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1 Introduction

Hybrid ARQ (H-ARQ) was one of the key technologies that led to the significant improvement that HSDPA provided over previous downlink transmission technologies, such as that in Rel '99. It can be expected that H-ARQ will once again play an important role in uplink enhancements that are being studied now.

Certain amount of signalling is necessary for H-ARQ operation. In this contribution, we discuss the signalling that is required for efficient H-ARQ operation. We remark that we shall use the term E-DCH loosely in this document, and can be understood to represent a modification of an existing transport channel, or a new transport channel, or a new transport *and* physical channel. However, the loose use of the term should not cause any confusion in understanding the material presented here.

Finally, we assume asynchronous H-ARQ operation. Some overhead reduction may be possible in the case of synchronous H-ARQ operation [1]. A discussion of the pros and cons of synchronous, partly asynchronous and asynchronous H-ARQ is outside the scope of this contribution.

2 Scheduling

The signalling required for H-ARQ operation depends on the mode of E-DCH transmission. So, we begin b discussing briefly on the different ways in which the UE can decide the time at which it schedules an uplink transmission.

This time can be determined in one of the two ways described in this section. We note that a thorough discussion of the benefits or drawbacks of the following schemes is not within the scope of this contribution. Furthermore, we will not address the enabling technologies that are required for each (i.e., is a new transport channel required, or is a new transport channel *and* physical channel required?). However, we will briefly motivate the reason why each method is being considered.

2.1 Node-B controlled scheduling

Here, the UE's uplink transmission is in response to a schedule grant message transmitted by the Node-B. Therefore, there is a strict timing relationship between the transmission of the schedule grant message and the corresponding uplink data transmission. The duration of the uplink transmission is a TTI. The schedule grant message contains H-ARQ parameters, transport block size (TBS) indication, and modulation and coding scheme (MCS). Additionally, the Node-B may also specify the spreading factor that the UE should use, redundancy version (in the case of IR), and/or some information controlling the UE's traffic and pilot transmit power.

Node-B controlled scheduling has the following benefits:

- It allows for better noise rise management, resource utilization, and allows the Node-B to exploit multi-user diversity in the cell.
- Information-theoretically, the optimum scheduling strategy is to allow only the best UE to transmit at maximum power at any given instant of time. Of course, the presence of power-controlled legacy and voice users imposes noise rise constraints, which prevents the best UE from transmitting at its maximum power. However, it is still beneficial to let the best UE to transmit at a power or rate subject to noise rise constraints.

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As a result, Node-B controlled scheduling may be better suited for high data rate transmissions. However, Node-B controlled scheduling does pose some challenges in soft handoff (SHO), where the UE can get multiple conflicting schedule grant messages from multiple Node-Bs. Furthermore, since the Node-Bs are, in general, uncoordinated, the parameters for data transmission commanded by one of the Node-Bs in the active set of the UE may cause undesirably high interference to the others. As mentioned earlier, a detailed evaluation of the pros and cons of such a scheme is outside the scope of this contribution, and is for further study.

2.2 Autonomous Transmissions by the UE

Here, the UE autonomously decides the *time* at which it shall transmit to the Node-B. Parameters associated with the transmission are TBS value, H-ARQ parameters, MCS, redundancy version and/or spreading factor used. These parameters, especially the data rate used for the transmission, are chosen based on some constraints set down by the Node-B or RNC. The Node-B or RNC can periodically adjust these constraints (hereafter referred to as simply "rate control").

Such autonomous transmissions are particularly attractive for the transmission of time-critical data (such as TCP ACKs, etc.), for the UE does not need to wait for Node-B to transmit a schedule grant message in order to transmit. Furthermore, it may also be useful for UEs in SHO.

However, since the time at which the UE is going to transmit data is not determined by the Node-B, and data traffic is typically very bursty, resource utilization and noise rise management may not be as efficient as in the case of Node-B controlled scheduling. Additionally, if the rate control is being done by the RNC, then it may be difficult to exploit multi-user diversity. In the case where the rate control is done by the Node-B, better exploitation of multi-user diversity may be possible. Of course, the extent to which this may be possible will depend on the manner and frequency of the rate control.

3 Associated Signalling

In this section, we look more closely at the signalling required for H-ARQ operation for each of the two cases considered above. Since H-ARQ operation in SHO poses significant challenges, we shall only consider the case where the UE is not in SHO. So, we shall assume that Node-Bs are aware of the "SHO status" of each UE in the cell. In particular, each Node-B knows how many Node-Bs are in the active set of the UE. The exact manner in which this information is made available to the Node-B is for further study. The following discussion pertains to the case when only one Node-B lies in the active set of the UE.

3.1 Node-B Controlled Scheduling

In this case, the parameters that are signalled by the Node-B were described in Section 2.1, and was said to include at least H-ARQ parameters, transport block size (TBS) indication, and modulation and coding scheme (MCS). We now consider the signalling required from the UE.

3.1.1 UE Operation and Signalling

The signalling from the UE depends on whether the UE is allowed to override the parameters signalled by the Node-B. In Sections 3.1.1.1 and 3.1.1.2, we consider the two cases in greater detail.

3.1.1.1 Autonomous Rate Selection by UE

The signalling done by the UE depends on whether or not the UE is allowed to override the parameters signalled by the Node-B. In the case, where the UE is allowed to override Node-B's commands (as in [2]), it will have to necessarily signal transport block size (TBS) indication, and modulation and coding scheme (MCS). Additionally, it may also be required to signal redundancy version (in the case of IR), and/or spreading factor used for the transmission, and/or H-ARQ channel indicator if it is also allowed to override the Node-B's command about the H-ARQ channel. Clearly, this signalling is done out-of-band. It may be necessary to introduce a HS-DPCCH-like channel for this signalling. However, the exact manner in which this signalling is performed is for further study.

Although this allows the UE more flexibility in selecting the parameters for its transmission based on the available resources at the UE, it can result in significant overheads. For example, in [2], this signalling required a rate of 20.5kbps. Furthermore, since the Node-B can decode the traffic channel only if it can decode this signalling information signalled by the UE, it is essential to ensure sufficient reliability for the control channel; e.g., detection probabilities have to be greater than 99%. Without the benefit of H-ARQ for control channels, sufficient margins have to be built in. Note that these overheads are incurred even when the UE does not override Node-B's commands.

3.1.1.2 Rate Selection by Node-B

Alternately, the UE should always follow the Node-B's command, and use the parameters dictated by Node-B in the schedule grant message for uplink data transmission. Clearly, this method of operation obviates the need for the associated signalling, thereby reducing uplink overheads. However, it does reduce the flexibility at the UE in selecting the parameters for uplink data transmission. This flexibility may be beneficial in the following cases:

- The power margin available at the UE is not sufficient to support the data rate commanded by the Node-B for the given TBS, so that a lower MCS or smaller TBS is preferable. Note that the UE cannot be allowed to select a higher MCS as that could affect the noise rise at the Node-B.
- The buffer contents at the UE can be transmitted more efficiently using a lower MCS.

In the first scenario, if the UE were to select the commanded MCS, then the available power margin would not be sufficient for the data transmission. As a result, the transmission would fail with high probability. However, because of H-ARQ Chase combining or IR for the traffic channel, this should not result in any inefficient usage of resources or loss in performance. Turning next to the second condition, it is clear that this should not arise as long as frequent buffer status reports for each UE are available at the Node-B.

3.1.2 Other Signalling from the UE

For efficient Node-B controlled scheduling (irrespective of whether the rate selection is done by the UE or Node-B), it is necessary for the UE to transmit power margin availability and buffer status frequently to the Node-B. Note that this is the equivalent of CQI transmitted by the UE to Node-B for efficient MCS selection and scheduling in HSDPA.

In the case where the UE is allowed to autonomously select the data rate for transmission, the UE can signal the power margin availability and buffer status out-of-band along with the other signalling information transmitted by the UE. Alternately, the UE can transmit this information in-band, i.e., they are multiplexed with the data, covered with a single CRC, encoded, and then transmitted over the channel.

In the case where the UE is not allowed to override the parameters selected by the Node-B, the power margin availability and buffer status is best transmitted in-band with the data. An example of data transmission between a UE and a Node-B in this case is shown in Figure 1. In this example, we assume that the mobile is already registered with the system and is in the CELL_DCH state. A time t_1, data shows up at the UE buffer. At time t_2, UE sends its buffer status and power margin information to the Node-B. This transmission could be done, e.g., over an HS-DPCCH-like channel. After receiving the buffer status and power margin information, the Node-B decides to schedule the mobile and sends the scheduling grant at time t_3. At time t_4, the UE transmits at the data rate commanded by the Node-B. Note that the buffer status and power margin information is carried in each data block transmitted in response to a schedule grant received from the Node-B. Therefore, when a UE sends data to the Node-B, buffer status and power margin information get updated as well. In case the transmission at time t_4 fails, the buffer status and power margin availability information can be obtained by the Node-B from a subsequent successful transmission of a new packet or successful retransmission of the same packet. Since the UE is not in SHO, for the period in between successive data transmissions by the mobile, and the associated transmission of buffer status and power margin information, the Node-B can estimate the power margin availability by tracking the power control commands transmitted by the Node-B to the UE.

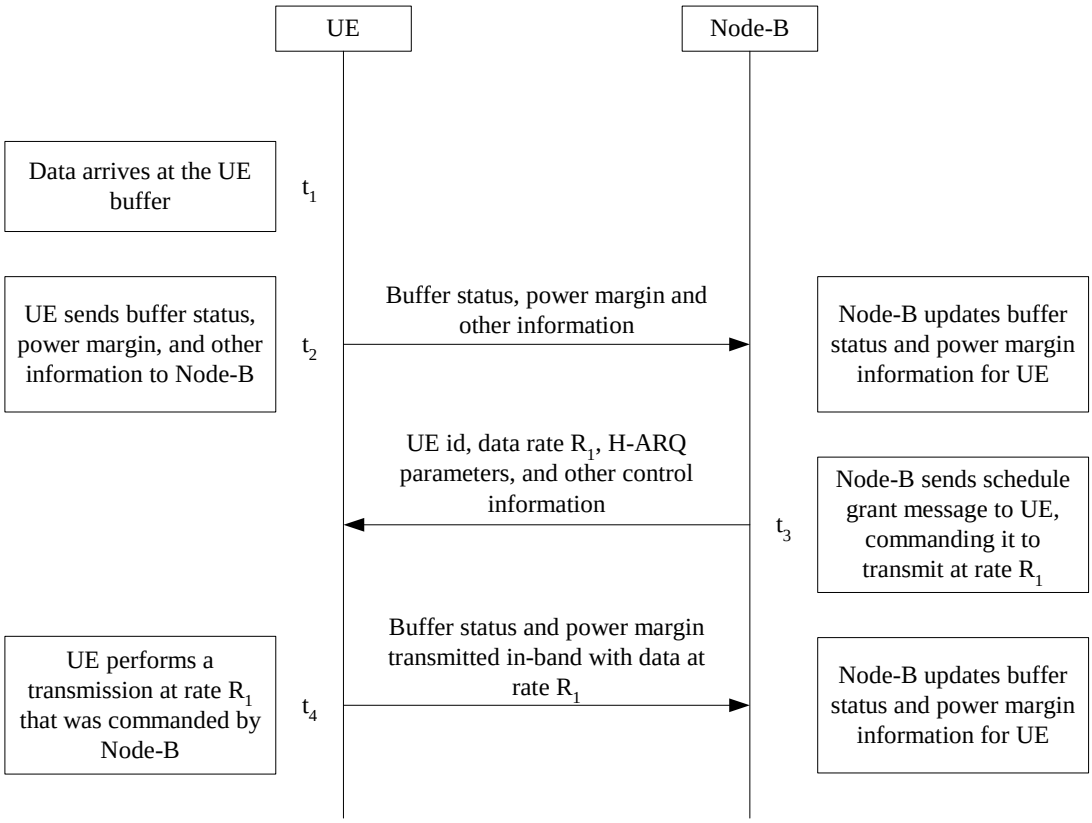
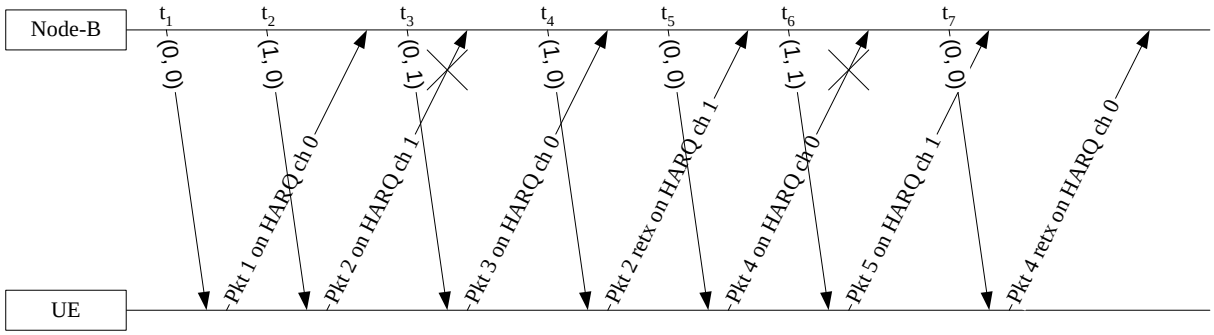


Figure 1. Data transmission between a UE and the Node-B.

3.1.3 Signalling of ACK/NACKs

Downlink signalling of ACK/NACKs by the Node-B can be done implicitly by using the New Data Indicator (NDI) bit(s) in the case of Node-B controlled scheduling. Precisely, if the New Data Indicator has not changed compared to the value in the previous received transmission of a given H-ARQ process, it implies a NACK. Conversely, if the New Data Indicator has changed compared to the value in the previous received transmission of a given H-ARQ process, it implies an ACK.



(x, y) : x is the H-ARQ SAW channel, y is the New Data Indicator

Figure 2. Implicit signalling of H-ARQ ACK/NACKs by Node-B

Figure 2 illustrates the method by means of an example. At time t_1, Node-B schedules a transmission on H-ARQ channel 0, with NDI set equal to 0. The UE transmits the first packet in response, which is decoded correctly by the Node-B. The schedule grant message sent by Node-B at time t_3 changes the NDI value for H-ARQ channel 0, which implicitly indicates to the UE that the first packet was received correctly. So, the UE transmits a new packet on H-ARQ channel in response. Similarly, the second packet transmitted by the UE in response to the schedule grant message transmitted by the Node-B at time t_2 was received in error at the Node-B. The schedule grant message transmitted by

the Node-B to the UE at time t_4 uses the same values for NDI and H-ARQ channel as at time t_2, which implicitly indicates to the UE that the second packet was received in error. In response, therefore, the UE retransmits the second packet. The rest of figure is now self-explanatory.

3.2 Autonomous Transmission by a UE

In this case, the UE necessarily signals H-ARQ process, transport block size (TBS) indication, and modulation and coding scheme (MCS). Additionally, it may also be required to signal redundancy version (in the case of IR), and/or spreading factor used for the transmission [4].

4 Conclusions

This document discusses the signalling associated with H-ARQ for E-DCH. It is shown that the signalling necessary depends on the UE operation. In particular, it depends on whether the UE transmission is in response to a schedule grant message by the Node-B (i.e., Node-B controlled scheduling) or an autonomous transmission made by the UE under some Node-B or RNC supervision. Furthermore, in the case of Node-B controlled scheduling, the signalling necessary from the UE depends on whether the UE is allowed any/some autonomy in rate selection.

5 References

[1] R1-03-0144, “Text Proposal for Enhanced Uplink DCH TR – Section 7.2,” Motorola, San Diego, USA, January 2003.

[2] R1-03-0145, “Text Proposal for Enhanced Uplink DCH TR – Section 7.5,” Motorola, San Diego, USA, January 2003.

[3] R1-03-0181, “Node B Controlled Scheduling by Fast TFCS Restriction Control,” Nokia, Tokyo, February 2003.

[4] R1-03-0176, “HARQ Overview,” Nokia, Tokyo, February 2003.