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Title: Combination of ACK/NACKs for TDD
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1. Introduction

For TDD, the number of ACK/NACKs that could be transmitted in an UL subframe from a certain UE depends on the asymmetry, since there is no one-to-one correspondence between DL and UL subframe as in FDD. Besides, the number of required ACK/NACKs in any UL subframe depends on the MIMO mode used in the DL transmissions. To improve coverage, capacity and simplify the design, it has been proposed to consider some form of combination of multiple ACK/NACKs. This is also referred to as ACK/NACK compression or bundling [1,2].

2. Bundling of ACK/NACKs

In Figure 1, an example of an UL-DL configuration with 3DL+DwPTS:1UL and 5ms switch point periodicity is shown. In this example, the minimum processing time between transmissions on DL-SCH and generation of ACK/NAK is 3ms minus the round trip time.

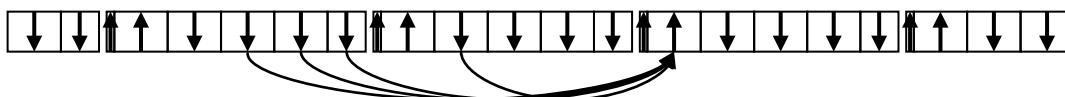


Figure 1 Example of association between UL and DL. ACK/NACKs in response to DL transmissions in four DL subframes (including DwPTS) are transmitted in a single UL subframe.

According to the example in Figure 1, data in four subframes including DwPTS can be assigned to one user and the ACK/NACKs in response to DL transmission from these four subframes are to be transmitted in a single UL subframe. For the case with MIMO, the number of required ACK/NACK reports may be eight. Similarly, for the case of 10ms DL/UL switching period, the extreme DL/UL asymmetry (i.e. 9:1) would require up to 18 ACK/NACKs to be transmitted, when DwPTS is also used for data transmission [4].

For simplicity, let us consider the single code block case in which a single ACK/NACK is generated for each DL subframe and that PUCCH formats carrying a single ACK/NACK bit are used. The idea with bundling is then to generate a single ACK/NACK report based on the ACK/NACKs of the assigned subframes. A simple rule is to generate an ACK only if all assigned DL subframes are received correctly, whereas a NACK is generated otherwise.

The main advantages of the above mentioned bundling are the improvement of UL coverage and capacity. Initial performance evaluations indicates that PUCCH format 0 may be the channel that limits the UL coverage; and since transmission of multiple ACK/NAK requires higher SNR it follows that this may be the even more limiting channel in the uplink. This problem is also pointed out in [2]. Another possible problem is that the multiplexing capacity goes down as the number of possible ACK/NACKs per UE increases, see also [1]. Hence, provisioning for multiple ACK/NACK feedback may lead to large overhead in the UL in addition to possible coverage and capacity problems.

A significant advantage in bundling is that already defined PUCCH formats may be used. The drawback of bundling is that the eNodeB can not determine how many and which of the DL subframes that were erroneously decoded. One simple and conservative solution is to retransmit all the transmitted DL subframes. This leads to a degradation of the DL throughput.

Initial simplified system level evaluations with TCP traffic and a non-optimized scheduler indicate that the loss in terms of user throughput is acceptable and typically decreasing as the number of users increases. An explanation is that the probability that a user gets scheduled more than once during each DL period decreases when the number of users increases. By further optimizing the scheduler, the loss can be made even smaller.

Thus with bundling, scheduling constraints can be avoided, thus the constraints on the DL user throughput can also be avoided.

2.1. Impact of 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 choose to (re)transmit an appropriate redundancy version.

With bundling, 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 needs to handle the problem with the associated additional delay.

Further, considering the target error probabilities for the L1/L2 control signaling as given in [5], 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 assignment 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.

3. Conclusion

We propose

- To support an ACK/NACK bundling mode
- For this ACK/NACK bundling mode
 - Associate each DL subframe with an UL subframe. Each UL subframe is then associated with K subframes, where K can be zero, one or up to nine depending on the actual UL-DL configuration.
 - ACK/NACK reports from the set of associated DL subframes are combined to generate a single ACK/NACK report for the K associated DL subframes;
 - The single ACK/NACK report is generated as follows
 - An ACK is generated if all assigned DL subframes are ACK
 - A NACK is generated if all or at least one of the assigned DL subframes is NACK and the rest are ACK
 - Otherwise, a NACK or DTX is generated
 - A solution to handle missed DL assignments is adopted so that the target error probabilities for the L1/L2 control signaling can be met.

The same principle applies also for the case with MIMO and the use of PUCCH format 1.

4. References

- [1] R1-071894, Uplink transmission of ACK/NACK for E-UTRA TDD, Ericsson, Beijing, China, April 17 – 20, 2007, 3GPP RAN1 Ad Hoc
- [2] R1-80316, Multi-ACK transmission in PUCCH for TDD, Nokia, Nokia Siemens Networks, Seville, Spain, 14 - 18 January 2008, 3GPP RAN1 #51bis
- [3] 3GPP TS 36.211, v8.1.0 (2007-11)
- [4] R1-080344, Multiple ACK/NACK transmissions on PUCCH for TDD, Ericsson, Seville, Spain, January 14-18, 2008, 3GPP RAN1 #51bis.
- [5] R4-070711, LS on target quality on L1/L2 control channel, 3GPP TSG RAN WG4 Meeting #43, Kobe, Japan, 7-11 May 2007.