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1 Introduction

In the HSDPA system design for UMTS, the proposed HS-DSCH will share power and code space resources with the dynamically varying traffic using dedicated channels. The need to vary the effective code rate to create new sets of modulation and coding schemes (MCS) / rates for adaptive modulation and coding (AMC) based on the number of available multi-codes is established in this contribution. Furthermore, the additional degree of freedom offered by variable transmission time interval (TTI) [1], allows adaptation to large changes in code space available for the HS-DSCH. Additionally, the ability to dynamically vary the TTI presents a tremendous advantage in adapting the hybrid ARQ (H-ARQ) retransmissions to the prevailing channel conditions and resources.

The need for varying the effective code rate to create new sets of MCS based on the changing code space is motivated with the example of H-ARQ in the next section. The constraints imposed by H-ARQ are sufficient but not necessary to motivate this topic.

2 H-ARQ Constraints

Data rate is defined via the following simple equation:

$$R_{data} = B/(n.T_{min}) \qquad (1)$$

where,
B is the number of information bits in the transmitted or re-transmitted packet, sub-packet or frame
T_{min} is the smallest transmission time interval or slot interval
n is the number of slots or frames used for transmission or re-transmission

Another equation expressing the relation between data rate, modulation coding parameters and the chip rate can be written as:

$$R_{data} = mR_{coding}R_{chip}\left(\frac{NW^i}{i}\right)A\,[\text{Kb/s}] \qquad (2)$$

where,
m: modulation order, 2,3, or 4 for QPSK, 8-PSK, and 16-QAM respectively.
R_{coding}: the effective coding rate after encoding followed by puncturing/repetition.
R_{chip}: chip rate (e.g., 3840 kcps).
NW^i: number of i-ary Walsh codes available for data.
A: the multiple antenna MIMO factor; A=1 with single antenna, 4 with 4x4 BLAST

Rewriting both equations above together as one single equation yields:

$$m.R_{coding}.A.\left(\frac{NW^{i}}{i}\right).n = B/(T_{\min}.R_{chip}) \tag{3}$$

Note that the terms gathered together on the right hand side are all assumed as constants. B will be a constant for sub-packets of the same encoder packet or frames across re-transmissions. T_{min} and R_{chip} are clearly system constants.

It is important to note that the last equation (3) must be exactly satisfied for every transmission. Furthermore, the right hand side is a constant between H-ARQ re-transmissions of the same packet or frame, whereas the quantities on the left may be allowed to vary, such that the following holds between the j^{th} and k^{th} re-transmission of the same packet or frame:

$$m_{j}R_{coding,j}.A_{j}.\left(\frac{NW^{i}}{i}\right)_{j}.n_{j} = m_{k}.R_{coding,k}.A_{k}.\left(\frac{NW^{i}}{i}\right)_{.k}n_{k} \tag{4}$$

Typically, the first three terms (m, R_{coding}, A) are chosen as a function of the channel conditions and the available resources. This is termed as the rate and antenna (RAI) information in Lucent's proposal [1]. The fourth term, in brackets, namely the available code space fraction, is an independently varying resource depending on the number of dedicated channel users and other overhead channels

First consider the case when the term in brackets, i.e. fraction of i-ary Walsh codes remains constant between re-transmissions. They can hence be eliminated from both sides of the last equation (4). If the channel conditions change between the re-transmissions, then the modulation, coding and antenna parameters can be picked in inverse proportion to the number of slots of re-transmission. For example, the rate of the re-transmission can be doubled, by doubling the $m.R_{coding}.A$ and halving the n, if the channel conditions so improve and vice-versa if the channel conditions so deteriorate. This is the key idea behind Lucent's *Adaptive* AIR [3]. However, in the case of fixed transmission time interval (i.e. n constant = 1; for example, as proposed by Motorola [2]), the modulation and coding rate (MCS) must remain the same in the re-transmitted frame if the code space does not vary *regardless* of change in channel conditions or available power. If the channel conditions/ power were to worsen, then forcing adoption of the same MCS can degrade the quality of the re-transmitted frame significantly reducing the gains due to rate adaptation and HARQ combining. Conversely, if the channel conditions / power were to improve, then not taking advantage of it may turn out to be wasteful.

Now consider the case when the term in brackets, i.e. fraction of i-ary Walsh codes decrease between re-transmissions due to the addition of some voice users. Let us also assume that the power available to data also decreases in proportion such that the power per code remains the same. Then to keep the equation satisfied, either the $m.R_{coding}.A$ term has to increase and/or the n term has to increase. In other words, for the case of fixed transmission time interval (i.e. n constant = 1 [2]), the modulation and coding rate product must increase in the next sub-packet *regardless* of channel conditions. So if the channel conditions worsen, the quality of this next re-transmitted frame (with higher code rate and modulation) will degrade significantly, which may force a decision to abort this packet. Conversely, when the code space expands, the modulation and effective coding rate must decrease and forcing this in the case of fixed TTI even as the channel conditions improve may be wasteful.

The situation with fixed TTI [2] gets more complicated when the serving cell changes between re-transmissions owing to FCSS. Chances are that the code space available between the two cells is quite different. Furthermore, the channel conditions and the power available at the new cell could be significantly different. Requiring that the MCS and number of multi-codes used in the previous transmission from the old cell be kept identical in re-transmissions from the new cell is a major performance impacting constraint.

This information must further be conveyed by the UE to the new cell as an additional overhead on top of the C/I feedback. These issues are moot in Lucent's proposal that uses *Adaptive* AIR [3].

3 Context (code space) sensitive MCS set

In Lucent's proposal [3], Adaptive AIR scheme works in a way to select the RAI purely as a function of channel conditions and resources available (power and code space). Small changes in code space between re-transmissions are accounted for by inversely varying the code rate while keeping the rate constant, i.e. n is held constant. Note that since n is an integer, such situations are better suited to slight modifications of the fractional code rate. Changes in channel conditions and power availability can be tracked by varying the rate during each transmission or re-transmission, i.e. n is allowed to vary appropriately. Large changes in code space can be accounted for in the same way by varying the number of time slots n, which changes the rate as well. This would be the case when the code space expands or contracts by an integer factor, i.e. halves, doubles or triples. In Lucent's proposal [3], the UE could pick a re-transmission (or new transmission) rate so large that it is defined only for a larger number of information bits B' > B (or B' > buffer contents). In this case, the node B will pick the corresponding largest rate defined for the original B bits (or buffer contents) and indicates the corresponding information block size id to the UE in the header (preamble).

In the following tables, an example illustrating how the code rate should change with small changes in code space (19 and 20 32-ary codes) is presented. In table 2, there is a one-to-one correspondence between the MCS in the two cases based on similar channel conditions. Since both the node B and the UE share the information about current available code space (via broadcast message from node B to UE), there is no increase in the MCS set signaled. The same mode (RAI) bits are used to signal one of the MCS elements in the appropriate column that is selected based on the current code space context. This is an example of context sensitive modulation and coding sets which is a form of rate matching.

Table 1

R_{chip}	3840000
T_{min}	0.000667
B	5120
i	32

Table 2 (example)

Mode	n	R_{data}	NW^i/i		$m.R_{coding}.A$		A	m	R_{coding}	
			$NW^i = 20$	$NW^i = 19$	$NW^i = 20$	$NW^i = 19$			$NW^i = 20$	$NW^i = 19$
1	1	7680000	0.625	0.59375	3.2	3.368421	1	4	0.8	0.842105
2	2	3840000	0.625	0.59375	1.6	1.684211	1	2	0.8	0.842105
3	4	1920000	0.625	0.59375	0.8	0.842105	1	2	0.4	0.421053
4	8	960000	0.625	0.59375	0.4	0.421053	1	2	0.2	0.210526
5	16	480000	0.625	0.59375	0.2	0.210526	1	2	0.1	0.105263

This specific type of rate matching has been derived in consideration of H-ARQ re-transmissions when the code space varies within a cell or across cells. However, it is important to note that the above context (code space) sensitive coding cannot be avoided simply by tweaking operation of the H-ARQ protocol (for example, by aborting the re-transmissions when code space changes). So long as the physical layer air interface is defined to handle a fixed set of information block sizes and a fixed set of TTIs, then the set of code rates has to vary to adapt to changes (especially fractional) in the available code space.

4 Text Proposal for TR

Based on the arguments presented in this document, the need for code space sensitive MCS sets for AMC should be considered as part of the feasibility study. Therefore, the following text is recommended to be included in Section 6.2, "Adaptive Modulation and Coding" of 3G TR25.848.

In a HSDPA system design with AMC that is defined to handle a fixed set of information block sizes and a fixed set of TTIs, small variations in the code space available for the HS-DSCH will have to be compensated by fine changes in the code rate. With both the Node B and the UE aware of the code space context via appropriate overhead signaling, the MCS set does not increase in size and does not require additional bits for signaling. Code space sensitive MCS sets can also use the additional dimension offered by variable TTI to deal with large changes in code space.

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5 References

[1] Lucent Technologies, "Downlink and Uplink Channel Structures for HSDPA," TSGR1#17(00) 1381, Stockholm, Sweden, November 2000.

[2] Motorola, "HSDPA System Performance Based on Simulations (II)", TSGR1#17(00) 1397, Stockholm, Sweden, November 2000.

[3] Asynchronous and Adaptive Incremental Redundancy (A^2IR)", Lucent Technologies, R1-00-1382.