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Agenda Item:	**12.1**
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Title:	**Control Signalling Design for Supporting Carrier Aggregation**
Document for:	**Discussion**

1. Introduction

With the agreement on MAC-to-PHY mapping reached in the last meeting, i.e., "there is one transport block (in absence of spatial multiplexing) and one HARQ entity per scheduled component carrier (from the UE perspective)", the question of how to design the control signalling mechanism to support the downlink and uplink transmission (including HARQ retransmission) of such multiple TBs naturally arises. In this document, we discuss various DL control signalling design options to support bandwidth extension for LTE Advanced.

2. PDCCH

PDCCH carries the information of DL or UL resource allocation which is now for multiple TBs with each being mapped to a component carrier. One question of first importance is the corresponding relationship between PDCCH(s) and TB(s), for example, whether a PDCCH message can contain resource assignment of multiple component carriers.

In addition to the issue of PDCCH content, the transmission structure itself (i.e., how resources are organized for the transmission of control channels) is also important and its design affects the deployment flexibility, system robustness, and UE processing requirements.

2.1. PDCCH Structure

Given that each TB is confined to a single component carrier, it makes sense to agree on that each PDCCH transmission is also confined to a single component carrier due to the following observations:

- Any benefit of additional frequency diversity gain by transmitting PDCCH across multiple carriers for improving the reliability of PDCCH could be minimal.
- When PDCCH is sent across multiple component carriers, the mechanisms that attempt to reduce UE power consumption by allowing the UE to monitor only a single component carrier, especially when resources of other carrier do not have to be used, cannot be efficiently supported.
- Any new PDCCH structure that enables CCE allocation/aggregation over multiple component carriers can be quite restricted considering that the new allocation rules for that structure must not affect the existing Rel8 CCE allocation mechanisms for Rel8 UEs, especially if a component carrier needs to support Rel8 UEs.

While confining a PDCCH to a single component carrier is more consistent with the design of confining one TB to one component carrier, we believe that, allowing one PDCCH transmitted from one DL component carrier to schedule resources on other DL component carriers (or other UL component carriers that are not the default pairing with that DL component carrier) can have the following desirable benefits.

1. In a system where both Rel8 compatible and Rel8 non-compatible carriers are configured, the PDCCH in Rel8 carriers can be utilised to grant resources in non Rel8 compatible carriers (especially in a design/configuration where the non Rel8 compatible carrier carries no PDCCH or even no control signalling at all)
2. The scheduler has the flexibility of assigning resources for multiple component carriers from the best or designated component carrier (e.g., the component carrier with strongest CQI or the “anchor” carrier). This flexibility helps to improve control signalling efficiency and robustness of system operations.
3. In the case of asymmetric aggregation such as two UL component carriers and one DL carriers, PDCCH will need to grant resources for 2 UL TBs.

We note that all these benefits may not be realisable in some particular deployment scenarios such as scenarios where schedulers for different component carriers cannot operate in a co-ordinated manner. Considering this, our view on resource assignment methodology is

> *In addition to having an option that uses one PDCCH to schedule resources in one component carrier, which is the simplest extension of Rel8 operation, the option of allowing a PDCCH transmitted from one DL component carrier to schedule resources in other DL component carriers should also be considered.*

2.2. PDCCH Content

Many contributions (e.g.,[1][2][3][4]) have given some overhead analysis for the two options:

1. *Separate PDCCH for each component carrier*: Each PDCCH assigns only a single TB (in absence of spatial multiplexing), as done in Rel-8. Existing DCI formats may be reused. If each separate PDCCH is sent on the same component carrier as the corresponding TB, then the PDCCH-TB correspondence is implicitly implied. If the DL component carrier used for PDCCH transmission is allowed to be different from the DL component carriers occupied by the TB, additional bits to convey the PDCCH-TB correspondence will be needed, which may make it impossible to reuse the exact Rel-8 DCI formats.
2. *Common PDCCH for multiple component carriers*: Resource assignment and MCS information for all TBs, corresponding to multiple component carriers, is signalled in a common PDCCH.
    - In [2], a slightly modified option (denoted as option “2a” here) where one PDCCH that contains only common fields and another PDCCH containing a joint resource assignment was also proposed. The overhead of this option is a bit larger than having only one PDCCH, but can potentially improve the robustness of PDCCH detection reliability.

The two options are illustrated in Figure 1.

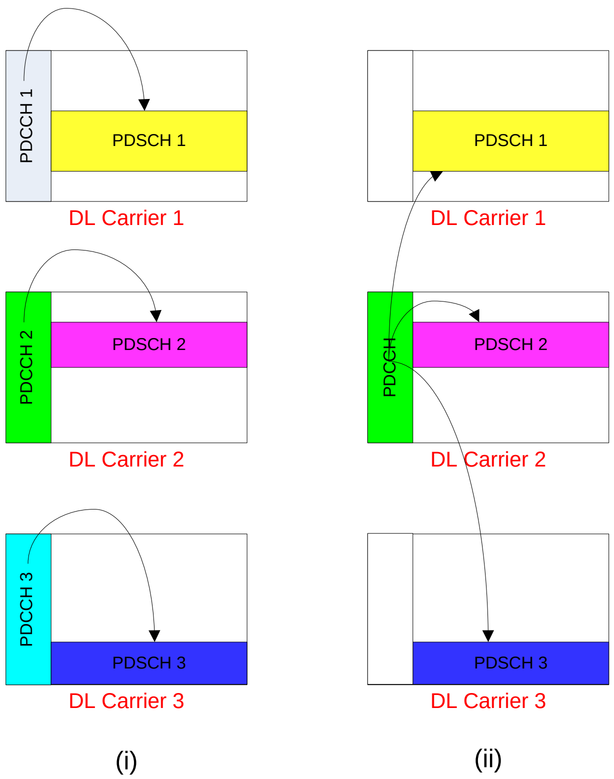

Figure 1 – Separate and Common PDCCH.

The pros and cons of each option may be seen from the following perspectives:

- Overhead: The biggest overhead reduction for option-2 comes from the fact that a single CRC (or two CRCs for option-2a) is needed as opposed to "M" 16-bit CRC with "M" being the number of component carriers.
- Blind decoding: Option-1 requires "M" times of the number of Rel-8 blind decoding. Option-2 will result in a DCI format size that depends on the number of component carriers used, i.e., number of TBs. If a UE does not know the number of TBs in the common PDCCH and hence must blindly detect all possible DCI formats, there will be an increase of blind decoding too, in addition to that required to decode Rel-8 DCI formats (note decoding of Rel-8 DCI may not be necessary if LTE-A UEs are required to decode only LTE-A DCI formats).
- Impact to existing PDCCH structure: Given that LTE-A PDCCH may well multiplexed in a subframe with Rel-8 PDCCH messages intended for Rel-8 UEs, the PDCCH structure in terms of aggregation rule is better kept unchanged. A common PDCCH could sometimes result in a new DCI format of large size so that the coding rate under the existing aggregation rule becomes too high and thus making PDCCH reception unreliable, especially for cell-edge users that require carrier aggregation to satisfy their high data rate needs. Further investigation is needed in this topic.
- PDCCH error event handling: In case of any PDCCH error, option-1 has a localized impact. The probability of any one of "M" PDCCHs in error for option-1 can be higher than the error rate of option-2 if we can assume the code rate of separate PDCCH and common PDCCH is the same.

Considering the above three options, our view on PDCCH contents is

In scenarios where TBs for multiple component carriers are scheduled from a single component carrier, resource assignment mechanisms (and PDCCH structures) that exploit commonality between individual component carrier assignments are beneficial as they reduce signalling overhead.

2.3. PDCCH Beam-forming

Beam-forming of the PDCCH based on, for example, PMI feedback or dedicated pilots has been shown to significantly improve performance and coverage [5]. When compared to open-loop transmit diversity techniques such as cyclic shift transmit diversity, beam-forming is most beneficial when four or more transmit antennas are available. Therefore, it is recommended that PDCCH performance enhancement techniques such as beam-forming should be investigated for LTE-A.

3. SCH and P-BCH

Structure

No additions to existing P/S-SCH and P-BCH structure are envisioned. However, the transmission of SCH and P-BCH may not always be needed for non Rel-8 compatible carriers. Flexibility of configuring a component carrier non-backward-compatible (e.g., LTE-A only) can be desirable for future deployment. If so configured, Rel-8 P/S-SCH and P-BCH may not be transmitted, possibly along with other Rel-8 messages such as SIBs. Note that the overhead saving by removing only P-BCH is rather small, especially for large component carrier bandwidth (0.17% for 20MHz and 2.8% at 1.4MHz). It is still possible to convey the system configuration information of non Rel-8 component using SIBs sent on a Rel-8 compatible component carrier.

Content

Modified P-BCH may be used to support additional signalling related to bandwidth extension information that can be beneficial to LTE-A UEs if such information is made available. Additional spare bits that are already available in MIB may be employed for this purpose.

4. P-CFICH Structure

No additions to existing P-CFICH structure are envisioned. Some co-ordination on values signalled on P-CFICH of different component carriers may be helpful, especially if a common PDCCH within an anchor component carrier conveys the RA information for PDSCH in different component carriers. UE implementation may be slightly simplified if it can assume that same 'number of control symbols' is used in all aggregated component carriers. Otherwise, the resource allocation for each component carrier may need to include information on the starting symbols of each TB.

5. P-HICH Structure

If a PDCCH on one DL component carrier is allowed to grant resources for multiple UL component carriers (e.g., in asymmetric aggregation with more UL components than DL components), then that DL component carrier should also signal ACK/NACK corresponding to multiple UL component carriers. In such a scenario, additional PHICH resources may be required to support bandwidth extension.

6. PUCCH under Asymmetric Aggregation

Spectrum availability could result in asymmetric aggregation in theory. One may think of a case where a new acquired TDD spectrum is used either for DL or UL only (i.e., 100% DL or UL) so that an operator does not have to deploy a TDD network to make use the spectrum. However, one has to realize that regulation may often not allow 100% DL/UL due to coexistence issue with other TDD networks on neighboring bands.

Asymmetric aggregation could also result from spectrum reconfiguration. For example, two adjacent 20MHz-DL 10-MHz-UL system could be reconfigured as two DL component and one 120MHz-UL component for better UL efficiency.

The above asymmetric aggregation scenarios are system-wide that affects all UEs in the system. Asymmetric aggregation can also be UE-specific due to implementation limitation or cost saving. For example, a UE can support only one UL component carrier, even though the network has multiple UL component carriers. Note that even in this case a UE may still be able to support a different UL component carrier at a different time, on a semi-static basis.

In this section, we will discuss the different configuration options and the associated compatibility limitations, as well as the impact on PUCCH design. We will focus on the case of more DL component carriers than UL carriers, but the case of more UL carriers may of interest to some applications with high UL traffic (enterprise, fixed CPE, etc.).

6.1. Deployment Option 1

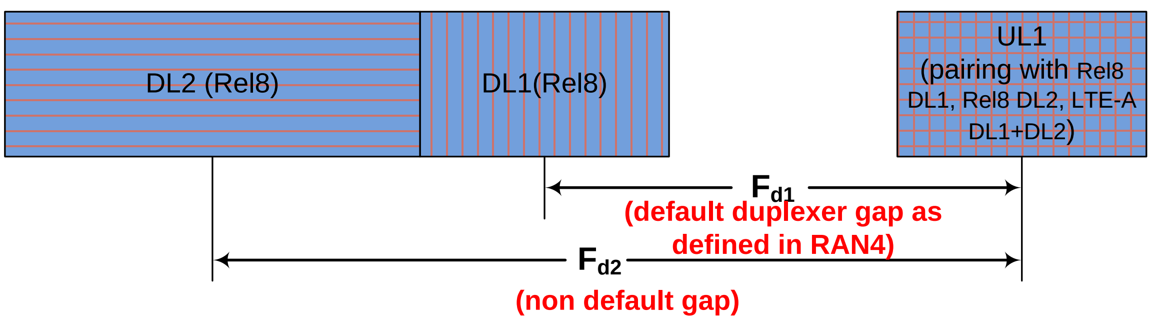

Figure 2 – Asymmetric aggregation where all DL carriers are Rel8 accessible

As shown in Figure 2, one deployment option is configure all the DL aggregated carriers to be Rel8 accessible[1]. Note that since current RAN4 specifications only test a Rel8 UE under a single band specific Tx-Rx duplexer separation (Section 5.7.4 in [6]). In Figure 2, we show that F_{D1} is the band specific default Tx-Rx separation that is tested for Rel8 (a Rel8 UE accessing component carrier DL1 could, by default, transmit in an uplink resource cantered with Tx-Rx separation F_{D1}). In order to notify a UE that DL component carrier DL2 is also paired with UL1, eNB will have to transmit an “ul-EARFCN” value in SIB2 corresponding to Tx-Rx separation F_{D2} to inform the UE to transmit in component carrier UL1. However,

[1] *By Rel8 accessible we mean - a Rel8 UE can locate the P-SCH, S-SCH transmitted by that carrier and also possibly download the MIB and SIBs*

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