)}\cdot N_{symb}^{PUSCH\text{-}initial(2)}\cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C^{(1)}-1} K_r^{(1)}\cdot M_{sc}^{PUSCH\text{-}initial(2)}\cdot N_{symb}^{PUSCH\text{-}initial(2)}+\sum_{r=0}^{C^{(2)}-1} K_r^{(2)}\cdot M_{sc}^{PUSCH\text{-}initial(1)}\cdot N_{symb}^{PUSCH\text{-}initial(1)}} \right\rceil$$

where

O is the number of HARQ-ACK bits, rank indicator bits or CRI bits, and

$Q'_{min}=O$ if $O\le 2$, $Q'_{min}=\lceil 2O/Q'_m\rceil$ if $3\le O\le 11$ with Q'_{min} (Q_m^1, Q_m^2) where Q_m^x, $x=\{1,2\}$ is the modulation order of transport block "x", and $Q'_{min}=\lceil 2O_1/Q'_m\rceil+\lceil 2O_2/Q'_m\rceil$ if $O>11$ with $O_1=\lceil O/2\rceil$ and $O_2=O-\lceil O/2\rceil$.

$M_{sc}^{PUSCH\text{-}initial(x)}, x=\{1,2\}$ are the scheduled bandwidths for PUSCH transmission in the initial sub-frame for the first and second transport block, respectively, expressed as a number of subcarriers in [2], and

$N_{symb}^{PUSCH\text{-}initial(x)}, x=\{1,2\}$ are the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the first and second transport block given by $N_{symb}^{PUSCH\text{-}initial(x)}=(2\cdot(N_{symb}^{UL}-1)-N_{SRS}^{(x)}), x=\{1,2\}$, where

$N_{SRS}^{(x)}, x=\{1,2\}$ is equal to 1

if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or

if UE transmits PUSCH and SRS in the same subframe in the same serving cell for initial transmission of transport block "x", or

if the PUSCH resource allocation for initial transmission of transport bock "x" even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or

if the subframe for initial transmission of transport block "x" in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or

if the subframe for initial transmission of transport block "x" in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.

Otherwise $N_{SRS}^{(x)}, x=\{1,2\}$ is equal to 0.

$M_{sc}^{PUSCH\text{-}initial(x)}$, $x=\{1,2\}$, $C^{(x)}$, $x=\{1,2\}$, and $K_r^{(x)}$, $x=\{1,2\}$ are obtained from the initial PDCCH or EPDCCH for the corresponding transport block.

For HARQ-ACK, $Q_{ACK}=Q_m Q'$ and $\beta_{offset}^{PUSCH}=\beta_{offset}^{HARQ\text{-}ACK}$, where Q_m is the modulation order of a given transport block. For UEs configured with no more than five DL cells, $\beta_{offset}^{HARQ\text{-}ACK}$ shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH. For UEs configured with more than five DL cells, $\beta_{offset}^{HARQ\text{-}ACK}$ shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH and the number of HARQ-ACK feedback bits.

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$$Q'_{temp}=\left\lceil \frac{O\cdot M_{sc}^{PUSCH-initial(1)}\cdot N_{symb}^{PUSCH-initial(1)}\cdot M_{sc}^{PUSCH-initial(2)}\cdot N_{symb}^{PUSCH-initial(2)}\cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C^{(1)}-1} K_r^{(1)}\cdot M_{sc}^{PUSCH-initial(2)}\cdot N_{symb}^{PUSCH-initial(2)}+\sum_{r=0}^{C^{(2)}-1} K_r^{(2)}\cdot M_{sc}^{PUSCH-initial(1)}\cdot N_{symb}^{PUSCH-initial(1)}} \right\rceil$$

where

- O is the number of HARQ-ACK bits, rank indicator bits or CRI bits, and
- $Q'_{\min}=O$ if $O\le 2$, $Q'_{\min}=\lceil 2O/Q'_m\rceil$ if $3\le O\le 11$ with $Q'_m=\min\left(Q_m^1,Q_m^2\right)$ where $Q_m^x, x=\{1,2\}$ is the modulation order of transport block "x", and $Q'_{\min}=\lceil 2O_1/Q'_m\rceil+\lceil 2O_2/Q'_m\rceil$ if $O>11$ with $O_1=\lceil O/2\rceil$ and $O_2=O-\lceil O/2\rceil$.
- $M_{sc}^{PUSCH\text{-}initial(x)}, x=\{1,2\}$ are the scheduled bandwidths for PUSCH transmission in the initial sub-frame for the first and second transport block, respectively, expressed as a number of subcarriers in [2], and
- $N_{symb}^{PUSCH\text{-}initial(x)}, x=\{1,2\}$ are the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the first and second transport block given by $N_{symb}^{PUSCH\text{-}initial(x)}=\left(2\cdot\left(N_{symb}^{UL}-1\right)-N_{SRS}^{(x)}\right), x=\{1,2\}$, where
  - $N_{SRS}^{(x)}, x=\{1,2\}$ is equal to 1
    - if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or
    - if UE transmits PUSCH and SRS in the same subframe in the same serving cell for initial transmission of transport block "x", or
    - if the PUSCH resource allocation for initial transmission of transport bock "x" even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2] , or
    - if the subframe for initial transmission of transport block "x" in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or
    - if the subframe for initial transmission of transport block "x" in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.
  - Otherwise $N_{SRS}^{(x)}, x=\{1,2\}$ is equal to 0.
- $M_{sc}^{PUSCH-initial(x)}, x=\{1,2\}$, $C^{(x)}, x=\{1,2\}$, and $K_r^{(x)}, x=\{1,2\}$ are obtained from the initial PDCCH or EPDCCH for the corresponding transport block.

For HARQ-ACK, $Q_{ACK}=Q_m\cdot Q'$ and $\beta_{offset}^{PUSCH}=\beta_{offset}^{HARQ-ACK}$, where Q_m is the modulation order of a given transport block. For UEs configured with no more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH. For UEs configured with more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH and and the number of HARQ-ACK feedback bits.

For rank indication or CRI, $Q_{RI}=Q_m\cdot Q'$, $Q_{CRI}=Q_m\cdot Q'$ and $\beta_{offset}^{PUSCH}=\beta_{offset}^{RI}$, where Q_m is the modulation order of a given transport block, and β_{offset}^{RI} shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH, and on the uplink power control subframe set for the corresponding PUSCH when two uplink power control subframe sets are configured by higher layers for the cell.

For HARQ-ACK

For rank indication or CRI, $Q_{RI}=Q_m\cdot Q'$, $Q_{CRI}=Q_m\cdot Q'$ and $\beta_{offset}^{PUSCH}=\beta_{offset}^{RI}$, where Q_m is the modulation order of a given transport block, and β_{offset}^{RI} shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH, and on the uplink power control subframe set for the corresponding PUSCH when two uplink power control subframe sets are configured by higher layers for the cell.
For HARQ-ACK

Each positive acknowledgement (ACK) is encoded as a binary '1' and each negative acknowledgement (NACK) is encoded as a binary '0'

If HARQ-ACK feedback consists of 1-bit of information, i.e., $[o_0^{ACK}]$, it is first encoded according to Table 5.2.2.6-1.

If HARQ-ACK feedback consists of 2-bits of information, i.e., $[o_0^{ACK}\ o_1^{ACK}]$ with o_0^{ACK} corresponding to HARQ-ACK bit for codeword 0 and or o_1^{ACK} corresponding to that for codeword 1, or if HARQ-ACK feedback consists of 2-bits of information as a result of the aggregation of HARQ-ACK bits corresponding to two DL cells with which the UE is configured by higher layers, or if HARQ-ACK feedback consists of 2-bits of information corresponding to two subframes for TDD, it is first encoded according to Table 5.2.2.6-2 where $o_2^{ACK}=(o_0^{ACK}+o_1^{ACK}) \bmod 2$.

[Table 5.2.2.6-1 of 3GPP TS 36.212 v13.0.0, Entitled "Encoding of 1-Bit HARQ-ACK", is Reproduced as FIG. **7**]

[Table 5.2.2.6-2 of 3GPP TS 36.212 v13.0.0, Entitled "Encoding of 2-Bit HARQ-ACK", is Reproduced as FIG. **8**]

If HARQ-ACK feedback consists of $3\le O^{ACK}\le 11$ bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, i.e., o_0^{ACK}, o_1^{ACK}, ..., $o_{O^{ACK}-1}^{ACK}$, then a coded bit sequence $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \ldots, \tilde{q}_{31}^{ACK}$ is obtained by using the bit sequence $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ as the input to the channel coding block described in section 5.2.2.6.4. In turn, the bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is obtained by the circular repetition of the bit sequence $\tilde{q}_0^{ACK}\tilde{q}_1^{ACK}, \ldots, \tilde{q}_{31}^{ACK}$ so that the total bit sequence length is equal to Q_{ACK}.

If HARQ-ACK feedback consists of $11<O^{ACK}\le 22$ bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, i.e., o_0^{ACK}, o_1^{ACK}, ..., $o_{O^{ACK}-1}^{ACK}$, then the coded bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is obtained by using the bit sequence $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ as the input to the channel coding block described in section 5.2.2.6.5.

If HARQ-ACK feedback consists of $O^{ACK}>22$ bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, the coded bit sequence is denoted by $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$. The CRC attachment, channel coding and rate matching of the HARQ-ACK bits are performed according to sections 5.1.1 setting L to 8 bits, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The "x" and "y" in Table 5.2.2.6-1 and 5.2.2.6-2 are placeholders for [2] to scramble the HARQ-ACK bits in a way that maximizes the Euclidean distance of the modulation symbols carrying HARQ-ACK information.

For FDD or TDD HARQ-ACK multiplexing or the aggregation of more than one DL cell including at least one cell using FDD and at least one cell using TDD when HARQ-ACK consists of one or two bits of information, the bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is obtained by concatenation of multiple encoded HARQ-ACK blocks where Q_{ACK} is the total number of coded bits for all the encoded HARQ-ACK blocks. The last concatenation of the encoded HARQ-ACK block may be partial so that the total bit sequence length is equal to Q_{ACK}.

For UEs configured by higher layers with codebooksizeDetermination-r13=0, the bit sequence $\delta_0^{ACK}\delta_1^{ACK}\ldots\delta_{O^{ACK}-1}^{ACK}$ is determined according to the Downlink Assignment Index (DAI) as in Table 5.3.3.1.1-2 and as defined in [3]. Otherwise, the bit sequence $\delta_0^{ACK}\delta_1^{ACK}, \ldots, \delta_{O^{ACK}-1}^{ACK}$ is determined as below.

For FDD when HARQ ACK consists of 2 or more bits of information as a result of the aggregation of more than one DL cell, the bit sequence $\delta_0^{ACK}\delta_1^{ACK}\ldots\delta_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for the multiple DL cells according to the following pseudo-code:

```
Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
Set N_cells^DL to the number of cells configured by higher layers for the UE
while C < N_cells^DL
  if transmission mode configured in cell c ∈ {1,2,5,6,7} - 1 bit HARQ-ACK feedback for this cell
    δ_j^ACK = HARQ-ACK bit of this cell
    j = j + 1
  else
    if the UE is not configured with spatial bundling on PUSCH by higher layers
      δ_j^ACK = HARQ-ACK bit corresponding to the first codeword of this cell
      j = j + 1
      δ_j^ACK = HARQ-ACK bit corresponding to the second codeword of this cell
      j = j + 1
    else
      δ_j^ACK = binary AND operation of the HARQ-ACK bits corresponding to the first
      and second codewords of this cell
      j = j + 1
    end if
  end if
  c = c + 1
end while
```

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Each positive acknowledgement (ACK) is encoded as a binary '1' and each negative acknowledgement (NACK) is encoded as a binary '0'

If HARQ-ACK feedback consists of 1-bit of information, i.e., $[o_0^{ACK}]$, it is first encoded according to Table 5.2.2.6-1.

If HARQ-ACK feedback consists of 2-bits of information, i.e., $[o_0^{ACK}\ o_1^{ACK}]$ with o_0^{ACK} corresponding to HARQ-ACK bit for codeword 0 and o_1^{ACK} corresponding to that for codeword 1, or if HARQ-ACK feedback consists of 2-bits of information as a result of the aggregation of HARQ-ACK bits corresponding to two DL cells with which the UE is configured by higher layers, or if HARQ-ACK feedback consists of 2-bits of information corresponding to two subframes for TDD, it is first encoded according to Table 5.2.2.6-2 where $o_2^{ACK}=(o_0^{ACK}+o_1^{ACK}) \bmod 2$.

Table 5.2.2.6-1: Encoding of 1-bit HARQ-ACK.

Q_m	Encoded HARQ-ACK
2	$[o_0^{ACK}$ y]
4	$[o_0^{ACK}$ y x x]
6	$[o_0^{ACK}$ y x x x x]

Table 5.2.2.6-2: Encoding of 2-bit HARQ-ACK.

Q_m	Encoded HARQ-ACK
2	$[o_0^{ACK}\ o_1^{ACK}\ o_2^{ACK}\ o_0^{ACK}\ o_1^{ACK}\ o_2^{ACK}]$
4	$[o_0^{ACK}\ o_1^{ACK}$ x x $o_2^{ACK}\ o_0^{ACK}$ x x $o_1^{ACK}\ o_2^{ACK}$ x x]
6	$[o_0^{ACK}\ o_1^{ACK}$ x x x x $o_2^{ACK}\ o_0^{ACK}$ x x x x $o_1^{ACK}\ o_2^{ACK}$ x x x x]

If HARQ-ACK feedback consists of $3 \le O^{ACK} \le 11$ bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, i.e., $o_0^{ACK}\ o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$, then a coded bit sequence $\tilde{q}_0^{ACK}\ \tilde{q}_1^{ACK},...,\tilde{q}_{31}^{ACK}$ is obtained by using the bit sequence $o_0^{ACK}\ o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$ as the input to the channel coding block described in section 5.2.2.6.4. In turn, the bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK},..., q_{Q_{ACK}-1}^{ACK}$ is obtained by the circular repetition of the bit sequence $\tilde{q}_0^{ACK}\ \tilde{q}_1^{ACK},...,\tilde{q}_{31}^{ACK}$ so that the total bit sequence length is equal to Q_{ACK}.

If HARQ-ACK feedback consists of $11 < O^{ACK} \le 22$ bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, i.e., $o_0^{ACK}\ o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$, then the coded bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK},..., q_{Q_{ACK}-1}^{ACK}$ is obtained by using the bit sequence $o_0^{ACK}\ o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$ as the input to the channel coding block described in section 5.2.2.6.5.

If HARQ-ACK feedback consists of O^{ACK}>22 bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, the coded bit sequence is denoted by $q_0^{ACK}, q_1^{ACK}, q_2^{ACK},..., q_{Q_{ACK}-1}^{ACK}$. The CRC attachment, channel coding and rate matching of the HARQ-ACK bits are performed according to sections 5.1.1 setting L to 8 bits, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $o_0^{ACK}\ o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The "x" and "y" in Table 5.2.2.6-1 and 5.2.2.6-2 are placeholders for [2] to scramble the HARQ-ACK bits in a way that maximizes the Euclidean distance of the modulation symbols carrying HARQ-ACK information.

For rank indication or CRI, $Q_{RI}=Q_m \cdot Q'$, $Q_{CRI}=Q_m \cdot Q'$ and $\beta_{offset}^{PUSCH-RI}=\beta_{offset}^{RI}$, where Q_m is the modulation order of a given transport block, and β_{offset}^{RI} shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH, and on the uplink power control subframe set for the corresponding PUSCH when two uplink power control subframe sets are configured by higher layers for the cell.

For HARQ-ACK

Each positive acknowledgement (ACK) is encoded as a binary '1' and each negative acknowledgement (NACK) is encoded as a binary '0'

If HARQ-ACK feedback consists of 1-bit of information, i.e., $[o_0^{ACK}]$, it is first encoded according to Table 5.2.2.6-1.

If HARQ-ACK feedback consists of 2-bits of information, i.e., $[o_0^{ACK}\ o_1^{ACK}]$ with o_0^{ACK} corresponding to HARQ-ACK bit for codeword 0 and or o_1^{ACK} corresponding to that for codeword 1, or if HARQ-ACK feedback consists of 2-bits of information as a result of the aggregation of HARQ-ACK bits corresponding to two DL cells with which the UE is configured by higher layers, or if HARQ-ACK feedback consists of 2-bits of information corresponding to two subframes for TDD, it is first encoded according to Table 5.2.2.6-2 where $o_2^{ACK}=(o_0^{ACK}+o_1^{ACK}) \bmod 2$.

[Table 5.2.2.6-1 of 3GPP TS 36.212 V13.0.0, Entitled "Encoding of 1-Bit HARQ-ACK", is Reproduced as FIG. 7]

[Table 5.2.2.6-2 of 3GPP TS 36.212 V13.0.0, Entitled "Encoding of 2-Bit HARQ-ACK", is Reproduced as FIG. 8]

If HARQ-ACK feedback consists of $3 \le O^{ACK} \le 11$ bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, i.e., $o_0^{ACK}\ o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$, then a coded bit sequence $\tilde{q}_0^{ACK}\ \tilde{q}_1^{ACK},...,\tilde{q}_{31}^{ACK}$ is obtained by using the bit sequence $o_0^{ACK}\ o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$ as the input to the channel coding block described in section 5.2.2.6.4. In turn, the bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK},..., q_{Q_{ACK}-1}^{ACK}$ is obtained by the circular repetition of the bit sequence $\tilde{q}_0^{ACK}\ \tilde{q}_1^{ACK},...,\tilde{q}_{31}^{ACK}$ so that the total bit sequence length is equal to Q_{ACK}.

If HARQ-ACK feedback consists of $11 < O^{ACK} \le 22$ bits of information as a result of the aggregation of HARQ-

ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, i.e., $o_0^{ACK}\ o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$, then the coded bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK},..., q_{Q_{ACK}-1}^{ACK}$ is obtained by using the bit sequence $o_0^{ACK}\ o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$ as the input to the channel coding block described in section 5.2.2.6.5.

If HARQ-ACK feedback consists of O^{ACK}>22 bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, the coded bit sequence is denoted by $q_0^{ACK}, q_1^{ACK}, q_2^{ACK},..., q_{Q_{ACK}-1}^{ACK}$. The CRC attachment, channel coding and rate matching of the HARQ-ACK bits are performed according to sections 5.1.1 setting L to 8 bits, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $o_0^{ACK}\ o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The "x" and "y" in Table 5.2.2.6-1 and 5.2.2.6-2 are placeholders for [2] to scramble the HARQ-ACK bits in a way that maximizes the Euclidean distance of the modulation symbols carrying HARQ-ACK information.

For FDD or TDD HARQ-ACK multiplexing or the aggregation of more than one DL cell including at least one cell using FDD and at least one cell using TDD when HARQ-ACK consists of one or two bits of information, the bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK},..., q_{Q_{ACK}-1}^{ACK}$ is obtained by concatenation of multiple encoded HARQ-ACK blocks where Q_{ACK} is the total number of coded bits for all the encoded HARQ-ACK blocks. The last concatenation of the encoded HARQ-ACK block may be partial so that the total bit sequence length is equal to Q_{ACK}.

For UEs configured by higher layers with codebooksizeDetermination-r13=0, the bit sequence $\delta_0^{ACK}\ \delta_1^{ACK},...,\delta_{O^{ACK}-1}^{ACK}$ is determined according to the Downlink Assignment Index (DAI) as in Table 5.3.3.1-2 and as defined in [3]. Otherwise, the bit sequence $\delta_0^{ACK}\ \delta_1^{ACK},...,\delta_{O^{ACK}-1}^{ACK}$ is determined as below.

For FDD when HARQ ACK consists of 2 or more bits of information as a result of the aggregation of more than one DL cell, the bit sequence $\delta_0^{ACK}\ \delta_1^{ACK},...,\delta_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for the multiple DL cells according to the following pseudo-code:

Q_m	Encoded HARQ-ACK
2	$[o_0^{ACK}$ y]
4	$[o_0^{ACK}$ y x x]
6	$[o_0^{ACK}$ y x x x x]

FIG. 7 (PRIOR ART)

Q_m	Encoded HARQ-ACK
2	$[o_0^{ACK}\ o_1^{ACK}\ o_2^{ACK}\ o_0^{ACK}\ o_1^{ACK}\ o_2^{ACK}]$
4	$[o_0^{ACK}\ o_1^{ACK}$ x x $o_2^{ACK}\ o_0^{ACK}$ x x $o_1^{ACK}\ o_2^{ACK}$ x x]
6	$[o_0^{ACK}\ o_1^{ACK}$ x x x x $o_2^{ACK}\ o_0^{ACK}$ x x x x $o_1^{ACK}\ o_2^{ACK}$ x x x x]

FIG. 8 (PRIOR ART)

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For FDD or TDD HARQ-ACK multiplexing or the aggregation of more than one DL cell including at least one cell using FDD and at least one cell using TDD when HARQ-ACK consists of one or two bits of information, the bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is obtained by concatenation of multiple encoded HARQ-ACK blocks where Q_{ACK} is the total number of coded bits for all the encoded HARQ-ACK blocks. The last concatenation of the encoded HARQ-ACK block may be partial so that the total bit sequence length is equal to Q_{ACK}.

For UEs configured by higher layers with *codebooksizeDetermination-r13 = 0*, the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is determined according to the Downlink Assignment Index (DAI) as in Table 5.3.3.1.1-2 and as defined in [3]. Otherwise, the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is determined as below.

For FDD when HARQ ACK consists of 2 or more bits of information as a result of the aggregation of more than one DL cell, the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for the multiple DL cells according to the following pseudo-code:

```
Set c = 0 – cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 – HARQ-ACK bit index
Set N_cells^DL to the number of cells configured by higher layers for the UE
while c < N_cells^DL
    if transmission mode configured in cell c ∈ {1,2,5,6,7} – 1 bit HARQ-ACK feedback for this cell
        õ_j^ACK = HARQ-ACK bit of this cell
        j = j + 1
    else
        if the UE is not configured with spatial bundling on PUSCH by higher layers
            õ_j^ACK = HARQ-ACK bit corresponding to the first codeword of this cell
            j = j + 1
            õ_j^ACK = HARQ-ACK bit corresponding to the second codeword of this cell
            j = j + 1
        else
            õ_j^ACK = binary AND operation of the HARQ-ACK bits corresponding to the first and second codewords of this cell
            j = j + 1
        end if
    end if
    c = c + 1
end while
```

For the aggregation of more than one DL cell including a primary cell using FDD and at least one secondary cell using TDD, the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for one or multiple DL cells. Define N_{cells}^{DL} as the number of cells configured by higher layers for the UE and B_c^{DL} as the number

For rank indication or CRI, $Q_{RI}=Q_m \cdot Q'$, $Q_{CRI}=Q_m \cdot Q'$ and $\beta_{offset}^{PUSCH}=\beta_{offset}^{RI}$, where Q_m is the modulation order of a given transport block, and β_{offset}^{RI} shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH, and on the uplink power control subframe set for the corresponding PUSCH when two uplink power control subframe sets are configured by higher layers for the cell.

For HARQ-ACK

Each positive acknowledgement (ACK) is encoded as a binary '1' and each negative acknowledgement (NACK) is encoded as a binary '0'

If HARQ-ACK feedback consists of 1-bit of information, i.e., $[o_0^{ACK}]$, it is first encoded according to Table 5.2.2.6-1.

If HARQ-ACK feedback consists of 2-bits of information, i.e., $[o_0^{ACK}\ o_1^{ACK}]$ with o_0^{ACK} corresponding to HARQ-ACK bit for codeword 0 and or o_1^{ACK} corresponding to that for codeword 1, or if HARQ-ACK feedback consists of 2-bits of information as a result of the aggregation of HARQ-ACK bits corresponding to two DL cells with which the UE is configured by higher layers, or if HARQ-ACK feedback consists of 2-bits of information corresponding to two subframes for TDD, it is first encoded according to Table 5.2.2.6-2 where $o_2^{ACK}=(o_0^{ACK}+o_1^{ACK}) \bmod 2$.

[Table 5.2.2.6-1 of 3GPP TS 36.212 v13.0.0, Entitled "Encoding of 1-Bit HARQ-ACK", is Reproduced as FIG. 7]

[Table 5.2.2.6-2 of 3GPP TS 36.212 V13.0.0, Entitled "Encoding of 2-Bit HARQ-ACK", is Reproduced as FIG. 8]

If HARQ-ACK feedback consists of $3 \le O^{ACK} \le 11$ bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, i.e., $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$, then a coded bit sequence $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \ldots, \tilde{q}_{31}^{ACK}$ is obtained by using the bit sequence $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ as the input to the channel coding block described in section 5.2.2.6.4. In turn, the bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is obtained by the circular repetition of the bit sequence $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \ldots, \tilde{q}_{31}^{ACK}$ so that the total bit sequence length is equal to Q_{ACK}.

If HARQ-ACK feedback consists of $11 < O^{ACK} \le 22$ bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, i.e., $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$, then the coded bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is obtained by using the bit sequence $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ as the input to the channel coding block described in section 5.2.2.6.5.

If HARQ-ACK feedback consists of $O^{ACK} > 22$ bits of information as a result of the aggregation of HARQ-ACK bits corresponding to one or more DL cells with which the UE is configured by higher layers, the coded bit sequence is denoted by $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$. The CRC attachment, channel coding and rate matching of the HARQ-ACK bits are performed according to sections 5.1.1 setting L to 8 bits, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The "x" and "y" in Table 5.2.2.6-1 and 5.2.2.6-2 are placeholders for [2] to scramble the HARQ-ACK bits in a way that maximizes the Euclidean distance of the modulation symbols carrying HARQ-ACK information.

For FDD or TDD HARQ-ACK multiplexing or the aggregation of more than one DL cell including at least one cell using FDD and at least one cell using TDD when HARQ-ACK consists of one or two bits of information, the bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is obtained by concatenation of multiple encoded HARQ-ACK blocks where Q_{ACK} is the total number of coded bits for all the encoded HARQ-ACK blocks. The last concatenation of the encoded HARQ-ACK block may be partial so that the total bit sequence length is equal to Q_{ACK}.

For UEs configured by higher layers with codebooksizeDetermination-r13=0, the bit sequence $\delta_0^{ACK}, \delta_1^{ACK}, \ldots, \delta_{O^{ACK}-1}^{ACK}$ is determined according to the Downlink Assignment Index (DAI) as in Table 5.3.3.1.1-2 and as defined in [3]. Otherwise, the bit sequence $\delta_0^{ACK}, \delta_1^{ACK}, \ldots, \delta_{O^{ACK}-1}^{ACK}$ is determined as below.

For FDD when HARQ ACK consists of 2 or more bits of information as a result of the aggregation of more than one DL cell, the bit sequence $\delta_0^{ACK}, \delta_1^{ACK}, \ldots, \delta_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for the multiple DL cells according to the following pseudo-code:

```
Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
Set N_cells^DL to the number of cells configured by higher layers for the UE
while C < N_cells^DL
    if transmission mode configured in cell c ∈ {1,2,5,6,7} - 1 bit HARQ-ACK feedback for this cell
        δ_j^ACK = HARQ-ACK bit of this cell
        j = j + 1
    else
        if the UE is not configured with spatial bundling on PUSCH by higher layers
            δ_j^ACK = HARQ-ACK bit corresponding to the first codeword of this cell
            j = j + 1
            δ_j^ACK = HARQ-ACK bit corresponding to the second codeword of this cell
            j = j + 1
        else
            δ_j^ACK = binary AND operation of the HARQ-ACK bits corresponding to the first
            and second codewords of this cell
            j = j + 1
        end if
    end if
    c = c + 1
end while
```

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For FDD or TDD HARQ-ACK multiplexing or the aggregation of more than one DL cell including at least one cell using FDD and at least one cell using TDD when HARQ-ACK consists of one or two bits of information, the bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is obtained by concatenation of multiple encoded HARQ-ACK blocks where Q_{ACK} is the total number of coded bits for all the encoded HARQ-ACK blocks. The last concatenation of the encoded HARQ-ACK block may be partial so that the total bit sequence length is equal to Q_{ACK}.

For UEs configured by higher layers with *codebooksizeDetermination-r13* = *0*, the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is determined according to the Downlink Assignment Index (DAI) as in Table 5.3.3.1.1-2 and as defined in [3]. Otherwise, the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is determined as below.

For FDD when HARQ ACK consists of 2 or more bits of information as a result of the aggregation of more than one DL cell, the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for the multiple DL cells according to the following pseudo-code:

Set c = 0 – cell index: lower indices correspond to lower RRC indices of corresponding cell

Set j = 0 – HARQ-ACK bit index

Set N_{cells}^{DL} to the number of cells configured by higher layers for the UE

while $c < N_{cells}^{DL}$

if transmission mode configured in cell $c \in \{1,2,5,6,7\}$ – 1 bit HARQ-ACK feedback for this cell

$\tilde{o}_j^{ACK}$ = HARQ-ACK bit of this cell

$j = j + 1$

else

if the UE is not configured with spatial bundling on PUSCH by higher layers $\tilde{o}_j^{ACK}$ = HARQ-ACK bit corresponding to the first codeword of this cell

$j = j + 1$

$\tilde{o}_j^{ACK}$ = HARQ-ACK bit corresponding to the second codeword of this cell

$j = j + 1$

else

$\tilde{o}_j^{ACK}$ = binary AND operation of the HARQ-ACK bits corresponding to the first and second codewords of this cell

$j = j + 1$

end if

end if

$c = c + 1$

end while

For the aggregation of more than one DL cell including a primary cell using FDD and at least one secondary cell using TDD, the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for one or multiple DL cells. Define N_{cells}^{DL} as the number of cells configured by higher layers for the UE and B_c^{DL} as the number

For the aggregation of more than one DL cell including a primary cell using FDD and at least one secondary cell using TDD, the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for one or multiple DL cells. Define N_{cells}^{DL} as the number of cells configured by higher layers for the UE and B_c^{DL} as the number of subframes for which the UE needs to feed back HARQ-ACK bits in UL subframe n for the c-th serving cell. For a cell using TDD, the subframes are determined by the DL-reference UL/DL configuration if the UE is configured

with higher layer parameter eimta-HARQ-ReferenceConfig, and determined by the UL/DL configuration otherwise. For a cell using TDD, B_c^{DL}=1 if subframe n−4 in the cell is a DL subframe or a special subframe with special subframe configurations 1/2/3/4/6/7/8/9 and normal downlink CP or a special subframe with special subframe configurations 1/2/3/5/6/7 and extended downlink CP, and B_c^{DL}=0 otherwise. For a cell using FDD, B_c^{DL}=1.

The bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is performed according to the following pseudo-code:

```
Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
while c < N_cells^DL
  if B_c^DL = 1
    if transmission mode configured in cell c ∈ {1,2,5,6,7} - 1 bit HARQ-ACK feedback
    for this cell
      õ_j^ACK = HARQ-ACK bit of this cell
      j = j + 1
    else
      if the UE is not configured with spatial bundling on PUSCH by higher
      layers
      õ_j^ACK = HARQ-ACK bit corresponding to the first codeword of this
      cell
      j = j + 1
      õ_j^ACK = HARQ-ACK bit corresponding to the second codeword of
      this cell
      j = j + 1
    else
      õ_j^ACK = binary AND operation of the HARQ-ACK bits corresponding
      to the first and second codewords of this cell
      j = j + 1
    end if
  end if
  c = c + 1
end while
```

For the cases with TDD primary cell when HARQ-ACK is for the aggregation of one or more DL cells and the UE is configured with PUCCH format 3, PUCCH format 4 or PUCCH format 5 [3], the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for the one or more DL cells configured by higher layers and the multiple subframes as defined in [3]. Define N_{cells}^{DL} as the number of cells configured by higher layers for the UE and B_c^{DL} as the number of subframes for which the UE needs to feed back HARQ-ACK bits as defined in Section 7.3 of [3].

The number of HARQ-ACK bits for the UE to convey if it is configured with PUCCH format 3, PUCCH format 4 or PUCCH format 5 is computed as follows:

```
Set k = 0 - counter of HARQ-ACK bits
Set c=0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
while c < N_cells^DL
  set / = 0;
  while / < B_c^DL
    if transmission mode configured in cell c ∈ {1,2,5,6,7} -- 1 bit HARQ-ACK feedback for this
  cell
      k = k + 1
    else
      k = k + 2
    end if
    / = /+1
  end while
  c = c + 1
end while
```

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of subframes for which the UE needs to feed back HARQ-ACK bits in UL subframe n for the *c*-th serving cell. For a cell using TDD, the subframes are determined by the DL-reference UL/DL configuration if the UE is configured with higher layer parameter *eimta-HARQ-ReferenceConfig*, and determined by the UL/DL configuration otherwise. For a cell using TDD, $B_c^{DL}=1$ if subframe n-4 in the cell is a DL subframe or a special subframe with special subframe configurations 1/2/3/4/6/7/8/9 and normal downlink CP or a special subframe with special subframe configurations 1/2/3/5/6/7 and extended downlink CP, and $B_c^{DL}=0$ otherwise. For a cell using FDD, $B_c^{DL}=1$.

The bit sequence $\tilde{o}_0^{ACK}\ \tilde{o}_1^{ACK},\ldots,\tilde{o}_{O^{ACK}-1}^{ACK}$ is performed according to the following pseudo-code:

```
Set c = 0 – cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 – HARQ-ACK bit index
while c < N_cells^DL
  if B_c^DL = 1
    if transmission mode configured in cell c supports at most one transport block
      õ_j^ACK = HARQ-ACK bit of this cell
      j = j + 1
    else
      if the UE is not configured with spatial bundling on PUSCH by higher layers
        õ_j^ACK = HARQ-ACK bit corresponding to the first codeword of this cell
        j = j + 1
        õ_j^ACK = HARQ-ACK bit corresponding to the second codeword of this cell
        j = j + 1
      else
        õ_j^ACK = binary AND operation of the HARQ-ACK bits corresponding to the first and second codewords of this cell
        j = j + 1
      end if
    end if
  end if
  c = c + 1
end while
```

For the cases with TDD primary cell when HARQ-ACK is for the aggregation of one or more DL cells and the UE is configured with PUCCH format 3, PUCCH format 4 or PUCCH format 5 [3], the bit sequence $\tilde{o}_0^{ACK}\ \tilde{o}_1^{ACK},\ldots,\tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for the one or more DL cells configured by higher layers and the multiple subframes as defined in [3].

Define N_{cells}^{DL} as the number of cells configured by higher layers for the UE and B_c^{DL} as the number of subframes for which the UE needs to feed back HARQ-ACK bits as defined in Section 7.3 of [3].

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For the aggregation of more than one DL cell including a primary cell using FDD and at least one secondary cell using TDD, the bit sequence $\tilde{o}_0^{ACK}\tilde{o}_1^{ACK},\ldots,\tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for one or multiple DL cells. Define N_{cells}^{DL} as the number of cells configured by higher layers for the UE and B_c^{DL} as the number of subframes for which the UE needs to feed back HARQ-ACK bits in UL subframe n for the c-th serving cell. For a cell using TDD, the subframes are determined by the DL-reference UL/DL configuration if the UE is configured

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with higher layer parameter eimta-HARQ-ReferenceConfig, and determined by the UL/DL configuration otherwise. For a cell using TDD, $B_c^{DL}=1$ if subframe n−4 in the cell is a DL subframe or a special subframe with special subframe configurations 1/2/3/4/6/7/8/9 and normal downlink CP or a special subframe with special subframe configurations 1/2/3/5/6/7 and extended downlink CP, and $B_c^{DL}=0$ otherwise. For a cell using FDD, $B_c^{DL}=1$.
The bit sequence $\tilde{o}_0^{ACK}\tilde{o}_1^{ACK},\ldots,\tilde{o}_{O^{ACK}-1}^{ACK}$ is performed according to the following pseudo-code:

```
Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
while c < N_cells^DL
  if B_c^DL = 1
    if transmission mode configured in cell c ∈ {1,2,5,6,7} - 1 bit HARQ-ACK feedback for this cell
      õ_j^ACK = HARQ-ACK bit of this cell
      j = j + 1
    else
      if the UE is not configured with spatial bundling on PUSCH by higher layers
        õ_j^ACK = HARQ-ACK bit corresponding to the first codeword of this cell
        j = j + 1
        õ_j^ACK = HARQ-ACK bit corresponding to the second codeword of this cell
        j = j + 1
      else
        õ_j^ACK = binary AND operation of the HARQ-ACK bits corresponding to the first and second codewords of this cell
        j = j + 1
      end if
    end if
  end if
  c = c + 1
end while
```

For the cases with TDD primary cell when HARQ-ACK is for the aggregation of one or more DL cells and the UE is configured with PUCCH format 3, PUCCH format 4 or PUCCH format 5 [3], the bit sequence $\tilde{o}_0^{ACK}\tilde{o}_1^{ACK},\ldots,\tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for the one or more DL cells configured by higher layers and the multiple subframes as defined in [3]. Define N_{cells}^{DL} as the number of cells configured by higher layers for the UE and B_c^{DL} as the number of subframes for which the UE needs to feed back HARQ-ACK bits as defined in Section 7.3 of [3].

The number of HARQ-ACK bits for the UE to convey if it is configured with PUCCH format 3, PUCCH format 4 or PUCCH format 5 is computed as follows:

```
Set k = 0 - counter of HARQ-ACK bits
Set c=0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
while c < N_cells^DL
  set / = 0;
  while / < B_c^DL
    if transmission mode configured in cell c ∈ {1,2,5,6,7} -- 1 bit HARQ-ACK feedback for this cell
      k = k + 1
    else
      k = k + 2
    end if
    / = /+1
  end while
  c = c + 1
end while
```

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The number of HARQ-ACK bits for the UE to convey if it is configured with PUCCH format 3, PUCCH format 4 or PUCCH format 5 is computed as follows:

Set $k = 0$ – counter of HARQ-ACK bits

Set c=0 – cell index: lower indices correspond to lower RRC indices of corresponding cell

while c < N_{cells}^{DL}

  set $l = 0$;

  while $l < B_c^{DL}$

    if transmission mode configured in cell $c \in \{1,2,5,6,7\}$ -- 1 bit HARQ-ACK feedback for this cell

      $k = k + 1$

    else

      $k = k + 2$

    end if

    $l = l+1$

  end while

  $c = c + 1$

end while

When PUCCH format 3 is configured, if $k \leq 20$ when TDD is used in all the configured serving cell(s) of the UE, or if $k \leq 21$ when FDD is used in at least one of the configured serving cells with TDD primary cell; or when PUCCH format 4 or PUCCH format 5 is configured and when the UE is not configured with spatial bundling on PUSCH by higher layers, the multiplexing of HARQ-ACK bits is performed according to the following pseudo-code:

Set $c = 0$ – cell index: lower indices correspond to lower RRC indices of corresponding cell

Set $j = 0$ – HARQ-ACK bit index

while c < N_{cells}^{DL}

  set $l = 0$;

  while $l < B_c^{DL}$

    if transmission mode configured in cell $c \in \{1,2,5,6,7\}$ -- 1 bit HARQ-ACK feedback for this cell

      $\tilde{o}_j^{ACK} = o_{c,l}^{ACK}$ HARQ-ACK bit of this cell as defined in Section 7.3 of [3]

      $j = j + 1$

    else

      $[\tilde{o}_j^{ACK}, \tilde{o}_{j+1}^{ACK}] = [o_{c,2l}^{ACK}, o_{c,2l+1}^{ACK}]$ HARQ-ACK bits of this cell as defined in Section 7.3 of [3]

      $j = j + 2$

    end if

    $l = l+1$

  end while

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For the aggregation of more than one DL cell including a primary cell using FDD and at least one secondary cell using TDD, the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for one or multiple DL cells. Define N_{cells}^{DL} as the number of cells configured by higher layers for the UE and B_c^{DL} as the number of subframes for which the UE needs to feed back HARQ-ACK bits in UL subframe n for the c-th serving cell. For a cell using TDD, the subframes are determined by the DL-reference UL/DL configuration if the UE is configured with higher layer parameter eimta-HARQ-ReferenceConfig, and determined by the UL/DL configuration otherwise. For a cell using TDD, $B_c^{DL}=1$ if subframe n−4 in the cell is a DL subframe or a special subframe with special subframe configurations 1/2/3/4/6/7/8/9 and normal downlink CP or a special subframe with special subframe configurations 1/2/3/5/6/7 and extended downlink CP, and $B_c^{DL}=0$ otherwise. For a cell using FDD, $B_c^{DL}=1$.

The bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is performed according to the following pseudo-code:

Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
while c < N_{cells}^{DL}
  if B_c^{DL} = 1
    if transmission mode configured in cell c ∈ {1,2,5,6,7} - 1 bit HARQ-ACK feedback for this cell
      $\tilde{o}_j^{ACK}$ = HARQ-ACK bit of this cell
      j = j + 1
    else
      if the UE is not configured with spatial bundling on PUSCH by higher layers
        $\tilde{o}_j^{ACK}$ = HARQ-ACK bit corresponding to the first codeword of this cell
        j = j + 1
        $\tilde{o}_j^{ACK}$ = HARQ-ACK bit corresponding to the second codeword of this cell
        j = j + 1
      else
        $\tilde{o}_j^{ACK}$ = binary AND operation of the HARQ-ACK bits corresponding to the first and second codewords of this cell
        j = j + 1
      end if
    end if
  end if
  c = c + 1
end while

For the cases with TDD primary cell when HARQ-ACK is for the aggregation of one or more DL cells and the UE is configured with PUCCH format 3, PUCCH format 4 or PUCCH format 5 [3], the bit sequence $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ is the result of the concatenation of HARQ-ACK bits for the one or more DL cells configured by higher layers and the multiple subframes as defined in [3]. Define N_{cells}^{DL} as the number of cells configured by higher layers for the UE and B_c^{DL} as the number of subframes for which the UE needs to feed back HARQ-ACK bits as defined in Section 7.3 of [3].

The number of HARQ-ACK bits for the UE to convey if it is configured with PUCCH format 3, PUCCH format 4 or PUCCH format 5 is computed as follows:

Set k = 0 - counter of HARQ-ACK bits
Set c=0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
while c < N_{cells}^{DL}
  set / = 0;
  while / < B_c^{DL}
    if transmission mode configured in cell c ∈ {1,2,5,6,7} -- 1 bit HARQ-ACK feedback for this cell
      k = k + 1
    else
      k = k + 2
    end if
    / = /+1
  end while
  c = c + 1
end while

The number of HARQ-ACK bits for the UE to convey if it is configured with PUCCH format 3, PUCCH format 4 or PUCCH format 5 is computed as follows:

Set $k = 0$ – counter of HARQ-ACK bits

Set c=0 – cell index: lower indices correspond to lower RRC indices of corresponding cell

while c < N_{cells}^{DL}

set $l = 0$;

while $l < B_c^{DL}$

if transmission mode configured in cell $c \in \{1,2,5,6,7\}$ -- 1 bit HARQ-ACK feedback for this cell

$k = k + 1$

else

$k = k + 2$

end if

$l = l+1$

end while

$c = c + 1$

end while

When PUCCH format 3 is configured, if $k \leq 20$ when TDD is used in all the configured serving cell(s) of the UE, or if $k \leq 21$ when FDD is used in at least one of the configured serving cells with TDD primary cell; or when PUCCH format 4 or PUCCH format 5 is configured and when the UE is not configured with spatial bundling on PUSCH by higher layers, the multiplexing of HARQ-ACK bits is performed according to the following pseudo-code:

Set $c = 0$ – cell index: lower indices correspond to lower RRC indices of corresponding cell

Set $j = 0$ – HARQ-ACK bit index

while c < N_{cells}^{DL}

set $l = 0$;

while $l < B_c^{DL}$

if transmission mode configured in cell $c \in \{1,2,5,6,7\}$ -- 1 bit HARQ-ACK feedback for this cell

$\tilde{o}_j^{ACK} = o_{c,l}^{ACK}$ HARQ-ACK bit of this cell as defined in Section 7.3 of [3]

$j = j + 1$

else

$[\tilde{o}_j^{ACK}, \tilde{o}_{j+1}^{ACK}] = [o_{c,2l}^{ACK}, o_{c,2l+1}^{ACK}]$ HARQ-ACK bits of this cell as defined in Section 7.3 of [3]

$j = j + 2$

end if

$l = l+1$

end while

When PUCCH format 3 is configured, if k≤20 when TDD is used in all the configured serving cell(s) of the UE, or if k≤21 when FDD is used in at least one of the configured serving cells with TDD primary cell; or when PUCCH format 4 or PUCCH format 5 is configured and when the UE is not configured with spatial bundling on PUSCH by higher layers, the multiplexing of HARQ-ACK bits is performed according to the following pseudo-code:

```
Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
while c < N_cells^DL
  set l = 0;
  while l < B_c^DL
    if transmission mode configured in cell c ∈ {1,2,5,6,7} -- 1 bit HARQ-ACK feedback for this
  cell
      õ_j^ACK = o_c,l^ACK HARQ-ACK bit of this cell as defined in Section 7.3 of [3]
      j = j + 1
    else
      [õ_j^ACK, õ_j+1^ACK] = [o_c,2l^ACK, o_c,2l+1^ACK] HARQ-ACK bits of this cell as defined in
Section 7.3 of [3]
      j = j + 2
    end if
    l = l+1
  end while
  c = c + 1
end while
```

When PUCCH format 3 is configured, if k>20 when TDD is used in all the configured serving cell(s) of the UE, or if k>21 when FDD is used in at least one of the configured serving cells with TDD primary cell, spatial bundling is applied to all subframes in all cells; or when PUCCH format 4 or PUCCH format 5 is configured and when the UE is configured with spatial bundling on PUSCH by higher layers, the multiplexing of HARQ-ACK bits is performed according to the following pseudo-code:

```
Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
while c < N_cells^DL
  set l = 0;
  while l < B_c^DL
    if transmission mode configured in cell c ∈ {1,2,5,6,7} - 1 bit HARQ-ACK feedback
  for this cell
      õ_j^ACK = o_c,l^ACK HARQ-ACK bit of this cell as defined in Section 7.3 of [3]
      j = j + 1
    else
      õ_j^ACK = o_c,l^ACK binary AND operation of the HARQ-ACK bits corresponding
      to the first and second codewords of this cell as defined in Section 7.3 of
      [3]
      j = j + 1
    end if
    l = l+1
  end while
  c = c + 1
end while
```

For $o^{ACK} \leq 11$ or $o^{ACK} > 22$, the bit sequence $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ is obtained by setting $o_i^{ACK} = \tilde{o}_i^{ACK}$.
For $11 < o^{ACK} \leq 22$, $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ is obtained by setting $o_i^{ACK} = \tilde{o}_i^{ACK}$ if i is even and $o_{\lfloor i/2 \rfloor + (i-1)/2}^{ACK} = \tilde{o}_i^{ACK}$ if i is odd.
For the cases with TDD primary cell when HARQ-ACK is for the aggregation of two DL cells and the UE is configured with PUCCH format 1b with channel selection, the bit sequence $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ is obtained as described in section 7.3 of [3].
For TDD HARQ-ACK bundling, a bit sequence $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \tilde{q}_2^{ACK}, \ldots, \tilde{q}_{Q_{ACK}-1}^{ACK}$ is obtained by concatenation of multiple encoded HARQ-ACK blocks where Q_{ACK} is the total number of coded bits for all the encoded HARQ-ACK blocks. The last concatenation of the encoded HARQ-ACK block may be partial so that the total bit sequence length is equal to Q_{ACK}. A scrambling sequence $[w_0^{ACK} w_1^{ACK} w_2^{ACK} w_3^{ACK}]$ is then selected from Table 5.2.2.6-A with index $i=(N_{bundled}-1) \bmod 4$, where $N_{bundled}$ is determined as described in section 7.3 of [3]. The bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is then generated by setting m=1 if HARQ-ACK consists of 1-bit and m=3 if HARQ-ACK consists of 2-bits and then scrambling $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \tilde{q}_2^{ACK}, \ldots, \tilde{q}_{Q_{ACK}-1}^{ACK}$ as follows

```
Set i ,k to 0
while i < Q_ACK
  if q̃_i^ACK = y        // place-holder repetition bit
```

-continued

```
    q_k^ACK = (q̃_i-1^ACK + w_k[k%4]^ACK)mod 2
    k = (k + 1)mod4m
  else
    if q̃_i^ACK = x        // a place-holder bit
      q_k^ACK = q̃_i^ACK
    else                  // coded bit
      q_k^ACK = (q̃_i^ACK + w_k[k%4]^ACK)mod2
      k = (k + 1)mod4m
```

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$c = c + 1$

end while

When PUCCH format 3 is configured, if $k > 20$ when TDD is used in all the configured serving cell(s) of the UE, or if $k > 21$ when FDD is used in at least one of the configured serving cells with TDD primary cell, spatial bundling is applied to all subframes in all cells; or when PUCCH format 4 or PUCCH format 5 is configured and when the UE is configured with spatial bundling on PUSCH by higher layers, the multiplexing of HARQ-ACK bits is performed according to the following pseudo-code:

Set $c = 0$ – cell index: lower indices correspond to lower RRC indices of corresponding cell

Set $j = 0$ – HARQ-ACK bit index

while c < N_{cells}^{DL}

set $l = 0$;

while $l < B_c^{DL}$

if transmission mode configured in cell $c \in \{1,2,5,6,7\}$ – 1 bit HARQ-ACK feedback for this cell

$\tilde{o}_j^{ACK} = o_{c,l}^{ACK}$ HARQ-ACK bit of this cell as defined in Section 7.3 of [3]

$j = j + 1$

else

$\tilde{o}_j^{ACK} = o_{c,l}^{ACK}$ binary AND operation of the HARQ-ACK bits corresponding to the first and second codewords of this cell as defined in Section 7.3 of [3]

$j = j + 1$

end if

$l = l+1$

end while

$c = c + 1$

end while

For $o^{ACK} \leq 11$ or $o^{ACK} > 22$, the bit sequence $o_0^{ACK} o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$ is obtained by setting $o_i^{ACK} = \tilde{o}_i^{ACK}$.

For $11 < o^{ACK} \leq 22$, the bit sequence $o_0^{ACK} o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$ is obtained by setting $o_{i/2}^{ACK} = \tilde{o}_i^{ACK}$ if i is even and $o_{\lfloor o^{ACK}/2 \rfloor + (i-1)/2}^{ACK} = \tilde{o}_i^{ACK}$ if i is odd.

For the cases with TDD primary cell when HARQ-ACK is for the aggregation of two DL cells and the UE is configured with PUCCH format 1b with channel selection, the bit sequence $o_0^{ACK} o_1^{ACK},...,o_{O^{ACK}-1}^{ACK}$ is obtained as described in section 7.3 of [3].

For TDD HARQ-ACK bundling, a bit sequence $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \tilde{q}_2^{ACK},...,\tilde{q}_{Q_{ACK}-1}^{ACK}$ is obtained by concatenation of multiple encoded HARQ-ACK blocks where Q_{ACK} is the total number of coded bits for all the encoded HARQ-ACK blocks. The last concatenation of the encoded HARQ-ACK block may be partial so that the total bit sequence length is equal to Q_{ACK}. A scrambling sequence $\left[w_0^{ACK} w_1^{ACK} w_2^{ACK} w_3^{ACK}\right]$ is then selected from Table 5.2.2.6-A with index $i = (N_{bundled} - 1) \bmod 4$, where N_{bundled} is determined as described in section 7.3 of [3]. The bit sequence

When PUCCH format 3 is configured, if k≤20 when TDD is used in all the configured serving cell(s) of the UE, or if k≤21 when FDD is used in at least one of the configured serving cells with TDD primary cell; or when PUCCH format 4 or PUCCH format 5 is configured and when the UE is not configured with spatial bundling on PUSCH by higher layers, the multiplexing of HARQ-ACK bits is performed according to the following pseudo-code:

Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
while c < N_{cells}^{DL}
  set / = 0;
  while / < B_c^{DL}
    if transmission mode configured in cell c ∈ {1,2,5,6,7} -- 1 bit HARQ-ACK feedback for this cell
      $\tilde{o}_j^{ACK} = o_{c,l}^{ACK}$ HARQ-ACK bit of this cell as defined in Section 7.3 of [3]
      j = j + 1
    else
      $[\tilde{o}_j^{ACK} \tilde{o}_{j+1}^{ACK}] = [o_{c,2j}^{ACK} o_{c,2j+1}^{ACK}]$ HARQ-ACK bits of this cell as defined in Section 7.3 of [3]
      j = j + 2
    end if
    / = /+1
  end while
  c = c + 1
end while

When PUCCH format 3 is configured, if k>20 when TDD is used in all the configured serving cell(s) of the UE, or if k>21 when FDD is used in at least one of the configured serving cells with TDD primary cell, spatial bundling is applied to all subframes in all cells; or when PUCCH format 4 or PUCCH format 5 is configured and when the UE is configured with spatial bundling on PUSCH by higher layers, the multiplexing of HARQ-ACK bits is performed according to the following pseudo-code:

Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
while c < N_{cells}^{DL}
  set / = 0;
  while / < B_c^{DL}
    if transmission mode configured in cell c ∈ {1,2,5,6,7} - 1 bit HARQ-ACK feedback for this cell
      $\tilde{o}_j^{ACK} = o_{c,l}^{ACK}$ HARQ-ACK bit of this cell as defined in Section 7.3 of [3]
      j = j + 1
    else
      $\tilde{o}_j^{ACK} = o_{c,l}^{ACK}$ binary AND operation of the HARQ-ACK bits corresponding to the first and second codewords of this cell as defined in Section 7.3 of [3]
      j = j + 1
    end if
    / = /+1
  end while
  c = c + 1
end while

For $o^{ACK} \leq 11$ or $o^{ACK} > 22$, the bit sequence $o_0^{ACK} o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ is obtained by setting $o_i^{ACK} = \tilde{o}_i^{ACK}$.
For $11 < o^{ACK} \leq 22$, $o_0^{ACK} o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ is obtained by setting $o_{i/2}^{ACK} = \tilde{o}_i^{ACK}$ if i is even and $o_{\lfloor o^{ACK}/2 \rfloor + (i-1)/2}^{ACK} = \tilde{o}_i^{ACK}$ if i is odd.
For the cases with TDD primary cell when HARQ-ACK is for the aggregation of two DL cells and the UE is configured with PUCCH format 1b with channel selection, the bit sequence $o_0^{ACK} o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ is obtained as described in section 7.3 of [3].
For TDD HARQ-ACK bundling, a bit sequence $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \tilde{q}_2^{ACK}, \ldots, \tilde{q}_{Q_{ACK}-1}^{ACK}$ is obtained by concatenation of multiple encoded HARQ-ACK blocks where Q_{ACK} is the total number of coded bits for all the encoded HARQ-ACK blocks. The last concatenation of the encoded HARQ-ACK block may be partial so that the total bit sequence length is equal to Q_{ACK}. A scrambling sequence $[w_0^{ACK} w_1^{ACK} w_2^{ACK} w_3^{ACK}]$ is then selected from Table 5.2.2.6-A with index $i = (N_{bundled} - 1) \bmod 4$, where $N_{bundled}$ is determined as described in section 7.3 of [3]. The bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is then generated by setting

total number of coded bits for all the encoded HARQ-ACK blocks. The last concatenation of the encoded HARQ-ACK block may be partial so that the total bit sequence length is equal to Q_{ACK}. A scrambling sequence $[w_0^{ACK} w_1^{ACK} w_2^{ACK} w_3^{ACK}]$ is then selected from Table 5.2.2.6-A with index $i = (N_{bundled} - 1) \bmod 4$, where $N_{bundled}$ is determined as described in section 7.3 of [3]. The bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is then generated by setting

m=1 if HARQ-ACK consists of 1-bit and m=3 if HARQ-ACK consists of 2-bits and then scrambling $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \tilde{q}_2^{ACK}, \ldots, \tilde{q}_{Q_{ACK}-1}^{ACK}$ as follows

Set i ,k to 0
while i < Q_{ACK}
  if $\tilde{q}_i^{ACK}$ = y // place-holder repetition bit

-continued

  $q_i^{ACK} = (\tilde{q}_{i-1}^{ACK} + w_{\lfloor k/m \rfloor}^{ACK}) \bmod 2$
  k = (k + 1)mod4m
else
  if $\tilde{q}_i^{ACK}$ = x // a place-holder bit
    $q_i^{ACK} = \tilde{q}_i^{ACK}$
  else // coded bit
    $q_i^{ACK} = (\tilde{q}_i^{ACK} + w_{\lfloor k/m \rfloor}^{ACK}) \bmod 2$
    k = (k + 1)mod4m

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$q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is then generated by setting $m = 1$ if HARQ-ACK consists of 1-bit and $m = 3$ if HARQ-ACK consists of 2-bits and then scrambling $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \tilde{q}_2^{ACK}, \ldots, \tilde{q}_{Q_{ACK}-1}^{ACK}$ as follows

Set i, k to 0

while $i < Q_{ACK}$

if $\tilde{q}_i^{ACK} = y$ // place-holder repetition bit

$q_i^{ACK} = \left(\tilde{q}_{i-1}^{ACK} + w_{\lfloor k/m \rfloor}^{ACK}\right) \bmod 2$

$k = (k+1) \bmod 4m$

else

if $\tilde{q}_i^{ACK} = x$ // a place-holder bit

$q_i^{ACK} = \tilde{q}_i^{ACK}$

else // coded bit

$q_i^{ACK} = \left(\tilde{q}_i^{ACK} + w_{\lfloor k/m \rfloor}^{ACK}\right) \bmod 2$

$k = (k+1) \bmod 4m$

end if

$i = i + 1$

end while

Table 5.2.2.6-A: Scrambling sequence selection for TDD HARQ-ACK bundling.

i	$\left[w_0^{ACK} w_1^{ACK} w_2^{ACK} w_3^{ACK}\right]$
0	[1 1 1 1]
1	[1 0 1 0]
2	[1 1 0 0]
3	[1 0 0 1]

When HARQ-ACK information is to be multiplexed with UL-SCH at a given PUSCH, the HARQ-ACK information is multiplexed in all layers of all transport blocks of that PUSCH, For a given transport block, the vector sequence output of the channel coding for HARQ-ACK information is denoted by $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \ldots, \underline{q}_{Q'_{ACK}-1}^{ACK}$, where $\underline{q}_i^{ACK}$, $i = 0, \ldots, Q'_{ACK} - 1$ are column vectors of length $(Q_m \cdot N_L)$ and where $Q'_{ACK} = Q_{ACK} / Q_m$ is obtained as follows:

Set i, k to 0

while $i < Q_{ACK}$

$\hat{\underline{q}}_k^{ACK} = [q_i^{ACK} \ldots q_{i+Q_m-1}^{ACK}]$ -- temporary row vector

$\underline{q}_k^{ACK} = [\overbrace{\hat{\underline{q}}_k^{ACK} \cdots \hat{\underline{q}}_k^{ACK}}^{N_L}]^T$ -- replicating the row vector $\hat{\underline{q}}_k^{ACK}$ N_L times and transposing into a column vector

When PUCCH format 3 is configured, if k≤20 when TDD is used in all the configured serving cell(s) of the UE, or if k≤21 when FDD is used in at least one of the configured serving cells with TDD primary cell; or when PUCCH format 4 or PUCCH format 5 is configured and when the UE is not configured with spatial bundling on PUSCH by higher layers, the multiplexing of HARQ-ACK bits is performed according to the following pseudo-code:

```
Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
while c < N_cells^DL
  set i = 0;
  while i < B_c^DL
    if transmission mode configured in cell c ∈ {1,2,5,6,7} -- 1 bit HARQ-ACK feedback for this
    cell
      õ_j^ACK = o_c,i^ACK HARQ-ACK bit of this cell as defined in Section 7.3 of [3]
      j = j + 1
    else
      [õ_j^ACK õ_j+1^ACK] = [o_c,2i^ACK o_c,2i+1^ACK] HARQ-ACK bits of this cell as defined in
Section 7.3 of [3]
      j = j + 2
    end if
    i = i+1
  end while
  c = c + 1
end while
```

When PUCCH format 3 is configured, if k>20 when TDD is used in all the configured serving cell(s) of the UE, or if k>21 when FDD is used in at least one of the configured serving cells with TDD primary cell, spatial bundling is applied to all subframes in all cells; or when PUCCH format 4 or PUCCH format 5 is configured and when the UE is configured with spatial bundling on PUSCH by higher layers, the multiplexing of HARQ-ACK bits is performed according to the following pseudo-code:

```
Set c = 0 - cell index: lower indices correspond to lower RRC indices of corresponding cell
Set j = 0 - HARQ-ACK bit index
while c < N_cells^DL
  set i = 0;
  while i < B_c^DL
    if transmission mode configured in cell c ∈ {1,2,5,6,7} - 1 bit HARQ-ACK feedback
    for this cell
      õ_j^ACK = o_c,j^ACK HARQ-ACK bit of this cell as defined in Section 7.3 of [3]
      j = j + 1
    else
      õ_j^ACK = o_c,j^ACK binary AND operation of the HARQ-ACK bits corresponding
      to the first and second codewords of this cell as defined in Section 7.3 of
      [3]
      j = j + 1
    end if
    i = i+1
  end while
  c = c + 1
end while
```

For $o^{ACK} \leq 11$ or $o^{ACK} > 22$, the bit sequence $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ is obtained by setting $o_i^{ACK} = \tilde{o}_i^{ACK}$.
For $11 < o^{ACK} \leq 22$, $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ is obtained by setting $o_i^{ACK} = \tilde{o}_i^{ACK}$ if i is even and $o_{\lfloor o^{ACK}/2 \rfloor + (i-1)/2} = \tilde{o}_i^{ACK}$ if i is odd.
For the cases with TDD primary cell when HARQ-ACK is for the aggregation of two DL cells and the UE is configured with PUCCH format 1b with channel selection, the bit sequence $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ is obtained as described in section 7.3 of [3].
For TDD HARQ-ACK bundling, a bit sequence $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \tilde{q}_2^{ACK}, \ldots, \tilde{q}_{Q_{ACK}-1}^{ACK}$ is obtained by concatenation of multiple encoded HARQ-ACK blocks where Q_{ACK} is the total number of coded bits for all the encoded HARQ-ACK blocks. The last concatenation of the encoded HARQ-ACK block may be partial so that the total bit sequence length is equal to Q_{ACK}. A scrambling sequence $[w_0^{ACK} w_1^{ACK} w_2^{ACK} w_3^{ACK}]$ is then selected from Table 5.2.2.6-A with index $i = (N_{bundled} - 1) \bmod 4$, where $N_{bundled}$ is determined as described in section 7.3 of [3]. The bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is then generated by setting

m=1 if HARQ-ACK consists of 1-bit and m=3 if HARQ-ACK consists of 2-bits and then scrambling $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \tilde{q}_2^{ACK}, \ldots, \tilde{q}_{Q_{ACK}-1}^{ACK}$ as follows

```
Set i ,k to 0
while i < Q_ACK
  if q̃_i^ACK = y          // place-holder repetition bit
```

-continued

```
  q_i^ACK = (q̃_i-1^ACK + w_⌊k/m⌋^ACK) mod 2
  k = (k + 1)mod4m
else
  if q̃_i^ACK = x          // a place-holder bit
    q_i^ACK = q̃_i^ACK
else                      // coded bit
  q_i^ACK = (q̃_i^ACK + w_⌊k/m⌋^ACK)mod2
  k = (k + 1)mod4m
```

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$q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is then generated by setting $m = 1$ if HARQ-ACK consists of 1-bit and $m = 3$ if HARQ-ACK consists of 2-bits and then scrambling $\tilde{q}_0^{ACK}, \tilde{q}_1^{ACK}, \tilde{q}_2^{ACK}, \ldots, \tilde{q}_{Q_{ACK}-1}^{ACK}$ as follows

Set i, k to 0

while $i < Q_{ACK}$

if $\tilde{q}_i^{ACK} = y$ // place-holder repetition bit

$q_i^{ACK} = \left(\tilde{q}_{i-1}^{ACK} + w_{\lfloor k/m \rfloor}^{ACK}\right) \bmod 2$

$k = (k+1) \bmod 4m$

else

if $\tilde{q}_i^{ACK} = x$ // a place-holder bit

$q_i^{ACK} = \tilde{q}_i^{ACK}$

else // coded bit

$q_i^{ACK} = \left(\tilde{q}_i^{ACK} + w_{\lfloor k/m \rfloor}^{ACK}\right) \bmod 2$

$k = (k+1) \bmod 4m$

end if

$i = i + 1$

end while

Table 5.2.2.6-A: Scrambling sequence selection for TDD HARQ-ACK bundling.

i	$\left[w_0^{ACK} w_1^{ACK} w_2^{ACK} w_3^{ACK}\right]$
0	[1 1 1 1]
1	[1 0 1 0]
2	[1 1 0 0]
3	[1 0 0 1]

When HARQ-ACK information is to be multiplexed with UL-SCH at a given PUSCH, the HARQ-ACK information is multiplexed in all layers of all transport blocks of that PUSCH, For a given transport block, the vector sequence output of the channel coding for HARQ-ACK information is denoted by $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \ldots, \underline{q}_{Q'_{ACK}-1}^{ACK}$, where $\underline{q}_i^{ACK}$, $i = 0, \ldots, Q'_{ACK}-1$ are column vectors of length $(Q_m \cdot N_L)$ and where $Q'_{ACK} = Q_{ACK} / Q_m$ is obtained as follows:

Set i, k to 0

while $i < Q_{ACK}$

$\hat{\underline{q}}_k^{ACK} = [q_i^{ACK} \ldots q_{i+Q_m-1}^{ACK}]$ -- temporary row vector

$\underline{q}_k^{ACK} = [\overbrace{\hat{\underline{q}}_k^{ACK} \cdots \hat{\underline{q}}_k^{ACK}}^{N_L}]^T$ -- replicating the row vector $\hat{\underline{q}}_k^{ACK}$ N_L times and transposing into a column vector

-continued

end if
i = i +1
end while

[Table 5.2.2.6-A of 3GPP TS 36.212 v13.0.0, Entitled "Scrambling Sequence Selection for TDD HARQ-ACK Bundling", is Reproduced as FIG. 9]

When HARQ-ACK information is to be multiplexed with UL-SCH at a given PUSCH, the HARQ-ACK information is multiplexed in all layers of all transport blocks of that PUSCH, For a given transport block, the vector sequence output of the channel coding for HARQ-ACK information is denoted by $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \ldots, \underline{q}_{Q'_{ACK}-1}^{ACK}$, where $\underline{q}_i^{ACK}$, i=0, . . . , $Q'_{ACK}-1$ are column vectors of length $(Q_m \cdot N_L)$ and where $Q'_{ACK}=Q_{ACK}/Q_m$ is obtained as follows:

Set i, k to 0
while i < Q_{ACK}
$\hat{\underline{q}}_k^{ACK} = [q_i^{ACK} \ldots q_{i+Q_m-1}^{ACK}]$ -- temporary row vector
$\underline{q}_k^{ACK} = [\overbrace{\hat{\underline{q}}_k^{ACK} \ldots \hat{\underline{q}}_k^{ACK}}^{N_L}]^T$ -- replicating the row vector $\hat{\underline{q}}_k^{ACK}$ N_L times and transposing into a column vector
i = i + Q_m
k = k + 1
end while

where N_L is the number of layers onto which the UL-SCH transport block is mapped.

For rank indication (RI) (RI only, joint report of RI and i1, joint report of CRI and RI, joint report of CRI,RI and i1,joint report of CRI,RI, and PTI, and joint report of RI and PTI) or CRI

The corresponding bit widths for CRI feedback for PDSCH transmissions are given by Tables 5.2.2.6.1-3A, 5.2.2.6.2-3A, 5.2.2.6.3-3A, 5.2.3.3.1-3D,

The corresponding bit widths for RI feedback for PDSCH transmissions are given by Tables 5.2.2.6.1-2, 5.2.2.6.2-3, 5.2.2.6.2-3B, 5.2.2.6.3-3, 5.2.2.6.3-3B, 5.2.3.3.1-3, 5.2.3.3.1-3A, 5.2.3.3.1-3D, 5.2.3.3.1-3C, 5.2.3.3.1-3D, 5.2.3.3.2-4, and 5.2.3.3-4B, 5.2.3.3.2-4C, 5.2.3.3.2-4D whic assuming the maximum number of l

If the maxLayersMIMO-r10 is confi cell, the maximum number of lay according to maxLayersMIMO-r1

Else,

If the UE is configured with trans and the supportedMIMO-Cap is included in the UE-EUTR maximum number of layers is d ing to the minimum of the conf CSI-RS ports and the maximu UE downlink MIMO capabilit band in the corresponding band

If the UE is configured with transm Class B CSI reporting with K> are transmitted in the same repo the supportedMIMO-Capability included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.

If the UE is configured with transmission mode 9, and the supportedMIMO-CapabilityDL-r10 is not included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the configured number of CSI-RS ports and ue-Category (without suffix).

If the UE is configured with transmission mode 9 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is not included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources and ue-Category (without suffix).

If the UE is configured with transmission mode 10, and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability, the maximum number of layers for each CSI process is determined according to the minimum of the configured number of CSI-RS ports for that CSI process and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.

If the UE is configured with transmission mode 10 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability, the maximum number of layers for each CSI process is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources in that CSI process and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.

If the UE is configured with transmission mode 10, and the supportedMIMO-CapabilityDL-r10 field is not included in the UE-EUTRA-Capability, the maximum number of layers for each CSI process is determined according to the minimum of the

[o_0^{RI} o_1^{RI}] to RI mapping is given by Table 5.2.2.6.

If RI feedback consists of 2-bits of information, i.e., [o_0^{RI} o_1^{RI}] with o_0^{RI} corresponding to MSB of 2-bit input and o_1^{RI} corresponding to LSB, it is first encoded according to Table 5.2.2.6-4 where $o_2^{RI}=(o_0^{RI}+o_1^{RI}) \bmod 2$. The [$o_0^{RI}$ o_1^{RI}] to RI mapping is given by Table 5.2.2.6.

i	$\left[w_0^{ACK} w_1^{ACK} w_2^{ACK} w_3^{ACK}\right]$
0	[1 1 1 1]
1	[1 0 1 0]
2	[1 1 0 0]
3	[1 0 0 1]

FIG. 9 (PRIOR ART)

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$i = i + Q_m$

$k = k + 1$

end while

where N_L is the number of layers onto which the UL-SCH transport block is mapped.

For rank indication (RI) (RI only, joint report of RI and i1, joint report of CRI and RI, joint report of CRI,RI and i1,joint report of CRI,RI, and PTI, and joint report of RI and PTI) or CRI

- The corresponding bit widths for CRI feedback for PDSCH transmissions are given by Tables 5.2.2.6.1-3A, 5.2.2.6.2-3A, 5.2.2.6.3-3A, 5.2.3.3.1-3D,
- The corresponding bit widths for RI feedback for PDSCH transmissions are given by Tables 5.2.2.6.1-2, 5.2.2.6.2-3, 5.2.2.6.2-3B, 5.2.2.6.3-3, 5.2.2.6.3-3B, 5.2.3.3.1-3, 5.2.3.3.1-3A, 5.2.3.3.1-3B, 5.2.3.3.1-3C, 5.2.3.3.1-3D, 5.2.3.3.2-4, and 5.2.3.3.2-4A, 5.2.3.3.2-4B, 5.2.3.3.2-4C, 5.2.3.3.2-4D which are determined assuming the maximum number of layers as follows:
  - If the *maxLayersMIMO-r10* is configured for the DL cell, the maximum number of layers is determined according to *maxLayersMIMO-r10* for the DL cell
  - Else,
    - If the UE is configured with transmission mode 9, and the *supportedMIMO-CapabilityDL-r10* field is included in the *UE-EUTRA-Capability*, the maximum number of layers is determined according to the minimum of the configured number of CSI-RS ports and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.
    - If the UE is configured with transmission mode 9 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination,.
    - If the UE is configured with transmission mode 9, and the *supportedMIMO-CapabilityDL-r10* field is not included in the *UE-EUTRA-Capability*, the maximum number of layers is determined according to the minimum of the configured number of CSI-RS ports and *ue-Category* (without suffix).
    - If the UE is configured with transmission mode 9 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is not included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources and ue-Category (without suffix).
    - If the UE is configured with transmission mode 10, and the *supportedMIMO-CapabilityDL-r10* field is included in the *UE-EUTRA-Capability*, the maximum number of layers for each CSI process is determined according to the minimum of the configured number of CSI-RS ports for that CSI process and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.
    - If the UE is configured with transmission mode 10 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability, the maximum number of layers for each CSI process is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources in that CSI process and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.
    - If the UE is configured with transmission mode 10, and the *supportedMIMO-CapabilityDL-r10* field is not included in the *UE-EUTRA-Capability*, the maximum number of layers for each CSI process is determined according to the minimum of the configured number of CSI-RS ports for that CSI process and *ue-Category* (without suffix).

-continued

end if
i = i +1
end while

[Table 5.2.2.6-A of 3GPP TS 36.212 v13.0.0, Entitled "Scrambling Sequence Selection for TDD HARQ-ACK Bundling", is Reproduced as FIG. 9]

When HARQ-ACK information is to be multiplexed with UL-SCH at a given PUSCH, the HARQ-ACK information is multiplexed in all layers of all transport blocks of that PUSCH, For a given transport block, the vector sequence output of the channel coding for HARQ-ACK information is denoted by $q_0^{ACK}, q_1^{ACK}, \ldots, q_{Q'_{ACK}-1}^{ACK}$, where q_i^{ACK} $i=0, \ldots, Q'_{ACK}-1$ are column vectors of length $(Q_m \cdot N_L)$ and where $Q'_{ACK}=Q_{ACK}/Q_m$ is obtained as follows:

Set i, k to 0
while i < Q_{ACK}
$\tilde{q}_k^{ACK} = [q_i^{ACK} \ldots q_{i+Q_m-1}^{ACK}]$ -- temporary row vector
$q_k^{ACK} = [\overbrace{\tilde{q}_k^{ACK} \ldots \tilde{q}_k^{ACK}}^{N_L}]^T$ -- replicating the row vector $\tilde{q}_k^{ACK}$ N_L times and transposing into a column vector
i = i + Q_m
k = k + 1
end while

where N_L is the number of layers onto which the UL-SCH transport block is mapped.

For rank indication (RI) (RI only, joint report of RI and i1, joint report of CRI and RI, joint report of CRI,RI and i1,joint report of CRI,RI, and PTI, and joint report of RI and PTI) or CRI

The corresponding bit widths for CRI feedback for PDSCH transmissions are given by Tables 5.2.2.6.1-3A, 5.2.2.6.2-3A, 5.2.2.6.3-3A, 5.2.3.3.1-3D,

The corresponding bit widths for RI feedback for PDSCH transmissions are given by Tables 5.2.2.6.1-2, 5.2.2.6.2-3, 5.2.2.6.2-3B, 5.2.2.6.3-3, 5.2.2.6.3-3B, 5.2.3.3.1-3, 5.2.3.3.1-3A, 5.2.3.3.1-3B, 5.2.3.3.1-3C, 5.2.3.3.1-3D, 5.2.3.3.2-4, and 5.2.3.3.2-4A, 5.2.3.3.2-4B, 5.2.3.3.2-4C, 5.2.3.3.2-4D which are determined assuming the maximum number of layers as follows:

If the maxLayersMIMO-r10 is configured for the DL cell, the maximum number of layers is determined according to maxLayersMIMO-r10 for the DL cell

Else,

If the UE is configured with transmission mode 9, and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the configured number of CSI-RS ports and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.

If the UE is configured with transmission mode 9 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.

If the UE is configured with transmission mode 9, and the supportedMIMO-CapabilityDL-r10 field is not included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the configured number of CSI-RS ports and ue-Category (without suffix).

If the UE is configured with transmission mode 9 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is not included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources and ue-Category (without suffix).

If the UE is configured with transmission mode 10, and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability, the maximum number of layers for each CSI process is determined according to the minimum of the configured number of CSI-RS ports for that CSI process and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.

If the UE is configured with transmission mode 10 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability, the maximum number of layers for each CSI process is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources in that CSI process and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.

If the UE is configured with transmission mode 10, and the supportedMIMO-CapabilityDL-r10 field is not included in the UE-EUTRA-Capability, the maximum number of layers for each CSI process is determined according to the minimum of the configured number of CSI-RS ports for that CSI process and ue-Category (without suffix).

If the UE is configured with transmission mode 10 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is not included in the UE-EUTRA-Capability, the maximum number of layers for each CSI process is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources in that CSI process and ue-Category (without suffix).

Otherwise the maximum number of layers is determined according to the minimum of the number of PBCH antenna ports and ue-Category (without suffix).

If RI feedback consists of 1-bit of information, i.e., $[o_0^{RI}]$, it is first encoded according to Table 5.2.2.6-3. The $[o_0^{RI}]$ to RI mapping is given by Table 5.2.2.6-5.

If RI feedback consists of 2-bits of information, i.e., $[o_0^{RI}$ $o_1^{RI}]$ with o_0^{RI} corresponding to MSB of 2-bit input and o_1^{RI} corresponding to LSB, it is first encoded according to Table 5.2.2.6-4 where $o_2^{RI}=(o_0^{RI}+o_1^{RI}) \bmod 2$. The $[o_0^{RI}$ $o_1^{RI}]$ to RI mapping is given by Table 5.2.2.6-6.

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- If the UE is configured with transmission mode 10 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is not included in the UE-EUTRA-Capability, the maximum number of layers for each CSI process is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources in that CSI process and ue-Category (without suffix).
- Otherwise the maximum number of layers is determined according to the minimum of the number of PBCH antenna ports and *ue-Category* (without suffix).

- If RI feedback consists of 1-bit of information, i.e., $[o_0^{RI}]$, it is first encoded according to Table 5.2.2.6-3. The $[o_0^{RI}]$ to RI mapping is given by Table 5.2.2.6-5.
- If RI feedback consists of 2-bits of information, i.e., $[o_0^{RI}\ o_1^{RI}]$ with o_0^{RI} corresponding to MSB of 2-bit input and o_1^{RI} corresponding to LSB, it is first encoded according to Table 5.2.2.6-4 where $o_2^{RI}=(o_0^{RI}+o_1^{RI}) \bmod 2$. The $[o_0^{RI}\ o_1^{RI}]$ to RI mapping is given by Table 5.2.2.6-6.

Table 5.2.2.6-3: Encoding of 1-bit RI.

Q_m	Encoded RI
2	$[o_0^{RI}\ y]$
4	$[o_0^{RI}\ y\ x\ x]$
6	$[o_0^{RI}\ y\ x\ x\ x\ x\ ]$

Table 5.2.2.6-4: Encoding of 2-bit RI.

Q_m	Encoded RI
2	$[o_0^{RI}\ o_1^{RI}\ o_2^{RI}\ o_0^{RI}\ o_1^{RI}\ o_2^{RI}]$
4	$[o_0^{RI}\ o_1^{RI}\ x\ x\ o_2^{RI}\ o_0^{RI}\ x\ x\ o_1^{RI}\ o_2^{RI}\ x\ x]$
6	$[o_0^{RI}\ o_1^{RI}\ x\ x\ x\ x\ o_2^{RI}\ o_0^{RI}\ x\ x\ x\ x\ o_1^{RI}\ o_2^{RI}\ x\ x\ x\ x]$

Table 5.2.2.6-5: o_0^{RI} to RI mapping.

o_0^{RI}	RI
0	1
1	2

Table 5.2.2.6-6: o_0^{RI}, o_1^{RI} to RI mapping.

o_0^{RI}, o_1^{RI}	RI
0, 0	1
0, 1	2
1, 0	3
1, 1	4

-continued

```
        end if
        i = i +1
    end while
```

[Table 5.2.2.6-A of 3GPP TS 36.212 v13.0.0, En... "Scrambling Sequence Selection for TDD HARQ-... Bundling", is Reproduced as FIG. 9]

When HARQ-ACK information is to be multiplexed... UL-SCH at a given PUSCH, the HARQ-ACK info... is multiplexed in all layers of all transport blocks o... PUSCH, For a given transport block, the vector sequ... output of the channel coding for HARQ-ACK informat... denoted by $q_0^{ACK}, q_1^{ACK}, \ldots, q_{Q'_{ACK}-1}^{ACK}$, where q... i=0, . . . , Q'_{ACK}−1 are column vectors of length (Q_m·N... where $Q'_{ACK}=Q_{ACK}/Q_m$ is obtained as follows:

```
Set i, k to 0
while i < Q_ACK
    g_k^ACK = [q_i^ACK ... q_{i+Q_m-1}^ACK] -- temporary row vector
    g_k^ACK = [ḡ_k^ACK ... ḡ_k^ACK]^T -- replicating the row vecto... (N_L times)
    g_k^ACK  N_L times and transposing into a
    column vector
    i = i + Q_m
    k = k + 1
end while
```

where N_L is the number of layers onto which the UL-SCH transport block is mapped.

For rank indication (RI) (RI only, joint report of RI a... joint report of CRI and RI, joint report of CRI,RI and i1... report of CRI,RI, and PTI, and joint report of RI and... or CRI

The corresponding bit widths for CRI feedb... PDSCH transmissions are given by Tables 5.2.2... 3A, 5.2.2.6.2-3A, 5.2.2.6.3-3A, 5.2.3.3.1-3D,

The corresponding bit widths for RI feedback for PD... transmissions are given by Tables 5.2.2.6... 5.2.2.6.2-3, 5.2.2.6.2-3B, 5.2.2.6.3-3, 5.2.2.6.3... 5.2.3.3.1-3, 5.2.3.3.1-3A, 5.2.3.3.1-3B, 5.2.3.3.1-3C, 5.2.3.3.1-3D, 5.2.3.3.2-4, and 5.2.3.3.2-4A, 5.2.3.3.2-4B, 5.2.3.3.2-4C, 5.2.3.3.2-4D which are determined assuming the maximum number of layers as follows:

If the maxLayersMIMO-r10 is configured for the DL cell, the maximum number of layers is determined according to maxLayersMIMO-r10 for the DL cell

Else,

If the UE is configured with transmission mode 9, and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the configured number of CSI-RS ports and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination.

If the UE is configured with transmission mode 9 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability, the maximum number of layers is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources and the maximum of the reported UE downlink

r10 field is included in the UE-EUTRA-Capability, the maximum number of layers for each CSI

is determined according to the minimum of the configured number of CSI-RS ports for that CSI process and ue-Category (without suffix).

If the UE is configured with transmission mode 10 and Class B CSI reporting with K>1 and RI and CRI are transmitted in the same reporting instance, and the supportedMIMO-CapabilityDL-r10 field is not included in the UE-EUTRA-Capability, the maximum number of layers for each CSI process is determined according to the minimum of the maximum of number of antenna port of the configured CSI-RS resources in that CSI process and ue-Category (without suffix).

Otherwise the maximum number of layers is determined according to the minimum of the number of PBCH antenna ports and ue-Category (without suffix).

If RI feedback consists of 1-bit of information, i.e., $[o_0^{RI}]$, it is first encoded according to Table 5.2.2.6-3. The $[o_0^{RI}]$ to RI mapping is given by Table 5.2.2.6-5.

If RI feedback consists of 2-bits of information, i.e., $[o_0^{RI}\ o_1^{RI}]$ with o_0^{RI} corresponding to MSB of 2-bit input and o_1^{RI} corresponding to LSB, it is first encoded according to Table 5.2.2.6-4 where $o_2^{RI}=(o_0^{RI}+o_1^{RI}) \bmod 2$. The $[o_0^{RI}\ o_1^{RI}]$ to RI mapping is given by Table 5.2.2.6-6.

Q_m	Encoded RI
2	$[o_0^{RI}\ y]$
4	$[o_0^{RI}\ y\ x\ x]$
6	$[o_0^{RI}\ y\ x\ x\ x\ x\ ]$

FIG. 10 (PRIOR ART)

Q_m	Encoded RI
2	$[o_0^{RI}\ o_1^{RI}\ o_2^{RI}\ o_0^{RI}\ o_1^{RI}\ o_2^{RI}]$
4	$[o_0^{RI}\ o_1^{RI}\ x\ x\ o_2^{RI}\ o_0^{RI}\ x\ x\ o_1^{RI}\ o_2^{RI}\ x\ x]$
6	$[o_0^{RI}\ o_1^{RI}\ x\ x\ x\ x\ o_2^{RI}\ o_0^{RI}\ x\ x\ x\ x\ o_1^{RI}\ o_2^{RI}\ x\ x\ x\ x]$

FIG. 11 (PRIOR ART)

o_0^{RI}	RI
0	1
1	2

FIG. 12 (PRIOR ART)

o_0^{RI}, o_1^{RI}	RI
0, 0	1
0, 1	2
1, 0	3
1, 1	4

FIG. 13 (PRIOR ART)

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Table 5.2.2.6-7: o_0^{RI}, o_1^{RI}, o_2^{RI} to RI mapping.

o_0^{RI}, o_1^{RI}, o_2^{RI}	RI
0, 0, 0	1
0, 0, 1	2
0, 1, 0	3
0, 1, 1	4
1, 0, 0	5
1, 0, 1	6
1, 1, 0	7
1, 1, 1	8

If RI feedback for a given DL cell consists of 3-bits of information, i.e., $[o_0^{RI}\ o_1^{RI}\ o_2^{RI}]$ with o_0^{RI} corresponding to MSB of 3-bit input and o_2^{RI} corresponding to LSB. The $[o_0^{RI}\ o_1^{RI}\ o_2^{RI}]$ to RI mapping is given by Table 5.2.2.6-7.

If RI feedback consists of $3 \le O^{RI} \le 11$ bits of information, i.e., $[o_0^{RI}\ o_1^{RI},...,o_{O^{RI}-1}^{RI}]$, then a coded bit sequence $[\tilde{q}_0^{RI}\ \tilde{q}_1^{RI},...,\tilde{q}_{31}^{RI}]$ is obtained by using the bit sequence $[o_0^{RI}\ o_1^{RI},...,o_{O^{RI}-1}^{RI}]$ as the input to the channel coding block described in section 5.2.2.6.4.

If RI feedback consists of $11 < O^{RI} \le 22$ bits of information as a result of the aggregation of RI bits corresponding to multiple DL cells or multiple CSI processes, i.e., $[o_0^{RI}\ o_1^{RI},...,o_{O^{RI}-1}^{RI}]$, then the coded bit sequence $q_0^{RI}, q_1^{RI}, q_2^{RI},...,q_{Q_{RI}-1}^{RI}$ is obtained by using the bit sequence $[o_0^{RI}\ o_1^{RI},...,o_{O^{RI}-1}^{RI}]$ as the input to the channel coding block described in section 5.2.2.6.5.

If RI feedback consists of $O^{RI} > 22$ bits of information as a result of the aggregation of RI bits corresponding to multiple DL cells or multiple CSI processes, i.e., $[o_0^{RI}\ o_1^{RI},...,o_{O^{RI}-1}^{RI}]$, then the coded bit sequence is denoted by $q_0^{RI}, q_1^{RI}, q_2^{RI},...,q_{Q_{RI}-1}^{RI}$. The CRC attachment, channel coding and rate matching of the HARQ-ACK bits are performed according to sections 5.1.1 setting L to 8 bits, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $[o_0^{RI}\ o_1^{RI},...,o_{O^{RI}-1}^{RI}]$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The "x" and "y" in Table 5.2.2.6-3 and 5.2.2.6-4 are placeholders for [2] to scramble the RI bits in a way that maximizes the Euclidean distance of the modulation symbols carrying rank information.

For the case where RI feedback for more than one DL cell is to be reported, the RI report for each DL cell is concatenated prior to coding in increasing order of cell index.

For the case where RI feedback for more than one CSI process is to be reported, the RI reports are concatenated prior to coding first in increasing order of CSI process index for each DL cell and then in increasing order of cell index.

For the case where RI feedback consists of one or two bits of information the bit sequence $q_0^{RI}, q_1^{RI}, q_2^{RI},...,q_{Q_{RI}-1}^{RI}$ is obtained by concatenation of multiple encoded RI blocks where Q_{RI} is the total number of coded bits for all the encoded RI blocks. The last concatenation of the encoded RI block may be partial so that the total bit sequence length is equal to Q_{RI}.

For the case where RI feedback consists of $3 \le O^{RI} \le 11$ bits of information, the bit sequence $q_0^{RI}, q_1^{RI}, q_2^{RI},...,q_{Q_{RI}-1}^{RI}$ is obtained by the circular repetition of the bit sequence $\tilde{q}_0^{RI}\ \tilde{q}_1^{RI},...,\tilde{q}_{31}^{RI}$ so that the total bit sequence length is equal to Q_{RI}.

o_0^{RI}, o_1^{RI}, o_2^{RI}	RI
0, 0, 0	1
0, 0, 1	2
0, 1, 0	3
0, 1, 1	4
1, 0, 0	5
1, 0, 1	6
1, 1, 0	7
1, 1, 1	8

FIG. 14 (PRIOR ART)

[Table 5.2.2.6-6 of 3GPP TS 36.212 v13.0.0, Entitled "o_0^{RI}, o_1^{RI} to RI Mapping", is Reproduced as FIG. **13**]

[Table 5.2.2.6-7 of 3GPP TS 36.212 v13.0.0, Entitled "o_0^{RI}, o_1^{RI}, o_2^{RI} to RI Mapping", is Reproduced as FIG. **14**]

If RI feedback for a given DL cell consists of 3-bits of information, i.e., $[o_0^{RI}\ o_1^{RI}\ o_2^{RI}]$ with o_0^{RI} corresponding to MSB of 3-bit input and o_2^{RI} corresponding to LSB. The $[o_0^{RI}\ o_1^{RI}\ o_2^{RI}]$ to RI mapping is given by Table 5.2.2.6-7.

If RI feedback consists of $3 \le O^{RI} \le 11$ bits of information, i.e., $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$, then a coded bit sequence $[\tilde{q}_0^{RI}\ \tilde{q}_1^{RI}, \ldots, \tilde{q}_{31}^{RI}]$ is obtained by using the bit sequence $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$ as the input to the channel coding block described in section 5.2.2.6.4.

If RI feedback consists of $11 \le O^{RI} \le 22$ bits of information as a result of the aggregation of RI bits corresponding to multiple DL cells or multiple CSI processes, i.e., $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$, then the coded bit sequence, $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q_{RI}-1}^{RI}$ is obtained by using the bit sequence $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$ as the input to the channel coding block described in section 5.2.2.6.5.

If RI feedback consists of $O^{RI} > 22$ bits of information as a result of the aggregation of RI bits corresponding to multiple DL cells or multiple CSI processes, i.e., $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$, then the coded bit sequence is denoted by $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q_{RI}-1}^{RI}$. The CRC attachment, channel coding and rate matching of the HARQ-ACK bits are performed according to sections 5.1.1 setting L to 8 bits, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The "x" and "y" in Table 5.2.2.6-3 and 5.2.2.6-4 are placeholders for [2] to scramble the RI bits in a way that maximizes the Euclidean distance of the modulation symbols carrying rank information.

For the case where RI feedback for more than one DL cell is to be reported, the RI report for each DL cell is concatenated prior to coding in increasing order of cell index.

For the case where RI feedback for more than one CSI process is to be reported, the RI reports are concatenated prior to coding first in increasing order of CSI process index for each DL cell and then in increasing order of cell index.

For the case where RI feedback consists of one or two bits of information the bit sequence $q_0, q_1, q_2, \ldots, q_{Q_{RI}-1}$ is obtained by concatenation of multiple encoded RI blocks where Q_{RI} is the total number of coded bits for all the encoded RI blocks. The last concatenation of the encoded RI block may be partial so that the total bit sequence length is equal to Q_{RI}.

For the case where RI feedback consists of $3 < O^{RI} \le 11$ bits of information, the bit sequence $q_0, q_1, q_2, \ldots, q_{Q_{RI}-1}$ is obtained by the circular repetition of the bit sequence $\tilde{q}_0\ \tilde{q}_1, \ldots, \tilde{q}_{31}$ so that the total bit sequence length is equal to Q_{RI}.

When rank information is to be multiplexed with UL-SCH at a given PUSCH, the rank information is multiplexed in all layers of all transport blocks of that PUSCH. For a given

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rt block, the vector sequence output of the channel for rank information is denoted by $q_0, q_1, \ldots$, where q_i, $i=0, \ldots, Q'_{RI}-1$ are column vectors of $(Q_m \cdot N_L)$ and where $Q'_{RI}=Q_{RI}/Q_m$. The vector ce is obtained as follows:

k to 0

while $i<Q_{RI}$

$q_k=[q_i \ldots q_{i+Q_m-1}]$—temporary row vector

$$g_k^{RI} = [\tilde{g}_k^{RI} \cdots \tilde{g}_k^{RI}]^T$$

—replicating the row vector $\tilde{q}_k^{RI}$ N_L times and transposing into a column vector

$i=i+Q_m$

$k=k+1$

end while

where N_L is the number of layers onto which the UL-SCH transport block is mapped.

The same procedures for encoding of RI and RI multiplexing with UL-SCH at a given PUSCH are applied for CRI, using CRI instead of RI in the equations.

For channel quality control information (CQI and/or PMI denoted as CQI/PMI);

When the UE transmits channel quality control information bits, it shall determine the number of modulation coded symbols per layer Q' for channel quality information as

$$Q' = \min\left(\left\lceil \frac{(O+L)\cdot M_{sc}^{PUSCH\text{-}initial(s)} \cdot N_{symb}^{PUSCH\text{-}initial(s)} \cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C(s)-1} K_r^{(s)}} \right\rceil, M_{sc}^{PUSCH} \cdot N_{symb}^{PUSCH} - \frac{Q_{RI}^{(s)}}{Q_m^{(s)}}\right)$$

where

O is the number of CQI/PMI bits, and

L is the number of CRC bits given by

$$L = \begin{cases} 0 & O \le 11 \\ 8 & \text{otherwise} \end{cases},$$

and

$Q_{CQI}=Q_{\beta_{offset}^{CQI}}^{(s)} \cdot Q'$ and $\beta_{offset}^{PUSCH}=\beta_{offset}^{CQI}$, where β_{offset}^{CQI} shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH, and on the uplink power control subframe set for the corresponding PUSCH when two uplink power control subframe sets are configured by higher layers for the cell.

If RI or CRI is not transmitted then $Q_{RI}^{(s)}=0$.

The variable "x" in $K_r^{(x)}$ represents the transport block index corresponding to the highest I_{MCS} value indicated by the initial UL grant. In case the two transport blocks have the same I_{MCS} value in the corresponding initial UL grant,

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When rank information is to be multiplexed with UL-SCH at a given PUSCH, the rank information is multiplexed in all layers of all transport blocks of that PUSCH. For a given transport block, the vector sequence output of the channel coding for rank information is denoted by $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$, where $\underline{q}_i^{RI}$, $i = 0, \ldots, Q'_{RI}-1$ are column vectors of length $(Q_m \cdot N_L)$ and where $Q'_{RI} = Q_{RI} / Q_m$. The vector sequence is obtained as follows:

Set i, j, k to 0

while $i < Q_{RI}$

$\hat{\underline{q}}_k^{RI} = [q_i^{RI} \ldots q_{i+Q_m-1}^{RI}]$ -- temporary row vector

$\underline{q}_k^{RI} = [\overbrace{\hat{\underline{q}}_k^{RI} \cdots \hat{\underline{q}}_k^{RI}}^{N_L}]^T$ -- replicating the row vector $\hat{\underline{q}}_k^{RI}$ N_L times and transposing into a column vector

$i = i + Q_m$

$k = k + 1$

end while

where N_L is the number of layers onto which the UL-SCH transport block is mapped.

The same procedures for encoding of RI and RI multiplexing with UL-SCH at a given PUSCH are applied for CRI, using CRI instead of RI in the equations.

For channel quality control information (CQI and/or PMI denoted as CQI/PMI);

When the UE transmits channel quality control information bits, it shall determine the number of modulation coded symbols per layer Q' for channel quality information as

$$Q' = \min\left(\left\lceil \frac{(O+L)\cdot M_{sc}^{PUSCH-initial(x)} \cdot N_{symb}^{PUSCH-initial(x)} \cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C^{(x)}-1} K_r^{(x)}} \right\rceil, M_{sc}^{PUSCH} \cdot N_{symb}^{PUSCH} - \frac{Q_{RI}^{(x)}}{Q_m^{(x)}}\right)$$

where

- O is the number of CQI/PMI bits, and
- L is the number of CRC bits given by $L = \begin{cases} 0 & O \le 11 \\ 8 & \text{otherwise} \end{cases}$, and
- $Q_{CQI} = Q_m^{(x)} \cdot Q'$ and $\beta_{offset}^{PUSCH} = \beta_{offset}^{CQI}$, where β_{offset}^{CQI} shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH, and on the uplink power control subframe set for the corresponding PUSCH when two uplink power control subframe sets are configured by higher layers for the cell.
- If RI or CRI is not transmitted then $Q_{RI}^{(x)} = 0$.

The variable "x" in $K_r^{(x)}$ represents the transport block index corresponding to the highest I_{MCS} value indicated by the initial UL grant. In case the two transport blocks have the same I_{MCS} value in the corresponding initial UL grant, "x =1", which corresponds to the first transport block. $M_{sc}^{PUSCH-initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ are obtained from the initial PDCCH or EPDCCH for the same transport block. If there is no initial PDCCH or EPDCCH with DCI format 0 for the same transport block, $M_{sc}^{PUSCH-initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ shall be determined from:

[Table 5.2.2.6-3 of 3GPP TS 36.212 v13.0.0, Entitled "Encoding of 1-Bit RI", is Reproduced as FIG. **10**]

[Table 5.2.2.6-4 of 3GPP TS 36.212 v13.0.0, Entitled "Encoding of 2-Bit RI", is Reproduced as FIG. **11**]

[Table 5.2.2.6-5 of 3GPP TS 36.212 v13.0.0, Entitled "o_0^{RI} to RI Mapping", is Reproduced as FIG. 12]

[Table 5.2.2.6-6 of 3GPP TS 36.212 v13.0.0, Entitled "o_0^{RI}, o_1^{RI} to RI Mapping", is Reproduced as FIG. **13**]

[Table 5.2.2.6-7 of 3GPP TS 36.212 v13.0.0, Entitled "o_0^{RI}, o_1^{RI}, o_2^{RI} to RI Mapping", is Reproduced as FIG. **14**]

If RI feedback for a given DL cell consists of 3-bits of information, i.e., $[o_0^{RI}\ o_1^{RI}\ o_2^{RI}]$ with o_0^{RI} corresponding to MSB of 3-bit input and o_2^{RI} corresponding to LSB. The $[o_0^{RI}\ o_1^{RI}\ o_2^{RI}]$ to RI mapping is given by Table 5.2.2.6-7.

If RI feedback consists of $3 \le O^{RI} \le 11$ bits of information, i.e., $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$, then a coded bit sequence $[\tilde{q}_0^{RI}\ \tilde{q}_1^{RI}, \ldots, \tilde{q}_{31}^{RI}]$ is obtained by using the bit sequence $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$ as the input to the channel coding block described in section 5.2.2.6.4.

If RI feedback consists of $11 \le O^{RI} \le 22$ bits of information as a result of the aggregation of RI bits corresponding to multiple DL cells or multiple CSI processes, i.e., $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$, then the coded bit sequence, $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q_{RI}-1}^{RI}$ is obtained by using the bit sequence $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$ as the input to the channel coding block described in section 5.2.2.6.5.

If RI feedback consists of $O^{RI} > 22$ bits of information as a result of the aggregation of RI bits corresponding to multiple DL cells or multiple CSI processes, i.e., $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$, then the coded bit sequence is denoted by $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q_{RI}-1}^{RI}$. The CRC attachment, channel coding and rate matching of the HARQ-ACK bits are performed according to sections 5.1.1 setting L to 8 bits, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $[o_0^{RI}\ o_1^{RI}, \ldots, o_{O^{RI}-1}^{RI}]$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation. The "x" and "y" in Table 5.2.2.6-3 and 5.2.2.6-4 are placeholders for [2] to scramble the RI bits in a way that maximizes the Euclidean distance of the modulation symbols carrying rank information.

For the case where RI feedback for more than one DL cell is to be reported, the RI report for each DL cell is concatenated prior to coding in increasing order of cell index.

For the case where RI feedback for more than one CSI process is to be reported, the RI reports are concatenated prior to coding first in increasing order of CSI process index for each DL cell and then in increasing order of cell index.

For the case where RI feedback consists of one or two bits of information the bit sequence $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q_{RI}-1}^{RI}$ is obtained by concatenation of multiple encoded RI blocks where Q_{RI} is the total number of coded bits for all the encoded RI blocks. The last concatenation of the encoded RI block may be partial so that the total bit sequence length is equal to Q_{RI}.

For the case where RI feedback consists of $3 < O^{RI} \le 11$ bits of information, the bit sequence $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q_{RI}-1}^{RI}$ is obtained by the circular repetition of the bit sequence $\tilde{q}_0^{RI}, \tilde{q}_1^{RI}, \ldots, \tilde{q}_{31}^{RI}$ so that the total bit sequence length is equal to Q_{RI}.

When rank information is to be multiplexed with UL-SCH at a given PUSCH, the rank information is multiplexed in all layers of all transport blocks of that PUSCH. For a given transport block, the vector sequence output of the channel coding for rank information is denoted by $q_0^{RI}, q_1^{RI}, \ldots, q_{Q'_{RI}-1}^{RI}$, where q_i^{RI}, $i=0, \ldots, Q'_{RI}-1$ are column vectors of length $(Q_m \cdot N_L)$ and where $Q'_{RI} = Q_{RI}/Q_m$. The vector sequence is obtained as follows:

Set i, j, k to 0

while $i < Q_{RI}$

$\hat{q}_k^{RI} = [q_i^{RI} \ldots q_{i+Q_m-1}^{RI}]$—temporary row vector

$q_k^{RI} = [\overbrace{\hat{q}_k^{RI} \cdots \hat{q}_k^{RI}}^{N_L}]^T$

—replicating the row vector $\hat{q}_k^{RI}$ N_L times and transposing into a column vector

$i = i + Q_m$

$k = k + 1$

end while

where N_L is the number of layers onto which the UL-SCH transport block is mapped.

The same procedures for encoding of RI and RI multiplexing with UL-SCH at a given PUSCH are applied for CRI, using CRI instead of RI in the equations.

For channel quality control information (CQI and/or PMI denoted as CQI/PMI);

When the UE transmits channel quality control information bits, it shall determine the number of modulation coded symbols per layer Q' for channel quality information as

$$Q' = \min\left(\left\lceil \frac{(O+L)\cdot M_{sc}^{PUSCH-initial(x)} \cdot N_{symb}^{PUSCH-initial(x)} \cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C^{(x)}-1} K^{(x)}} \right\rceil, M_{sc}^{PUSCH} \cdot N_{symb}^{PUSCH} - \frac{Q_{RI}^{(x)}}{Q_m^{(x)}}\right)$$

where

O is the number of CQI/PMI bits, and

L is the number of CRC bits given by

$$L = \begin{cases} 0 & O \le 11 \\ 8 & \text{otherwise} \end{cases},$$

and

$Q_{CQI} = Q_{RI}^{(x)} \cdot Q'$ and $\beta_{offset}^{PUSCH} = \beta_{offset}^{CQI}$, where β_{offset}^{CQI} shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH, and on the uplink power control subframe set for the corresponding PUSCH when two uplink power control subframe sets are configured by higher layers for the cell.

If RI or CRI is not transmitted then $Q_{RI}^{(x)} = 0$.

The variable "x" in $K_r^{(x)}$ represents the transport block index corresponding to the highest I_{MCS} value indicated by the initial UL grant. In case the two transport blocks have the same I_{MCS} value in the corresponding initial UL grant,

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When rank information is to be multiplexed with UL-SCH at a given PUSCH, the rank information is multiplexed in all layers of all transport blocks of that PUSCH. For a given transport block, the vector sequence output of the channel coding for rank information is denoted by $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$, where $\underline{q}_i^{RI}$, $i = 0, \ldots, Q'_{RI}-1$ are column vectors of length $(Q_m \cdot N_L)$ and where $Q'_{RI} = Q_{RI} / Q_m$. The vector sequence is obtained as follows:

Set i, j, k to 0

while $i < Q_{RI}$

$\hat{\underline{q}}_k^{RI} = [q_i^{RI} \ldots q_{i+Q_m-1}^{RI}]$ -- temporary row vector

$\underline{q}_k^{RI} = [\overbrace{\hat{\underline{q}}_k^{RI} \cdots \hat{\underline{q}}_k^{RI}}^{N_L}]^T$ -- replicating the row vector $\hat{\underline{q}}_k^{RI}$ N_L times and transposing into a column vector

$i = i + Q_m$

$k = k + 1$

end while

where N_L is the number of layers onto which the UL-SCH transport block is mapped.

The same procedures for encoding of RI and RI multiplexing with UL-SCH at a given PUSCH are applied for CRI, using CRI instead of RI in the equations.

For channel quality control information (CQI and/or PMI denoted as CQI/PMI);

When the UE transmits channel quality control information bits, it shall determine the number of modulation coded symbols per layer Q' for channel quality information as

$$Q' = \min\left(\left\lceil \frac{(O+L)\cdot M_{sc}^{PUSCH-initial(x)} \cdot N_{symb}^{PUSCH-initial(x)} \cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C^{(x)}-1} K_r^{(x)}} \right\rceil, M_{sc}^{PUSCH} \cdot N_{symb}^{PUSCH} - \frac{Q_{RI}^{(x)}}{Q_m^{(x)}}\right)$$

where

- O is the number of CQI/PMI bits, and
- L is the number of CRC bits given by $L = \begin{cases} 0 & O \le 11 \\ 8 & \text{otherwise} \end{cases}$, and
- $Q_{CQI} = Q_m^{(x)} \cdot Q'$ and $\beta_{offset}^{PUSCH} = \beta_{offset}^{CQI}$, where β_{offset}^{CQI} shall be determined according to [3] depending on the number of transmission codewords for the corresponding PUSCH, and on the uplink power control subframe set for the corresponding PUSCH when two uplink power control subframe sets are configured by higher layers for the cell.
- If RI or CRI is not transmitted then $Q_{RI}^{(x)} = 0$.

The variable "x" in $K_r^{(x)}$ represents the transport block index corresponding to the highest I_{MCS} value indicated by the initial UL grant. In case the two transport blocks have the same I_{MCS} value in the corresponding initial UL grant, "x =1", which corresponds to the first transport block. $M_{sc}^{PUSCH-initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ are obtained from the initial PDCCH or EPDCCH for the same transport block. If there is no initial PDCCH or EPDCCH with DCI format 0 for the same transport block, $M_{sc}^{PUSCH-initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ shall be determined from:

"x=1", which corresponds to the first transport block. $M_{sc}^{PUSCH-initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ are obtained from the initial PDCCH or EPDCCH for the same transport block. If there is no initial PDCCH or EPDCCH with DCI format 0 for the same transport block, $M_{sc}^{PUSCH-initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ shall be determined from:

- the most recent semi-persistent scheduling assignment PDCCH or EPDCCH, when the initial PUSCH for the same transport block is semi-persistently scheduled, or,
- the random access response grant for the same transport block, when the PUSCH is initiated by the random access response grant.

$N_{symb}^{PUSCH-initial(x)}$ is the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the same transport block.

For UL-SCH data information $G = N_L^{(x)} \cdot (N_{symb}^{PUSCH} \cdot M_{sc}^{PUSCH} \cdot Q_m^{(x)} - Q_{CQI} - Q_{RI}^{(x)})$, where

- $N_L^{(x)}$ is the number of layers the corresponding UL-SCH transport block is mapped onto, and
- M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current sub-frame for the transport block, and
- N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current PUSCH transmission sub-frame given by $N_{symb}^{PUSCH} = (2 \cdot (N_{symb}^{UL} - 1) - N_{SRS})$, where
- N_{SRS} is equal to 1
  - if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or
  - if UE transmits PUSCH and SRS in the same subframe for the current subframe in the same serving cell, or
  - if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or
  - if the current subframe in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or
  - if the current subframe in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.
- Otherwise N_{SRS} is equal to 0.

In case of CQI/PMI report for more than one DL cell, $o_0, o_1, o_2, \ldots, o_{O-1}$ is the result of concatenating the CQI/PMI report for each DL cell in increasing order of cell index. For the case where CQI/PMI feedback for more than one CSI process is to be reported, $o_0, o_1, o_2, \ldots, o_{O-1}$ is the result of concatenating the CQI/PMI reports in increasing order of CSI process index for each DL cell and then in increasing order of cell index.

If the payload size is less than or equal to 11 bits, the channel coding of the channel quality information is performed according to section 5.2.2.6.4 with input sequence $o_0, o_1, o_2, \ldots, o_{O-1}$.

For payload sizes greater than 11 bits, the CRC attachment, channel coding and rate matching of the channel quality information is performed according to sections 5.1.1, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $o_0, o_1, o_2, \ldots, o_{O-1}$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The output sequence for the channel coding of channel quality information is denoted by $q_0, q_1, q_2, q_3, \ldots, \underline{q}_{N_L Q_{CQI}-1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

3GPP TS 36.212 v13.0.0 also states:

5.2.2.7 Data and Control Multiplexing

The control and data multiplexing is performed such that HARQ-ACK information is present on both slots and is mapped to resources around the demodulation reference signals. In addition, the multiplexing ensures that control and data information are mapped to different modulation symbols.

The inputs to the data and control multiplexing are the coded bits of the control information denoted by $q_0, q_1, q_2, q_3, \ldots, q_{N_L Q_{CQI}-1}$ and the coded bits of the UL-SCH denoted by $f_0, f_1, f_2, f_3, \ldots, f_{G-1}$. The output of the data and control multiplexing operation is denoted by $g_0, g_1, g_2, g_3, \ldots, g_{H'-1}$, where $H = (G + N_L \cdot Q_{CQI})$ and $H' = H/(N_L \cdot Q_m)$, and where $\underline{g}_i$, $i = 0, \ldots, H'-1$ are column vectors of length $(Q_m \cdot N_L)$. H is the total number of coded bits allocated for UL-SCH data and CQI/PMI information across the N_L transmission layers of the transport block.

In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the CQI/PMI information is multiplexed with data only on the UL-SCH transport block with highest I_{MCS} value on the initial grant. In case the two transport blocks have the same I_{MCS} value in the corresponding initial UL grant, the CQI/PMI information is multiplexed with data only on the first transport block. For that UL-SCH transport block or in the case of single transport block transmission, and assuming that N_L is the number of layers onto which the UL-SCH transport block is mapped, the control information and the data shall be multiplexed as follows:

```
Set i, j, k to 0
while j < N_L Q_CQI -- first place the control information
    g_k = [q_j ... q_{j+N_L Q_m - 1}]^T
    j = j + N_L · Q_m
    k = k + 1
end while
while i < G -- then place the data
    g_k = [f_i ... f_{i+Q_m N_L - 1}]^T
    i = i + Q_m · N_L
    k = k + 1
end while
```

5.2.2.8 Channel Interleaver

The channel interleaver described in this section in conjunction with the resource element mapping for PUSCH in [2] implements a time-first mapping of modulation symbols onto the transmit waveform while ensuring that the HARQ-ACK and RI information are present on both slots in the subframe. HARQ-ACK information is mapped to resources around the uplink demodulation reference signals while RI information is mapped to resources around those used by HARQ-ACK.

The input to the channel interleaver are denoted by $g_0, g_1, g_2, \ldots, g_{H'-1}$, $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q'_{RI}-1}^{RI}$ and $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q'_{ACK}-1}^{ACK}$. In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the HARQ-ACK and RI information are multiplexed with data on both UL-SCH transport blocks.

The number of modulation symbols per layer in the subframe is given by $H'_{total} = H' + Q'_{RI}$. The output bit sequence from the channel interleaver is derived as follows:

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- the most recent semi-persistent scheduling assignment PDCCH or EPDCCH, when the initial PUSCH for the same transport block is semi-persistently scheduled, or,
- the random access response grant for the same transport block, when the PUSCH is initiated by the random access response grant.

$N_{symb}^{PUSCH-initial(x)}$ is the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the same transport block.

For UL-SCH data information $G = N_L^{(x)} \cdot \left(N_{symb}^{PUSCH} \cdot M_{sc}^{PUSCH} \cdot Q_m^{(x)} - Q_{CQI} - Q_{RI}^{(x)}\right)$, where

- $N_L^{(x)}$ is the number of layers the corresponding UL-SCH transport block is mapped onto, and
- M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current sub-frame for the transport block, and
- N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current PUSCH transmission sub-frame given by $N_{symb}^{PUSCH} = \left(2 \cdot \left(N_{symb}^{UL} - 1\right) - N_{SRS}\right)$, where
  - N_{SRS} is equal to 1
    - if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or
    - if UE transmits PUSCH and SRS in the same subframe for the current subframe in the same serving cell, or
    - if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or
    - if the current subframe in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or
    - if the current subframe in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.
  - Otherwise N_{SRS} is equal to 0.

In case of CQI/PMI report for more than one DL cell, $o_0, o_1, o_2, ..., o_{O-1}$ is the result of concatenating the CQI/PMI report for each DL cell in increasing order of cell index. For the case where CQI/PMI feedback for more than one CSI process is to be reported, $o_0, o_1, o_2, ..., o_{O-1}$ is the result of concatenating the CQI/PMI reports in increasing order of CSI process index for each DL cell and then in increasing order of cell index.

– If the payload size is less than or equal to 11 bits, the channel coding of the channel quality information is performed according to section 5.2.2.6.4 with input sequence $o_0, o_1, o_2, ..., o_{O-1}$.

– For payload sizes greater than 11 bits, the CRC attachment, channel coding and rate matching of the channel quality information is performed according to sections 5.1.1, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $o_0, o_1, o_2, ..., o_{O-1}$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The output sequence for the channel coding of channel quality information is denoted by $q_0, q_1, q_2, q_3, ..., q_{N_L \cdot Q_{CQI}-1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

"x=1", which corresponds to the first transport block. $M_{sc}^{PUSCH-initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ are obtained from the initial PDCCH or EPDCCH for the same transport block. If there is no initial PDCCH or EPDCCH with DCI format 0 for the same transport block, $M_{sc}^{PUSCH-initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ shall be determined from:

the most recent semi-persistent scheduling assignment PDCCH or EPDCCH, when the initial PUSCH for the same transport block is semi-persistently scheduled, or,

the random access response grant for the same transport block, when the PUSCH is initiated by the random access response grant.

$N_{symb}^{PUSCH-initial(x)}$ is the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the same transport block.

For UL-SCH data information $G=N_L^{(x)} \cdot (N_{symb}^{PUSCH} \cdot M_{sc}^{PUSCH} \cdot Q_m^{(x)} - Q_{CQI} - Q_{RI}^{(x)})$, where

$N_L^{(x)}$ is the number of layers the corresponding UL-SCH transport block is mapped onto, and

M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current sub-frame for the transport block, and

N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current PUSCH transmission sub-frame given by $N_{symb}^{PUSCH}=(2 \cdot (N_{symb}^{UL}-1)-N_{SRS})$, where

N_{SRS} is equal to 1

if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or

if UE transmits PUSCH and SRS in the same subframe for the current subframe in the same serving cell, or

if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or

if the current subframe in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or

if the current subframe in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.

Otherwise N_{SRS} is equal to 0.

In case of CQI/PMI report for more than one DL cell, $o_0, o_1, o_2, \ldots, o_{O-1}$ is the result of concatenating the CQI/PMI report for each DL cell in increasing order of cell index. For the case where CQI/PMI feedback for more than one CSI process is to be reported, $o_0, o_1, o_2, \ldots, o_{O-1}$ is the result of concatenating the CQI/PMI reports in increasing order of CSI process index for each DL cell and then in increasing order of cell index.

If the payload size is less than or equal to 11 bits, the channel coding of the channel quality information is performed according to section 5.2.2.6.4 with input sequence $o_0, o_1, o_2, \ldots, o_{O-1}$.

For payload sizes greater than 11 bits, the CRC attachment, channel coding and rate matching of the channel quality information is performed according to sections 5.1.1, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $o_0, o_1, o_2, \ldots, o_{O-1}$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The output sequence for the channel coding of channel quality information is denoted by $q_0, q_1, q_2, q_3, \ldots, q_{N_L \cdot Q_{CQI}-1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

3GPP TS 36.212 V13.0.0 also states:

5.2.2.7 Data and Control Multiplexing

The control and data multiplexing is performed such that HARQ-ACK information is present on both slots and is mapped to resources around the demodulation reference signals. In addition, the multiplexing ensures that control and data information are mapped to different modulation symbols.

The inputs to the data and control multiplexing are the coded bits of the control information denoted by $q_0, q_1, q_2, q_3, \ldots, q_{N_L \cdot Q_{CQI}-1}$ and the coded bits of the UL-SCH denoted by $f_0, f_1, f_2, f_3, \ldots, f_{G-1}$. The output of the data and control multiplexing operation is denoted by $g_0, g_1, g_2, g_3, \ldots, g_{H'-1}$, where $H=(G+N_L \cdot Q_{CQI})$ and $H'=H/(N_L \cdot Q_m)$, and where g_i, $i=0, \ldots, H'-1$ are column vectors of length $(Q_m \cdot N_L)$. H is the total number of coded bits allocated for UL-SCH data and CQI/PMI information across the N_L transmission layers of the transport block.

In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the CQI/PMI information is multiplexed with data only on the UL-SCH transport block with highest I_{MCS} value on the initial grant. In case the two transport blocks have the same I_{MCS} value in the corresponding initial UL grant, the CQI/PMI information is multiplexed with data only on the first transport block. For that UL-SCH transport block or in the case of single transport block transmission, and assuming that N_L is the number of layers onto which the UL-SCH transport block is mapped, the control information and the data shall be multiplexed as follows:

```
Set i, j, k to 0
while j < N_L Q_CQI -- first place the control information
    g_k = [q_j ... q_{j+N_L Q_m-1}]^T
    j = j + N_L · Q_m
    k = k + 1
end while
while i < G -- then place the data
    g_k = [f_i ... f_{i+Q_m N_L-1}]^T
    i = i+Q_m · N_L
    k = k + 1
end while
```

5.2.2.8 Channel Interleaver

The channel interleaver described in this section in conjunction with the resource element mapping for PUSCH in [2] implements a time-first mapping of modulation symbols onto the transmit waveform while ensuring that the HARQ-ACK and RI information are present on both slots in the subframe. HARQ-ACK information is mapped to resources around the uplink demodulation reference signals while RI information is mapped to resources around those used by HARQ-ACK.

The input to the channel interleaver are denoted by $g_0, g_1, g_2, \ldots, g_{H'-1}$, $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q'_{RI}-1}^{RI}$ and $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q'_{ACK}-1}^{ACK}$. In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the HARQ-ACK and RI information are multiplexed with data on both UL-SCH transport blocks.

The number of modulation symbols per layer in the subframe is given by $H'_{total}=H'+Q'_{RI}$. The output bit sequence from the channel interleaver is derived as follows:

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5.2.2.6.5 Channel coding for more than 11 bits of HARQ-ACK information

The HARQ-ACK bits input to the channel coding block are denoted by $o_0^{ACK}, o_1^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ where $11 < O^{ACK} \leq 22$ is the number of bits.

The sequences of bits $o_0^{ACK}, o_1^{ACK}, o_2^{ACK}, \ldots, o_{\lceil O^{ACK}/2 \rceil - 1}^{ACK}$ and $o_{\lceil O^{ACK}/2 \rceil}^{ACK}, o_{\lceil O^{ACK}/2 \rceil + 1}^{ACK}, o_{\lceil O^{ACK}/2 \rceil + 2}^{ACK}, \ldots, o_{O^{ACK}-1}^{ACK}$ are encoded as follows

$$\tilde{q}_i = \sum_{n=0}^{\lceil O^{ACK}/2 \rceil - 1} \left(o_n^{ACK} \cdot M_{i,n} \right) \bmod 2$$

and

$$\tilde{\tilde{q}}_i = \sum_{n=0}^{O^{ACK} - \lceil O^{ACK}/2 \rceil - 1} \left(o_{\lceil O^{ACK}/2 \rceil + n}^{ACK} \cdot M_{i,n} \right) \bmod 2$$

where $i = 0, 1, 2, \ldots, 31$ and the basis sequences $M_{i,n}$ are defined in Table 5.2.2.6.4-1.

The output bit sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q_{ACK}-1}^{ACK}$ is obtained by the concatenation and circular repetition of the bit sequences $\tilde{q}_0, \tilde{q}_1, \tilde{q}_2, \ldots, \tilde{q}_{31}$ and $\tilde{\tilde{q}}_0, \tilde{\tilde{q}}_1, \tilde{\tilde{q}}_2, \ldots, \tilde{\tilde{q}}_{31}$ as follows:

Set $i = 0$

while $i < \lceil Q'/2 \rceil \cdot Q_m$

$q_i^{ACK} = \tilde{q}_{i \bmod 32}$

$i = i + 1$

end while

Set $i = 0$

while $i < (Q' - \lceil Q'/2 \rceil) \cdot Q_m$

$q_{\lceil Q'/2 \rceil Q_m + i}^{ACK} = \tilde{\tilde{q}}_{i \bmod 32}$

$i = i + 1$

end while

5.2.2.7 Data and control multiplexing

The control and data multiplexing is performed such that HARQ-ACK information is present on both slots and is mapped to resources around the demodulation reference signals. In addition, the multiplexing ensures that control and data information are mapped to different modulation symbols.

The inputs to the data and control multiplexing are the coded bits of the control information denoted by $q_0, q_1, q_2, q_3, \ldots, q_{N_L \cdot Q_{CQI}-1}$ and the coded bits of the UL-SCH denoted by $f_0, f_1, f_2, f_3, \ldots, f_{G-1}$. The output of the data and control multiplexing operation is denoted by $\underline{g}_0, \underline{g}_1, \underline{g}_2, \underline{g}_3, \ldots, \underline{g}_{H'-1}$, where $H = (G + N_L \cdot Q_{CQI})$ and $H' = H/(N_L \cdot Q_m)$, and where $\underline{g}_i$, $i = 0, \ldots, H'-1$ are column vectors of length $(Q_m \cdot N_L)$. H is the total number of coded bits allocated for UL-SCH data and CQI/PMI information across the N_L transmission layers of the transport block.

"x=1", which corresponds to the first transport block. $M_{sc}^{PUSCH\text{-}initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ are obtained from the initial PDCCH or EPDCCH for the same transport block. If there is no initial PDCCH or EPDCCH with DCI format 0 for the same transport block, $M_{sc}^{PUSCH\text{-}initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ shall be determined from:

- the most recent semi-persistent scheduling assignment PDCCH or EPDCCH, when the initial PUSCH for the same transport block is semi-persistently scheduled, or,
- the random access response grant for the same transport block, when the PUSCH is initiated by the random access response grant.

$N_{symb}^{PUSCH\text{-}initial(x)}$ is the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the same transport block.

For UL-SCH data information $G = N_{symb}^{PUSCH} \cdot M_{sc}^{PUSCH} \cdot Q_m^{(x)} - Q_{CQI} - Q_{RI}^{(x)}$, where

- $N_L^{(x)}$ is the number of layers the corresponding UL-SCH transport block is mapped onto, and
- M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current sub-frame for the transport block, and
- N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current PUSCH transmission sub-frame given by $N_{symb}^{PUSCH} = (2 \cdot (N_{symb}^{UL} - 1) - N_{SRS})$, where
  - N_{SRS} is equal to 1
    - if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or
    - if UE transmits PUSCH and SRS in the same sub-frame for the current subframe in the same serving cell, or
    - if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or
    - if the current subframe in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or
    - if the current subframe in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.
  - Otherwise N_{SRS} is equal to 0.

In case of CQI/PMI report for more than one DL cell, $o_0, o_1, o_2, \ldots, o_{O-1}$ is the result of concatenating the CQI/PMI report for each DL cell in increasing order of cell index. For the case where CQI/PMI feedback for more than one CSI process is to be reported, $o_0, o_1, o_2, \ldots, o_{O-1}$ is the result of concatenating the CQI/PMI reports in increasing order of CSI process index for each DL cell and then in increasing order of cell index.

If the payload size is less than or equal to 11 bits, the channel coding of the channel quality information is performed according to section 5.2.2.6.4 with input sequence $o_0, o_1, o_2, \ldots, o_{O-1}$.

For payload sizes greater than 11 bits, the CRC attachment, channel coding and rate matching of the channel quality information is performed according to sections 5.1.1, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $o_0, o_1, o_2, \ldots, o_{O-1}$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The output sequence for the channel coding of channel quality information is denoted by $q_0, q_1, q_2, q_3, \ldots, q_{N_L \cdot Q_{CQI}-1}$ where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

3GPP TS 36.212 v13.0.0 also states:

5.2.2.7 Data and Control Multiplexing

The control and data multiplexing is performed such that HARQ-ACK information is present on both slots and is mapped to resources around the demodulation reference signals. In addition, the multiplexing ensures that control and data information are mapped to different modulation symbols.

The inputs to the data and control multiplexing are the coded bits of the control information denoted by $q_0, q_1, q_2, q_3, \ldots, q_{N_L \cdot Q_{CQI}-1}$ and the coded bits of the UL-SCH denoted by $f_0, f_1, f_2, f_3, \ldots, f_{G-1}$. The output of the data and control multiplexing operation is denoted by $g_0, g_1, g_2, g_3, \ldots, g_{H'-1}$, where $H = (G + N_L \cdot Q_{CQI})$ and $H' = H/(N_L \cdot Q_m)$, and where g_i, $i = 0, \ldots, H'-1$ are column vectors of length $(Q_m \cdot N_L)$. H is the total number of coded bits allocated for UL-SCH data and CQI/PMI information across the N_L transmission layers of the transport block.

In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the CQI/PMI information is multiplexed with data only on the UL-SCH transport block with highest I_{MCS} value on the initial grant. In case the two transport blocks have the same I_{MCS} value in the corresponding initial UL grant, the CQI/PMI information is multiplexed with data only on the first transport block. For that UL-SCH transport block or in the case of single transport block transmission, and assuming that N_L is the number of layers onto which the UL-SCH transport block is mapped, the control information and the data shall be multiplexed as follows:

```
Set i, j, k to 0
while j < N_L Q_CQI -- first place the control information
    g_k = [q_j ... q_{j+N_L Q_m - 1}]^T
    j = j + N_L · Q_m
    k = k + 1
end while
while i < G -- then place the data
    g_k = [f_i ... f_{i+Q_m N_L - 1}]^T
    i = i + Q_m · N_L
    k = k + 1
end while
```

5.2.2.8 Channel Interleaver

The channel interleaver described in this section in conjunction with the resource element mapping for PUSCH in [2] implements a time-first mapping of modulation symbols onto the transmit waveform while ensuring that the HARQ-ACK and RI information are present on both slots in the subframe. HARQ-ACK information is mapped to resources around the uplink demodulation reference signals while RI information is mapped to resources around those used by HARQ-ACK.

The input to the channel interleaver are denoted by $g_0, g_1, g_2, \ldots, g_{H'-1}$, $g_0^{RI}, g_1^{RI}, g_2^{RI}, \ldots, g_{Q'_{RI}-1}^{RI}$ and $g_0^{ACK}, g_1^{ACK}, g_2^{ACK}, \ldots, g_{Q'_{ACK}-1}^{ACK}$. In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the HARQ-ACK and RI information are multiplexed with data on both UL-SCH transport blocks.

The number of modulation symbols per layer in the subframe is given by $H'_{total} = H' + Q'_{RI}$. The output bit sequence from the channel interleaver is derived as follows:

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In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the CQI/PMI information is multiplexed with data only on the UL-SCH transport block with highest I_{MCS} value on the initial grant. In case the two transport blocks have the same I_{MCS} value in the corresponding initial UL grant, the CQI/PMI information is multiplexed with data only on the first transport block. For that UL-SCH transport block or in the case of single transport block transmission, and assuming that N_L is the number of layers onto which the UL-SCH transport block is mapped, the control information and the data shall be multiplexed as follows:

Set i, j, k to 0

while $j < N_L \cdot Q_{CQI}$ -- first place the control information

$$\underline{g}_k = [q_j \ldots q_{j+N_L \cdot Q_m - 1}]^T$$

$$j = j + N_L \cdot Q_m$$

$$k = k + 1$$

end while

while $i < G$ -- then place the data

$$\underline{g}_k = [f_i \ldots f_{i+Q_m \cdot N_L - 1}]^T$$

$$i = i + Q_m \cdot N_L$$

$$k = k + 1$$

end while

5.2.2.8 Channel interleaver

The channel interleaver described in this section in conjunction with the resource element mapping for PUSCH in [2] implements a time-first mapping of modulation symbols onto the transmit waveform while ensuring that the HARQ-ACK and RI information are present on both slots in the subframe. HARQ-ACK information is mapped to resources around the uplink demodulation reference signals while RI information is mapped to resources around those used by HARQ-ACK.

The input to the channel interleaver are denoted by $\underline{g}_0, \underline{g}_1, \underline{g}_2, \ldots, \underline{g}_{H'-1}$, $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$ and $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \underline{q}_2^{ACK}, \ldots, \underline{q}_{Q'_{ACK}-1}^{ACK}$. In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the HARQ-ACK and RI information are multiplexed with data on both UL-SCH transport blocks.

The number of modulation symbols per layer in the subframe is given by $H'_{total} = H' + \overset{'}{Q}_{RI}$. The output bit sequence from the channel interleaver is derived as follows:

(1) Assign $C_{mux} = N_{\text{symb}}^{\text{PUSCH}}$ to be the number of columns of the matrix. The columns of the matrix are numbered 0, 1, 2,..., $C_{mux} - 1$ from left to right. $N_{\text{symb}}^{\text{PUSCH}}$ is determined according to section 5.2.2.6.

(2) The number of rows of the matrix is $R_{mux} = (H'_{total} \cdot Q_m \cdot N_L)/C_{mux}$ and we define $R'_{mux} = R_{mux}/(Q_m \cdot N_L)$.

The rows of the rectangular matrix are numbered 0, 1, 2,..., $R_{mux} - 1$ from top to bottom.

(3) If rank information is transmitted in this subframe, the vector sequence $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$ is written onto the columns indicated by Table 5.2.2.8-1, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code.

Set i, j to 0.

"x=1", which corresponds to the first transport block. $M_{sc}^{PUSCH\text{-}initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ are obtained from the initial PDCCH or EPDCCH for the same transport block. If there is no initial PDCCH or EPDCCH with DCI format 0 for the same transport block, $M_{sc}^{PUSCH\text{-}initial(x)}$, $C^{(x)}$, and $K_r^{(x)}$ shall be determined from:

- the most recent semi-persistent scheduling assignment PDCCH or EPDCCH, when the initial PUSCH for the same transport block is semi-persistently scheduled, or,
- the random access response grant for the same transport block, when the PUSCH is initiated by the random access response grant.

$N_{symb}^{PUSCH\text{-}initial(x)}$ is the number of SC-FDMA symbols per subframe for initial PUSCH transmission for the same transport block.

For UL-SCH data information $G=N_L^{(x)} \cdot (N_{symb}^{PUSCH} \cdot M_{sc}^{PUSCH} \cdot Q_m^{(x)} - Q_{CQI} - Q_{RI}^{(x)})$, where

- $N_L^{(x)}$ is the number of layers the corresponding UL-SCH transport block is mapped onto, and
- M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current sub-frame for the transport block, and
- N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current PUSCH transmission sub-frame given by $N_{symb}^{PUSCH} = (2 \cdot (N_{symb}^{UL} - 1) - N_{SRS})$, where
- N_{SRS} is equal to 1
  - if UE configured with one UL cell is configured to send PUSCH and SRS in the same subframe for initial transmission, or
  - if UE transmits PUSCH and SRS in the same sub-frame for the current subframe in the same serving cell, or
  - if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or
  - if the current subframe in the same serving cell is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or
  - if the current subframe in the same serving cell is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs.
- Otherwise N_{SRS} is equal to 0.

In case of CQI/PMI report for more than one DL cell, $o_0, o_1, o_2, \ldots, o_{O-1}$ is the result of concatenating the CQI/PMI report for each DL cell in increasing order of cell index. For the case where CQI/PMI feedback for more than one CSI process is to be reported, $o_0, o_1, o_2, \ldots, o_{O-1}$ is the result of concatenating the CQI/PMI reports in increasing order of CSI process index for each DL cell and then in increasing order of cell index.

If the payload size is less than or equal to 11 bits, the channel coding of the channel quality information is performed according to section 5.2.2.6.4 with input sequence $o_0, o_1, o_2, \ldots, o_{O-1}$.

For payload sizes greater than 11 bits, the CRC attachment, channel coding and rate matching of the channel quality information is performed according to sections 5.1.1, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $o_0, o_1, o_2, \ldots, o_{O-1}$. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The output sequence for the channel coding of channel quality information is denoted by $q_0, q_1, q_2, q_3, \ldots, q_{N_L \cdot Q_{CQI}-1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

3GPP TS 36.212 v13.0.0 also states:

5.2.2.7 Data and Control Multiplexing

The control and data multiplexing is performed such that HARQ-ACK information is present on both slots and is mapped to resources around the demodulation reference signals. In addition, the multiplexing ensures that control and data information are mapped to different modulation symbols.

The inputs to the data and control multiplexing are the coded bits of the control information denoted by $q_0, q_1, q_2, q_3, \ldots, q_{N_L \cdot Q_{CQI}-1}$ and the coded bits of the UL-SCH denoted by $f_0, f_1, f_2, f_3, \ldots, f_{G-1}$. The output of the data and control multiplexing operation is denoted by $g_0, g_1, g_2, g_3, \ldots, g_{H'-1}$, where $H=(G+N_L \cdot Q_{CQI})$ and $H'=H/(N_L \cdot Q_m)$, and where g_i, i=0, . . . , H'−1 are column vectors of length $(Q_m \cdot N_L)$. H is the total number of coded bits allocated for UL-SCH data and CQI/PMI information across the N_L transmission layers of the transport block.

In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the CQI/PMI information is multiplexed with data only on the UL-SCH transport block with highest I_{MCS} value on the initial grant. In case the two transport blocks have the same I_{MCS} value in the corresponding initial UL grant, the CQI/PMI information is multiplexed with data only on the first transport block. For that UL-SCH transport block or in the case of single transport block transmission, and assuming that N_L is the number of layers onto which the UL-SCH transport block is mapped, the control information and the data shall be multiplexed as follows:

```
Set i, j, k to 0
while j < N_L Q_CQI -- first place the control information
    g_k = [q_j ... q_{j+N_L Q_m - 1}]^T
    j = j + N_L · Q_m
    k = k + 1
end while
while i < G -- then place the data
    g_k = [f_i ... f_{i+Q_m N_L - 1}]^T
    i = i + Q_m · N_L
    k = k + 1
end while
```

5.2.2.8 Channel Interleaver

The channel interleaver described in this section in conjunction with the resource element mapping for PUSCH in [2] implements a time-first mapping of modulation symbols onto the transmit waveform while ensuring that the HARQ-ACK and RI information are present on both slots in the subframe. HARQ-ACK information is mapped to resources around the uplink demodulation reference signals while RI information is mapped to resources around those used by HARQ-ACK.

The input to the channel interleaver are denoted by $g_0, g_1, g_2, \ldots, g_{H'-1}$, $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q'_{RI}-1}^{RI}$ and $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q'_{ACK}-1}^{ACK}$. In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the HARQ-ACK and RI information are multiplexed with data on both UL-SCH transport blocks.

The number of modulation symbols per layer in the subframe is given by $H'_{total} = H' + Q'_{RI}$. The output bit sequence from the channel interleaver is derived as follows:

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In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the CQI/PMI information is multiplexed with data only on the UL-SCH transport block with highest I_{MCS} value on the initial grant. In case the two transport blocks have the same I_{MCS} value in the corresponding initial UL grant, the CQI/PMI information is multiplexed with data only on the first transport block. For that UL-SCH transport block or in the case of single transport block transmission, and assuming that N_L is the number of layers onto which the UL-SCH transport block is mapped, the control information and the data shall be multiplexed as follows:

Set i, j, k to 0

while $j < N_L \cdot Q_{CQI}$ -- first place the control information

$$\underline{g}_k = [q_j \ldots q_{j+N_L \cdot Q_m - 1}]^T$$

$$j = j + N_L \cdot Q_m$$

$$k = k + 1$$

end while

while $i < G$ -- then place the data

$$\underline{g}_k = [f_i \ldots f_{i+Q_m \cdot N_L - 1}]^T$$

$$i = i + Q_m \cdot N_L$$

$$k = k + 1$$

end while

5.2.2.8 Channel interleaver

The channel interleaver described in this section in conjunction with the resource element mapping for PUSCH in [2] implements a time-first mapping of modulation symbols onto the transmit waveform while ensuring that the HARQ-ACK and RI information are present on both slots in the subframe. HARQ-ACK information is mapped to resources around the uplink demodulation reference signals while RI information is mapped to resources around those used by HARQ-ACK.

The input to the channel interleaver are denoted by $\underline{g}_0, \underline{g}_1, \underline{g}_2, \ldots, \underline{g}_{H'-1}$; $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$ and $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \underline{q}_2^{ACK}, \ldots, \underline{q}_{Q'_{ACK}-1}^{ACK}$. In case where more than one UL-SCH transport block are transmitted in a subframe of an UL cell, the HARQ-ACK and RI information are multiplexed with data on both UL-SCH transport blocks.

The number of modulation symbols per layer in the subframe is given by $H'_{total} = H' + Q'_{RI}$. The output bit sequence from the channel interleaver is derived as follows:

(1) Assign $C_{mux} = N_{symb}^{PUSCH}$ to be the number of columns of the matrix. The columns of the matrix are numbered 0, 1, 2,…, $C_{mux} - 1$ from left to right. N_{symb}^{PUSCH} is determined according to section 5.2.2.6.

(2) The number of rows of the matrix is $R_{mux} = (H'_{total} \cdot Q_m \cdot N_L)/C_{mux}$ and we define $R'_{mux} = R_{mux}/(Q_m \cdot N_L)$.

The rows of the rectangular matrix are numbered 0, 1, 2,…, $R_{mux} - 1$ from top to bottom.

(3) If rank information is transmitted in this subframe, the vector sequence $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$ is written onto the columns indicated by Table 5.2.2.8-1, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code.

Set i, j to 0.

(1) Assign $C_{max}=N_{symb}^{PUSCH}$ to be the number of columns of the matrix. The columns of the matrix are numbered 0, 1, 2, . . . , $C_{max}-1$ from left to right. N_{symb}^{PUSCH} is determined according to section 5.2.2.6.

(2) The number of rows of the matrix is $R_{max}=(J'_{total}/Q_m \cdot N_L)/C_{max}$ and we define $R'_{max}=R_{max}/(Q_m \cdot N_L)$.
The rows of the rectangular matrix are numbered 0, 1, 2, . . . , $R_{max}-1$ from top to bottom.

(3) If rank information is transmitted in this subframe, the vector sequence $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q'_{RI}-1}^{RI}$ is written onto the columns indicated by Table 5.2.2.8-1, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code.

```
Set i, j to 0.
Set r to R_max' − 1
while i < Q'_RI
    c_RI = Column Set( j )
    y_{r×C_max+c_RI} = q_i^RI
    i = i + 1
    r = R_max' − 1 − [i/4]
    j = (j + 3)mod4
end while
```

Where ColumnSet is given in Table 5.2.2.8-1 and indexed left to right from 0 to 3.

(4) Write the input vector sequence, for k=0, 1, . . . , H'−1, into the $(R_{max} \times C_{max})$ matrix by sets of $(Q_m \cdot N_L)$ rows starting with the vector y_0 in column 0 and rows 0 to $(Q_m \cdot N_L - 1)$ and skipping the matrix entries that are already occupied:

$$\begin{bmatrix} y_0 & y_1 & y_2 & \cdots & y_{C_{max}-1} \\ y_{C_{max}} & y_{C_{max}+1} & y_{C_{max}+2} & \cdots & y_{2C_{max}-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ y_{(R'_{max}-1)\times C_{max}} & y_{(R'_{max}-1)\times C_{max}+1} & y_{(R'_{max}-1)\times C_{max}+2} & \cdots & y_{(R'_{max}\times C_{max}-1)} \end{bmatrix}$$

The pseudocode is as follows:

```
Set i, k to 0.
while k < H',
    if y_i is not assigned to RI symbols
        y_i = g_k
        k = k + 1
    end if
    i = i+1
end while
```

(5) If HARQ-ACK information is transmitted in this subframe, the vector sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q'_{ACK}-1}^{ACK}$ is written onto the columns indicated by Table 5.2.2.8-2, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code. Note that this operation overwrites some of the channel interleaver entries obtained in step (4).

```
Set i, j to 0.
Set r to R_max' − 1
while i < Q'_ACK
    c_ACK = ColumnSet(j)
    y_{r×C_max+c_ACK} = q_i^ACK
    i = i + 1
    r = R_max' − 1 − [i/4]
    j = (j + 3)mod4
end while
```


-continued

Where ColumnSet is given in Table 5.2.2.8-2 and indexed left to right from 0 to 3

(6) The output of the block interleaver is the bit sequence read out column by column from the $(R_{max} \times C_{max})$ matrix. The bits after channel interleaving are denoted by $h_0, h_1, h_2, \ldots, h_{H+N_L \cdot Q_{RI}-1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

[Table 5.2.2.8-1 of 3GPP TS 36.212 v13.0.0, Entitled "Column Set for Insertion of Rank Information", is Reproduced as FIG. **15**]

[Table 5.2.2.8-2 of 3GPP TS 36.212 v13.0.0, Entitled "Column Set for Insertion of HARQ-ACK Information", is Reproduced as FIG. **16**]

The same channel interleaver procedures for RI are applied for CRI, using CRI instead of RI in the equations.

3GPP TS 36.212 v13.0.0 also states:

5.2.4 Uplink Control Information on PUSCH without UL-SCH Data

When control data are sent via PUSCH without UL-SCH data, the following coding steps can be identified:

Channel coding of control information
Control information mapping
Channel interleaver

5.2.4.1 Channel Coding of Control Information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI), HARQ-ACK and rank indication. Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When the UE transmits HARQ-ACK bits or rank indicator bits, it shall determine the number of coded symbols Q' for HARQ-ACK or rank indicator as

$$Q' = \min\left(\left\lceil \frac{O \cdot M_{sc}^{PUSCH} \cdot N_{symb}^{PUSCH} \cdot P_{offset}^{PUSCH}}{O_{CQI-MIN}} \right\rceil, 4 \cdot M_{sc}^{PUSCH}\right)$$

where O is the number of HARQ-ACK bits as defined in section 5.2.2.6, or rank indicator bits, $O_{CQI-MIN}$ is the number of CQI bits including CRC bits assuming rank equals to 1 for all serving cells for which an aperiodic CSI report is triggered [3], M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current subframe expressed as a number of subcarriers in [2], and N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current

PUSCH transmission sub frame given by $N_{symb}^{PUSCH} = (2 \cdot (N_{symb}^{UL} - 1) - N_{SRS})$, where N_{SRS} is equal to 1 if UE is configured to send PUSCH and SRS in the same subframe for the current subframe, or if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or if the current subframe is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or if the current subframe is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs. Otherwise N_{SRS} is equal to 0.

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Set r to $R'_{mux}-1$

while $i < Q'_{RI}$

$c_{RI} = \text{ColumnSet}(j)$

$\underline{y}_{r \times C_{mux}+c_{RI}} = \underline{q}_i^{RI}$

$i = i+1$

$r = R'_{mux}-1-\lfloor i/4 \rfloor$

$j = (j+3) \bmod 4$

end while

Where ColumnSet is given in Table 5.2.2.8-1 and indexed left to right from 0 to 3.

(4) Write the input vector sequence, for $k = 0, 1, \ldots, H'-1$, into the $(R_{mux} \times C_{mux})$ matrix by sets of $(Q_m \cdot N_L)$ rows starting with the vector $\underline{y}_0$ in column 0 and rows 0 to $(Q_m \cdot N_L - 1)$ and skipping the matrix entries that are already occupied:

$$\begin{bmatrix} \underline{y}_0 & \underline{y}_1 & \underline{y}_2 & \cdots & \underline{y}_{C_{mux}-1} \\ \underline{y}_{C_{mux}} & \underline{y}_{C_{mux}+1} & \underline{y}_{C_{mux}+2} & \cdots & \underline{y}_{2C_{mux}-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \underline{y}_{(R'_{mux}-1)\times C_{mux}} & \underline{y}_{(R'_{mux}-1)\times C_{mux}+1} & \underline{y}_{(R'_{mux}-1)\times C_{mux}+2} & \cdots & \underline{y}_{(R'_{mux}\times C_{mux}-1)} \end{bmatrix}$$

The pseudocode is as follows:

Set i, k to 0.

while k < H',

if $\underline{y}_i$ is not assigned to RI symbols

$\underline{y}_i = \underline{g}_k$

k = k + 1

end if

i = i+1

end while

(5) If HARQ-ACK information is transmitted in this subframe, the vector sequence $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \underline{q}_2^{ACK}, \ldots, \underline{q}_{Q'_{ACK}-1}^{ACK}$ is written onto the columns indicated by Table 5.2.2.8-2, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code. Note that this operation overwrites some of the channel interleaver entries obtained in step (4).

Set i, j to 0.

Set r to $R'_{mux}-1$

while $i < Q'_{ACK}$

$c_{ACK} = \text{ColumnSet}(j)$

(1) Assign $C_{max}=N_{symb}^{PUSCH}$ to be the number of columns of the matrix. The columns of the matrix are numbered 0, 1, 2, . . . , $C_{max}-1$ from left to right. N_{symb}^{PUSCH} is determined according to section 5.2.2.6.

(2) The number of rows of the matrix is $R_{max}=(J'_{total}/Q_m \cdot N_L)/C_{max}$ and we define $R'_{max}=R_{max}/(Q_m \cdot N_L)$.

The rows of the rectangular matrix are numbered 0, 1, 2, . . . , $R_{max}-1$ from top to bottom.

(3) If rank information is transmitted in this subframe, the vector sequence $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q'_{RI}-1}^{RI}$ is written onto the columns indicated by Table 5.2.2.8-1, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code.

```
Set i, j to 0.
Set r to R_max' − 1
while i < Q_RI'
    c_RI = Column Set( j)
    y_{r×C_max+c_RI} = q_i^RI
    i = i + 1
    r = R_max' − 1 − ⌊i/4⌋
    j = (j + 3)mod4
end while
```

Where ColumnSet is given in Table 5.2.2.8-1 and indexed left to right from 0 to 3.

(4) Write the input vector sequence, for k=0, 1, . . . , H'−1, into the $(R_{max} \times C_{max})$ matrix by sets of $(Q_m \cdot N_L)$ rows starting with the vector y_0 in column 0 and rows 0 to $(Q_m \cdot N_L - 1)$ and skipping the matrix entries that are already occupied:

$$\begin{bmatrix} y_0 & y_1 & y_2 & \cdots & y_{C_{max}-1} \\ y_{C_{max}} & y_{C_{max}+1} & y_{C_{max}+2} & \cdots & y_{2C_{max}-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ y_{(R'_{max}-1)\times C_{max}} & y_{(R'_{max}-1)\times C_{max}+1} & y_{(R'_{max}-1)\times C_{max}+2} & \cdots & y_{(R'_{max}\times C_{max}-1)} \end{bmatrix}$$

The pseudocode is as follows:

```
Set i, k to 0.
while k < H',
    if y_i is not assigned to RI symbols
        y_i = g_k
        k = k + 1
    end if
    i = i+1
end while
```

(5) If HARQ-ACK information is transmitted in this subframe, the vector sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q'_{ACK}-1}^{ACK}$ is written onto the columns indicated by Table 5.2.2.8-2, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code. Note that this operation overwrites some of the channel interleaver entries obtained in step (4).

```
Set i, j to 0.
Set r to R_max' − 1
while i < Q_ACK'
    c_ACK = ColumnSet(j)
```


-continued

```
    y_{r×C_max+c_ACK} = q_i^ACK
    i = i + 1
    r = R_max' − 1 − ⌊i/4⌋
    j = (j + 3)mod4
end while
```

Where ColumnSet is given in Table 5.2.2.8-2 and indexed left to right from 0 to 3.

(6) The output of the block interleaver is the bit sequence read out column by column from the $(R_{max} \times C_{max})$ matrix. The bits after channel interleaving are denoted by $h_0, h_1, h_2, \ldots, h_{H+N_L \cdot Q_{RI}-1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

[Table 5.2.2.8-1 of 3GPP TS 36.212 v13.0.0, Entitled "Column Set for Insertion of Rank Information", is Reproduced as FIG. **15**]

[Table 5.2.2.8-2 of 3GPP TS 36.212 v13.0.0, Entitled "Column Set for Insertion of HARQ-ACK Information", is Reproduced as FIG. **16**]

The same channel interleaver procedures for RI are applied for CRI, using CRI instead of RI in the equations.

3GPP TS 36.212 v13.0.0 also states:

5.2.4 Uplink Control Information on PUSCH without UL-SCH Data

When control data are sent via PUSCH without UL-SCH data, the following coding steps can be identified:

Channel coding of control information

Control information mapping

Channel interleaver

5.2.4.1 Channel Coding of Control Information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI), HARQ-ACK and rank indication. Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When the UE transmits HARQ-ACK bits or rank indicator bits, it shall determine the number of coded symbols Q' for HARQ-ACK or rank indicator as

$$Q' = \min\left(\left\lceil \frac{O \cdot M_{sc}^{PUSCH} \cdot N_{symb}^{PUSCH} \cdot \beta_{offset}^{PUSCH}}{O_{CQI-MIN}} \right\rceil, 4 \cdot M_{sc}^{PUSCH}\right)$$

where O is the number of HARQ-ACK bits as defined in section 5.2.2.6, or rank indicator bits, $O_{CQI-MIN}$ is the number of CQI bits including CRC bits assuming rank equals to 1 for all serving cells for which an aperiodic CSI report is triggered [3], M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current subframe expressed as a number of subcarriers in [2], and N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current

PUSCH transmission sub frame given by $N_{symb}^{PUSCH}=2 \cdot (N_{symb}^{UL}-1)-N_{SRS}$, where N_{SRS} is equal to 1 if UE is configured to send PUSCH and SRS in the same subframe for the current subframe, or if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or if the current subframe is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or if the current subframe is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs. Otherwise N_{SRS} is equal to 0.

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$y_{r \times C_{mux}+C_{ACK}} = q_i^{ACK}$

$i = i+1$

$r = R'_{mux} - 1 - \lfloor i/4 \rfloor$

$j = (j+3) \bmod 4$

end while

Where ColumnSet is given in Table 5.2.2.8-2 and indexed left to right from 0 to 3.

(6) The output of the block interleaver is the bit sequence read out column by column from the $(R_{mux} \times C_{mux})$ matrix. The bits after channel interleaving are denoted by $h_0, h_1, h_2, \ldots, h_{H+N_L \cdot Q_{RI}-1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

Table 5.2.2.8-1: Column set for Insertion of rank information.

CP configuration	Column Set
Normal	{1, 4, 7, 10}
Extended	{0, 3, 5, 8}

Table 5.2.2.8-2: Column set for Insertion of HARQ-ACK information.

CP configuration	Column Set
Normal	{2, 3, 8, 9}
Extended	{1, 2, 6, 7}

The same channel interleaver procedures for RI are applied for CRI, using CRI instead of RI in the equations.

5.2.3 Uplink control information on PUCCH

Data arrives to the coding unit in the form of indicators for measurement indication, scheduling request and HARQ acknowledgement.

Three forms of channel coding are used as shown in Figure 5.2.3-1,

- one for HARQ-ACK and for combination of HARQ-ACK and periodic CSI transmitted on PUCCH format 3, including the cases with scheduling request,
- another for the channel quality information CQI/PMI transmitted on PUCCH format 2,
- and another for combination of CQI/PMI and HARQ-ACK transmitted on PUCCH format 2/2a/2b.

A fourth form of channel coding is used as shown in Figure 5.2.3-2, for HARQ-ACK and for combination of HARQ-ACK and periodic CSI transmitted on PUCCH format 4 or PUCCH format 5 including the cases with scheduling request, or for periodic CSI transmitted on PUCCH format 4 or PUCCH format 5 including the cases with scheduling request.

(1) Assign $C_{max}=N_{symb}^{PUSCH}$ to be the number of columns of the matrix. The columns of the matrix are numbered 0, 1, 2, . . . , $C_{max}-1$ from left to right. N_{symb}^{PUSCH} is determined according to section 5.2.2.6.
(2) The number of rows of the matrix is $R_{max}=(J'_{total}/Q_m \cdot N_L)/C_{max}$ and we define $R'_{max}=R_{max}/(Q_m \cdot N_L)$. The rows of the rectangular matrix are numbered 0, 1, 2, . . . , $R_{max}-1$ from top to bottom.
(3) If rank information is transmitted in this subframe, the vector sequence $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q'_{RI}-1}^{RI}$ is written onto the columns indicated by Table 5.2.2.8-1, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code.

```
Set i, j to 0.
Set r to R_mux' − 1
while i < Q_RI
    c_RI = Column Set( j )
    y_{r×C_mux+c_RI} = q_i^RI
    i = i + 1
    r = R_mux' − 1 − ⌊i/4⌋
    j = (j + 3)mod4
end while
```

Where ColumnSet is given in Table 5.2.2.8-1 and indexed left to right from 0 to 3.
(4) Write the input vector sequence, for k=0, 1, . . . , H'−1, into the $(R_{max} \times C_{max})$ matrix by sets of $(Q_m \cdot N_L)$ rows starting with the vector y_0 in column 0 and rows 0 to $(Q_m \cdot N_L-1)$ and skipping the matrix entries that are already occupied:

-continued

```
y_{r×C_mux+c_ACK} = q_i^ACK
i = i + 1
r = R_mux' − 1 − ⌊i/4⌋
j = (j + 3)mod4
end while
```

Where ColumnSet is given in Table 5.2.2.8-2 and indexed left to right from 0 to 3

(6) The output of the block interleaver is the bit sequence read out column by column from the $(R_{max} \times C_{max})$ matrix. The bits after channel interleaving are denoted by $h_0, h_1, h_2, \ldots, h_{H+N_L \cdot Q_{RI}-1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

[Table 5.2.2.8-1 of 3GPP TS 36.212 v13.0.0, Entitled "Column Set for Insertion of Rank Information", is Reproduced as FIG. **15**]

[Table 5.2.2.8-2 of 3GPP TS 36.212 v13.0.0, Entitled "Column Set for Insertion of HARQ-ACK Information", is Reproduced as FIG. **16**]

The same channel interleaver procedures for RI are applied for CRI, using CRI instead of RI in the equations.

3GPP TS 36.212 v13.0.0 also states:

5.2.4 Uplink Control Information on PUSCH without UL-SCH Data

When control data are sent via PUSCH without UL-SCH data, the following coding steps can be identified:

Channel coding of control information
Control information mapping
Channel interleaver

5.2.4.1 Channel Coding of Control Information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI), HARQ-ACK and rank indication. Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When the UE transmits HARQ-ACK bits or rank indicator bits, it shall determine the number of coded symbols Q' for HARQ-ACK or rank

$$Q' = \min\left(\left\lceil \frac{O \cdot M_{sc}^{PUSCH} \cdot N_{symb}^{PUSCH} \cdot \beta_{offset}^{PUSCH}}{O_{CQI-MIN}} \right\rceil, 4 \cdot M_{sc}^{PUSCH}\right)$$

the number of HARQ-ACK bits as defined in 2.6, or rank indicator bits, $O_{CQI-MIN}$ is the number its including CRC bits assuming rank equals to ving cells for which an aperiodic CSI report is], M_{sc}^{PUSCH} is the scheduled bandwidth for smission in the current subframe expressed as a ubcarriers in [2], and N_{symb}^{PUSCH} is the number A symbols in the current ransmission sub frame given by N_{symb}^{PUSCH-} 1)-N_{SRS}), where N_{SRS} is equal to 1 if UE is o send PUSCH and SRS in the same subframe nt subframe, or if the PUSCH resource allocaurrent subframe even partially overlaps with the SRS subframe and bandwidth configuration ction 5.5.3 of [2], or if the current subframe is e type-1 SRS subframe as defined in Section 8.2 he current subframe is a UE-specific type-0 SRS defined in section 8.2 of [3] and the UE is ith multiple TAGs. Otherwise N_{SRS} is equal to

CP configuration	Column Set
Normal	{1, 4, 7, 10}
Extended	{0, 3, 5, 8}

FIG. 15 (PRIOR ART)

CP configuration	Column Set
Normal	{2, 3, 8, 9}
Extended	{1, 2, 6, 7}

FIG. 16 (PRIOR ART)

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HARQ-ACK bits are denoted by a_0'' in case one HARQ-ACK bit or a_0'', a_1'' in case two HARQ-ACK bits are reported per subframe. Each positive acknowledgement (ACK) is encoded as a binary '1' and each negative acknowledgement (NACK) is encoded as a binary '0'.

The output of this channel coding block for normal CP is denoted by $b_0, b_1, b_2, b_3, ..., b_{B-1}$, where

$$b_i = b_i', i = 0, ..., B' - 1$$

In case one HARQ-ACK bit is reported per subframe:

$$b_{B'} = a_0'' \text{ and } B = (B' + 1)$$

In case two HARQ-ACK bits are reported per subframe:

$$b_{B'} = a_0'', b_{B'+1} = a_1'' \text{ and } B = (B' + 2)$$

When extended CP is used for uplink transmission, the channel quality information and the HARQ-ACK bits are jointly coded. The HARQ-ACK bits are denoted by a_0'' in case one HARQ-ACK bit or $[a_0'', a_1'']$ in case two HARQ-ACK bits are reported per subframe.

The channel quality information denoted by $a_0', a_1', a_2', a_3', ..., a_{A-1}'$ is multiplexed with the HARQ-ACK bits to yield the sequence $a_0, a_1, a_2, a_3, ..., a_{A-1}$ as follows

$$a_i = a_i', i = 0, ..., A' - 1$$

and

$a_{A'} = a_0''$ and $A = (A' + 1)$ in case one HARQ-ACK bit is reported per subframe, or

$a_{A'} = a_0''$, $a_{(A'+1)} = a_1''$ and $A = (A' + 2)$ in case two HARQ-ACK bits are reported per subframe.

The sequence $a_0, a_1, a_2, a_3, ..., a_{A-1}$ is encoded according to section 5.2.3.3 to yield the output bit sequence $b_0, b_1, b_2, b_3, ..., b_{B-1}$ where $B = 20$.

5.2.4 Uplink control information on PUSCH without UL-SCH data

When control data are sent via PUSCH without UL-SCH data, the following coding steps can be identified:

- Channel coding of control information
- Control information mapping
- Channel interleaver

5.2.4.1 Channel coding of control information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI), HARQ-ACK and rank indication. Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When the UE transmits HARQ-ACK bits or rank indicator bits, it shall determine the number of coded symbols Q' for HARQ-ACK or rank indicator as

$$Q' = \min\left(\left\lceil \frac{O \cdot M_{sc}^{PUSCH} \cdot N_{symb}^{PUSCH} \cdot \beta_{offset}^{PUSCH}}{O_{CQI-MIN}} \right\rceil, 4 \cdot M_{sc}^{PUSCH}\right)$$

where O is the number of HARQ-ACK bits as defined in section 5.2.2.6, or rank indicator bits, $O_{CQI-MIN}$ is the number of CQI bits including CRC bits assuming rank equals to 1 for all serving cells for which an aperiodic CSI report

(1) Assign $C_{max}=N_{symb}^{PUSCH}$ to be the number of columns of the matrix. The columns of the matrix are numbered 0, 1, 2, . . . , $C_{max}-1$ from left to right. N_{symb}^{PUSCH} is determined according to section 5.2.2.6.

(2) The number of rows of the matrix is $R_{max}=(J'_{total}/Q_m \cdot N_L)/C_{max}$ and we define $R'_{max}=R_{max}/(Q_m \cdot N_L)$.
The rows of the rectangular matrix are numbered 0, 1, 2, . . . , $R_{max}-1$ from top to bottom.

(3) If rank information is transmitted in this subframe, the vector sequence $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q'_{RI}-1}^{RI}$ is written onto the columns indicated by Table 5.2.2.8-1, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code.

```
Set i, j to 0.
Set r to R_max' − 1
while i < Q_RI
    c_RI = Column Set( j )
    y_{r×C_max+c_RI} = q_i^RI
    i = i + 1
    r = R_max' − 1 − [i/4]
    j = (j + 3)mod4
end while
```

Where ColumnSet is given in Table 5.2.2.8-1 and indexed left to right from 0 to 3.

(4) Write the input vector sequence, for k=0, 1, . . . , H'−1, into the $(R_{max} \times C_{max})$ matrix by sets of $(Q_m \cdot N_L)$ rows starting with the vector y_0 in column 0 and rows 0 to $(Q_m \cdot N_L-1)$ and skipping the matrix entries that are already occupied:

$$\begin{bmatrix} y_0 & y_1 & y_2 & \cdots & y_{C_{max}-1} \\ y_{C_{max}} & y_{C_{max}+1} & y_{C_{max}+2} & \cdots & y_{2C_{max}-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ y_{(R'_{max}-1)\times C_{max}} & y_{(R'_{max}-1)\times C_{max}+1} & y_{(R'_{max}-1)\times C_{max}+2} & \cdots & y_{(R'_{max}\times C_{max}-1)} \end{bmatrix}$$

The pseudocode is as follows:

```
Set i, k to 0.
while k < H',
    if y_i is not assigned to RI symbols
        y_i = g_k
        k = k + 1
    end if
    i = i+1
end while
```

(5) If HARQ-ACK information is transmitted in this subframe, the vector sequence $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q'_{ACK}-1}^{ACK}$ is written onto the columns indicated by Table 5.2.2.8-2, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code. Note that this operation overwrites some of the channel interleaver entries obtained in step (4).

```
Set i, j to 0.
Set r to R_max' − 1
while i < Q_ACK'
    c_ACK = ColumnSet(j)
    y_{r×C_max+c_ACK} = q_i^ACK
    i = i + 1
    r = R_max' − 1 − [i/4]
    j = (j + 3)mod4
end while
```


-continued

Where ColumnSet is given in Table 5.2.2.8-2 and indexed left to right from 0 to 3

(6) The output of the block interleaver is the bit sequence read out column by column from the $(R_{max} \times C_{max})$ matrix. The bits after channel interleaving are denoted by $h_0, h_1, h_2, \ldots, h_{H+N_L \cdot Q_{RI}-1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

[Table 5.2.2.8-1 of 3GPP TS 36.212 v13.0.0, Entitled "Column Set for Insertion of Rank Information", is Reproduced as FIG. **15**]

[Table 5.2.2.8-2 of 3GPP TS 36.212 v13.0.0, Entitled "Column Set for Insertion of HARQ-ACK Information", is Reproduced as FIG. **16**]

The same channel interleaver procedures for RI are applied for CRI, using CRI instead of RI in the equations.

3GPP TS 36.212 v13.0.0 also states:

5.2.4 Uplink Control Information on PUSCH without UL-SCH Data

When control data are sent via PUSCH without UL-SCH data, the following coding steps can be identified:

Channel coding of control information
Control information mapping
Channel interleaver

5.2.4.1 Channel Coding of Control Information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI), HARQ-ACK and rank indication. Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When the UE transmits HARQ-ACK bits or rank indicator bits, it shall determine the number of coded symbols Q' for HARQ-ACK or rank indicator as

$$Q' = \min\left(\left\lceil \frac{O \cdot M_{sc}^{PUSCH} \cdot N_{symb}^{PUSCH} \cdot \beta_{offset}^{PUSCH}}{O_{CQI-MIN}} \right\rceil, 4 \cdot M_{sc}^{PUSCH}\right)$$

where O is the number of HARQ-ACK bits as defined in section 5.2.2.6, or rank indicator bits, $O_{CQI-MIN}$ is the number of CQI bits including CRC bits assuming rank equals to 1 for all serving cells for which an aperiodic CSI report is triggered [3], M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current subframe expressed as a number of subcarriers in [2], and N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current

PUSCH transmission sub frame given by $N_{symb}^{PUSCH}=(2 \cdot (N_{symb}^{UL}-1)-N_{SRS})$, where N_{SRS} is equal to 1 if UE is configured to send PUSCH and SRS in the same subframe for the current subframe, or if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or if the current subframe is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or if the current subframe is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs. Otherwise N_{SRS} is equal to 0.

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is triggered [3], M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current subframe expressed as a number of subcarriers in [2], and N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current PUSCH transmission sub-frame given by $N_{symb}^{PUSCH} = \left(2 \cdot \left(N_{symb}^{UL} - 1\right) - N_{SRS}\right)$, where N_{SRS} is equal to 1 if UE is configured to send PUSCH and SRS in the same subframe for the current subframe, or if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or if the current subframe is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or if the current subframe is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs. Otherwise N_{SRS} is equal to 0.

For HARQ-ACK information $Q_{ACK} = Q_m \cdot Q'$ and $[\beta_{offset}^{PUSCH} = \beta_{offset}^{HARQ-ACK} / \beta_{offset}^{CQI}]$. For UEs configured with no more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3]. For UEs configured with more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3] depending on the number of HARQ-ACK feedback bits.

For rank indication or CRI, $Q_{RI} = Q_m \cdot Q'$, $Q_{CRI} = Q_m \cdot Q'$ and $[\beta_{offset}^{PUSCH} = \beta_{offset}^{RI} / \beta_{offset}^{CQI}]$, where β_{offset}^{RI} shall be determined according to [3].

For CQI and/or PMI information $Q_{CQI} = N_{symb}^{PUSCH} \cdot M_{sc}^{PUSCH} \cdot Q_m - Q_{RI}$.

The channel coding and rate matching of the control data is performed according to section 5.2.2.6. The coded output sequence for channel quality information is denoted by $q_0, q_1, q_2, q_3, \ldots, q_{Q_{CQI}-1}$, the coded vector sequence output for HARQ-ACK is denoted by $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \underline{q}_2^{ACK}, \ldots, \underline{q}_{Q_{ACK}-1}^{ACK}$ and the coded vector sequence output for rank indication or CRI, is denoted by $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q_{RI}-1}^{RI}$.

5.2.4.2 Control information mapping

The input are the coded bits of the channel quality information denoted by $q_0, q_1, q_2, q_3, \ldots, q_{Q_{CQI}-1}$. The output is denoted by $\underline{g}_0, \underline{g}_1, \underline{g}_2, \underline{g}_3, \ldots, \underline{g}_{H'-1}$, where $H = Q_{CQI}$ and $H' = H / Q_m$, and where $\underline{g}_i$, $i = 0, \ldots, H'-1$ are column vectors of length Q_m. H is the total number of coded bits allocated for CQI/PMI information.

The control information shall be mapped as follows:

Set j, k to 0

while $j < Q_{CQI}$

$\underline{g}_k = [q_j \cdots q_{j+Q_m-1}]^T$

$j = j + Q_m$

$k = k + 1$

end while

5.2.4.3 Channel interleaver

The vector sequences $\underline{g}_0, \underline{g}_1, \underline{g}_2, \ldots, \underline{g}_{H'-1}$, $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q_{RI}-1}^{RI}$ and $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \underline{q}_2^{ACK}, \ldots, \underline{q}_{Q'_{ACK}-1}^{ACK}$ are channel interleaved according section 5.2.2.8. The bits after channel interleaving are denoted by $h_0, h_1, h_2, \ldots, h_{H+Q_{RI}-1}$.

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(1) Assign C_{max}=N_{symb}^{PUSCH} to be the number of columns of the matrix. The columns of the matrix are numbered 0, 1, 2, . . . , C_{max}−1 from left to right. N_{symb}^{PUSCH} is determined according to section 5.2.2.6.

(2) The number of rows of the matrix is R_{max}= $(J'_{total}/Q_m \cdot N_L)/C_{max}$ and we define R'_{max}=R_{max}/$(Q_m \cdot N_L)$.
The rows of the rectangular matrix are numbered 0, 1, 2, . . . , R_{max}−1 from top to bottom.

(3) If rank information is transmitted in this subframe, the vector sequence $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$ is written onto the columns indicated by Table 5.2.2.8-1, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code.

```
Set i, j to 0.
Set r to R_max' − 1
while i < Q'_RI
    c_RI = Column Set( j )
    y_{r×C_max+c_RI} = q_i^RI
    i = i + 1
    r = R_max' − 1 − ⌊i/4⌋
    j = (j + 3)mod4
end while
```

Where ColumnSet is given in Table 5.2.2.8-1 and indexed left to right from 0 to 3.

(4) Write the input vector sequence, for k=0, 1, . . . , H'−1, into the (R_{max}×C_{max}) matrix by sets of $(Q_m \cdot N_L)$ rows starting with the vector $\underline{y}_0$ in column 0 and rows 0 to $(Q_m \cdot N_L - 1)$ and skipping the matrix entries that are already occupied:

$$\begin{bmatrix} \underline{y}_0 & \underline{y}_1 & \underline{y}_2 & \cdots & \underline{y}_{C_{max}-1} \\ \underline{y}_{C_{max}} & \underline{y}_{C_{max}+1} & \underline{y}_{C_{max}+2} & \cdots & \underline{y}_{2C_{max}-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \underline{y}_{(R'_{max}-1)\times C_{max}} & \underline{y}_{(R'_{max}-1)\times C_{max}+1} & \underline{y}_{(R'_{max}-1)\times C_{max}+2} & \cdots & \underline{y}_{(R'_{max}\times C_{max}-1)} \end{bmatrix}$$

The pseudocode is as follows:

```
Set i, k to 0.
while k < H',
    if y_i is not assigned to RI symbols
        y_i = g_k
        k = k + 1
    end if
    i = i+1
end while
```

(5) If HARQ-ACK information is transmitted in this subframe, the vector sequence $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \underline{q}_2^{ACK}, \ldots, \underline{q}_{Q'_{ACK}-1}^{ACK}$ is written onto the columns indicated by Table 5.2.2.8-2, and by sets of $(Q_m \cdot N_L)$ rows starting from the last row and moving upwards according to the following pseudo-code. Note that this operation overwrites some of the channel interleaver entries obtained in step (4).

```
Set i, j to 0.
Set r to R_max' − 1
while i < Q'_ACK
    c_ACK = ColumnSet(j)
```


-continued

```
    y_{r×C_max+c_ACK} = q_i^ACK
    i = i + 1
    r = R_max' − 1 − ⌊i/4⌋
    j = (j + 3)mod4
end while
```

Where ColumnSet is given in Table 5.2.2.8-2 and indexed left to right from 0 to 3.

(6) The output of the block interleaver is the bit sequence read out column by column from the (R_{max}×C_{max}) matrix. The bits after channel interleaving are denoted by $h_0, h_1, h_2, \ldots, h_{H+N_L \cdot Q_{RI}-1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

[Table 5.2.2.8-1 of 3GPP TS 36.212 v13.0.0, Entitled "Column Set for Insertion of Rank Information", is Reproduced as FIG. **15**]

[Table 5.2.2.8-2 of 3GPP TS 36.212 v13.0.0, Entitled "Column Set for Insertion of HARQ-ACK Information", is Reproduced as FIG. **16**]

The same channel interleaver procedures for RI are applied for CRI, using CRI instead of RI in the equations.

3GPP TS 36.212 v13.0.0 also states:

5.2.4 Uplink Control Information on PUSCH without UL-SCH Data

When control data are sent via PUSCH without UL-SCH data, the following coding steps can be identified:

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5.2.4.1 Channel Coding of Control Information

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$$Q' = \min\left(\left\lceil \frac{O \cdot M_{sc}^{PUSCH} \cdot N_{symb}^{PUSCH} \cdot \beta_{offset}^{PUSCH}}{O_{CQI-MIN}} \right\rceil, 4 \cdot M_{sc}^{PUSCH}\right)$$

where O is the number of HARQ-ACK bits as defined in section 5.2.2.6, or rank indicator bits, $O_{CQI-MIN}$ is the number of CQI bits including CRC bits assuming rank equals to 1 for all serving cells for which an aperiodic CSI report is triggered [3], M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current subframe expressed as a number of subcarriers in [2], and N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current

PUSCH transmission sub frame given by N_{symb}^{PUSCH}= $(2 \cdot (N_{symb}^{UL} - 1) - N_{SRS})$, where N_{SRS} is equal to 1 if UE is configured to send PUSCH and SRS in the same subframe for the current subframe, or if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or if the current subframe is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or if the current subframe is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs. Otherwise N_{SRS} is equal to 0.

is triggered [3], M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current subframe expressed as a number of subcarriers in [2], and N_{symb}^{PUSCH} is the number of SC-FDMA symbols in the current PUSCH transmission sub-frame given by $N_{symb}^{PUSCH} = \left(2 \cdot \left(N_{symb}^{UL} - 1\right) - N_{SRS}\right)$, where N_{SRS} is equal to 1 if UE is configured to send PUSCH and SRS in the same subframe for the current subframe, or if the PUSCH resource allocation for the current subframe even partially overlaps with the cell-specific SRS subframe and bandwidth configuration defined in section 5.5.3 of [2], or if the current subframe is a UE-specific type-1 SRS subframe as defined in Section 8.2 of [3], or if the current subframe is a UE-specific type-0 SRS subframe as defined in section 8.2 of [3] and the UE is configured with multiple TAGs. Otherwise N_{SRS} is equal to 0.

For HARQ-ACK information $Q_{ACK} = Q_m \cdot Q'$ and $[\beta_{offset}^{PUSCH} = \beta_{offset}^{HARQ-ACK} / \beta_{offset}^{CQI}]$. For UEs configured with no more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3]. For UEs configured with more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3] depending on the number of HARQ-ACK feedback bits.

For rank indication or CRI, $Q_{RI} = Q_m \cdot Q'$, $Q_{CRI} = Q_m \cdot Q'$ and $[\beta_{offset}^{PUSCH} = \beta_{offset}^{RI} / \beta_{offset}^{CQI}]$, where β_{offset}^{RI} shall be determined according to [3].

For CQI and/or PMI information $Q_{CQI} = N_{symb}^{PUSCH} \cdot M_{sc}^{PUSCH} \cdot Q_m - Q_{RI}$.

The channel coding and rate matching of the control data is performed according to section 5.2.2.6. The coded output sequence for channel quality information is denoted by $q_0, q_1, q_2, q_3, \ldots, q_{Q_{CQI}-1}$, the coded vector sequence output for HARQ-ACK is denoted by $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \underline{q}_2^{ACK}, \ldots, \underline{q}_{Q_{ACK}-1}^{ACK}$ and the coded vector sequence output for rank indication or CRI, is denoted by $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q_{RI}-1}^{RI}$.

5.2.4.2 Control information mapping

The input are the coded bits of the channel quality information denoted by $q_0, q_1, q_2, q_3, \ldots, q_{Q_{CQI}-1}$. The output is denoted by $\underline{g}_0, \underline{g}_1, \underline{g}_2, \underline{g}_3, \ldots, \underline{g}_{H'-1}$, where $H = Q_{CQI}$ and $H' = H / Q_m$, and where $\underline{g}_i$, $i = 0, \ldots, H'-1$ are column vectors of length Q_m. H is the total number of coded bits allocated for CQI/PMI information.

The control information shall be mapped as follows:

Set j, k to 0

while $j < Q_{CQI}$

$\underline{g}_k = [q_j \cdots q_{j+Q_m-1}]^T$

$j = j + Q_m$

$k = k + 1$

end while

5.2.4.3 Channel interleaver

The vector sequences $\underline{g}_0, \underline{g}_1, \underline{g}_2, \ldots, \underline{g}_{H'-1}$, $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q_{RI}-1}^{RI}$ and $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \underline{q}_2^{ACK}, \ldots, \underline{q}_{Q_{ACK}-1}^{ACK}$ are channel interleaved according section 5.2.2.8. The bits after channel interleaving are denoted by $h_0, h_1, h_2, \ldots, h_{H+Q_{RI}-1}$.

For HARQ-ACK information $Q_{ACK}=Q_m \cdot Q'$ and $[\beta_{offset}^{PUSCH}=\beta_{offset}^{HARQ-ACK}/\beta_{offset}^{CQI}]$. For UEs configured with no more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3]. For UEs configured with more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3] depending on the number of HARQ-ACK feedback bits.

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For CQI and/or PMI information $Q_{CQI}=N_{symb}^{PUSCH} \cdot M_{sc}^{PUSCH} \cdot Q_m - Q_{RI}$.

The channel coding and rate matching of the control data is performed according to section 5.2.2.6. The coded output sequence for channel quality information is denoted by $q_0, q_1, q_2, q_3, \ldots, q_{Q_{CQI}-1}$, the coded vector sequence output for HARQ-ACK is denoted by $q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, \ldots, q_{Q'_{ACK}-1}^{ACK}$ and the coded vector sequence output for rank indication or CRI, is denoted by $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q'_{RI}-1}^{RI}$.

5.2.4.2 Control Information Mapping

The input are the coded bits of the channel quality information denoted by $q_0, q_1, q_2, q_3, \ldots, q_{Q_{CQI}-1}$. The output is denoted by $\underline{g}_0, \underline{g}_1, \underline{g}_2, \underline{g}_3, \ldots, \underline{g}_{H'-1}$, where $H=Q_{CQI}$ and $H'=H/Q_m$, and where $\underline{g}_i$, $i=0, \ldots, H'-1$ are column vectors of length Q_m. H is the total number of coded bits allocated for CQI/PMI information.

The control information shall be mapped as follows:

Set j, k to 0
while $j < Q_{CQI}$
$\underline{g}_k = [q_j \cdots q_{j+Q_m-1}]^T$
$j = j + Q_m$
$k = k + 1$
end while

5.2.4.3 Channel Interleaver

The vector sequences $\underline{g}_0, \underline{g}_1, \underline{g}_2, \ldots, \underline{g}_{H'-1}$, $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$ and $\underline{q}_0^{ACK}, \underline{q}_1^{ACK}, \underline{q}_2^{ACK}, \ldots, \underline{q}_{Q'_{ACK}-1}^{ACK}$ are channel interleaved according section 5.2.2.8. The bits after channel interleaving are denoted by $h_0, h_1, h_2, \ldots, h_{H+Q_{RI}-1}$.

Semi-persistent scheduling enables a UE to consider a configured uplink grant occurs periodically after it is initiated. It may be initiated by receiving a network signaling to initiate SPS (Semi-Persistent Scheduling). No network signaling is needed to allocate the following configured uplink grant after SPS is initiated. Based on 3GPP RP-150310, fast uplink access may be achieved by a specific type of SPS. The specific type of SPS is assumed to be with small size and short interval, for example, less than 10 ms.

Further, the specific type of SPS is assumed to be pre-allocated. An eNB may allocate this kind of SPS resource to a UE without receiving any scheduling request or buffer status information. When the UE has data available for transmission (as discussed in 3GPP TS 36.321 v12.5.0), the UE can use resource configured by the SPS for uplink transmission. Compared with requesting uplink resource via scheduling request (as discussed in 3GPP TS 36.321 v12.5.0), the latency can then be reduced if the interval of the resource configured by the SPS is short enough.

Figure 2 of 3GPP RP-150310 is reproduced as FIG. **17**. In general, FIG. **17** shows how pre-allocated uplink grant (such as allocated by SPS) improves latency reduction compared with scheduling request procedure specified in 3GPP TS 36.321 v12.5.0). The resource configured by the specific type of SPS may be separated from the resource configured by the legacy SPS (with longer interval) or jointly used.

In addition, it is also mentioned in 3GPP RP-150310 that the requirement of sending padding when there is UL resource but no data is in buffer can be removed. The intention of removing the requirement is to save battery power.

Based on 3GPP TS 36.213 v12.5.0, when a physical control information (such as channel quality indicator (CQI), Precoding Matrix Index (PMI), Rank Indicator (RI), and/or HARQ feedback) needs to be transmitted in a TTI, a UE should transmit the physical control information via either PUSCH or PUCCH. Traditionally, if an uplink grant for PUSCH is not available or the UE is allowed to perform transmission on PUCCH and PUSCH simultaneously, the physical control information is transmitted on PUCCH. If HARQ-ACK repetition is not configured, an uplink grant for PUSCH is available, and the UE is not allowed to perform transmission on PUCCH and PUSCH simultaneously (e.g., due to UE capability, UE power limitation, or eNB configuration), the physical control information is transmitted on PUSCH multiplexed with upper layer data (e.g., MAC PDU). If HARQ-ACK repetition is not configured and an uplink grant for PUSCH is available, the physical control information is transmitted on PUCCH and data is not transmitted, irrespective of whether the UE is allowed to perform transmission on PUCCH and PUSCH simultaneously or not. Note that the UE which is configured with HARQ-ACK repetition is reasonably not allowed to perform transmission on PUCCH and PUSCH simultaneously, given transmitting PUCCH and PUSCH simultaneously require proper channel quality and are usually configured for cell center UEs.

Three following scenarios are considered:

Scenario 1—

When a physical control information needs to be transmitted in a TTI, if a UE is unable to perform transmission on PUCCH and PUSCH simultaneously and the UE has data available for transmission, the UE traditionally multiplexes the physical control information with the data and transmits them on PUSCH jointly. However, if an assigned UL resource for PUSCH is small (e.g., a pre-allocated configured uplink resource which is assumed to be small), multiplexing the physical control information into PUSCH may jeopardize the data delivery because coding rate of the data may be worse than normal so that data transmission is likely to fail. In addition, since network (e.g., eNB) may not know whether the UE transmits the physical control information on PUCCH or PUSCH which may depend on whether the UE has data available for transmission or not, complexity of decoding the UE transmission is increased.

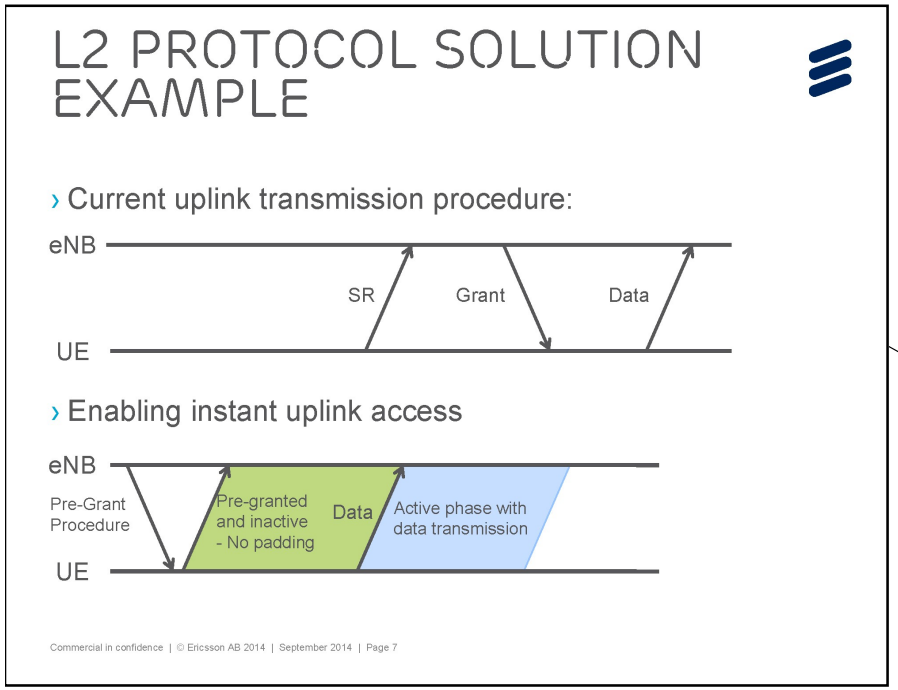
Scenario 2—

When a physical control information needs to be transmitted in a TTI, if a UE has data available for transmission and simultaneous transmission on PUCCH and PUSCH is enabled but the UE is not able to perform both transmissions on a control channel (e.g., PUCCH) and a data channel (e.g., PUSCH) with sufficient power, traditionally the UE prioritizes PUCCH transmission over PUSCH transmission. However, the data on PUSCH may not be transmitted in this TTI, or less power is used on PUSCH so that the PUSCH transmission is likely to fail.

Scenario 3—

If a UE does not have data available for transmission in a TTI, the UE would skip configured UL grant or dynamic uplink grant in that TTI. Thus, if the UE needs to transmit UCI (Uplink Control Information) in the TTI, UE would

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For HARQ-ACK information $Q_{ACK}=Q_m \cdot Q'$ and $[\beta_{offset}^{PUSCH}=\beta_{offset}^{HARQ-ACK}/\beta_{offset}^{CQI}]$. For UEs configured with no more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3]. For UEs configured with more than five DL cells, $\beta_{offset}^{HARQ-ACK}$ shall be determined according to [3] depending on the number of HARQ-ACK feedback bits.

For rank indication or CRI, $Q_{RI}=Q_m \cdot Q'$, $Q_{CRI}=Q_m \cdot Q'$ and $[\beta_{offset}^{PUSCH}=\beta_{offset}^{RI}/\beta_{offset}^{CQI}]$, where β_{offset}^{RI} shall be determined according to [3].

For CQI and/or PMI information $Q_{CQI}=N_{symb}^{PUSCH} \cdot M_{sc}^{PUSCH} \cdot Q_m - Q_{RI}$.

The channel coding and rate matching of the control data is performed according to section 5.2.2.6. The coded output sequence for channel quality information is denoted by q_0, q_1, q_2, q_3, . . . , $q_{Q_{CQI}-1}$, the coded vector sequence output for HARQ-ACK is denoted by q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, . . . , $q_{Q'_{ACK}-1}^{ACK}$ and the coded vector sequence output for rank indication or CRI, is denoted by q_0^{RI}, q_1^{RI}, q_2^{RI}, . . . , $q_{Q'_{RI}-1}^{RI}$.

5.2.4.2 Control Information Mapping

The input are the coded bits of the channel quality information denoted by q_0, q_1, q_2, q_3, . . . , $q_{Q_{CQI}-1}$. The output is denoted by g_0, g_1, g_2, g_3, . . . , $g_{H'-1}$, where $H=Q_{CQI}$ and $H'=H/Q_m$, and where g_i, $i=0$, . . . , $H'-1$ are column vectors of length Q_m. H is the total number of coded bits allocated for CQI/PMI information.

The control information shall be mapped as follows:

Set j, k to
while j <
$g_k = [q_j$
j = j +
k = k +
end while

5.2.4.3 Channel Interleaver

The vector sequences g_0, g_1, g_2, . . . , $g_{H'-1}$ and q_0^{RI}, q_1^{RI}, q_2^{RI}, . . . , $q_{Q'_{RI}-1}^{RI}$ and q_0^{ACK}, q_1^{ACK}, q_2^{ACK}, . . . , $q_{Q'_{ACK}-1}^{ACK}$ are channel interleaved according se
after channel interleaving are denote
$h_{H+Q_{ACK}-1}$.

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transmission (as discussed in 3GPP T
UE can use resource configured by the SPS for uplink transmission. Compared with requesting uplink resource via scheduling request (as discussed in 3GPP TS 36.321 v12.5.0), the latency can be reduced if the interval of the resource configured by the SPS is short enough.

Figure 2 of 3GPP RP-150310 is reproduced as FIG. **17**. In general, FIG. **17** shows how pre-allocated uplink grant (such as allocated by SPS) improves latency reduction compared with scheduling request procedure specified in 3GPP TS 36.321 v12.5.0). The resource configured by the specific type of SPS may be separated from the resource configured by the legacy SPS (with longer interval) or jointly used.

In addition, it is also mentioned in 3GPP RP-150310 that the requirement of sending padding when there is UL resource but no data is in buffer can be removed. The intention of removing the requirement is to save battery power.

Based on 3GPP TS 36.213 v12.5.0, when a physical control information (such as channel quality indicator (CQI), Precoding Matrix Index (PMI), Rank Indicator (RI), and/or HARQ feedback) needs to be transmitted in a TTI, a UE should transmit the physical control information via either PUSCH or PUCCH. Traditionally, if an uplink grant for PUSCH is not available or the UE is allowed to perform transmission on PUCCH and PUSCH simultaneously, the physical control information is transmitted on PUCCH. If HARQ-ACK repetition is not configured, an uplink grant for PUSCH is available, and the UE is not allowed to perform transmission on PUCCH and PUSCH simultaneously (e.g., due to UE capability, UE power limitation, or eNB configuration), the physical control information is transmitted on PUSCH multiplexed with upper layer data (e.g., MAC PDU). If HARQ-ACK repetition is not configured and an uplink grant for PUSCH is available, the physical control information is transmitted on PUCCH and data is not transmitted, irrespective of whether the UE is allowed to perform transmission on PUCCH and PUSCH simultaneously or not. Note that the UE which is configured with HARQ-ACK repetition is reasonably not allowed to perform transmission on PUCCH and PUSCH simultaneously, given transmitting PUCCH and PUSCH simultaneously require PUSCH) with sufficient power, traditionally the UE prioritizes PUCCH transmission over PUSCH transmission. However, the data on PUSCH may not be transmitted in this TTI, or less power is used on PUSCH so that the PUSCH transmission is likely to fail.

Scenario 3

If a UE does not have data available for transmission in a TTI, the UE would skip configured UL grant or dynamic uplink grant in that TTI. Thus, if the UE needs to transmit UCI (Uplink Control Information) in the TTI, UE would

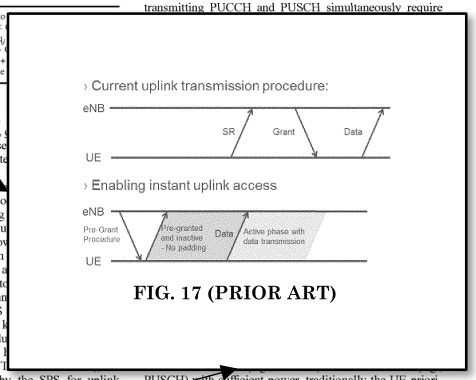


FIG. 17 (PRIOR ART)

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