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Title: **Adaptive HARQ for fixed TTI using soft acknowledgement**

Agenda Item: **AH24 (HSDPA)**

Document for: **Discussion**

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1. Introduction

For HSDPA fixed and variable TTI schemes have been proposed [1, 2, 3]. Potential advantages of the variable TTI proposal are high frame fill efficiency and the possibility to use different MCS levels for retransmissions (and thus to adapt to the channel, available power and code resources). The disadvantage is the higher complexity due to the varying TTI length.

This paper introduces a physical layer structure that offers some of the flexibility of the variable TTI approach while maintaining the simplicity of a fixed TTI scheme. It allows to change MCS levels for retransmissions while maintaining the code block length. In the case of retransmissions, up to two parallel code blocks are sent (from different HARQ channels, e.g., a retransmission and a new transmission). The MCS levels and coding rate of the two data streams are controlled based on a soft acknowledgement information. A fine tuning of the information bit energy can be achieved by an appropriate bit-to-symbol mapping of header, systematic and parity bits.

2. Extended HSDPA physical layer structure

Figure 1 shows the proposed physical layer structure. With respect to [4], it can be seen that not only systematic (S) and parity (P) bits are separated, but also header and payload. Additionally, two separate data streams are used, one for retransmissions (retr.) and one for initial transmissions (init. tr.). The rate matching units and the multiplexer are controlled based on the multi-bit acknowledgement.

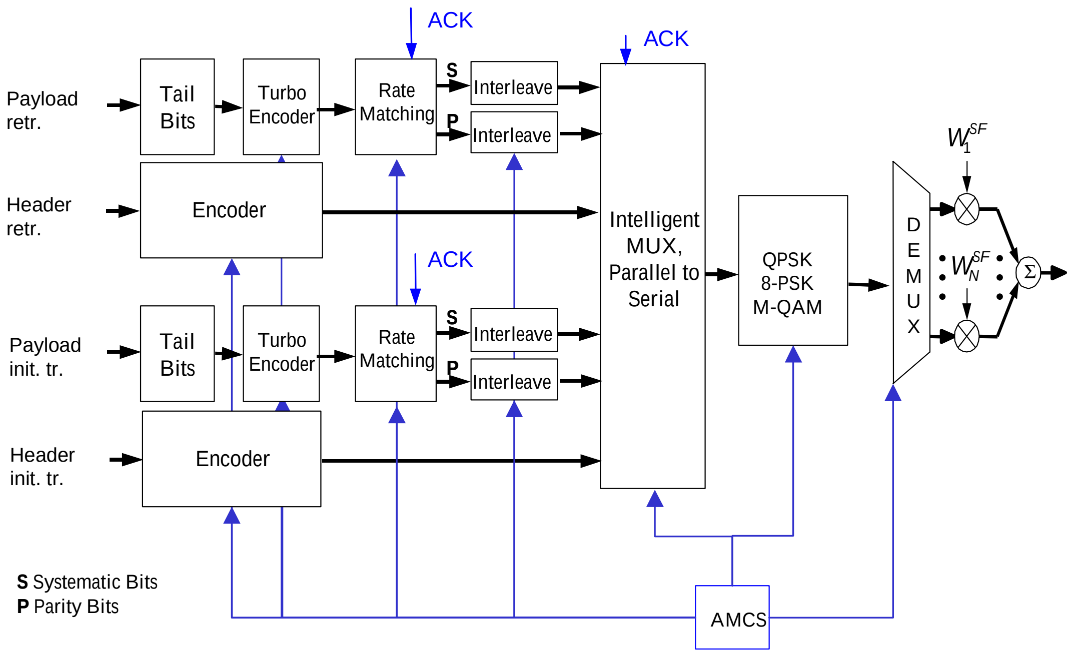

Figure 1: Extended HSDPA Physical Layer Structure

3. Soft acknowledgement states

A soft acknowledgement of the ARQ state using more than one bit is introduced. This allows to inform the transmitter about the estimated additional energy required for successful decoding. The transmitter can set the coding rate and possibly the bit-to-symbol mapping of the next retransmission accordingly. Table 1 details the possible acknowledgement states for a 2-bit acknowledgement.

NAK1	not acknowledged, highest priority, e.g., very bad soft values
NAK2	not acknowledged, medium priority, e.g., bad soft values
NAK3	not acknowledged, low priority, e.g., "almost" decoded correctly
ACK	acknowledged, successfully decoded

Table 1: 2-bit acknowledgement states

4. Code rates of parallel data streams and transition conditions

The FER curves for the higher MCS levels, e.g., in [2,5], show that each additional retransmission leads to a considerable shift in required I_{or}/I_{oc} (or accordingly reduces the FER by orders of magnitude for a fixed I_{or}/I_{oc}). It is obvious that in many cases retransmissions with less energy per information bit would have been sufficient. In our contribution, the physical layer structure of Figure 1 is used to match the MCS level of the retransmission to the required energy and therefore to reduce interference in an efficient way.

MCS level	code block length	Modulation	code bits per frame	info bits per frame	code rate[1] (including rate matching) retr.	init. tr.	NAK state
1.0	**200**	**QPSK**	**800**	**200**	**-**	**1/4**	
1.1		QPSK	800	200	1/4	-	NAK1
1.2		QPSK	800	400	1/2	1/2	NAK3
1.3		QPSK	800	400	3/8	3/4	NAK2
2.0	**400**	**QPSK**	**800**	**400**	**-**	**1/2**	
2.1		QPSK	800	400	1/2	-	NAK1
2.2		QPSK	800	800	3/2	3/4	
2.3		16QAM	1600	800	1/2	1/2	NAK3
2.4		16QAM	1600	800	3/8	3/4	NAK2
3.0	**600**	**QPSK**	**800**	**600**	**-**	**3/4**	
3.1		QPSK	800	600	3/4	-	NAK1
3.2		16QAM	1600	1200	3/2	1/2	NAK3
3.3		16QAM	1600	1200	3/4	3/4	NAK2
3.4		64QAM	2400	1200	1/2	1/2	
4.0	**900**	**8-PSK**	**1200**	**900**	**-**	**3/4**	
4.1		8-PSK	1200	900	3/4	-	NAK1, NAK2, NAK3
5.0	**800**	**16QAM**	**1600**	**800**	**-**	**1/2**	
5.1		16QAM	1600	800	1/2	-	NAK1
5.2		16QAM	1600	1600	3/2	3/4	
5.3		64QAM	2400	1600	1	1/2	NAK3
5.4		64QAM	2400	1600	3/5	3/4	NAK2
6.0	**1200**	**16QAM**	**1600**	**1200**	**-**	**3/4**	
6.1		16QAM	1600	1200	3/4	-	NAK1, NAK2
6.2		64QAM	2400	2400	3/2	3/4	NAK3
7.0	**1800**	**64QAM**	**2400**	**1800**	**-**	**3/4**	
7.1		64QAM	2400	1800	3/4	-	NAK1, NAK2, NAK3

Table 2: Code rates and transition conditions for different code block length (example for 3.33 ms frame length, 1 code)

[1] approximate values

In cases where no retransmission is required, conventional operation is used (i.e., no data in the second branch). If a retransmission is required a parallel transmission of two code blocks per TTI may be initiated based on the acknowledgement state. Introducing a second data stream allows to double the information bit rate without changing the code block length. Therefore soft combining of retransmitted code blocks in the receiver is still possible although different MCS levels are used. This allows to minimise the change of code block length, while still retransmissions are pending (and consequently to minimise the loss of the soft-combining advantage). Moreover, the use of a second data stream ensures high frame fill efficiency. Table 2 shows possible combinations for the example of a frame duration of 3.33 ms and one code channel. The Node B determines the format of the next transmission based on the NAK state and potentially further information.

As can be seen from Table 2, this approach allows to give the retransmission approximately the additional energy required for successful decoding and allocates the remaining part of the frame already for the next transmission block[2]. High priority retransmissions (NAK1) can still use the whole frame. Such high priority retransmissions can also be used if the corresponding block approaches the maximum number of retransmission or if it is at the lower end of the HARQ buffer window. In case of two retransmissions, an appropriate code rate setting can be chosen according to the current NAK states of both data streams.

5. Bit mapping

The higher-order modulation schemes proposed for HSDPA provide bits with different reliability within each symbol. This fact has attracted some interest recently. In [5], it is proposed to mitigate this effect using so-called Signal Constellation Rearrangement, which basically leads to a similar averaged reliability for all bits in the case of multiple retransmissions. In [4], instead, the idea is to benefit from the different reliabilities by proper mapping of systematic and parity bits. This paper elaborates the latter idea by taking further into account the different priorities of header and payload bits. For one data stream, the mapping of Table 3 can be used. Header bits are always mapped to high reliability bits. Systematic bits use high reliability bits as long as possible, while parity bits use low reliability bit as long as possible.

content	bit reliability
header	HIGH
systematic bits	HIGH (LOW[3])
parity bits	LOW (HIGH[4])

Table 3: Bit mapping for one transmission per TTI

Combining the bit-to-symbol mapping strategy of Table 3 with the physical layer structure in Figure 1 gives further flexibility in fine tuning the information bit energy. Therefore an appropriate multiplexing of the two data streams is used. The header information (i.e., the MAC header information and any potential in-channel signalling, like SAW channel id, etc.) of both data streams are mapped to bit positions with high reliability within each symbol. While systematic bits of the first transmissions are mapped to bits with high reliability (as long as possible) the systematic bits of the retransmission can be mapped to low reliability bits (high reliability bits are only used if any are left over). The parity bits are mapped to low reliability bits (high reliability bits are only used if any are left over).

content	bit reliability	
	init. tr.	retr.
header	HIGH	HIGH
systematic bits	HIGH (LOW[3])	LOW (HIGH[4])
parity bits	LOW (HIGH[4])	LOW (HIGH[4])

Table 4: Bit mapping for parallel transmissions

[2] the exact mapping of NAK states to MCS levels and coding rates is subject to further study
[3] if no bits with high reliability are left over
[4] if no bits with low reliability are left over

6. Complexity Evaluation

The additional complexity of the physical layer structure can be seen in Figure 1. Two separate turbo coder, rate matching and interleaving blocks will be necessary. If two data streams are used per TTI, two blocks must be decoded. However, both blocks have higher coding rate and thus require less decoding effort. The rate matching and multiplexing operation is controlled by the soft acknowledgement states, which must be derived in the UE and fed back to the Node B. This soft acknowledgement would increase the signalling overhead from 1 bit to 2 bit. In case of combined transmission two soft acknowledgements would be necessary per frame. The additional MCS level variants would require two additional signalling bits.

7. Conclusions

We showed a physical layer structure and coding scheme that combines the advantages of the conventional fixed and variable TTI proposals by allowing to use two parallel data streams for each TTI. The main benefits are:

- flexible mapping of required retransmission energy using MCS level and code rate adaptation, as well as bit mapping,
- reduced interference,
- allows soft-combining of retransmissions at different MCS levels,
- high frame fill efficiency,
- increased throughput,
- maintains simplicity of fixed TTI.

The concepts presented in this paper are suitable for incremental redundancy, but can also be adapted to Chase combining.

8. References

[1] TSGR1#17(00)1396, Motorola, "Performance Comparison of Hybrid-ARQ Schemes," Stockholm Sweden, November 2000.

[2] TSGR1#17(00)1428, Ericsson, "Performance Comparison of Chase Combining and Incremental Redundancy for HSDPA," Stockholm Sweden, November 2000.

[3] TSGR1#18(01)0079, Lucent, "Variable TTI for HSDPA," Boston, USA, January 2001.

[4] 12A010044, Samsung, "Enhanced Symbol Mapping Method for the Modulation of Turbo-coded Bits based on Bit Priority," 3GPP TSG RAN WG1/WG2 Joint Meeting on HSDPA, Sophia Antipolis, France, April 2001.

[5] TSGR1#19(01)0237, Panasonic, "Enhanced HARQ Method with Signal Constellation Rearrangement," Las Vegas, USA, March 2001.

[6] 3G TR25.848, "Physical Layer Aspects of UTRA High Speed Downlink Packet Access".