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Source: LG Electronics
Title: PUSCH multiplexing of data, control, and ACK/NACK information
Document for: Discussion & Decision

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1. Introduction

In Athens (#50) it was decided that when control information is to be multiplexed with data, data information is rate matched with control, and that the ACK/NACK information is to be inserted into PUSCH by either puncturing data or control information bits. Also it was decided that all control information should be positioned next to the reference signal, and positioned in both slots of the subframe. In this contribution we propose a simple multiplexing structure for data and control information and ACK/NACK puncturing position candidates.

2. PUSCH multiplexing structure for control information

The current description of TS36.212 shows that the control information is multiplexed with rate matched data information so that control information is always positioned near the Reference Signal (RS). Although the current description does not show the multiplexing structure when ACK/NACK is also to be multiplexed, the rate matched data and control information should not be configured differently depending on whether ACK/NACK is to be multiplexed or not. This is because the ACK/NACK should be punctured into the data and control multiplexed bit stream, to avoid erroneous exceptions in the UE procedure. This is shown in figure 1. In figure 1, virtual subcarrier is the logical input indices to the DFT transform which output is mapped to the physical subcarriers of the IFFT input in SC-FDMA. We have dubbed them virtual sub-carriers since they do not actually represent the physical subcarriers.

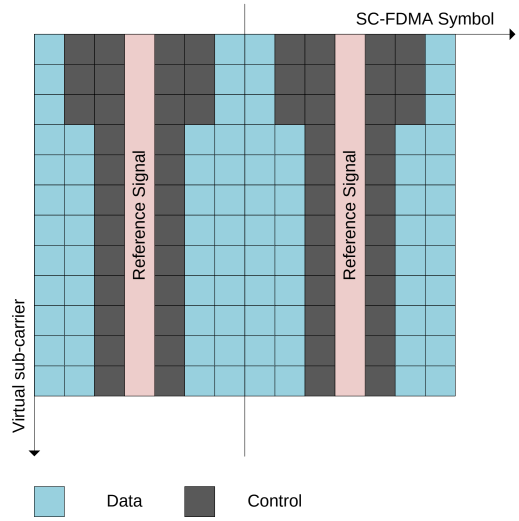
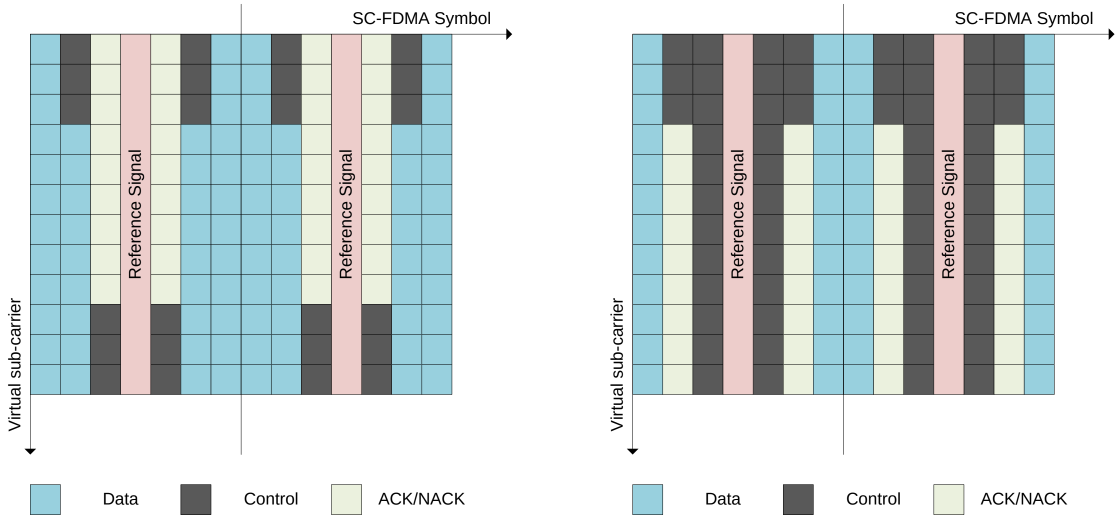


Figure 1. Example of data and control multiplex structure according to TS36.212

According to the working assumption ACK/NACK information is also to be positioned near the RS. There may be at least 2 options available. The first option is to position the ACK/NACK information right next the RS, effectively puncturing out either data or control information in the process. The second option is not to puncture out control information and only puncture out data information. The first option is not desirable due to disastrous cases where the ACK/NACK information may puncture out most of the control information, resulting in performance loss in control information as well as not able to meet the target error rate requirements. The difference between option 1 and option 2 is shown in figure 2.



(a) option 1 (b) option 2

Figure 2. Example of possible ACK/NACK puncturing positions

The key point of option 2 is that the control information is prioritized before ACK/NACK information, and positioned closer the RS. While this seems to be one feasible solution, in general ACK/NACK information is more important than control information which is basically the channel quality information of the downlink. We can even see this in the target quality requirements on the PUCCH [1]. Since positioning of control information near the RS is so that we may utilize better channel estimation performances in high UE mobility scenerios, it seems more logical to position the ACK/NACK closer to the RS than the control information. So one possibility is to switch the positions of control and ACK/NACK in option 2 so that the ACK/NACK is positioned closer to the RS, but this would mean that the control information would be positioned further away from the RS even in cases where there is no ACK/NACK multiplexed in the PUSCH. In this possibility, we would sacrifice control information performance (even though it may be slight) in all cases regardless whether we have ACK/NACK transmitting in PUSCH.

In light of these observations, we propose to multiplex the control information in a uniform manner across all SC-FDMA symbols. This would effectively mean that the control information is multiplexed so that it is not only positioned near the RS, rather positioned in all SD-FDMA symbols. Since the PUSCH is mapped to physical resources by a simple time-first mapping rule, our proposal would also mean that the control information is multiplexed with data by simple serial concatenation with data information and mapped altogether by this simple time-first mapping rule. This is illustrated in figure 3.

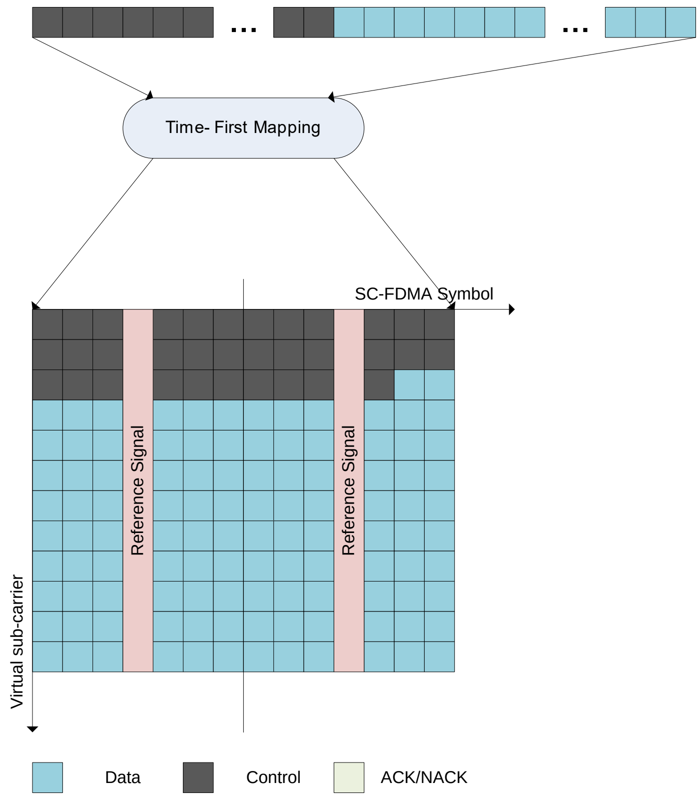


Figure 3. Proposed data and control multiplexing structure

This will simplify the control information multiplexing with data, compared to the current description of TS36.212. The current TS36.212 structure must incorporate different PUSCH subframe formats and control information size, and match them to one of the 18 tables and then multiplex the control information in between the data information so that the physical resource time-first mapping will position the control information near the RS. Using the proposed structure we only need to describe that the control information is serially concatenated with data information, and the physical resource time-first mapping will take care of the rest. It also has an advantage of having equal number of resource elements near the RS for each code block, when there are multiple code blocks, compared to the current description of TS36.212, where the number of resource elements near the RS for code block can be significantly different resulting in slightly different BLER performance for each code block in high UE mobility scenarios.

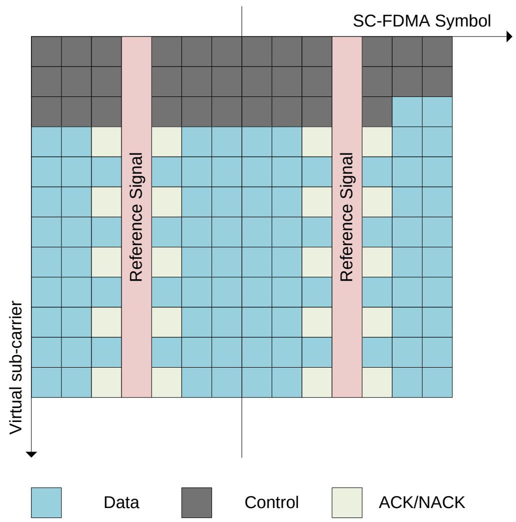


Figure 4. Possible ACK/NACK puncturing positions in the proposed multiplexing structure

The proposed structure also has the advantage of always being able to position the ACK/NACK information, which in our opinion by far more important than the channel quality information, near the RS. This is shown in figure 4. In this structure we may position the ACK/NACK information near the RS and always fully utilize better channel estimation effects. In figure 5, we have simulated BLER performance between the proposed control information mapping structure (called time uniform in the figures), and the current TS36.212 control information mapping structure (called Near RS in the figures). Simulation assumptions and more simulation results are given in the Annex.

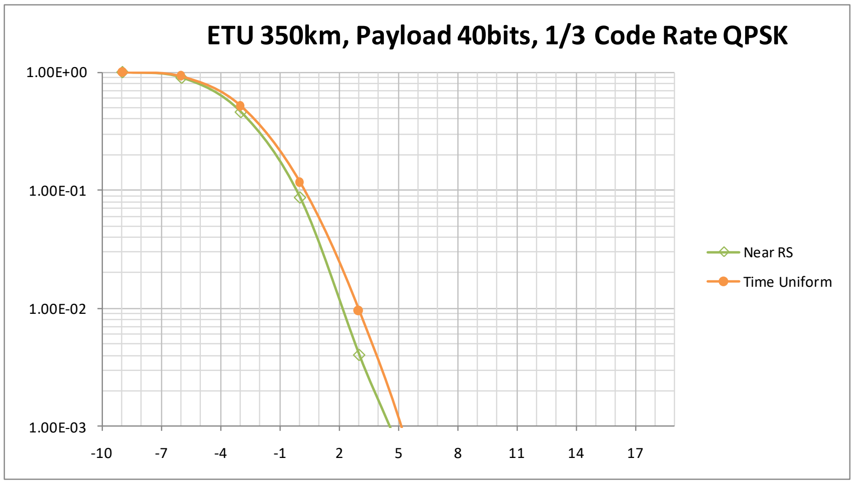


Figure 5. BLER performance of control information in PUSCH in 350km/hr UE mobility environment

For a target quality requirement of 1% BLER there is no difference between the control information uniform spread over time and control information positioned only near RS up to 120km/hr UE mobility cases. There is only 1dB performance difference in 350km/hr UE mobility scenarios, but it is questionable whereas to channel quality information at these extreme speeds is very important, so in our opinion this marginal performance loss has almost no impact in the system. We have also simulated BLER performance of ACK/NACK information transmitted in the PUSCH. The simulated results are shown in figures 6. In the figures 'Next to RS(1)' means that the ACK/NACK signal is positioned right next the RSes, 'Next to RS(2)' means that the ACK/NACK signal is positioned one SC-FDMA symbol further away, and 'Next to RS(3)' means that the ACK/NACK signal is positioned two SC-FDMA symbols further away, which is the most extreme case.

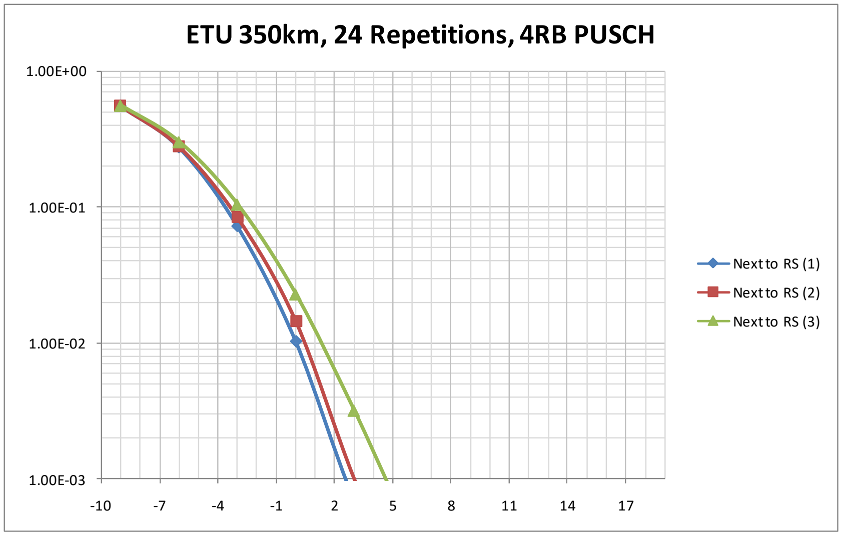


Figure 6. BLER performance of ACK/NACK in PUSCH in 350km/hr UE mobility environment

Since the proposed data, control and ACK/NACK multiplexing structure will always position the ACK/NACK information right next to the RS (even in the extreme cases), this can be seen as 'Next to RS(1)' or possibly mixture of 'Next to RS(1)' and 'Next to RS(2)'. For 350km/hr UE mobility and above in some cases the proposed structure may have 1 to 1.5dB gain in ACK/NACK performance.

3. Puncturing positions for ACK/NACK information

Currently the actual insertion position of the ACK/NACK information in the PUSCH is not yet agreed. When we decided on the ACK/NACK information position in the PUSCH we believe we also need to consider punctured out effects of the data information. From this point we shall call the current TS36.212 control information multiplexing structure to be structure A, and the proposed control information multiplexing structure to be structure B.

Data information multiplexed with control information may have several code blocks according to transport block payload size. Depending on how and how much the control information is multiplexed each code blocks in the data information will be placed in different resource elements. Figure 9 shows an example of where each code block is positioned in structure A. Due the control information multiplexing and time-first mapping rule, the number of virtual subcarriers used for each code block can be different. Basically the lowest code blocks may be mapped to more virtual subcarriers because control information has already taken place.

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