

INCREMENTAL REDUNDANCY (IR) SCHEMES FOR W-CDMA HS-DSCH

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Abstract – This paper compares two Hybrid Automatic Repeat Request (HARQ) schemes using Incremental Redundancy (IR) which have been proposed for the UMTS (W-CDMA) High Speed Downlink Shared Channel (HS-DSCH). Their relative throughput performance is reported for various channel conditions. It is shown that the two-stage rate-matching scheme has marginally worse performance compared to the alternative scheme for certain coding rates and under some channel conditions.

I. INTRODUCTION

The two fundamental forms of HARQ are Chase combining and incremental redundancy (IR). In Chase combining [1], each retransmission repeats the first transmission or part of it. In IR, each retransmission provides new code bits from the mother code to build a lower rate code [2]. While Chase combining is sufficient to make Adaptive Modulation and Coding (AMC) robust, IR offers the potential for better performance with high initial and successive code rates, at higher SNR estimation error and FER operating points (i.e., a greater probability that a transmission beyond the first will be needed), albeit at the cost of additional memory and decoding complexity. The consensus in the 3GPP UMTS standards bodies is to explicitly define and allow IR, while retaining Chase-like operation as a subset of IR since the memory requirements at the User Equipment (UE) for the highest data rate is derived based on Chase combining.

In this paper, two types of IR schemes for W-CDMA HS-DSCH are discussed: a) IR based on two-stage rate matching and b) IR based on block interleaving. The IR based on two-stage rate matching [3][4][9] is the agreed upon IR scheme for HS-DSCH. It uses two stages of rate matching where the first stage is used to match the amount of coded bits to the UE buffering capability and the second stage is used to generate the different redundancy versions. It may be noted that the first stage will be bypassed in case the UE has full buffering capability. IR based on block interleaving was proposed in [5][6]. The approach uses a block interleaver in the channel coding chain followed by a redundancy version selector and a virtual bit priority mapper. The block interleaver rows and columns are permuted according to UMTS-Release '99 internal turbo interleaver and 1st interleaver algorithms. This technique simplifies the Release-99 channel coding chain by removing the rate-matching block. The block interleaver acts both as a rate-matcher and channel interleaver followed

by a virtual bit priority mapper. In this scheme, orthogonal re-transmissions (i.e., each transmission contains unique parity bits) are guaranteed and as such the performance of this scheme is optimal. Section II describes the W-CDMA HS-DSCH IR scheme based on two-stage rate matching. Section III provides a brief description of the IR scheme based on block interleaving. Simulation results comparing these two methods are then presented in Section IV. Finally, conclusions are drawn in Section V.

II. HARQ BASED ON TWO-STAGE RATE-MATCHING

The 3GPP HARQ scheme for HS-DSCH is shown in Figure 1. This scheme is based on the rate-matching algorithm defined in Section 4.2.7 of [7] and can support both self-decodable and non self-decodable transmissions. The First Rate Matching block is used to adjust the number of available coded bits at the Node-B to the virtual UE's buffer size. The maximum number of soft bits available in the virtual IR buffer is signaled from higher layers for each HARQ process. The Second Rate Matching block is then used to rate-match and select the set of coded bits for transmission, given the redundancy version (RV) selected.

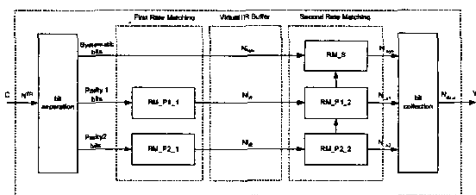


Figure 1. IR Scheme for HS-DSCH based on two-stage rate-matching.

Two parameters control the generation of the redundancy versions, a self-decodability parameter s and e_{ini} variation parameter r . The goal of the e_{ini} variation parameter is to enable robust retransmissions by orthogonalizing available redundancy versions that contain the same self-decodability parameter s . The number of RV's allowed for HS-DSCH is limited to 8. HARQ second stage rate matching is done with the general method described in 4.2.7.5 of [7]. The initial (e_{ini}), increment (e_{plus}) and decrement (e_{minus}) value of variable e in the rate matching pattern determination algorithm are based on the RV parameters s and r . The parameter s can take the value

0 or 1 to distinguish between prioritizing systematic and parity bits. The parameter r (range 0 to $r_{\max}$) changes the initial error variable e_{ini} in the case of puncturing. In case of repetition both parameters r and s change the initial error variable e_{ini} . The parameters X_i , e_{plus} and e_{minus} are calculated, as per Table 1 shown below.

	X_i	e_{plus}	e_{minus}
Systematic RM S	N_{sys}	N_{sys}	$ N_{sys} - N_{t,sys} $
Parity 1 RM P1_2	N_{p1}	$a \cdot N_{p1}$	$a \cdot N_{p1} - N_{t,p1} $
Parity 2 RM P2_2	N_{p2}	$a \cdot N_{p2}$	$a \cdot N_{p2} - N_{t,p2} $

Table 1. Parameters for the second-stage rate matching.

Denote the number of bits before second rate matching as N_{sys} for the systematic bits, N_{p1} for the parity 1 bits, and N_{p2} for the parity 2 bits, respectively. Denote the number of physical channels used for the Coded Composite Transport Channel (CCTrCH) by P . N_{data} is the number of bits available to the CCTrCH in one radio frame (defined as $N_{data} = P \times 3 \times N_{data1}$, where N_{data1} is given in [7]). The rate matching parameters are determined as follows.

For $N_{data} \leq N_{sys} + N_{p1} + N_{p2}$, puncturing is performed in the second rate matching stage. The number of transmitted systematic bits in a retransmission is $N_{t,sys} = \min\{N_{sys}, N_{data}\}$ for a transmission of self-decodable type and $N_{t,sys} = \max\{N_{data} - (N_{p1} + N_{p2}), 0\}$ in the non self-decodable case. For $N_{data} > N_{sys} + N_{p1} + N_{p2}$, repetition is performed in the second rate matching stage. A similar repetition rate in all bit streams is achieved by setting the number of transmitted systematic bits as follows

$$N_{t,sys} = \left\lceil N_{sys} \frac{N_{data}}{N_{sys} + 2N_{p2}} \right\rceil \quad (\text{Eq. 1})$$

The number of parity bits in a transmission is then

$$N_{t,p1} = \left\lceil \frac{N_{data} - N_{t,sys}}{2} \right\rceil \quad (\text{Eq. 2})$$

and

$$N_{t,p2} = \left\lceil \frac{N_{data} - N_{t,sys}}{2} \right\rceil \quad (\text{Eq. 3})$$

for the first and second parity stream, respectively. The parameter a in Table 1 is chosen using $a = 2$ for the first parity stream and $a = 1$ for the second parity stream.

The rate matching parameter e_{ini} is calculated for each bit stream according to the redundancy version parameters r and s using

$$e_{ini}(r) = \left\{ \left\lfloor X_i - \left(r \frac{e_{plus}}{r_{\max}} \right) - 1 \right\rfloor \bmod e_{plus} \right\} + 1 \quad (\text{Eq. 4})$$

in case of puncturing, and

$$e_{ini}(r) = \left\{ \left\lfloor X_i - \left((s + 2r) \frac{e_{plus}}{2r_{\max}} \right) - 1 \right\rfloor \bmod e_{plus} \right\} + 1 \quad (\text{Eq. 5})$$

in case of repetition, where $r \in \{0, 1, \dots, r_{\max} - 1\}$ and $r_{\max}$ is the total number of redundancy versions allowed. Note that $r_{\max}$ varies depending on the modulation mode (for 16-QAM, $r_{\max} = 2$ and for QPSK, $r_{\max} = 4$).

Subsequently, the bits out of the 2nd rate-matching stage are mapped based on priority via the HARQ bit collection unit, and interleaved via one or more Release '99 interleavers based on the modulation level (QPSK or 16-QAM). The HARQ bit collection is achieved using a rectangular interleaver of size $N_{row} \times N_{col}$. The number of rows and columns are determined from:

$$\begin{aligned} N_{row} &= \log_2(M) \\ N_{col} &= F / N_{row} \end{aligned} \quad (\text{Eq. 6})$$

where M is the modulation size and F is the number of coded and rate-matched bits to be transmitted. Data is written into the interleaver column by column, and read out of the interleaver column by column. The parameter $N_{t,sys}$ is the number of transmitted systematic bits. Intermediate values N_r and N_c are calculated using:

$$N_r = \left\lceil \frac{N_{t,sys}}{N_{col}} \right\rceil \quad (\text{Eq. 7})$$

and

$$N_c = \left(\frac{N_{t,sys}}{N_{col}} - N_r \right) \cdot N_{col} \quad (\text{Eq. 8})$$

If $N_c = 0$, the systematic bits are written into rows $1 \dots N_r$. Otherwise systematic bits are written into rows $1 \dots N_r + 1$ in the first N_c columns and rows $1 \dots N_r$ in the remaining N_c columns. The remaining space is filled with parity bits. The parity bits are written column wise into the remaining rows of the respective columns. Parity 1 and 2 bits are written in alternating order. In the case of 16-QAM for each column the bits are read out of the interleaver in the order row 1,

row 2, row 3, row 4. In the case of QPSK for each column the bits are read out of the interleaver in the order row1, row2, row 3, row 4. The interleaving after the bit collection unit is done using two Release '99 2nd interleaver with fixed size (32x30). For QPSK, only one interleaver is used whereas for 16-QAM, there are two identical interleavers of the same fixed size. For 16-QAM, the first two bits out of the bit collection unit are read into the first interleaver and the next two bits are read into the 2nd interleaver and so on.

III. HARQ BASED ON BLOCK-INTERLEAVING

This scheme was proposed in [5][6]. A block diagram illustrating the functionality of this simpler scheme is shown in Figure 2. It consists of a slightly modified Release '99 interleaver, a redundancy version selector, and a Bit Priority Mapper. The HARQ functionality is implemented by the block-interleaver and the redundancy version (RV) selector.

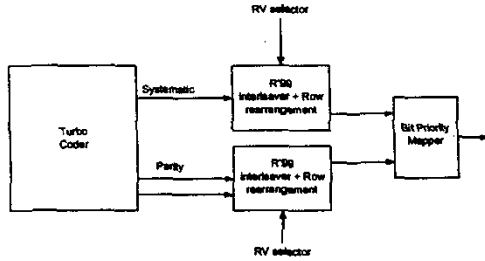


Figure 2. Simpler IR/BPM Scheme.

A. Block Interleaver

The encoder used here is the rate-1/3 Turbo encoder specified in [7]. The un-punctured codeword bits are separated into a systematic and a parity stream denoted by $x_{S,k}$, $x_{P,k}$ respectively where $x_{S,k} \in \{0,1\}$ and $x_{P,k} \in \{p_{1,k}, p_{2,k}\}$ (i.e., $x_{P,k} \in \{(0,0), \{0,1\}, \{1,0\}, \{1,1\}\}$). Each stream is read into an $N_{row} \times N_{col}$ block matrix interleaver while the tail bits are buffered separately and are later appended onto the un-punctured instantaneous codeword (where the instantaneous codeword is the codeword transmitted in a specific transmission time interval). Thus, the 12 buffered tail bits are always transmitted. As an example, if the first transmission is at $R=3/4$ and the number of information bits is 600, then 600 systematic, 188 parity are read from the Systematic and Parity interleaver respectively into the Virtual Bit Priority mapper. Finally the 12 tail bits are read. The number of columns in each interleaver is always fixed at 30 while the number of rows is variable (dependent on the number of information bits) and is determined in exactly the same manner as the turbo code internal interleaver defined for Release '99 in step 2 of section 4.2.3.2.3.1 of 25.212.

Data is read row-wise into each interleaver, with dummy bits padded if $N_{info} < N_{row} \times N_{col}$. This is identical to the procedure used for the Release '99 second interleaver. To facilitate flexibility in supporting variable coding rates, both columns and rows are permuted prior to reading out of the block matrix contents. The same column permutation is proposed for both the systematic and parity interleavers and is defined in [7]. The proposed row permutations are derived directly from the intra-row permutations of the Release '99 Turbo code internal interleaver.

B. Redundancy Version Selector

The redundancy version selector determines the subset of systematic and parity bits to be transmitted over the air. A salient feature of this method is that the selector does not suggest a particular order of transmission. Using this simple approach the selected redundancy version sequence may be chosen to support Chase, partial and full IR schemes. Each redundancy version j contains a starting column α_j in either the systematic or parity interleaver (i.e. $\alpha_j \in \{i,k\}$ for $j \in \{0, \dots, 7\}$, $i \in \{S, P\}$ and $k \in \{1, \dots, N_{i,max_col}\}$). The procedure for computing α_j is as follows. First, compute

$$N_{vr} = N_{S,max_col} + 2 \times N_{P,max_col} \quad (\text{Eq. 9})$$

then

$$VR_j = \left\lfloor \frac{2 \cdot \text{mod}(j,4) \cdot N_{vr}}{8} \right\rfloor - 2 \cdot \text{mod}(j,4) \quad (\text{Eq.10})$$

for $j \in \{0, \dots, 7\}$. Finally, calculate α_j via

$$\alpha_j = \{S, VR_j\} \quad (\text{Eq. 11})$$

if $VR_j < N_{S,max_col}$ and

$$\alpha_j = \left\{ P, \left\lfloor \frac{VR_j - N_{S,max_col}}{2} \right\rfloor \right\} \quad (\text{Eq. 12})$$

otherwise. This gives four unique starting columns evenly spaced throughout the lowest code rate supported by the mobile. Coded bits are read from the selected starting columns column-wise either in increasing order ($y'_{i,(k \times N_{row} + 1)}$, $y'_{i,(k \times N_{row} + 2)}$, ...) for $j \in \{0,1,2,3\}$ or in decreasing order ($y'_{i,(k \times N_{row} - 1)}$, $y'_{i,(k \times N_{row} - 2)}$, ...) for $j \in \{4,5,6,7\}$. Coded bits continue to be read until the end ($y'_{i,(k \times N_{max_col} \times N_{row})}$ for $j \in \{0,1,2,3\}$ or start ($y'_{i,1}$ for $j \in \{4,5,6,7\}$) of the interleaver is reached. Reading then continues column wise from the other interleaver $\hat{i}$, ($\hat{i} \in \{S, P\}$, $\hat{i} \neq i$) either from the first column or the last column.

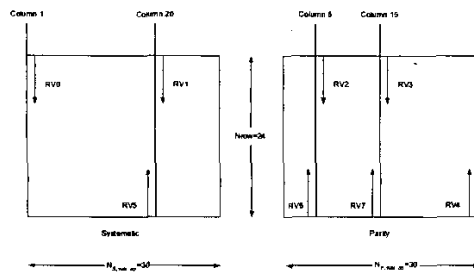


Figure 3. Example of Redundancy Version Selector and Codeword Selection.

As an example, consider the case shown in Figure 3 where the encoded message consists of 720 bits with the UE able to support the full rate 1/3 code. Assuming the redundancy versions chosen for transmission are RV0 and RV2 and each transmission consisting of 960 bits, then the first transmission will consist of codeword bits followed by the 12 tail bits and the second transmission will consist of the codeword bits followed by the 12 tail bits.

C. Virtual Bit Priority Mapper

Priority bit mapping is based on utilizing the differing bit reliability offered by higher order constellations (16-QAM or higher). Since the systematic portions of a codeword are of greater importance to decoder performance than the parity portions, they should be placed in positions of high reliability when higher order constellation is used. Since channel interleaving has already implicitly been performed, codeword bits can be read directly from the Systematic and Parity puncturing block interleavers, to form the desired 16-QAM symbol in a simple and straightforward manner.

IV. SIMULATION RESULTS

The effective code rate is defined as n_i/n_i+n_p where n_i is the number of information bits and n_p is the number of unique parity bits, after the second transmission is plotted as a function of the initial code rate for the above two schemes (assuming full buffering) in Figure 4. The two schemes have identical results for initial code rates lower than 1/2. At higher code rates, however, the rate-matching scheme cannot select only unique parity bits in the second transmission, thus resulting in a higher effective code rate. The block interleaving approach, however, is able to select all unique parity bits in subsequent transmissions. As a result, the optimality of the block interleaving based approach is evident from the figure since the block-interleaving approach could guarantee orthogonal transmissions as opposed to the two-stage rate-matching scheme.

Next, the two IR schemes are compared using a symbol-level simulator for HS-DSCH. The results presented here assume ideal channel estimation, QPSK/16-QAM modulation and non self-decodable re-transmissions. Table 2 lists additional relevant simulation parameters.

Parameter	Value
Carrier Frequency	2GHz
Channel conditions	AWGN, Flat Fading
HSDPA frame Length	2 msec (3 slots)
I_{or}/I_{oc}	Variable
Fast fading model	Jakes spectrum
Channel Coding	R=1/3 Turbo
Max no. of Decoder Iter	8
Metric for Turbo Coder	Max-Log-Map
Turbo Interleaver	Random

Table 2. Simulation Parameters.

Figure 5 compares the spectral efficiency of the two schemes under static AWGN channel for $N=720$ bits, $R=3/4$ and QPSK modulation. In this case, the block-interleaving based scheme has a marginal advantage over the rate-matching scheme at I_{or}/I_{oc} greater than -1.2 dB. Figure 6 compares the spectral efficiency vs. I_{or}/I_{oc} of the two schemes using QPSK modulation, $N=720$ bits, $R=3/4$ code under Rayleigh fading channel at 3 km/h. For the rate-matching approach, we assume $s=1$, $r=0$ on the first transmission, $s=0$, $r=0$ on the second transmission, $s=0$, $r=1$ on the third transmission, and $s=1$, $r=1$ on the fourth transmission for the rate matching approach. A maximum of 4 re-transmissions were allowed for the packet for both the above cases.

Figure 7 compares the performance using 16-QAM modulation at 120 kmph using $R=3/4$ code for a message size of 1,440 bits. For the rate-matching approach, we again select s and r as outlined above. It may be observed from both the figures that the block interleaving approach outperforms the two-stage rate-matching scheme by approximately 0.5 dB under fading channel conditions.

V. CONCLUSIONS

The block-interleaving scheme has the following advantages over the 3GPP two-stage rate-matching scheme. First, the systematic and parity interleavers in Figure 2 are analogous to the second rate-matching block combined with the Release '99 interleavers in that they interleave as well as rate match. As such, a single set of backwards-compatible interleavers serve as a simple approach for RV selection,

symbol mapping etc. Second, the performance of the block-interleaving approach is superior to IR based on two-stage rate-matching by approximately 0.5dB. Third, for the two-stage rate matching scheme, the rate-matching patterns must be determined for every redundancy version selected, whereas in the block-interleaving approach only the index of the starting location is needed. Lastly, not all re-transmissions are guaranteed to have unique parity bits due to the rate-matching algorithm, which degrades incremental redundancy performance.

ACKNOWLEDGEMENTS

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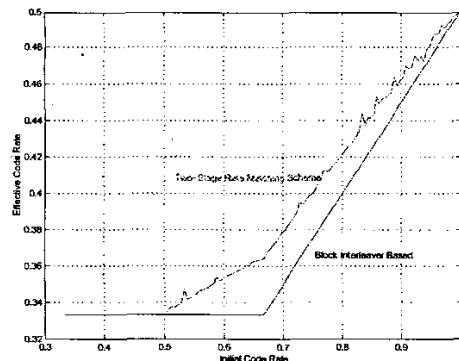


Figure 4. Effective Code Rate Comparison of IR based on two-stage rate-matching and block interleaving.

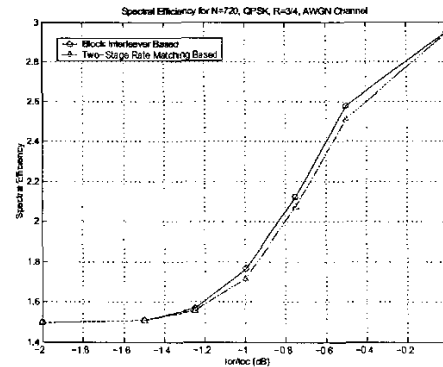


Figure 5. Spectral Efficiency for N=720, QPSK, R=3/4, AWGN Channel.

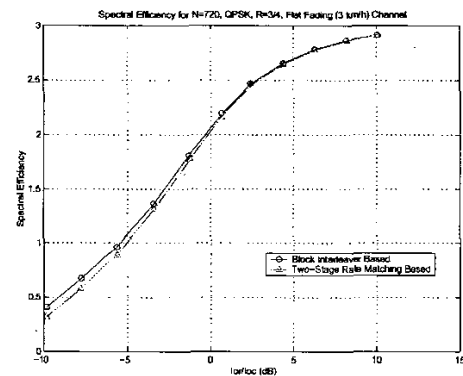


Figure 6. Spectral Efficiency for N=720, QPSK, R=3/4, Flat Fading channel (3 km/h).

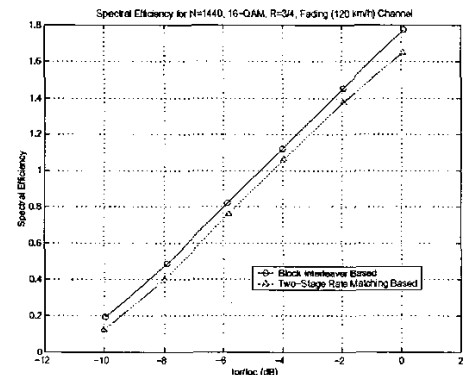


Figure 7. Spectral Efficiency for N=1440, R=3/4, 16-QAM, Flat Fading channel (120 km/h).