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Title: Control Signaling Location in Presence of Data in E-UTRA UL
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1. Introduction

This contribution considers the data-associated PUCCH transmission. In particular, placement aspects in the UL sub-frame for the ACK/NAK and CQI signals are considered with respect to performance and other general E-UTRA requirements.

The location of the data-associated CQI and ACK/NAK signals in the UL sub-frame has been addressed in [1, 2]. In [1], the suggestion is made for the CQI signaling to be placed at the first symbol of the sub-frame in order to reduce scheduling latency. However, as the demodulation RS (DM RS) is placed in the middle of the slot, this is not applicable. In [2], the ACK/NAK signal is assumed to be distributed substantially over the entire sub-frame (in particular, in the first 3 symbols of each slot).

The previous suggestions however have not considered two important aspects of the overall E-UTRA UL transmission. The first is that DM RS exists only in the middle symbol of each slot. This results to a substantially degraded channel estimate for the symbols at the beginning and end of each slot for the higher UE speeds that need to be supported in E-UTRA. This may be acceptable for the data transmission which is coded, has a relatively large target BLER of 10% or above, and can benefit from HARQ. Conversely, the PUCCH transmission has much stricter performance requirements, particularly the ACK/NAK signaling.

The second aspect is the transmission of a sounding RS (SRS) in synchronous systems. Clearly, the SRS cannot be transmitted at the middle symbol of each slot where the DM RS is placed. Distributing the CQI and ACK/NAK signals substantially over the entire UL sub-frame will either severely restrict the SRS placement or introduce additional complexity and performance loss in the reception of ACK/NAK and/or CQI signals as puncturing will be dynamically needed in a symbol depending on whether or not the SRS is transmitted in that symbol. Having as many as possible locations for SRS transmission is desirable because, for proper CQI and power control measurements, the SRS should capture interference from data transmission and not from other SRS transmission, that is, SRS transmission from neighboring cells and Node Bs should not coincide.

2. Raw BER Performance per UL Sub-Frame Symbol

The raw BER per UL sub-frame symbol is now evaluated as a function of the UE speed. **Table 1** gives the simulation assumptions. Several key ones are chosen so that they provide the most optimistic scenario for the raw BER performance loss of symbols further away from the DM RS. They include:

a) Transmission over 1 RB to maximize power per sub-carrier.
b) Large channel frequency selectivity and 2 uncorrelated receiver antennas in order to maximize the slope of the raw BER curve.
c) BER evaluation per QPSK symbol and no repetition of bits. This leads to higher SINR for a target raw BER. For ACK/NAK transmission, where a target raw BER should be achieved at SINRs as low as -5 dB or lower, the channel estimation losses will be (much) larger.

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Table 1: Simulation Assumptions

Parameters	Assumptions
Numerology	5MHz @ 2.6 GHz
Modulation	QPSK
Data Allocation	1 RB
UE Speed	3, 30, 120 and 350 kmph
Transmission Type	Localized at 3, 30 Kmph Frequency Hopping Between Slots at 120 and 350 Kmph
Channel Model	TU6
Number of Receive Antennas	2
Number of Transmit Antennas	1

Figure 1 presents the raw QPSK bit error rate (BER) for the examined cases outlined in **Table 1**. The BER at symbol locations symmetric to the DM RS is typically the same. This is clearly the case at 120 Kmph and 350 Kmph due to the frequency hopped transmission per slot. At low speeds, such as 3 Kmph, this is because the channel does not change. However, for some UE speeds such as 30 Kmph, the raw BER at equidistant symbols from the RS in a slot, is lower for the ones after the RS of the first slot and before the RS of the second slot as the channel estimate, that uses the RS of both slots, is more accurate. Nevertheless, for simplicity, the average BER of equidistant symbols from the DM RS is shown in **Figure 1** at 30 Kmph.

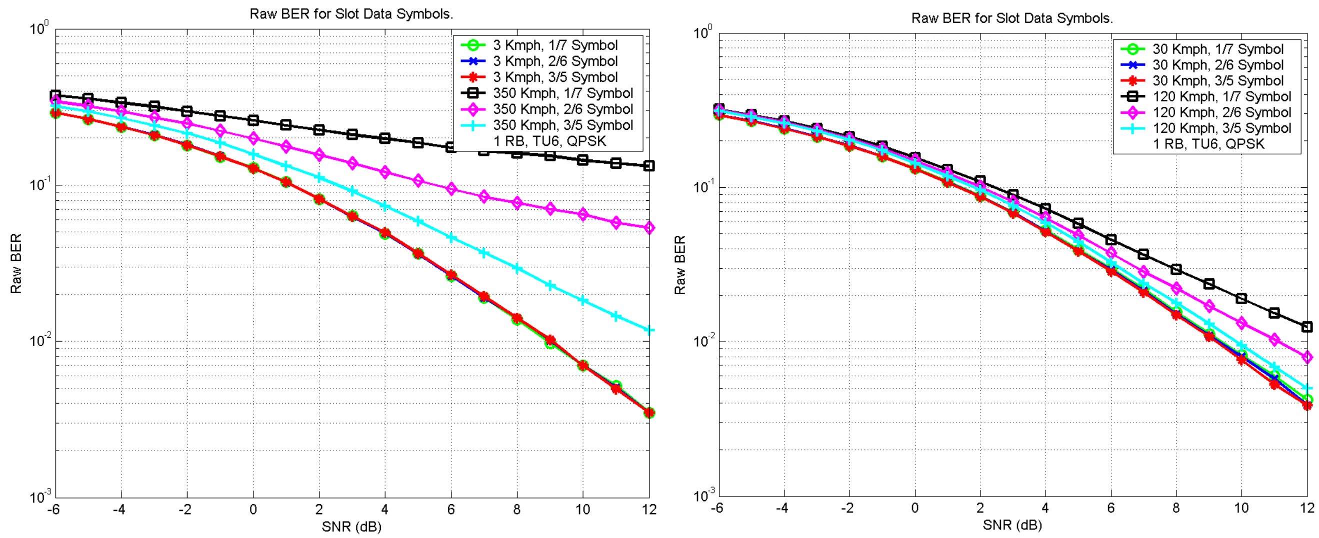

Figure 1: Raw BER as a Function of the Slot Symbol and the UE Speed.

Even under the previous, most optimistic, assumptions for the raw BER degradation at symbols further away from the DM RS, at 350 Kmph, the BER saturates at the $1^{st}/7^{th}$ and $2^{nd}/6^{th}$ symbols. However, the impact on the BER of the $3^{rd}/5^{th}$ symbols is rather contained and saturation is avoided (the difference relative to the BER at 3 Kmph is also partly due to the fact that the latter uses both RS in the sub-frame for channel estimation, that is, channel estimation is operating with 3 dB more SINR). The BER at 120 Kmph, relative to the one of the $3^{rd}/5^{th}$ symbols at about 1% BER, is also degraded by about 3 dB for the $1^{st}/7^{th}$ symbols and by about 1.5 dB for the $2^{nd}/6^{th}$ symbols. Obviously, due to the flattening of the BER curves for the $1^{st}/7^{th}$ and $2^{nd}/6^{th}$ symbols, the degradation will be much larger for operating points below 1% as needed for the NAK reception.

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3. Location of Data-Associated PUCCH

Based on the results in the previous section, it becomes apparent that the data-associated PUCCH should be placed immediately next to the DM RS. **Figure 2** shows an example for such placement when a UE transmits both ACK/NAK and CQI during a sub-frame by applying TDM with data.

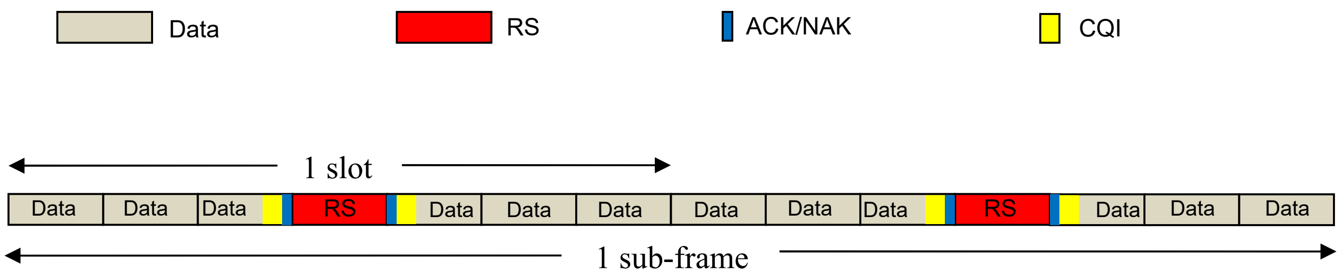

Figure 2: Placing of Data-Associated ACK/NAK and CQI Transmission

To minimize channel estimation losses, ACK/NAK should be placed with priority in the symbol after the first RS. Notice that this does not impact demodulation latency as a channel estimate is available only after the first RS (clearly, there is no use from earlier transmission with respect to latency).

Subsequently, to address low SINR or coverage issues, the ACK/NAK can be placed in the symbol before the second RS. The reason is that for medium UE speeds, this second ACK/NAK placement benefits from improved channel estimation and time diversity while for high UE speeds, it benefits from frequency and time diversity. The tradeoff is the increased latency which however is not critical for the ACK/NAK transmission (data non-associated PUCCH is assumed to be transmitted over the entire sub-frame). Even though LTE is optimized at low speeds, the CQI and ACK/NAK performance targets are similar at high UE speeds which the most challenging operating conditions.

Based on the results from [2], provisioning for ACK/NAK transmission in 2 symbols is comfortably adequate to achieve 1% BER even for the lowest geometries and transmission over 1 RB. Nevertheless, since the NAK reception has lower BER requirements, it is appropriate for robustness and to achieve time and frequency diversity, to have the ACK/NAK transmission over a number of sub-carriers in 1 symbol of each slot.

If further ACK/NAK transmissions are needed, because of SINR or coverage issues, or for some interference randomization in asynchronous systems, the other symbols next to the RS in the 2 slots may also be used. However, the number of symbols where ACK/NAK and CQI transmission may occur should be minimized as it directly affects the number of available symbols for SRS transmission in synchronous systems (as previously mentioned, for proper SRS operation, SRS from different cells or Node Bs should not overlap in time, as much as this is possible).

If latency is a concern for the CQI reception, it may be confined only in the first slot in **Figure 2**. This may be feasible for UEs in good SINR conditions but, in general, it will lead to worse performance due to losses from less accurate channel estimation and less diversity. However, as data non-associated CQI is already assumed to be transmitted over the entire sub-frame, minimizing latency for the data-associated CQI transmission becomes even less important and emphasis should be placed on performance.

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4. Conclusions

This contribution considered the placement of the data-associated PUCCH. Due to the non-uniformity of the RS across the sub-frame and the inability, in general, to interpolate across sub-frames, symbols closer to the RS are considerably more reliable at medium and high UE speeds, even under optimistic evaluation scenarios for the relative BER performance in symbols further away from the DM RS.

Therefore, the placement of ACK/NAK and CQI signaling, having low BER requirements and not being able to benefit from HARQ, should be at the symbols immediately next to the RS. To obtain time and/or frequency diversity, transmission in both slots should be utilized. CQI reporting latency may be minimized, for some performance loss, by confining the corresponding signaling only to the first slot.

The unequal BER at the various symbols of the sub-frame can also be exploited at the receiver by appropriately weighting the log-likelihood ratio (LLR) of the data bits provided to the turbo decoder in order to improve the BLER at high speeds.

References:

[1] R1-051395, "Mapping Position of Control Channel for Uplink SC-FDMA", Panasonic

[2] R1-072313, "ACK/NACK Transmission with UL Data", Nokia

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