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Title: Details of ACK/NAK bundling for TDD
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1. Introduction

At RAN1 #52, it was agreed that uplink hybrid-ARQ acknowledgements in TDD can be transmitted using single ACK/NAK format also for the case that a terminal is assigned several DL subframes. In the case that ACK/NACKs from several DL subframes are combined, or “bundled”, an AND operation is performed to generate a single A/N report. It was also agreed that PUCCH formats already defined for LTE are reused, see also [1].

2. Discussion

2.1. Association between DL subframes and UL subframes for

The timing relation between a PDSCH transmission in a certain DL subframe and the UL transmission in which the ACK/NACK is transmitted needs to be further clarified as discussed in [2], where no difference is made between the case with single ACK/NACK feedback, referred to in here as ACK/NAK bundling, and multiple ACK/NACK feedback in an UL subframe. When it comes to bundling, there are two basic alternatives:

- Use the first available UL subframe to transmit the ACK/NACK. This may be preferable from a latency perspective, and possibly also sufficient from a coverage perspective when bundling is used since only a single ACK/NAK is anyway transmitted. Drawback include performance degradation on the downlink channel due to less fine ACK/NAK feedback and possible implications on having different amount of PUCCH resources in the different UL subframes.
- Distribute the ACK/NACKs of different DL subframes as evenly as possible. This means that for some of UL:DL allocations with 10ms periodicity, additional delays are introduced for some DL subframes so that the maximum number of bundled ACK/NACKs from a single terminal is lowered. This would possibly make the PUCCH regions more even between the UL subframes, and would enable fewer constraints on the scheduling if bundling is to be avoided.

Thus it is not necessary to have the same timing relation for single ACK/NAK feedback and multiple ACK/NAK feedback. However, our starting point is that the timing relation should be the same. Independently of which principle is employed for the timing, we observe that each DL subframe will be associated with one DL subframe so that *each UL subframe has an associated set of DL subframes*. The sets of different UL subframes may have different size, and for the UL heavy case, certain UL subframes may have empty sets.

Proposal: Each UL subframe has a set of associated DL subframes, such that each DL subframe is associated with one and only UL subframe

In Table 1, the associated set of DL subframes is shown for the UL subframes of all configurations following the proposed timing relations of [2].

Configuration	UL subframe <i>n</i>									
	0	1 (DwPTS)	2	3	4	5	6 (DwPTS)	7	8	9
0 (2DL:3UL)	-	-	6	-	0	-	-	1	-	5
1 (3DL:2UL)	-	-	5,6	9	-	-	-	0,1	4	-
2 (4DL:1UL)	-	-	4,5,6,8	-	-	-	-	0,1,3,9	-	-
3 (7DL:3UL)	-	-	1,5,6	7,8	0,9	-	-	-	-	-

4 (8DL:2UL)	-	0,1,4,5	6,7,8,9	-	-	-	-	-	-	-
5 (9DL:1UL)	-	-	0,1,3,4,5,6,7,8,9	-	-	-	-	-	-	-
6 (5DL:5UL)	-	-	5	6	9	-	-	0	1	-

2.2. Control channel resource association

The UE will determine an index of a PUCCH resource for each PDSCH transmission corresponding to a PDCCH transmission with DCI format 1A/1/2 received in each DL subframe. For FDD; this mapping can be done on a single subframe basis. For TDD; the straight forward generalization appears to be to also account for the DL subframe number, this since the same control channel and control channel element can be used to schedule transmissions to different terminals in the different DL subframes. With the discussion in the previous section in mind it appears natural to refine this a bit so that for each UL subframe, the numbering is done within the set of associated DL subframes.

For the case with a single DL assignment in one of the DL subframes to each terminal, there is no ambiguity which PUCCH index to use. However, when the terminal receives DL assignments in several DL subframes, there is an ambiguity. Two basic approaches would involve using the index associated with the last received DL assignment or the first received DL assignments. A problem is that any of the assignments may be missed by the terminal. Scheduling of initial transmission and more importantly of retransmissions are done on a per subframe basis, and to avoid missed DL assignments, one alternative is to use DL signaling to inform the terminal about previous assignments, and for such a solution, it is preferable to use the index associated with the last DL assignments, since the eNodeB then knows that the UE received this DL assignment and hence bases the feedback on the signaling in that DL subframe. Furthermore, for per subframe scheduling it is not possible for the eNodeB to inform the terminal about future scheduling decisions.

Proposal: The UE determines the UL PUCCH index based on the lowest CCE index of the PDCCH and the DL subframe number within the set of associated DL subframes of the last received DL assignment in the set.

As side note, if the terminal will miss for example the last assignment in a set of associated subframes, it will use a feedback resource associated with the last received DL assignment and hence the eNodeB which may listen to the control channel resource of the last DL assignment will detect DTX.

2.3. Missed DL assignments

The DL resource allocation is done once per subframe, which means that PDCCH carries the DL assignment information of each DL subframe. For FDD and TDD without ACK/NACK bundling, if the UE misses a DL assignment, it will assume that nothing was transmitted and hence not transmit any ACK/NACK in the uplink. The eNodeB may detect this DTX, and can chose to (re)transmit an appropriate redundancy version.

As discussed in [3], the UE does not know in advance how many DL subframes it will get assigned and in addition, the UE may fail to decode the DL assignment. If the UE misses all DL assignments, the behavior is similar to FDD and TDD without ACK/NACK bundling in the sense that it does not transmit feedback report and the eNodeB can detect DTX. Similarly, in the case when the eNodeB assigns only a single DL subframe, the behavior is again similar for TDD with and without bundling. For the case that more than one DL subframe is assigned, there is a risk that the UE misses an assignment and that it does not provide any indication of this to the eNodeB, either in the form of DTX or in the form of a NACK. In such case, the RLC layer ARQ need to handle the problem with the associated additional delays.

Further, considering the target error probabilities for the L1/L2 control signaling as given in [6] it may be noted that the target error rate for a NACK to ACK error is around $1e-4$ to $1e-3$. This is also the same resulting target probability that the UE misses a DL assignments and that the eNodeB interprets the DTX as an ACK. This target error probability will not be met with bundling, since the target error rate for missed DL assignment is $1e-2$. Reducing the error rate for DL assignments down to $1e-4$ to $1e-3$ for this purpose appears too costly, and hence another solution needs to be adopted.

There are two basic strategies

- The eNodeB provides to the UE information on allocated DL subframes within the set of associated DL subframes
- The UE provides the eNodeB with information on which DL subframes within the set that was bundled.

Next, these two basic approaches are discussed

2.3.1 DL signaling of assignments

A straight forward solution would be for the terminal to signal as part of the downlink assignments which DL subframes that will be assigned, or has already been assigned to a certain UE so that the UE knows what to bundle. Since the UE can keep track of the number of received DL assignments, and is expected to combine them, it is sufficient that the eNodeB provides information to the UE on the number of assigned DL subframes within the set of associated DL subframes. More specifically, in each DL assignment, the eNodeB can provide information on the number of previously assigned DL subframes. Such a number can also include the number of persistent assignments. By comparing the signaled number DL assignments with the number of received DL assignments, the UE can detect that it has missed one or several assignments. An alternative, with slightly higher overhead, is that eNodeB informs the UE on which DL subframes it has been previously assigned.

We note that this solution will have an impact on the DL signaling, whereas the uplink control signaling including transmission of combinations of ACK/NACKs with scheduling requests, channel quality information and so on is left intact. Hence, this solution has impact on the downlink control signaling and no impact on the UL control signaling.

To cover all different UL-DL allocations, we note that up to three bits would be required. Some different ways to convey up to 3 bits include the following

- Add some form of index or counter information field to the PDCCH
- Include it on the PDSCH, for example by means of CRC scrambling
- Include it on the PDSCH by means of MAC L2 control signaling

Another way to include it on the PDSCH would be to employ some form of MAC L2 control signaling, similar to the timing advance mechanism. If per subframe scheduling is abandoned, one could also consider using some form of persistent scheduling configured by RRC signaling. If higher layer signaling is employed, it is also possible to convey more information to the terminal, such as exactly which DL subframes it was assigned.

2.3.2 UL signaling on the number bundled assignments

Another solution is that the UE signals to the eNodeB how many DL assignments that the bundled ACK/NAK is constructed from. This way, the eNodeB can determine whether an assignment was missed or not, but not which since it knows how many ACK/NACKs that should be combined. In principle, the UE could select which feedback resource to use based on how many ACK/NACKs it has bundled. If there is a misalignment between the number of bundled ACK/NACKs and the number of actually scheduled DL subframes, the UE will use a different feedback resource as compared to what the eNodeB is expecting, and hence the eNodeB will detect such an error case as DTX. This is a form of encoding of multiple ACK/NACKs, and possible drawbacks are that the UL control signaling design needs to be revisited to provide enough room and resources for transmission of the additional information. Furthermore, some care is needed to handle the combinations of ACK/NAK and CQI as well as scheduling requests.

2.3.3 Signaling on UL or DL?

Considering the impact of the two basic solutions and more specifically the impact on the UL control signaling in terms of capacity and coverage, our preference is to modify the DL (control) signaling, since such a solution is applicable for all different combinations of ACK/NACKs, CQI and scheduling requests. It can also be applied to both feedback on PUCCH as well as on PUSCH. Furthermore, considering also persistent scheduling, where there is no PDCCH signaling, our preference is to signal it by means of CRC scrambling of the PDSCH, even though a solution based on uplink signaling is applicable as well. This

Proposal: The eNodeB will by means of CRC scrambling of the PDSCH convey to the UE the number of previously transmitted DL subframes within the set of associated DL subframes. The UE will use the control signaling resource associated with the DL assignment in the last decoded subframe within the set of associated DL subframes

As a side note, a combination of both signalling on the uplink and downlink is possible.

3. Conclusion

We propose that

- As a function of the UL:DL asymmetry, each DL subframe is associated with a single UL subframe so that each UL subframe is associated with a set of DL subframes.
- The UE determines the UL PUCCH index based on the lowest CCE index of the PDCCH and the DL subframe number within the set of associated DL subframes of the last received DL assignment in the set.
- For each set of DL subframes, at least the number of DL subframes bundled within the set is exchanged between the eNodeB and the UE
- To consider (at least) the following solutions
 - CRC scrambling of the PDSCH to convey to the UE in each DL subframe the number of previously scheduled DL subframes within the set of associated DL subframes.
 - MAC control signaling to convey to the UE in each DL subframe the number of previously scheduled DL subframes within the set of associated DL subframes
 - Signaling on the PDCCH to convey to the UE in each DL subframe the number of previously DL subframes within the set of associated DL subframes
 - UL signaling, for example by means of selecting the PUCCH index based on the number of ACK/NACKs bundled.
 - Various forms of higher layer signaling with mechanisms similar to persistent scheduling.

4. References

- [1] R1-081110, "Multiple ACK/NAK for TDD," Ericsson, Motorola, Nokia, Nokia Siemens Networks, Qualcomm
- [2] R1-080890, "Uplink ACK/NACK timing for TDD," Ericsson
- [3] R1-080870, "Combination of ACK/NACKs for TDD," Ericsson
- [4] 3GPP TS 36.212 v.8.1.0 (2007-12)
- [5] R4-070711, LS on target quality on L1/L2 control channel, 3GPP TSG RAN WG4 Meeting #43, Kobe, Japan, 7-11 May 2007.