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Title:	**Enhanced HARQ Method with Signal Constellation Rearrangement**
Agenda Item:	**AH24 (HSDPA)**
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1 Introduction

Performance studies for HARQ schemes employing Chase Combining [1] and Incremental Redundancy for HSDPA have been carried out in [2] [3]. In this contribution an enhanced Hybrid ARQ method with signal constellation rearrangement for 16-QAM and 64-QAM modulation is presented. By averaging out reliabilities of bits carried by repeatedly transmitted symbols over retransmissions the new method shows a performance gain with respect to Chase Combining, where both system complexity and UE complexity are increased only slightly. The proposed method will be beneficial to Type II and Type III HARQ schemes employing retransmissions of previously transmitted symbols, which are carrying more than two bits. Thus this approach should be considered in the specification phase for HSDPA/HARQ.

The paper is organized as follows: Section 2 describes the basic idea of the proposed method and provides details on the retransmission strategies. Furthermore, UE complexity for 16-QAM and 64-QAM is evaluated. In section 3 frame-error-rate and throughput simulation results for MCS 5, MCS 6 and MCS 7 as defined in [4] are presented. Finally, in section 4 conclusions are derived.

2 Description of proposed Method

2.1 Basic Idea

For QAM modulation with an alphabet size higher than 4 the reliabilities of the bits Gray-mapped onto the modulated symbols vary tremendously from the most significant bits (e.g. i_1, q_1 in Figure 1) to the least significant bits (e.g. i_2, q_2 in Figure 1). These variations reduce the performance of the Turbo decoder with respect to having equal bit reliabilities.

In case of retransmitting copies of the initially sent packet and soft-combining its symbols/bits (i.e. Chase Combining) the variations in bit reliabilities remain biased. By rearranging the signal constellations for retransmissions the proposed method performs an averaging of the bit reliabilities over the retransmissions.

In case of Type II/III HARQ schemes where part of the redundancy is non-incremental, the bit reliabilities for the bits carried by the repeated symbols can be averaged out. Whereas the bits carried by incremental redundancy symbols will still show variations in bit reliabilities inherent to Gray-encoded signal constellation.

For both cases, due to a more homogeneous input of log-likelihood values to the Turbo decoder, an increase in decoder performance will occur compared to conventional soft-combining.

As a result of the rearrangement the data within the multiple received packets cannot be combined on a symbol-by-symbol basis. However, the soft-combining can be performed on bit-by-bit basis by adding up the log-likelihood ratios (*LLR*s)[1]. I.e. after each transmission the *LLR* for each received bit is calculated and added to the *LLR* obtained from previously received packets.

The following two sections provide a more detailed description how to perform the rearrangement for 16-QAM and 64-QAM under the constraint of having signal constellations for the first transmission as proposed in [4].

[1] The summation of the *LLR*s is not the correct metric to calculate the likelihood of the soft-combined bits. However, it is a fairly good approximation under the constraint of retaining a small UE buffer-size.

2.2 16-QAM Strategy

Figure 1 shows the signal constellation for 16-QAM as suggested for HSDPA [4]. Here, due to Gray-mapping bit i_1 is more reliable than i_2. Moreover, based on log-likelihood calculation different bit reliabilities for i_2 depending on the location (inner/outer column) of the transmitted symbol are obtained (i.e. the reliability depends not only on the position but also on the content). The same assumptions are valid for q-bits, since the q-bit mapping is equivalent to i-bit mapping but orthogonal. Hence, we propose to rearrange the 16-QAM signal constellation for the retransmission according to Table 1 to average out the bit reliabilities.

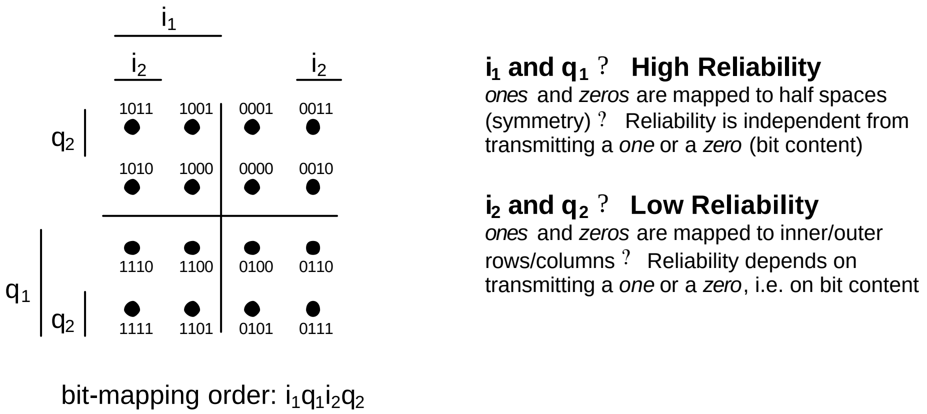
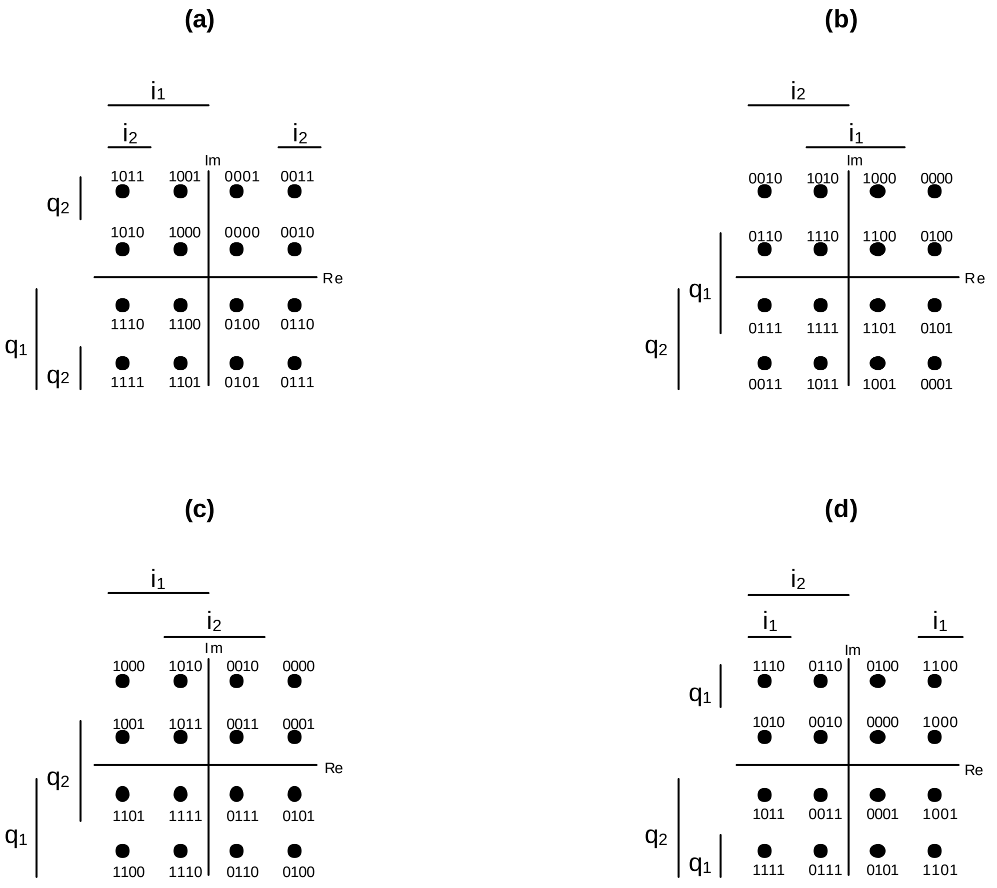


Figure 1. Gray-mapped signal constellation for 16-QAM resulting in variations in bit reliabilities.

Transmission No.	Figure	Comment
1. Transmission	Figure 2 (a)	Gray-encoded mapping as defined in [4], i_1 (q_1) more reliable than i_2 (q_2)
2. Transmission	Figure 2 (b)	i_2 (q_2) more reliable than i_1 (q_1), i.e. switch mapping of i_1 (q_1) and i_2 (q_2)
3. Transmission	Figure 2 (c)	i_1 (q_1) more reliable than i_2 and invert mapping of i_2 (q_2) with respect to initial transmission
4. Transmission	Figure 2 (d)	i_2 (q_2) more reliable than i_1 (q_1) and invert mapping of i_1 (q_1) with respect to 1. retransmission
Further transmissions	Figure 2 (a-d)	Repeatedly using constellations from transmissions 1 - 4

Table 1. 16-QAM constellation rearrangement strategy.



bit-mapping order for all constellations: $i_1q_1i_2q_2$

Figure 2. Signal Constellations for 16-QAM in order to average out bit reliabilities (all Gray-encoded).

2.3 64-QAM Strategy

In case of 64-QAM modulation there are 3 levels of bit reliabilities as shown in Figure 3. For bit i_2 we obtain different reliabilities either the transmitted symbol is mapped onto columns 1-2-7-8 or onto columns 3-4-5-6. Similarly, the reliability for i_3 depends on mapping onto columns 1-4-5-8 or onto columns 2-3-6-7. Analogue to 16-QAM same applies to q-bits. So i_2, i_3, q_2, and q_3 reliabilities depend again also on their contents. Hence, we propose to rearrange the 64-QAM signal constellation for the retransmission according to Table 2 to average out the bit reliabilities.

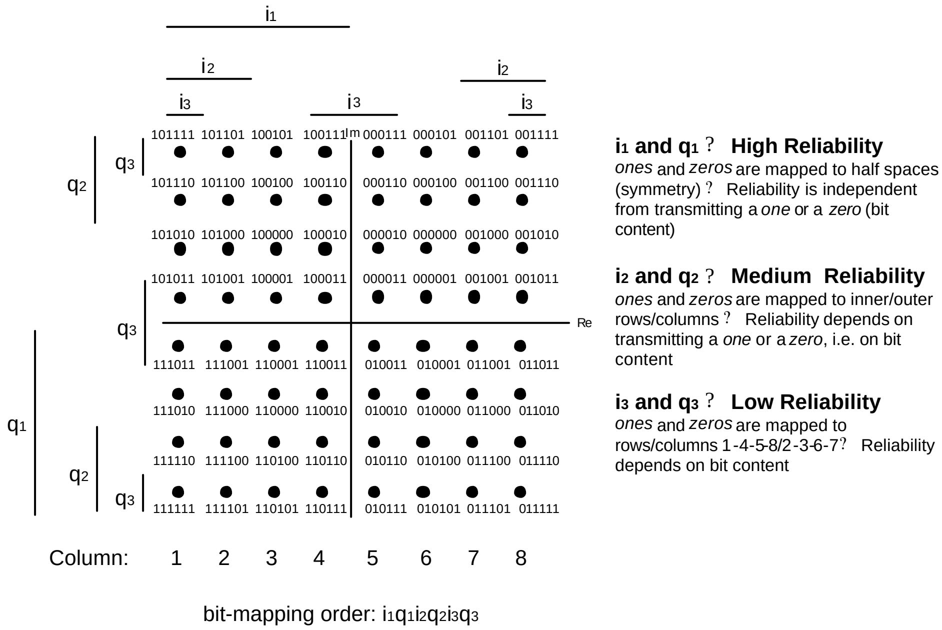
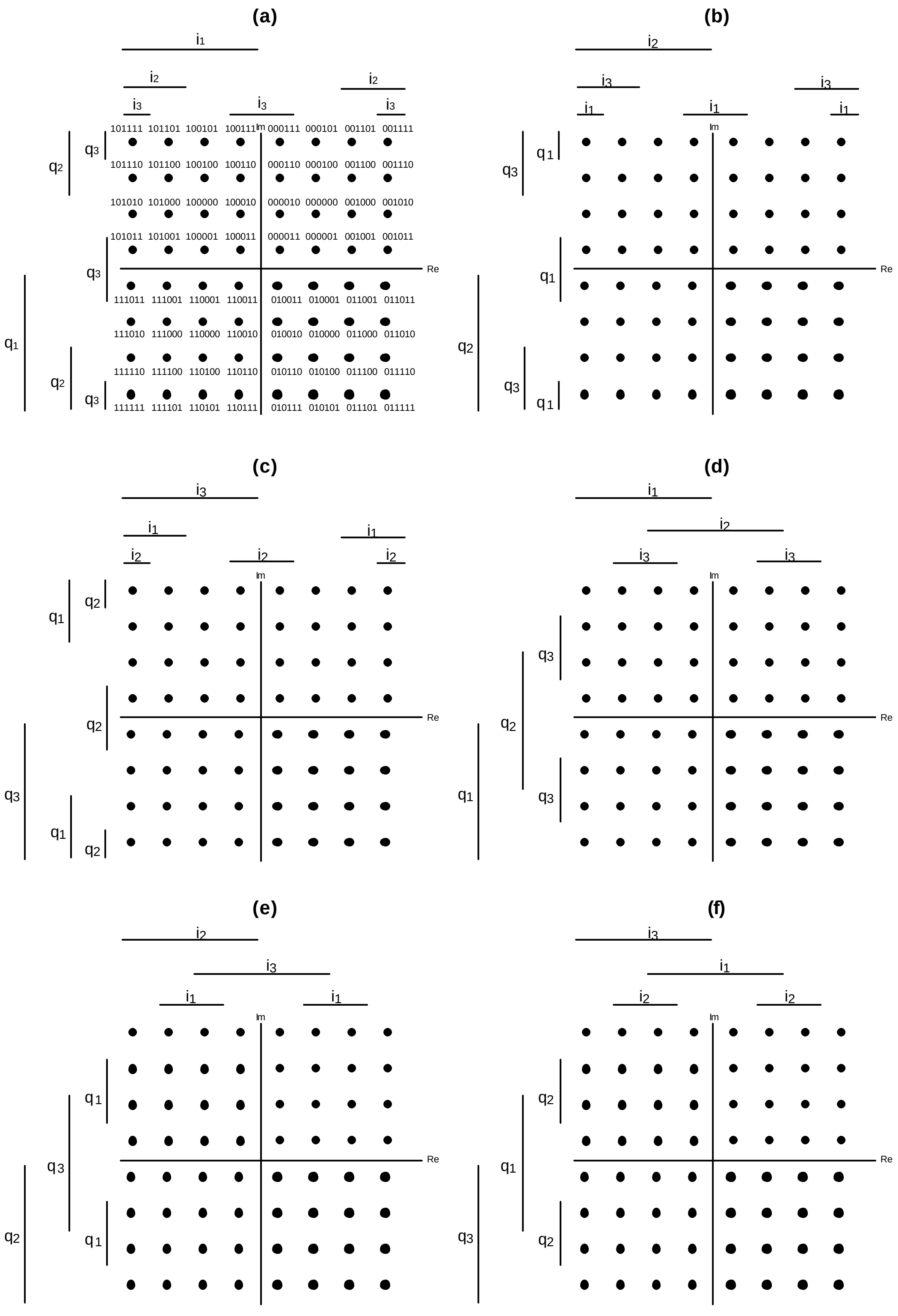


Figure 3. Gray-mapped signal constellation for 64-QAM resulting in variations in bit reliabilities.

Transmission No.	Figure	Comment
1. Transmission	Figure 4 (a)	Gray-encoded mapping as defined in [4], i_1 (q_1) high reliability, i_2 (q_2) medium reliability, i_3 (q_3) low reliability
2. Transmission	Figure 4 (b)	i_2 (q_2) high reliability, i_3 (q_3) medium reliability, i_1 (q_1) low reliability
3. Transmission	Figure 4 (c)	i_3 (q_3) high reliability, i_1 (q_1) medium reliability, i_2 (q_2) low reliability
4. Transmission	Figure 4 (d)	i_1 (q_1) high reliability, i_2 (q_2) medium reliability (inverted mapping to 1. transm.), i_3 (q_3) low reliability (inverted mapping to 1. transm.)
5. Transmission	Figure 4 (e)	i_2 (q_2) high reliability, i_3 (q_3) medium reliability (inverted mapping to 2. transm.), i_1 (q_1) low reliability (inverted mapping to 2. transm.)
6. Transmission	Figure 4 (f)	i_3 (q_3) high reliability, i_1 (q_1) medium reliability (inverted mapping to 3. transm.), i_2 (q_2) low reliability (inverted mapping to 3. transm.)
Further transmissions	Figure 4 (a-f)	Repeatedly using constellations from transmissions 1 - 6

Table 2. 64-QAM constellation rearrangement strategy.



bit-mapping order for all constellations: $i_1q_1i_2q_2i_3q_3$

Figure 4. Signal Constellations for 64-QAM in order to average out bit reliabilities (all Gray-encoded).

2.4 Complexity

Compared to Chase Combining using combining on a symbol-by-symbol basis for retransmissions the following issues regarding complexity have to be considered:

Node B Complexity

- additional tables for the signal constellations of the retransmissions have to be stored/selected, where the tables are equal for all UEs and, thus, have only to be stored once per Node B:
  - 16-QAM
    - 3 additional tables for optimum averaging (according to strategy described in section 2.2)
    - 1 additional table for sub-optimum averaging
  - 64-QAM
    - 5 additional tables for optimum averaging (according to strategy described in section 2.3)
    - 2 additional tables for sub-optimum averaging

UE Complexity

- additional tables for the signal constellations of the retransmissions have to be stored (see above)
- to apply correct signal constellation for demodulation UE has to be aware of the number of the current retransmissions
- Due to the bit-by-bit soft-combining required UE buffer-size will have to be increased compared to soft-combining on a symbol-by-symbol basis:
  - 16-QAM
    - symbol combining: I- and Q-part have to be stored per symbol
    - bit-combining: one LLR per bit and 4 bits per symbol

    ? 2 x buffer-size as for Chase Combining
  - 64-QAM
    - symbol combining: I- and Q-part have to be stored per symbol
    - bit-combining: one LLR per bit and 6 bits per symbol

    ? 3 x buffer-size as for Chase Combining

Comparing complexity with respect to incremental redundancy (IR) depends on the actual chosen IR scheme and, thus, has to be assessed case-by-case.

3 Simulations

3.1 Simulation Assumptions

Table 3 provides a list of simulation parameters.

Parameter	Value	Comment
Chip-rate	3.84Mcps	
Spreading Factor	32	
Number of code for HS-DSCH	1	
TPC	Off	
CPICH Ec/Ior	-10dB(10% of Ior)	
DSCH Ec/Ior	-1dB (80% of Ior)	
Channel Model	AWGN	
Channel Estimation	Ideal	
HSDPA Frame Length	3.33ms(5 slots)	transmission unit interval.
Tail bits	6	in each transmission unit.
Number of Iterations for Turbo Decoding	8	
Number of maximum retransmission	50	zero residual FER in performed simulations
STTD	Off	
Channel Coding	Turbo Code (rate ½, ¾)	Generated from rate 1/3 Turbo Code.
Log-Likelihood Calculation	Approximation	according to [4]
Modulation	16-QAM, 64-QAM	

Table 3. List of simulation parameters.

3.2 Simulation Results

In the following sections the AWGN simulation results for the frame-error-rate (FER) and throughput of the proposed HARQ method with constellation rearrangement vs. Chase Combining are presented. The MCS are defined according to Table 4 [4].

MCS	Modulation	Turbo Code Rate	Information bits per packet	Coded bits per packet	No. of Signal Constellations
5	16-QAM	½	800	1600	4
6	16-QAM	¾	1200	1600	4
7	64-QAM	¾	1800	2400	6

Table 4. List of MCS parameters.

3.2.1 MCS 5

In Figure 5 and Figure 6 the results for MCS 5 are presented. The proposed scheme has a gain over Chase Combining of about 1dB, 1.4dB and 1.8 dB for the first, second and third retransmission, respectively. I.e. instead of 3 retransmissions using Chase Combining two retransmissions with the proposed method would be sufficient.

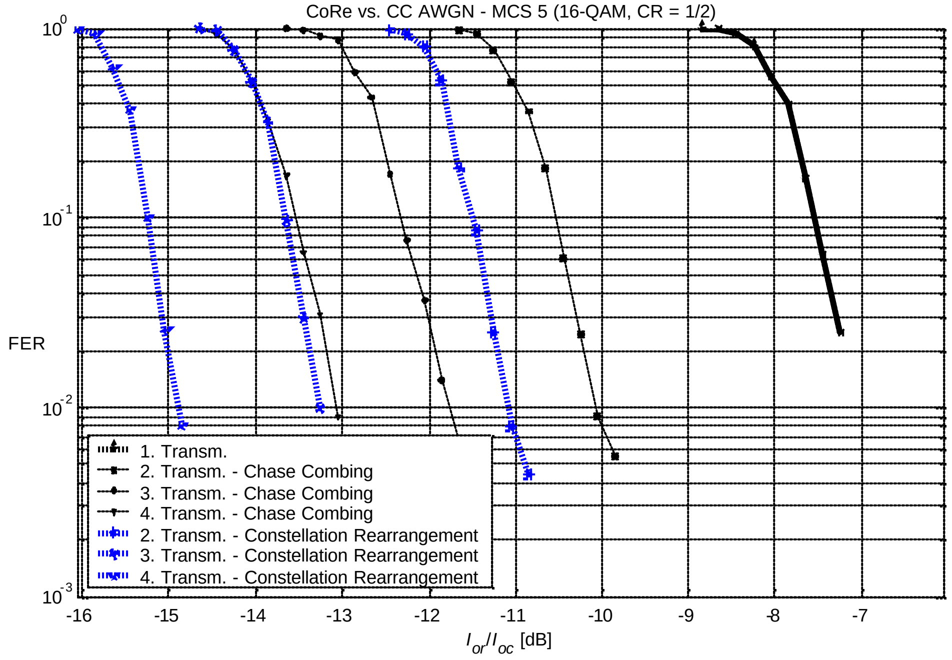


Figure 5. Frame-error-rates for MCS 5.

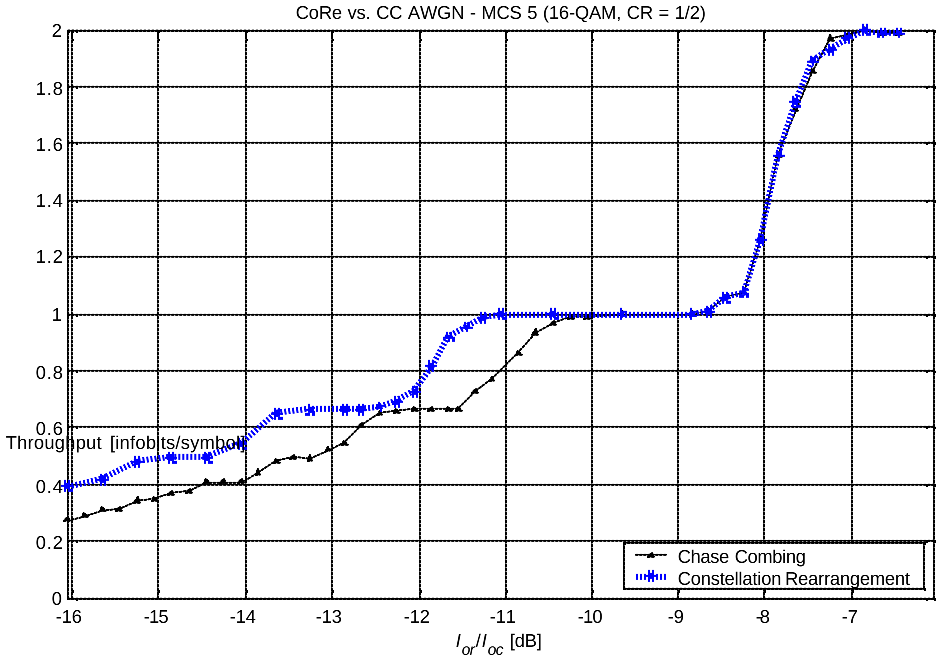


Figure 6. Throughput for MCS 5.

3.2.2 MCS 6

Figure 7 and Figure 8 show the comparison for MCS 6. The proposed method has a gain over Chase Combining of about 1.2 dB, 1.9 dB and 2.5 dB for the first, second and third retransmission, respectively. I.e. the 2nd retransmission of the proposed scheme performs significantly better than the 3rd retransmission using Chase Combining.

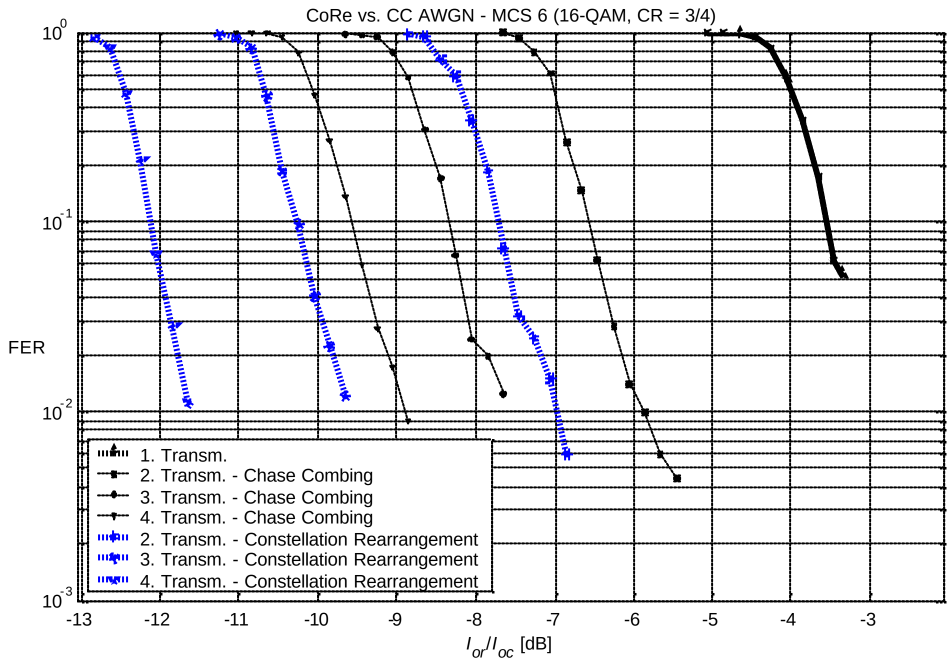


Figure 7. Frame-error-rates for MCS 6.

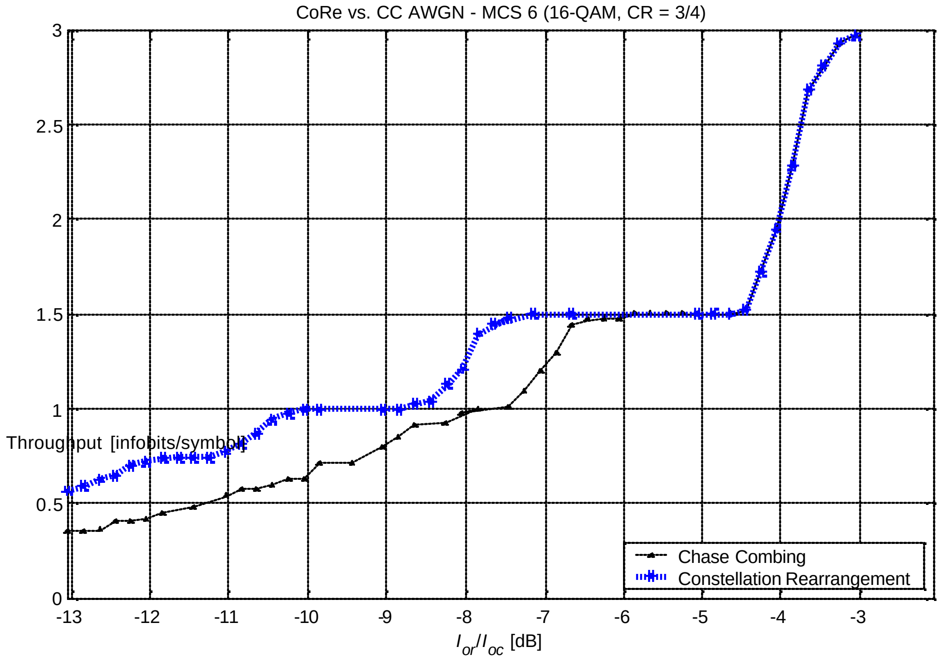


Figure 8. Throughput for MCS 6.

3.2.3 MCS 7

Figure 9 and Figure 10 show results obtained for MCS 7. The proposed scheme has a gain over Chase Combining of about 1.8 dB, 2.5 dB and 3.8 dB for the first, second and third retransmission, respectively. I.e. the 1st retransmission of the proposed scheme performs similar to the 2nd retransmission using Chase Combining.

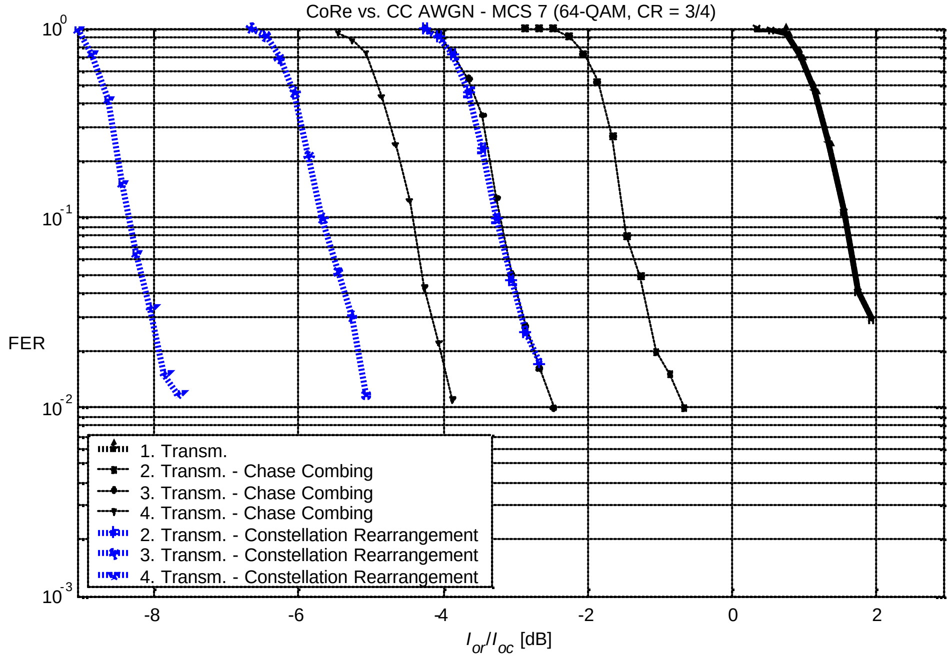


Figure 9. Frame-error-rates for MCS 7.

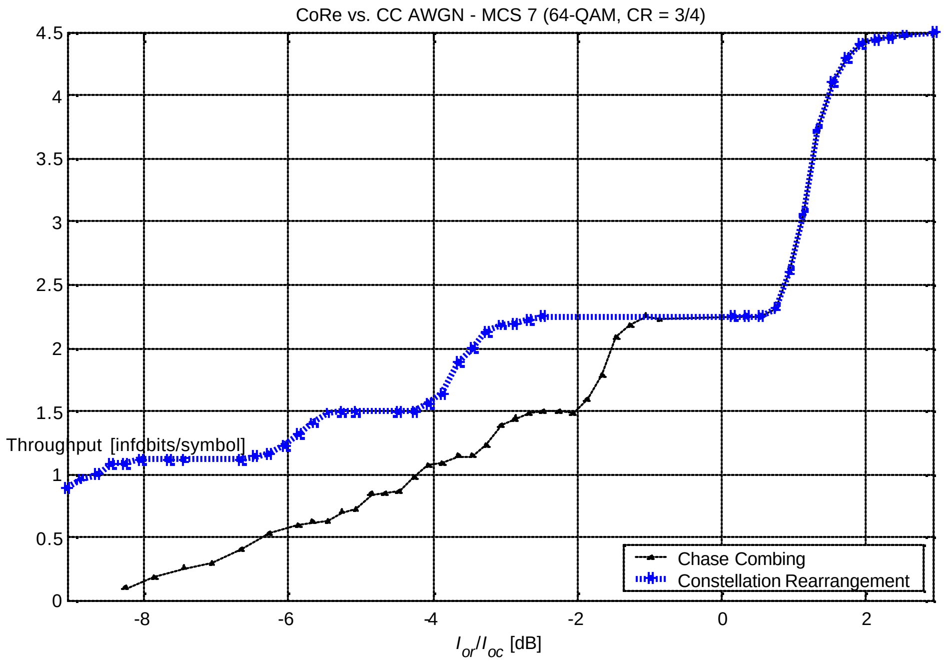


Figure 10. Throughput for MCS 7.

4 Conclusions

In this contribution a new HARQ method using signal constellation rearrangement was presented. It was explained that Turbo decoding performs sub-optimum due to varying bit reliabilities within symbols. By averaging out the bit reliabilities over the retransmissions the new method achieves a performance gain for 16-QAM (MCS 5, 6) and 64-QAM (MCS 7) compared to Chase Combining at the expense of only slightly increased complexity. The results for frame-error-rate and throughput for a transmission over an AWGN channel showed that the gain for code-rate ¾ is higher than for ½. Moreover, due to the more inhomogeneous bit reliabilities for 64-QAM a higher gain can be achieved than for 16-QAM.

The proposed method will be beneficial to Type II and Type III HARQ schemes employing retransmissions of previously transmitted symbols carrying more than two bits. The more non-incremental redundancy symbols are retransmitted the more performance gain can be achieved with respect to conventional soft-combining.

5 References

[1] D. Chase, "Code combining: A maximum-likelihood decoding approach for combining an arbitrary number of noisy packets," IEEE Trans. Commun., Vol. COM-33, pp. 385-393, May 1985.

[2] R1-00-1396, Motorola "Performance Comparison of Hybrid-ARQ Schemes" Stockholm, Sweden, November 21-24, 2000.

[3] R1-00-1428, Ericsson "Performance Comparison of Chase Combining and Incremental Redundancy for HSDPA" Stockholm, Sweden, November 21-24, 2000.

[4] R1-00-1093, Ericsson, Motorola and Nokia, "Link Evaluation Methods for High Speed Downlink Packet Access (HSDPA)," Berlin, Germany, August 21-24, 2000.