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Source: **Texas Instruments**
Title: **ACK/NAK Channel Transmission in E-UTRA Downlink**
Agenda Item: **6.9.2**
Document for: **Discussion and Decision**

1. Introduction

ACK/NAK transmission in E-UTRA downlink (DL) has been previously considered in [1-3]. Several principles are generally accepted.

The first principle is that the UE ID should not accompany the ACK/NAK transmission as the corresponding overhead (e.g. 16-bit UE ID) cannot be possibly accepted. Instead, implicit mapping should be used to derive the UE ID from the ACK/NAK signaling.

The second principle is that ACK/NAK transmission should exploit the frequency diversity the channel provides and should provide interference randomization/averaging. Two basic schemes have been proposed; FDM [1] and CDM [2, 3] with Walsh-Hadamard (WH) orthogonal spreading. Each of the proposed schemes has certain trade-offs.

Individual FDM for the ACK/NAK transmission [1] has the following attributes:

a) it allows for frequency diversity (with ACK/NAK repetition)
b) it allows for individual transmission power control (TPC)
c) it does not allow for interference randomization/averaging as each ACK/NAK is located on few sub-carriers making it susceptible to interference in general and especially with use of TPC
d) it does not allow for joint power balancing among several ACK/NAK signals which can lead to significant power variations per ACK/NAK sub-carrier and ineffective TPC for cell edge UEs.

CDM for the ACK/NAK transmission [2, 3] has the following attributes:

a) it allows for frequency diversity
b) it allows for both individual TPC and joint power balancing of multiple ACK/NAKs
c) it allows for interference randomization/averaging (spreading gain)
d) it relies on WH orthogonality to achieve previous properties. However, this orthogonality is destroyed in frequency selective channels assuming transmission substantially over the entire bandwidth for frequency diversity. Then, the ACK/NAK signals interfere (transmission is no longer orthogonal) and, with the application of TPC, this leads to "near-far" effects which severely limit the ACK/NAK detection performance (as demonstrated in this contribution).

To exploit the advantages of FDM and CDM while avoiding their corresponding shortcomings, hybrid CDM/FDM is considered for the ACK/NAK transmission for the same reasons it has been adopted for the ACK/NAK transmission in the UL.

2. Hybrid CDM/FDM

Figure 1 shows the hybrid CDM/FDM transmission for DL ACK/NAK. Its basic principles are:

a) Localized WH spreading over a narrow enough BW for the channel to have no frequency selectivity, thereby preserving CDM orthogonality.

b) Localized WH spreading is repeated in frequency several times to capture the frequency diversity of the channel. The frequency separation between two repetitions should be large enough for the frequency response of the channel to substantially change and small enough to capture all or most such changes.

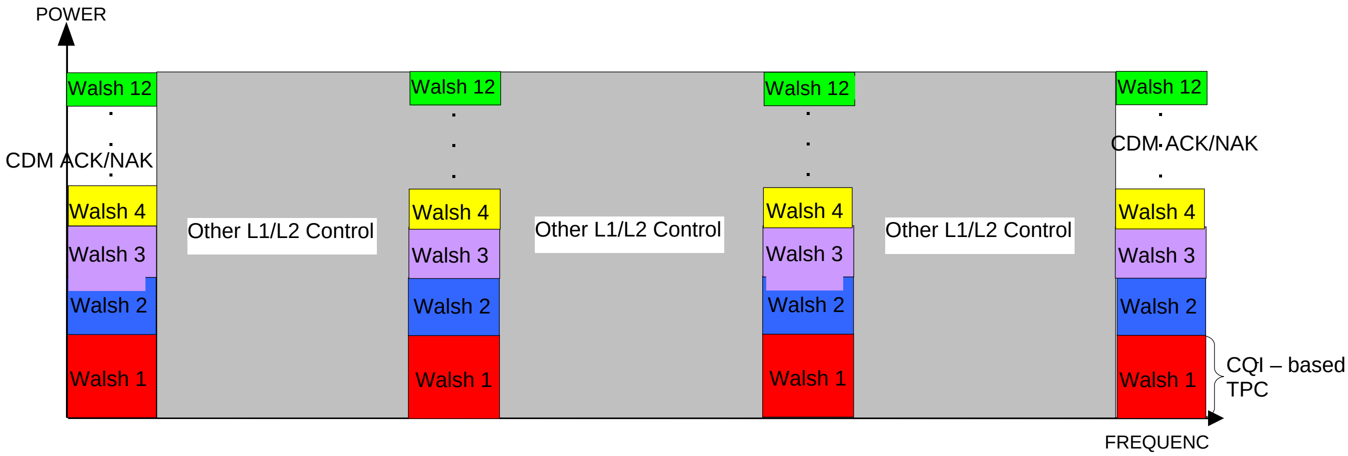

Figure 1: Downlink ACK/NAK Transmission.

Figure 1 considers WH sequences with length 12 which may be appropriate for 5 MHz operating BW having a maximum of 6 simultaneously scheduled UEs and a maximum of 6 VoIP groups. If VoIP does not support HARQ, a smaller WH sequence length (e.g. 8) can be used instead.

The WH sequence length, and therefore the number of occupied sub-carriers, can be static, semi-static, or dynamic. A constant (static) WH sequence length is selected to always accommodate the maximum possible number of ACK/NAKs (**Figure 1**). However, the larger the WH sequence, the larger the number of required sub-carriers to exploit the frequency diversity of the channel. This increase in bandwidth is offset by a corresponding reduction in power. Nevertheless, as bandwidth is more valuable than power (relative to capacity), the WH sequence length should only be as large as required to convey a certain number of ACK/NAK signals. **Figure 2** shows a possible semi-static or dynamic WH sequence length adaptation between two sub-frames.

The WH sequence length adaptation can be based on Cat0 of the L1/L2 control channel. For example, not considering VoIP groups for clarity (assuming VoIP employs HARQ), if Cat0 specifies that the maximum number of UL grants during a sub-frame is 7, a WH sequence of length 8 can be used for the ACK/NAK transmission. Similarly, if Cat0 specifies a maximum number of 4 UL grants during a sub-frame, the corresponding WH sequence length at a given subsequent sub-frame does not need to be larger than 4. The WH sequence length can vary between Cat0 transmission periods. **Figure 2** illustrates an exemplary application of this concept.

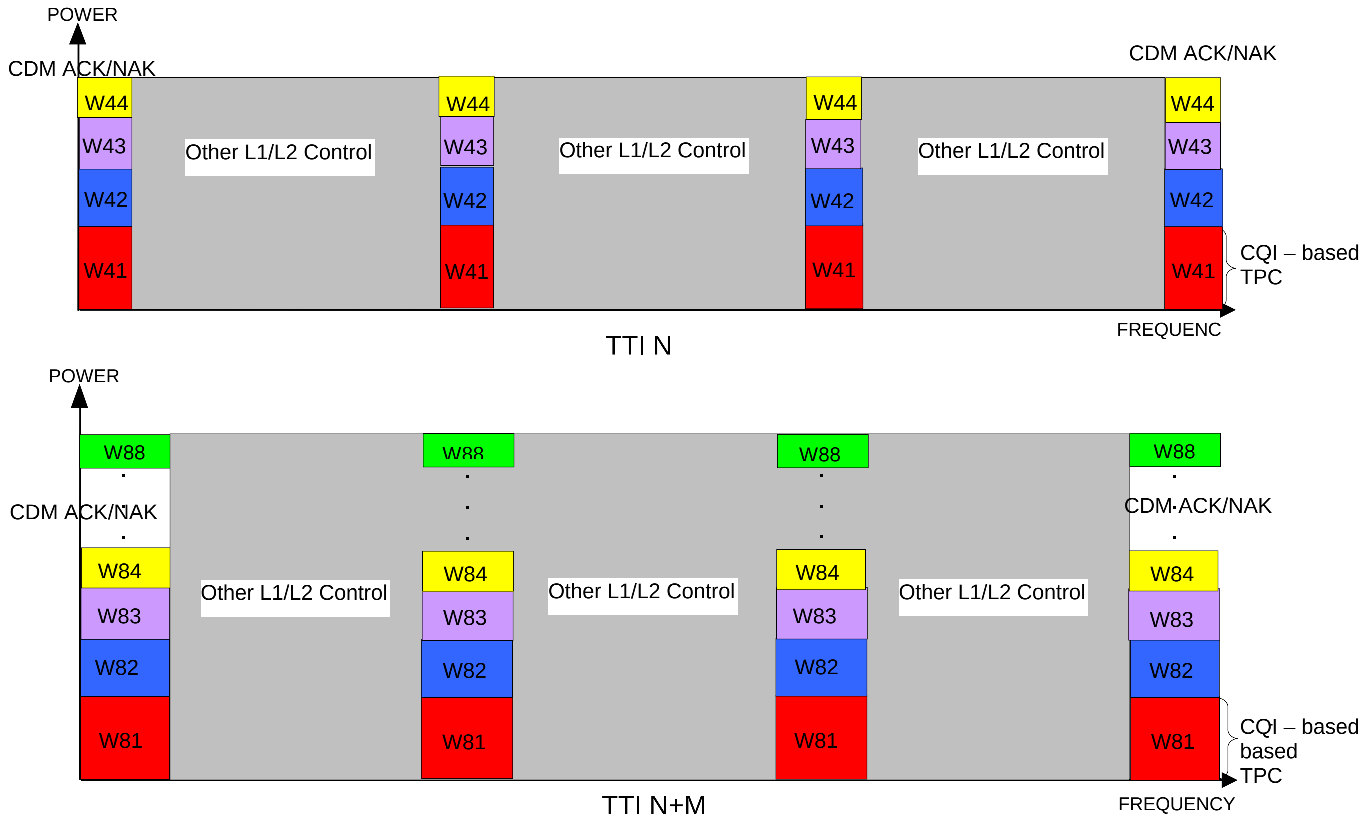

Figure 2: Adaptive Selection of the WH Sequence Size for ACK/NAK transmission.

A suggestion for implicit mapping of the ACK/NAK to the respective UE is to have the number of the WH sequence used to convey the ACK/NAK be the same as the number of the first RB where the UE was scheduled [2]. This approach has the following two shortcomings:

a) it cannot be used with MU-MIMO where a conflict exists

b) it assumes a fixed, maximum, WH length regardless of the number of scheduled UEs.

To improve the flexibility of the implicit ACK/NAK mapping, Cat0 can again be used and the mapping between the WH sequence conveying the ACK/NAK signal and the intended UE can be based on the code-word number where the UE finds its UL grant. For example, if Cat0 specifies that the number of UL grants during a sub-frame has a maximum value of P, a number of P code-words conveying UL grants is expected by each UE. If a UE finds its UL grant in code-word Q (with Q being smaller than or equal to P), it can then expect the WH sequence number Q to be used to convey the associated ACK/NAK at a specified subsequent sub-frame. Clearly, the WH sequence used should have length larger than or equal to P. Typically, if Cat0 is transmitted in every sub-frame to dimension that remaining L1/L2 control channel, all P L1/L2 control channel code-words have an UL grant. If Cat0 is transmitted less often than every sub-frame, one or more of these P L1/L2 code-words may not have an UL grant (no signal is transmitted if the number of UL grants is less than P ("empty" sub-carriers) – the UL grants between two consecutive Cat0 transmissions cannot exceed the maximum value specified by the most recent Cat0 transmission).

An alternative to using larger WH sequences to convey a larger number of ACK/NAK signals is to use multiple shorter WH sequences. This is applicable for the larger operating bandwidths (e.g. 5 MHz and above) where the maximum number of ACK/NAK signals would necessitate longer maximum WH sequences thereby creating orthogonality issues and “near-far” effects in frequency selective channels even with localized spreading. Then, the multiplexing in **Figure 1** can be equivalently accomplished with the multiplexing in **Figure 3**. The implicit mapping rule and occupied sub-carriers do not change and the only tradeoff is the somewhat reduced interference suppression capability which is offset by the absence of any orthogonality or “near-far” effects issues. The simulation results in the next section suggest that a WH sequence length of 4 or 8 and localized spreading completely avoids “near-far” effects in TU channels while some issues begin to appear for length 12.

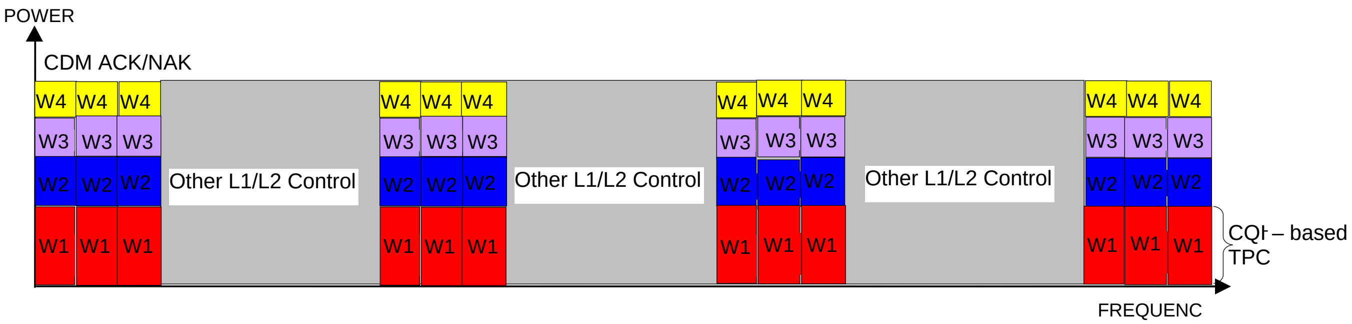

Figure 3: Using Multiple Localized Short WH Sequences for ACK/NAK transmission.

3. Performance Results

The simulation assumptions are provided in the Appendix. Antenna diversity (2 Tx) and actual channel estimation are applied. The operating bandwidth is 5 MHz and the TU6 channel is assumed (it should be noted that no performance difference was observed for flat channels, such as the PA, as expected). The ACK/NAK transmission is assumed to occur at the beginning of the sub-frame (as for L1/L2 control) to minimize latency. Several cases are considered including:

a) Multiplexing length 4 and length 12 WH sequences (4 and 12 ACK/NAK signals)

b) TPC application with various power levels for the ACK/NAK signals

c) Distributed and localized with various repetition factors CDM

Figures 4-6 provide the ACK/NAK BER when 4 and 12 ACK/NAK signals are transmitted having various power levels. The total power per sub-carrier is kept constant and the SNR is normalized for the WH sequence length (and hence normalized by the number of sub-carriers used for ACK/NAK transmission or equivalently the number of ACK/NAK signals). TPC is applied as:

a) 4 ACK/NAK case: No power variation for 2 ACK/NAK, 3 dB boost for 1 ACK/NAK (cell edge UE with low G) and 3 dB reduction for 1 ACK/NAK (e.g. cell interior UE with high G).

b) 12 ACK/NAK case: No power variation for 4 ACK/NAK, 3 dB power boost for 4 ACK/NAK, and 3 dB power reduction for 4 ACK/NAK.

The following can be observed:

a) The orthogonality loss for distributed CDM transmission in frequency selective channels leads to error floors which are particularly severe for signals transmitted with reduced power ("near-far" effect) and the larger the number of distributed sub-carriers, the more severe the impact.

b) Frequency diversity is highly beneficial to performance. Most gains are achieved with 4 repetitions of localized CDM transmission, which for 5 MHz transmission bandwidth implies repetition every 1.25 MHz (for the TU channel).

c) CDM over 4 sub-carriers (60 KHz) is somewhat preferable to CDM over 12 sub-carriers (180 KHz), especially for the ACK/NAK with reduced transmit power, as some channel selectivity does exist for the larger bandwidth and some manifestation of "near-far" effects is observed.

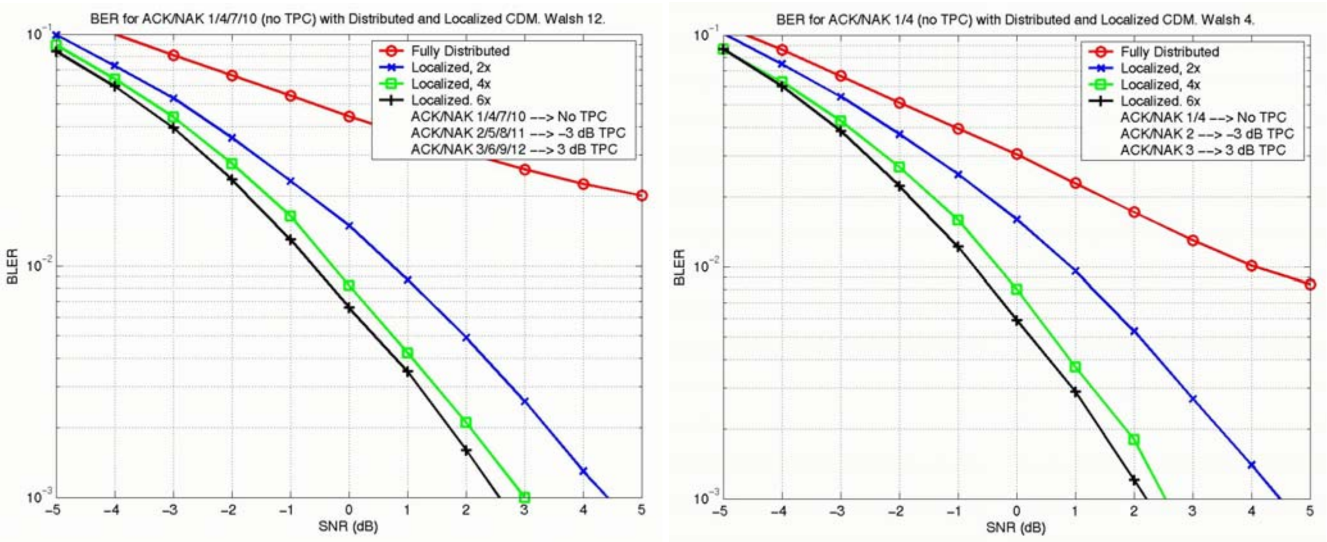

Figure 4: BER for ACK/NAK without power variation.

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