3GPP TSG-RAN
May 21-25, 2001
Busan, Korea

TSGR1#20(01)0574

Agenda item: 6

Source: Ericsson

Title: Packet Combining Scheme for HSDPA

Document for: Discussion and decision

1. Introduction

In this paper we compare two HARQ combining strategies that currently are considered for HSDPA. The two schemes are Chase combining, where the retransmissions are identical copies of the original transmission, and incremental redundancy (IR), where the retransmissions contain new parity bits from the channel encoder.

Based on the results presented in this paper we conclude that IR is a costly solution that does not provide any significant performance advantages compared to Chase combining. Therefore we propose that Chase combining shall be selected as the HARQ packet combining scheme for HSDPA.

2. Discussion

The drawbacks with IR compared to Chase combining are:

- Requires signaling of retransmission number in DL.
- Receiver buffer size increases for each retransmission.
- Retransmissions are not self-decodable.
- Requires buffering of soft bits instead of soft symbols in the UE.
- Current 3GPP rate matching scheme does not work with IR.

Thus if IR is to be implemented for HSDPA the complexity and cost of the system will be significantly higher. Therefor it is important to examine if there are any large performance gains with IR, or if Chase combining can provide equal performance at lower cost.

We showed in a previous paper [1] that the link-level performance of a HARQ type-II system can sometimes be significantly better with IR compared to Chase combining. The largest gains are obtained for high channel-coding rates and high modulation orders. For small modulation and coding schemes (MCSs), the link-level performance gains with IR are less significant.

Since the coverage area for the higher MCSs will be much smaller than for the lower MCSs only a relatively small percentage of the UEs will be able to benefit from any eventual gains with IR.

Furthermore, in a system using link adaptation we can not expect any significant gains with IR unless the link adaptation errors are very large. The reason for this is that Chase combining always gives 3 dB additional signal energy in the first retransmission and with reasonably good link adaptation we will not need the additional coding gain that can be achieved by IR.

Poor link adaptation can be caused by either high Doppler shifts which makes the channel difficult to predict, or rapid variations in the interference level. Large Doppler will cause not only poor link adaptation, but large errors in the receiver channel estimates as well. In this paper we therefore investigate the sensitivity towards channel estimation errors for different MCSs and we show that high MCSs can only be used when the receiver channel estimates are very accurate. Therefore, in cases with high Doppler it is only possible to use the lowest MCSs, for which the gains with IR are small.

Rapid and unpredictable variations in the received interference also causes poor link adaptation. For this scenario we argue that the most important gain with an HARQ system is the diversity effect it provides. If the interference level was high for the original transmission it is likely that the situation will improve for the retransmission. If the interference is constantly high it becomes predictable and the link adaptation will then become accurate.

Furthermore, we show that on fading channels there are situations when an IR system actually performs poorer than a Chase combining system. This is due to the systematic turbo encoder and the fact that all systematic bits are included in the first transmission. Therefore the retransmission when using IR consists only of new parity bits. If the systematic bits in the first transmission are destroyed by a fading dip the receiver would benefit more from a retransmission that includes the systematic bits (as in Chase combining) than from a retransmission that only contains parity bits (as in IR).

As alternatives to a full IR scheme there have been different solutions proposed addressing some of the drawbacks with IR. One alternative is to use a Partial IR scheme, where each retransmission consists of a repetition of the systematic bits and a new set of parity bits. Partial IR was studied by Motorola in [2, 3] as well as in the Panasonic proposal in [4]. Partial IR solves the problem with non self-decodable retransmissions. The other drawbacks that also the full IR scheme suffers remains however. Furthermore, for high MCSs only a small set of new parity bits is included in the retransmission and the difference in link level performance for Partial IR and Chase combining is therefore only minor.

The signal constellation rearrangement proposal from Panasonic [5] solves the problems with non self-decodable retransmissions and increasing buffer requirements for each retransmission (i.e. bullet two and three listed above). The scheme requires larger receiver buffers due to combining of soft bits instead of soft symbols. It also requires signaling of retransmission numbers in the downlink. Furthermore it does not work for the lowest MCSs that uses QPSK. The performance of the scheme is upper bounded by that of a full IR scheme, and hence Chase combining will provide equally good performance compared to this scheme as well.

Based on the observations listed above we conclude that Chase combining is the preferred HARQ packet combining scheme for HSDPA.

3. Numerical Results

The parameters used for the simulations in this paper are listed in Table 1. In the simulations performed, a number of transport blocks, K_{tot}, of size N_{TrBlk} are concatenated, and a CRC field of size m_{CRC} bits is added to form an encoding block of size $N_{uncoded} = K_{tot} \times N_{TrBlk} + m_{CRC}$. By letting N_{chip}, SF, L, and M denote the number of chips in a HSDPA transmission time interval, the spreading factor, the number of multi codes, and the modulation order, respectively, we obtain that the number of coded bits must equal $N_{coded} = L \times \log_2(M) \times N_{chip} / SF$. Consequently, the rate of the turbo encoder becomes $R = N_{uncoded} / N_{coded}$. In this paper we have used $N_{chip} = 2560$, $N_{TrBlk} = 320$, $m_{CRC} = 24$, $SF = 4$, and $L = 3$ in all simulations performed.

Table 1: Simulation parameters.

Parameter	Value	Comment
Spreading factor of HS-DSCH	4	
Number of multi-codes	3	
Propagation conditions	Static (AWGN) channel	
Allocated power for HS-DSCH	80% (-1dB)	
Closed loop power control	Off	
TTI	0.67 ms	1 slot
I_{or} / I_{oc}	Variable	
Channel estimation	Ideal	Unless explicitly stated
Number of CRC bits	24	One CRC field per TTI
Number of tail bits	6	
Number of decoder iterations	8	
Turbo decoder metric	Log-Max	
Turbo encoder rate	Variable	
Turbo interleaver	As in 3GPP	Random for > 5114 bits

Table 2: The modulation and coding schemes (MCSs) used in this paper.

MCS #	K_{tot}	M	R
1	3	4	0.25
2	6	4	0.50
3	9	16	0.38
4	15	16	0.63
5	21	64	0.58
6	27	64	0.75

Six different modulation and coding schemes (MCS1-MCS6) are simulated and the parameters of these six MCSs are listed in Table 2. In Figure 1 and Figure 2 the results with Chase combining and IR are compared in terms of the slot error rate versus the ratio of the total received power (I_{or}) and total interference (I_{oc}). Results for MCS1 (K_{tot} = 3) are shown in Figure 1 and results for MCS6 (K_{tot} = 27) are shown in Figure 2. In these two figures we see the performance of Chase combining (white markers) and IR (black markers) after the second, third and fourth transmissions (i.e. first, second, and third retransmissions). We clearly see that the gain with IR is significant only for MCS6 and not for MCS1.

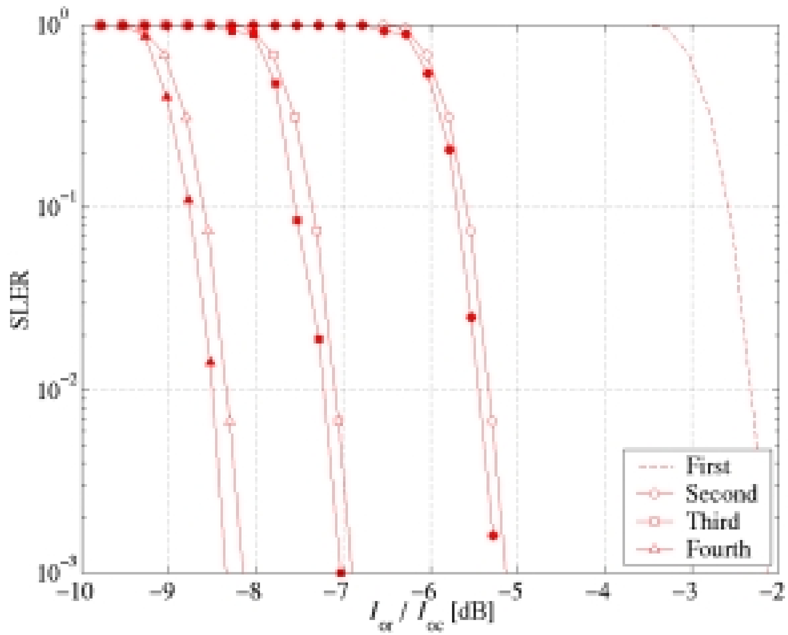

Figure 1: Simulated slot error rate versus I_{or} / I_{oc} in dB for MCS1 (K_{tot} = 3). White and black markers are used for Chase combining and IR, respectively.

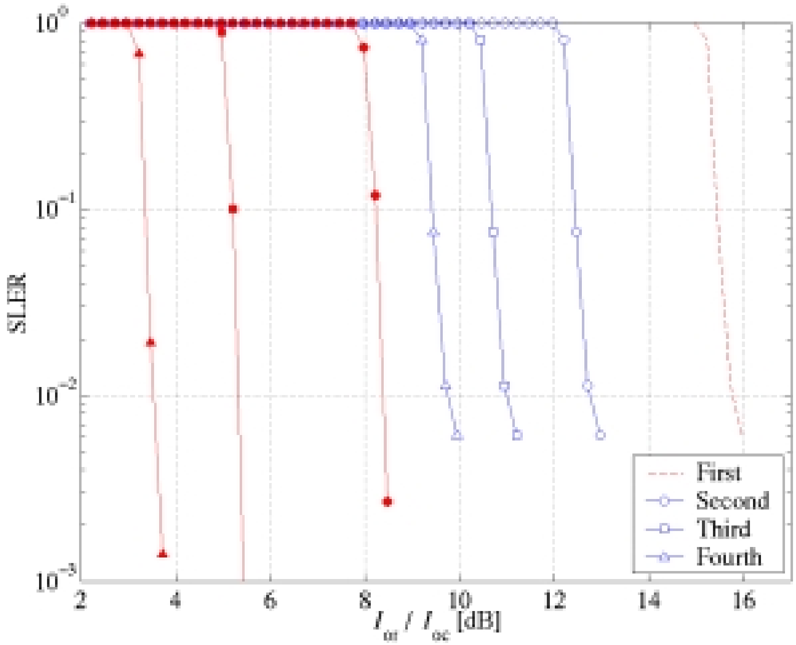

Figure 2: Simulated slot error rate versus I_{or} / I_{oc} in dB for MCS6 (K_{tot} = 27). White and black markers are used for Chase combining and IR, respectively.

The gains with IR compared to Chase combining in terms of I_{or} / I_{oc} required to achieve a slot error rate of 10% are listed for all MCSs in Table 3. From Table 3 we conclude that IR gives significantly better link-level performance compared to Chase combining for large modulations and coding schemes (MCS4-MCS6) and that only small differences are observed for smaller modulation and coding schemes (MCS1-MCS3).

Table 3: Achievable gain with IR compared to Chase combining at SLER = 0.1 on an AWGN channel.

MCS #	IR Gain 2nd Trans. [dB]	IR Gain 3rd Trans. [dB]	IR Gain 4th Trans. [dB]
1	0.1	0.2	0.2
2	0.8	1.0	1.0
3	1.0	1.0	1.0
4	2.2	2.7	2.7
5	3.0	4.0	4.2
6	4.2	5.4	6.1

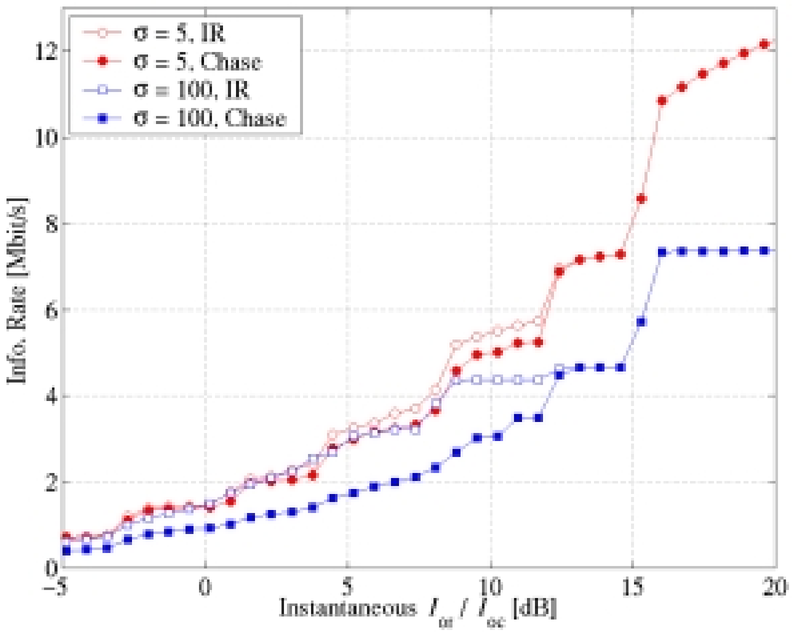

Figure 3: Throughput versus instantaneous I_{or} / I_{oc} in dB. The parameter σ is the standard deviation or the channel quality estimate error.

The transmitter will select which modulation and coding scheme to use based on some channel quality estimate. If the error of this channel quality estimate is small, then the gains that we saw in Table 3 may not be visible when comparing the throughput of the systems with Chase combining and IR respectively. Since Chase combining always gives 3 dB additional signal energy in the first retransmission we may not need the additional coding gain that can be achieved by IR. In Figure 3 we show the throughput that can be achieved with IR and Chase combining, respectively. Which MCS to use in each transmission is based on the channel quality estimate and is selected by comparing with predefined switching points in a lookup table. The channel quality estimate is assumed to be normally distributed in a logarithmic scale with a mean value equal to the true channel quality and a standard deviation of σ. Significant gains with IR are observed for the case when the scheduler has almost no knowledge of the actual channel quality (i.e. σ = 100).

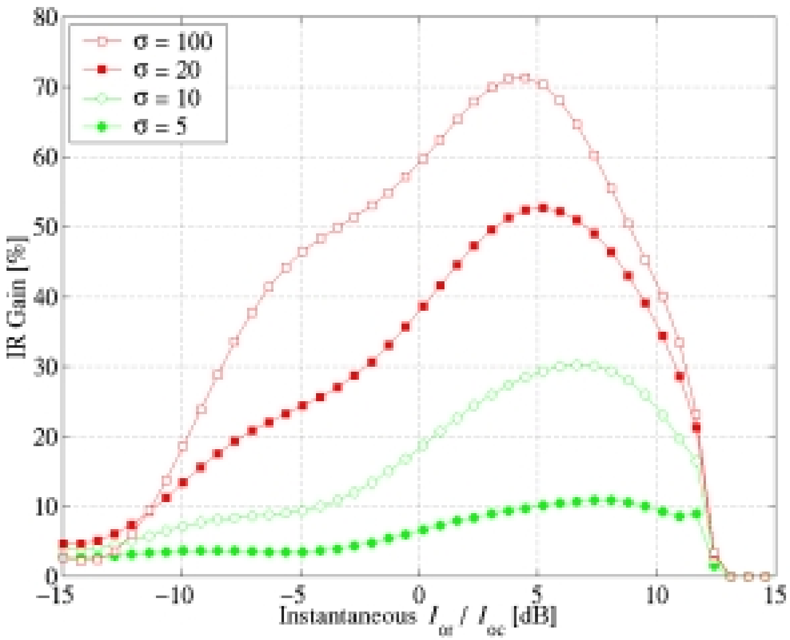

Figure 4: Achievable throughput gain with IR compared to Chase combining versus the instantaneous I_{or} / I_{oc} in dB. Results are shown for channel quality estimation errors σ of 5, 10, 20, and 100 dB.

In Figure 4 we show the relative throughput increase in percent that can be achieved by introducing incremental redundancy. We see that when the scheduler has almost no knowledge of the channel quality (σ = 100) then the gains with IR can be as high as 70% increased throughput. However for smaller errors in the channel quality estimate the gains are much smaller. For σ<5 there is no significant difference between Chase combining and IR.

It is important to note that the results in Figure 4 are obtained with perfect channel estimates in the receiver. In many cases it is not reasonable to assume that the Node-B have very poor knowledge of the channel quality while the receiver has perfect channel knowledge. Even though there are scenarios, e.g. situations involving soft handover, when this assumption might be reasonable, it is more likely that the error variance of the channel quality estimate in the transmitter and the channel estimate in the receiver are highly correlated most of the times. In Table 3 we saw that the largest gains with IR comes from the large signal constellations (i.e. 64 QAM). With poor channel estimates in the receiver these high constellations can not be used and the gains with IR will become significantly smaller than what we see in Figure 4.

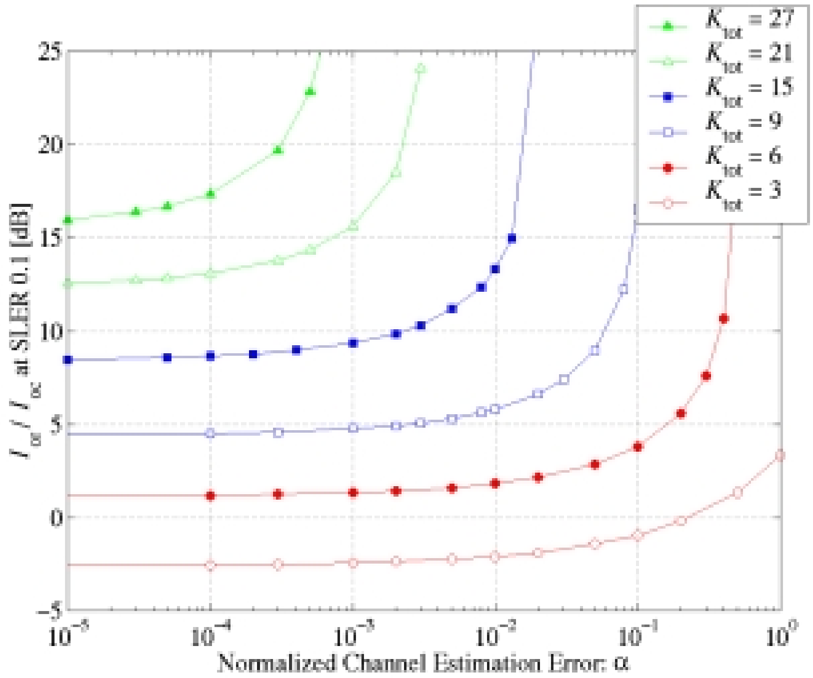

Figure 5: The required I_{or} / I_{oc} in dB to achieve a slot error rate of 10% versus the normalized channel estimation error $\alpha = \sigma_e^2 / \sigma_h^2$.

In Figure 5 we study the sensitivity of channel estimation errors in the receiver. The required I_{or} / I_{oc} at 10% slot error rate is shown, versus the normalized channel estimation error $\alpha = \sigma_e^2 / \sigma_h^2$, for MCS1-MCS6. We see that the required accuracy of the channel estimates varies several orders of magnitude from MCS1 to MCS6. Hence the highest MCSs does not only require good channel quality, but also much more accurate channel estimates in the receiver.

For users on the cell border, or users with high mobility it is reasonable to assume that only the lower MCSs can be used. Since we have seen that there is no significant gain with IR when the link adaptation works properly it is interesting to compare the results obtained when only some low MCSs can be selected. In Figure 6 we show the gain that can be achieved with IR if we are only allowed to use the three smallest MCSs, i.e. MCS1-MCS3. We see that the gains with IR are only about 5% in increased throughput, even for such large link adaptation errors σ as 10 dB.

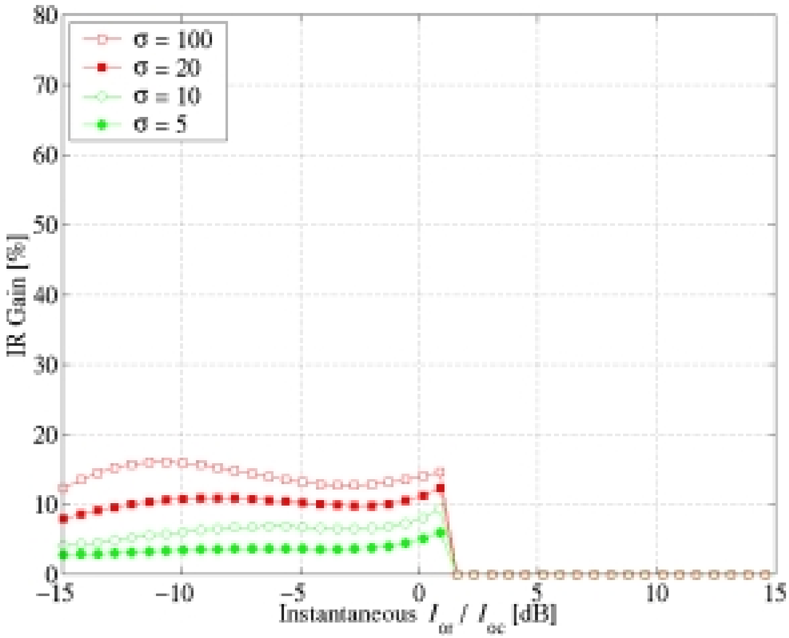

Figure 6: Achievable throughput gain with IR compared to Chase combining when using only MCS1-MCS3. Results are shown versus the instantaneous I_{or} / I_{oc} in dB for channel quality estimation errors σ of 5, 10, 20, and 100 dB.

When introducing HSDPA it is desirable to reuse as much as possible of the existing functionality in the WCDMA system, such as e.g. the turbo encoder. The turbo encoder that is used in WCDMA is a systematic encoder. This means that the original transmission must contain all systematic bits and, when IR is used, that the retransmissions will contain only additional parity bits. On a fading channel the channel quality may change from the time of the first transmission to the time of the retransmission. Thus, with IR we can expect some degradation if the receiver only receives the parity bits in the retransmission while the systematic bits in the original transmission are lost. For Chase combining however, the retransmission is identical to the original transmission and therefore Chase combining is expected to be more robust in this sense. In Figure 7 we examine this effect by varying the ratio γ of received power in the original transmission and the retransmission while keeping the total received power constant. A positive value of γ thus means that the original transmission contains more energy than the retransmission. The curves show for different MCSs, the I_{or} / I_{oc} required to obtain a slot error rate of 10%. For Chase combining (dashed lines) the performance is independent of γ and for IR the best performance is achieved when the received power of the original and the re-transmissions are equal (γ = 0 dB). We see that for γ = 20 dB, almost all received power is put on the original transmission and hence there are almost no difference between Chase combining and IR in this case. For very small values of γ we can actually see that Chase combining performs better that IR. The 5% increased throughput that we observed for σ = 10 dB in Figure 6 assumed that the channel did not change from the original transmission until the retransmission. However if the channel does change (i.e. $\gamma \neq 0$), we see in Figure 7 that the gains with IR compared to Chase combining will be even smaller.

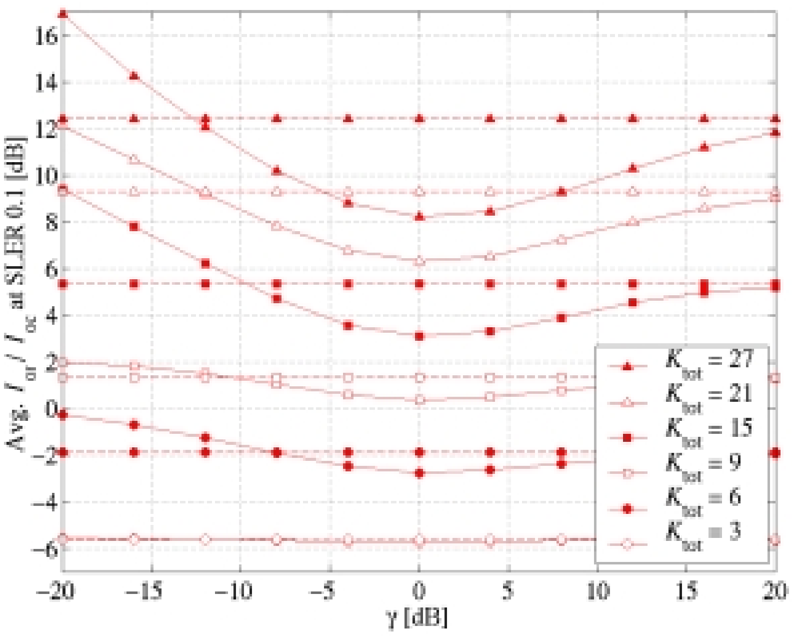

Figure 7: Average I_{or} / I_{oc} in dB that is required to obtain a slot error rate of 10% versus γ in dB. γ is the ratio of the received power in the original transmission and the retransmission. Results are shown for Chase combining(dashed lines) and IR (solid lines).

4. Conclusions

Since IR implies larger memory requirements for the mobile receivers and a larger amount of control signaling compared to Chase combining, it is important that the increased complexity also results in improved performance. In this paper we show that this is not the case for HSDPA. Therefor we propose that Chase combining shall be used as the HARQ packet combining method for HSDPA.

5. References

[1] Ericsson, "Performance comparison of Chase combining and incremental redundancy for HSDPA," TSGR1#17(00)1428.

[2] Motorola, "Performance comparison of hybrid-ARQ schemes," TSGR1#17(00)1396.

[3] Motorola, "Performance comparison of hybrid-ARQ schemes: Additional results," TSGR1#18(00)0044.

[4] Panasonic, "Proposal of bit mapping for type-III HARQ," TRGR1#18(01)0031.

[5] Panasonic, "Enhanced HARQ method with signal constellation rearrangement," TSGR1#19(01)0237.