TSG-RAN Working Group 1 meeting #14 *TSGR1#14(00)0869*

Oulu, Finland

July 4 – 7, 2000

Agenda item:

Source: Nokia

Title: Hybrid ARQ methods for FDD in Release 2000

Document for: Discussion

---

1 Introduction

In RAN meeting #7 hybrid ARQ (HARQ) was approved as one working item for Release 2000 work. This contribution provides performance studies by Nokia, comparing possible ways of employing hybrid ARQ. The purpose of this document is to give information on the different schemes; currently Nokia is not endorsing any specific HARQ scheme for Release 2000.

Type I hybrid ARQ without combining

The ARQ method used in the current 3GPP specification is referred to as type I HARQ without combining in this document. In this basic type I HARQ the CRC is added and the data is encoded with a forward error correction (FEC) code. In the receiver the FEC code is decoded and the quality of the packet is checked. If there are errors in the packet, a retransmission of the packet (RLC-PDU) is requested. The erroneous packet is discarded and retransmission uses the same FEC code as during the first transmission.

Type I hybrid AQR with soft combining

With type I HARQ it is also possible to store the erroneous packet in the receiver and combine it with a retransmitted packet. This is a kind of incremental redundancy coding scheme in the form of repetition code. The encoding stage is the same as with the current HARQ scheme in 3GPP specification. The main difference is a need for buffering in the receiver and soft combining of packets. Depending on the accuracy desired in soft combining one needs to decide on with how many bits the received soft symbols are represented in the receiver. This directly affects the memory size in the implementation.

Type II hybrid ARQ with full retransmissions

The type II HARQ is a so-called Incremental Redundancy ARQ scheme. This means that an RLC-PDU that is to be transmitted is not discarded but is combined with some incremental redundancy information provided by the transmitter for subsequent decoding.

For type II HARQ the retransmissions are typically not identical with the original transmission. The retransmitted part carries additional redundancy information for error correction purposes. This additional redundancy is combined with the previously received packet and the resulting more powerful FEC code word is decoded. In the full retransmission schemes of type II HARQ, the retransmitted amount of redundancy is always the same and in practice the data can be recovered from any transmission without need for combining.

Type II hybrid ARQ with partial retransmissions

In type II HARQ partial retransmission schemes the retransmitted block is smaller than the first transmission. Thus, in general the data cannot be recovered from the retransmitted packet without combining. In this document, only full retransmission schemes are considered.

2 Link simulations

2.2 Criteria for comparison

The average throughput, the average number of transmissions (delay) and the single cell capacity will be calculated from simulation results and will be used as basis for the comparison.

2.2.2 Throughput

The average throughput is measured in kbit/s and is plotted as a function of tx_Ec/Ior, where tx_Ec is the transmitted chip energy. During DTX tx_Ec = 0. Tx_Ic is the average energy per chip for a particular Walsh channel, measured at the *base station*. Its value changes due to the power control commands. Note that during DTX tx_Ic ≠ 0. If the frame format does not contain any DTX then tx_Ic = tx_Ec. Ior is the total power density of the base stations in soft handover with the mobile, measured at the base station.

If different amount of DTX has been used in simulations for different schemes, the throughput will be scaled such that each scheme is effectively having the same amount of DTX, preferably no DTX. If the throughput is scaled up to the no DTX case, then tx_Ec and tx_Ic become the same and effectively we are plotting the results as a function of tx_Ic/Ior. (Here we assume that instead of DTX more data could be transmitted. If the scheme is such that DTX is needed and cannot be replaced with more data, then tx_Ic/Ior measured in the simulation should be used directly.)

This effectively leads to the definition of throughput as (this is the transmission efficiency used in simulation results plots)

$$h_u = \frac{1}{T_r} R_c \tag{1}$$

where T_r is the average number of transmissions and R_c is the code rate where the same spreading factor (SF) is assumed to be used.

2.2.3 Delay (number of transmissions)

The delay is estimated here simply by the number of transmissions assuming that the delay between each transmission and retransmission is constant. More detailed delay analysis requires protocol simulations, which is out of the scope of this document. Both average delay and the delay distribution are considered, i.e., the average number of transmissions T_r and the distribution of the number of transmissions. The average number of transmissions can be calculated as

$$T_r = 1 + P_1 + P_{12} + P_{123} + \ldots \tag{2}$$

where P_1 is the probability that the first transmission is in error, P_{12} is the joint probability that the first and the second packet are in error as well as the combined packet, etc. If we utilize this we need not simulate the actual retransmissions in the link simulator. We can estimate each probability term separately.

The average delay can be calculated as

$$delay = (T_r - 1)D + TTI \tag{3}$$

where D is the delay between each transmission of a given packet and TTI is the transmission time interval for a single packet.

2.2.4 Single cell downlink capacity estimate

In downlink link simulations the performance is typically measured as a function of tx_Ic/Ior which tells the proportion of the total power that a single user requires. Therefore, assuming that all users require the same tx_Ic/Ior, the number of users in the cell is inversely proportional to the required tx_Ic/Ior

$$K_u \propto \frac{1}{tx\_I_c / I_{or}} \tag{4}$$

The single user throughput h_u for a given tx_Ic/Ior can be defined as average bit rate measured in kbit/s (the retransmissions are taken into account and reduce the average bit rate). The cell throughput can then be defined as

$$h_c = K_u h_u \propto \frac{h_u}{tx\_I_c / I_{or}} \text{ [kbit/s]} \tag{5}$$

2.3 Simulation cases

The link simulations are geometry (G) simulations where the own cell interference is modeled explicitly (common pilot channel and N other users with random data) and other cell interference with Gaussian noise. The geometry G is defined as the ratio of the received own cell power to other cell interference:

$$G = \frac{average(rx\_I_{or})}{I_{oc} + N_0} \tag{6}$$

In practice, the thermal noise and the other cell interference are modeled with white Gaussian noise. Power control is modeled only for the desired user, for interfering users no power control is used. The common pilot channel is also transmitted with constant power.

Table 1 shows assumptions used for simulations.

Table 1. Simulation assumptions

Parameter	Explanation/Assumption
Chip Rate	3.84 Mcps
Closed loop Power Control	ON
PC error rate	4%
PC delay	1 slot
Propagation Conditions	Pedestrian A 3 km/h
Number of bits in AD converter	Floating point simulations
Downlink Physical Channels and Power Levels	CPICH_Ec/Ior = -10 dB No PCCPCH No SCH OCNS_Ec/Ior = power needed to get total power spectral density (Ior) to 1, divided equally between interfering users DPCH_Ec/Ior = total power needed to meet the required BLER target
Number of interfering users	20
Bit rates	8, 32 kbit/s
$\hat{I}_{or} / I_{oc}$ values (G)	3 dB
D (delay between transmissions of a packet)	6 TTIs

2.4 Simulation results

2.4.2 Simulation models

2.4.2.1 Hybrid ARQ with Soft Combining

The same packet is coded and sent through the channel twice, with a delay in between. At the receiver the two packets are combined and decoded together in the Viterbi decoder. The Block Error Rate (BLER) of the combined packet as well as the individual packet can be calculated. The throughput, number of transmissions and the system capacity is found out using the BLER.

2.4.2.2 Type II Hybrid ARQ

The simulations were conducted for 2 different types of Type II Hybrid ARQ schemes.

1) Type II hybrid ARQ with code rates R1 = 2/3, R2 = 1/3 (the first transmission as well as the retransmission is having the same code rate 2/3 so that after the first retransmission we get a rate 1/3 code). The first packet and the retransmitted packet were send through the channel with a delay in between. At the receiver two packets are combined and the probability of error of the combined packet is obtained. The puncturing scheme used for the for the first transmission is

$$\begin{matrix} 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{matrix}$$

2) Type II hybrid ARQ with code rates R1 = 1/1, R2= 1/2 and R3 = 1/3, where Ri is the code rate after i transmissions. The code is obtained from rate R = 1/3 by transmitting each output separately. The first transmitted packets and the two retransmitted packets were sent through the channel with a delay in between. At the receiver the transmitted packets and the two retransmitted packets are combined. The probability of error of the first transmitted packet (P_1) as well as the combined packets (P_{12} & P_{123}) can be found out. The throughput, number of transmissions and the system capacity can be found out using these Block Error Rates.

2.4.2.3 Assumptions used in simulations

The delay between transmissions is assumed to be 6 TTIs, i.e., 60 ms or 120 ms depending on the TTI used.

The joint probability of error of the combined packets, first transmitted packet and the retransmitted packets is upper bounded by

$$P_{12} \leq P(D_{12}) \tag{7}$$

$$P_{123} \leq P(D_{123}) \tag{8}$$

where $P(D_{12})$ and $P(D_{123})$ are the probability of the error of the combined packet

So the Average number of transmissions (Tr) is upper bounded by

$$Tr(UpperBound) = 1 + \left(\frac{P(R_1) + P(D_{12})}{1 - P(D_{12})} \right) \tag{9}$$

for Type I Hybrid ARQ with Soft Combining and for Type II (2/3, 1/3) scheme and

$$Tr(UpperBound) = 1 + \left(\frac{P(R_1) + P(D_{12}) + P(D_{123})}{1 - P(D_{123})} \right) \tag{10}$$

for Type II Hybrid ARQ (1, ½, 1/3) scheme.

The Transmission Efficiency and System Capacity Estimates are obtained from Average number of transmissions (Tr) as explained in the previous section. The upper bound of *Tr* can be used to obtain a lower bound of Transmission Efficiency and System Capacity.

2.4.3 Simulation Results

In all simulations results presented here Pedestrian A channel with 3 km/h was used.

2.4.3.1 Simple Hybrid ARQ with different Code Rates

The simulation results in these section shows the comparison between Type I Hybrid ARQ schemes with different code rates. The simulations were done for an input data rate of 8 kbit/s.

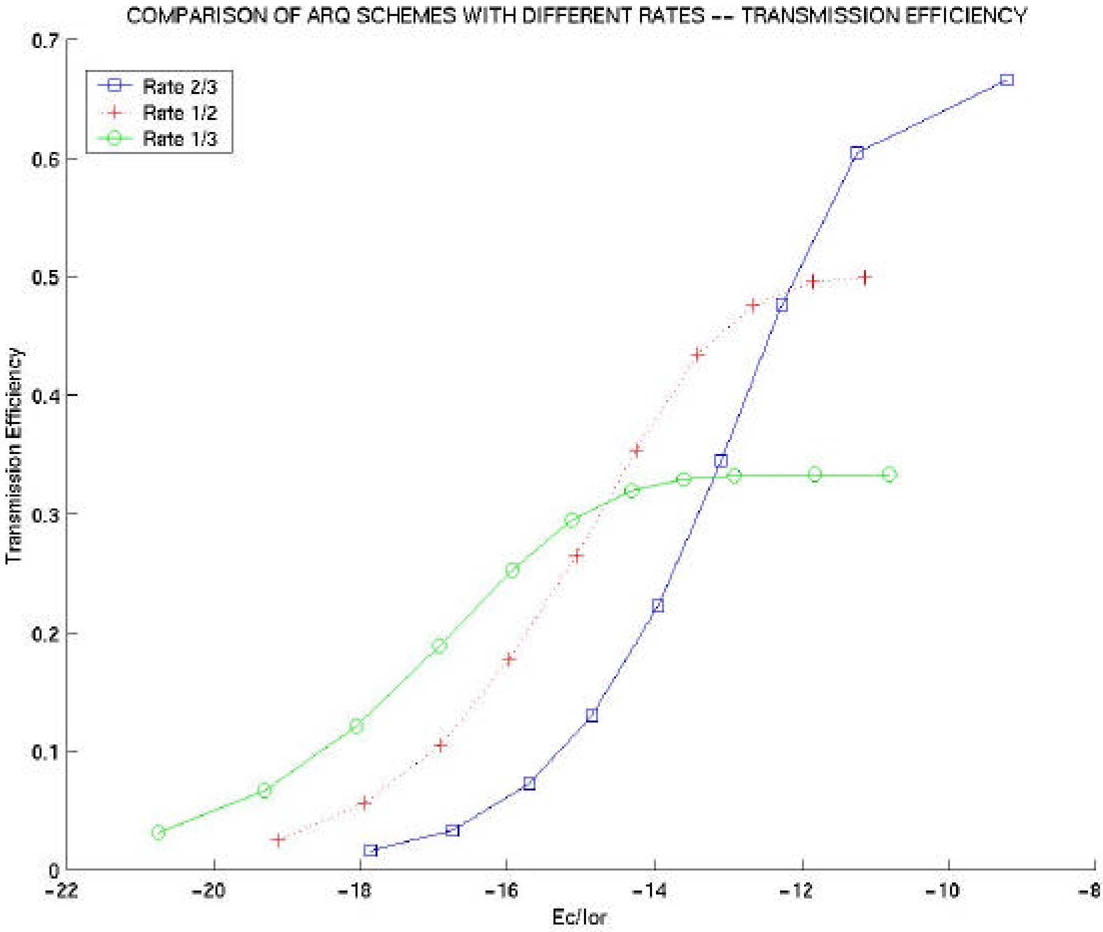


Figure 2.4.3.1-1 Transmission Efficiency

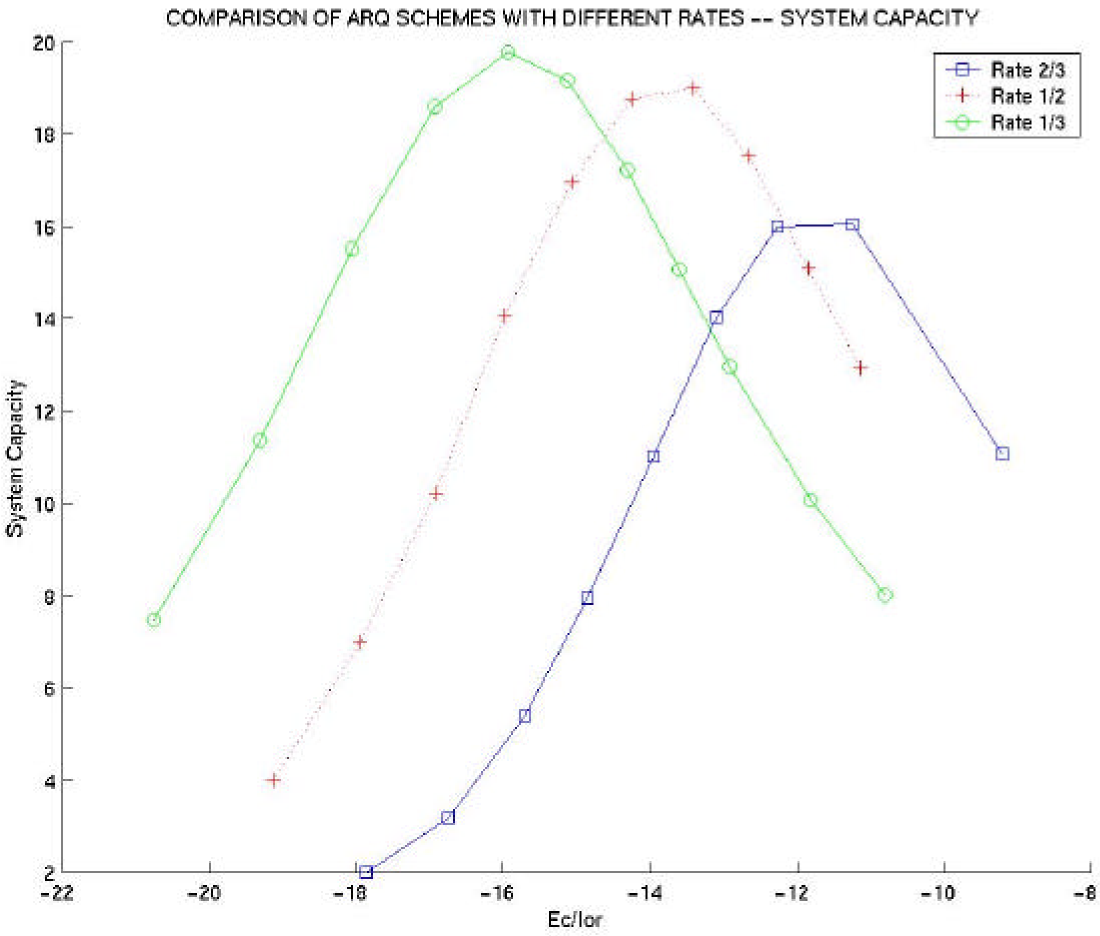


Figure 2.4.3.1-2 Cell Capacity

The simulation plots shows that the rate 1/3 code gives the maximum cell capacity. The capacity of rate ½ code is close to the capacity of rate 1/3 code. However the capacity of 2/3 code is seen to be lower than ½ and 1/3 codes.

2.4.3.2 A Comparison of Type I and Type II Hybrid ARQ

The simulation results in this section show the comparison between Type I Hybrid ARQ with soft combining and Type II Hybrid ARQ. The source rate was 32 kbit/s and the code rate for the first transmission is 2/3 and the code rate for the second transmission is also 2/3.

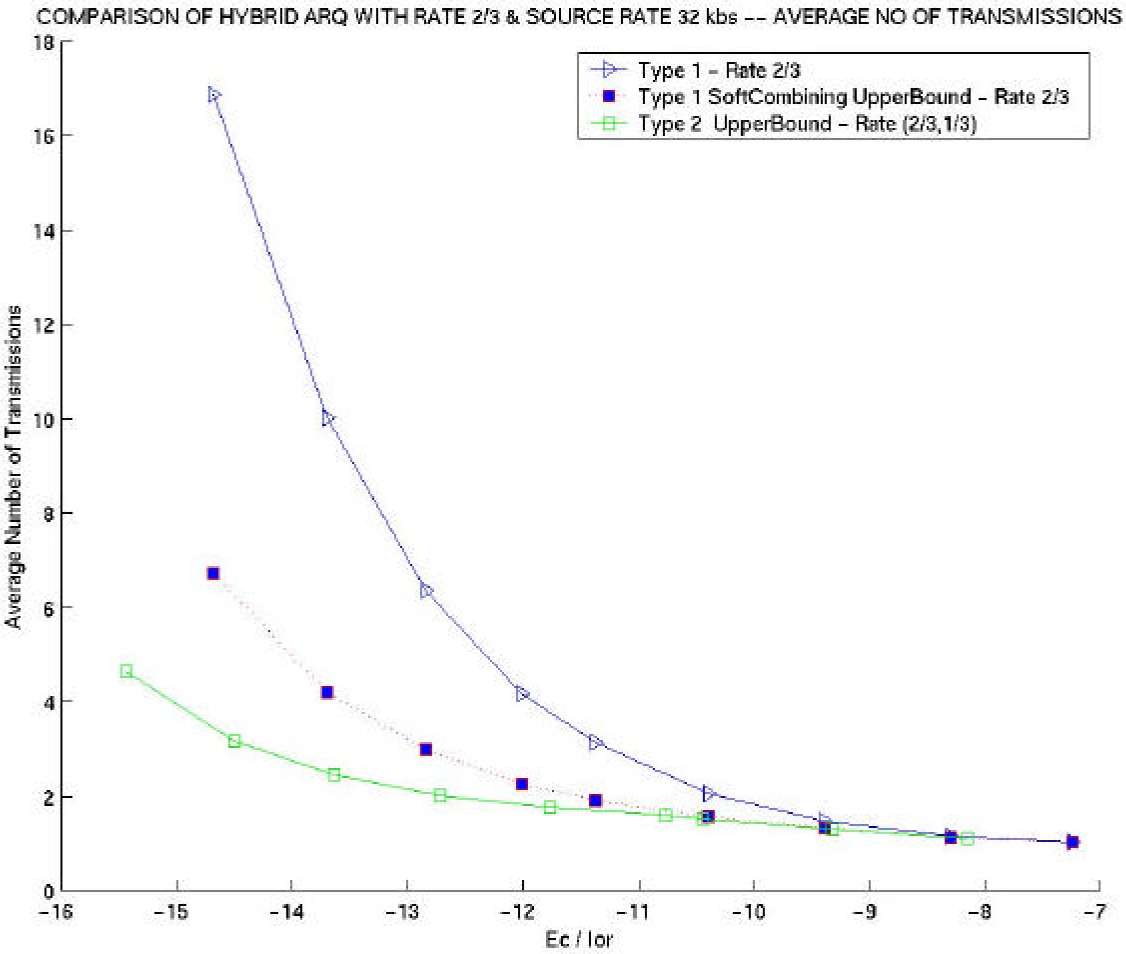


Figure 2.4.3.2-1Average Number of Transmissions

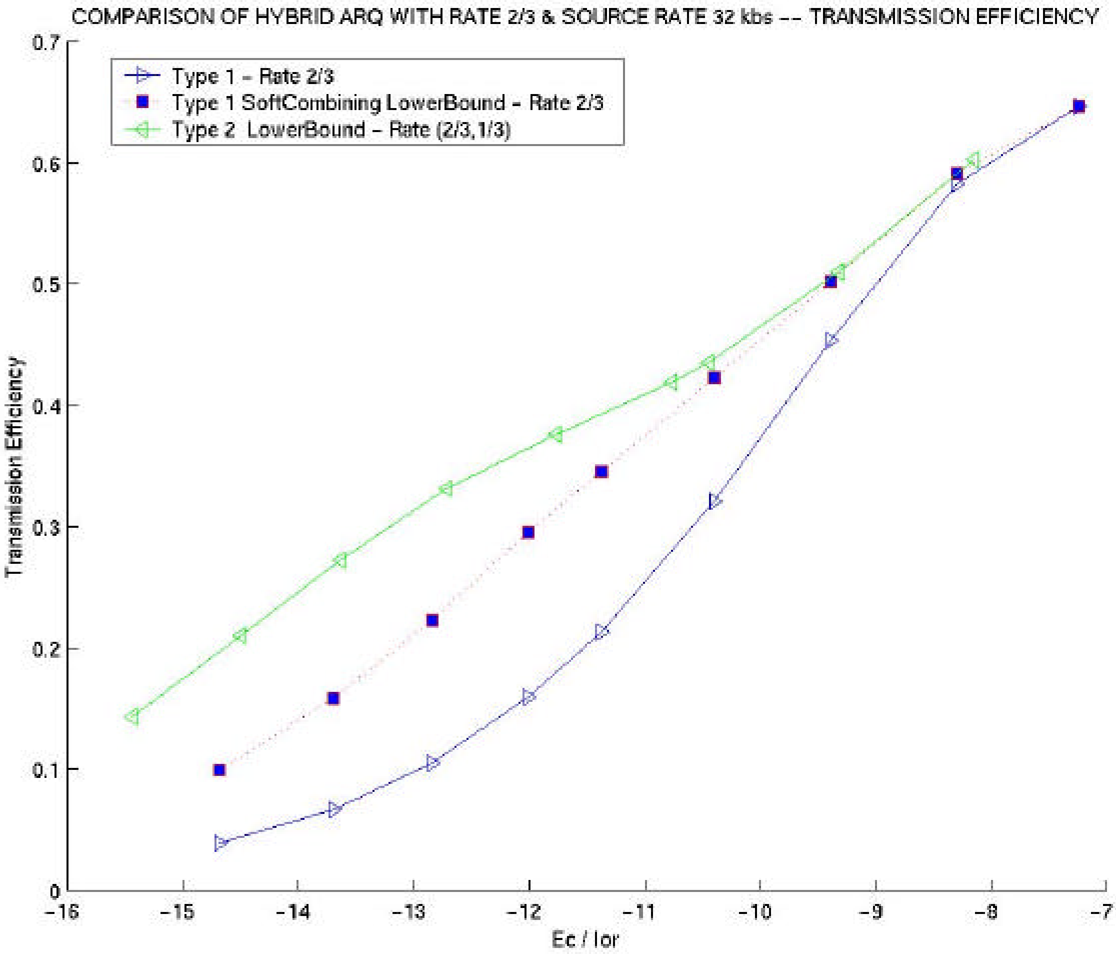


Figure 2.4.3.2-2 Transmission Efficiency

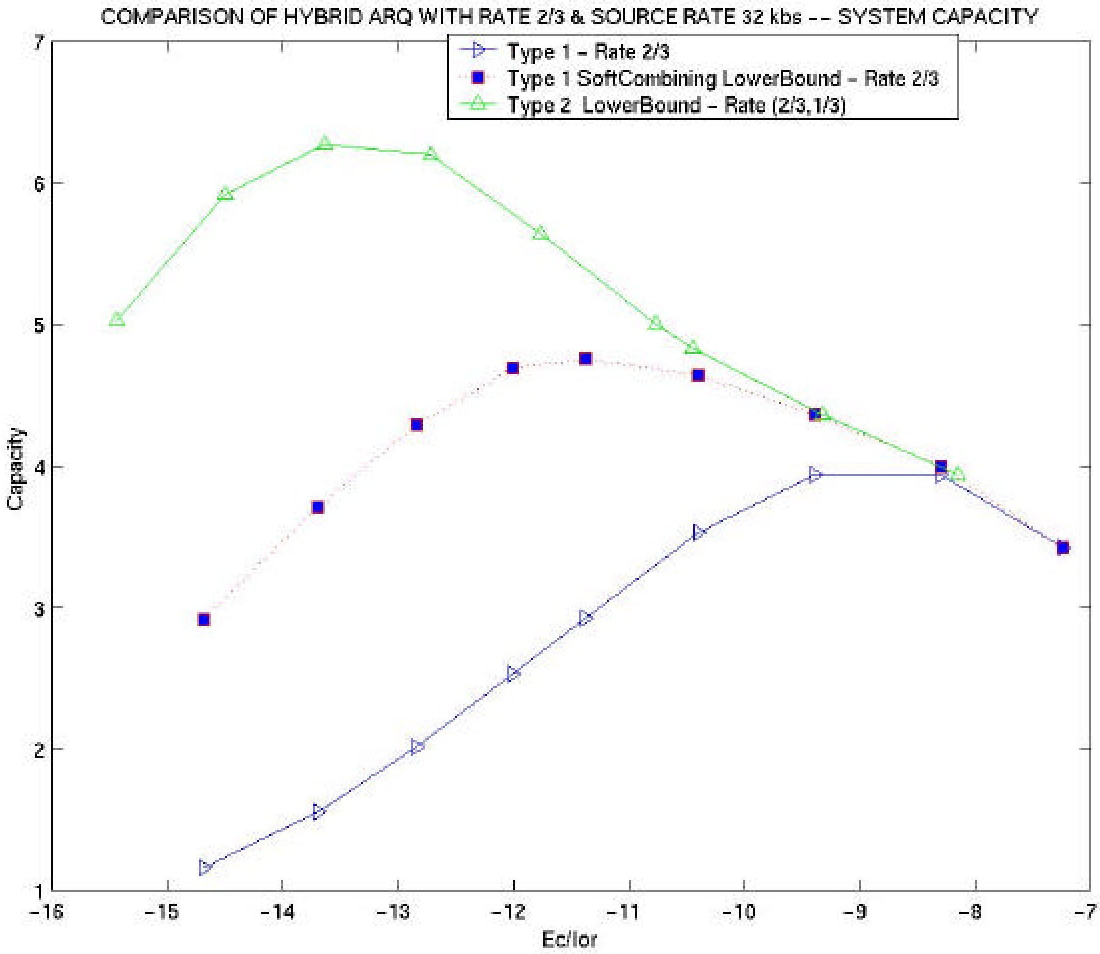
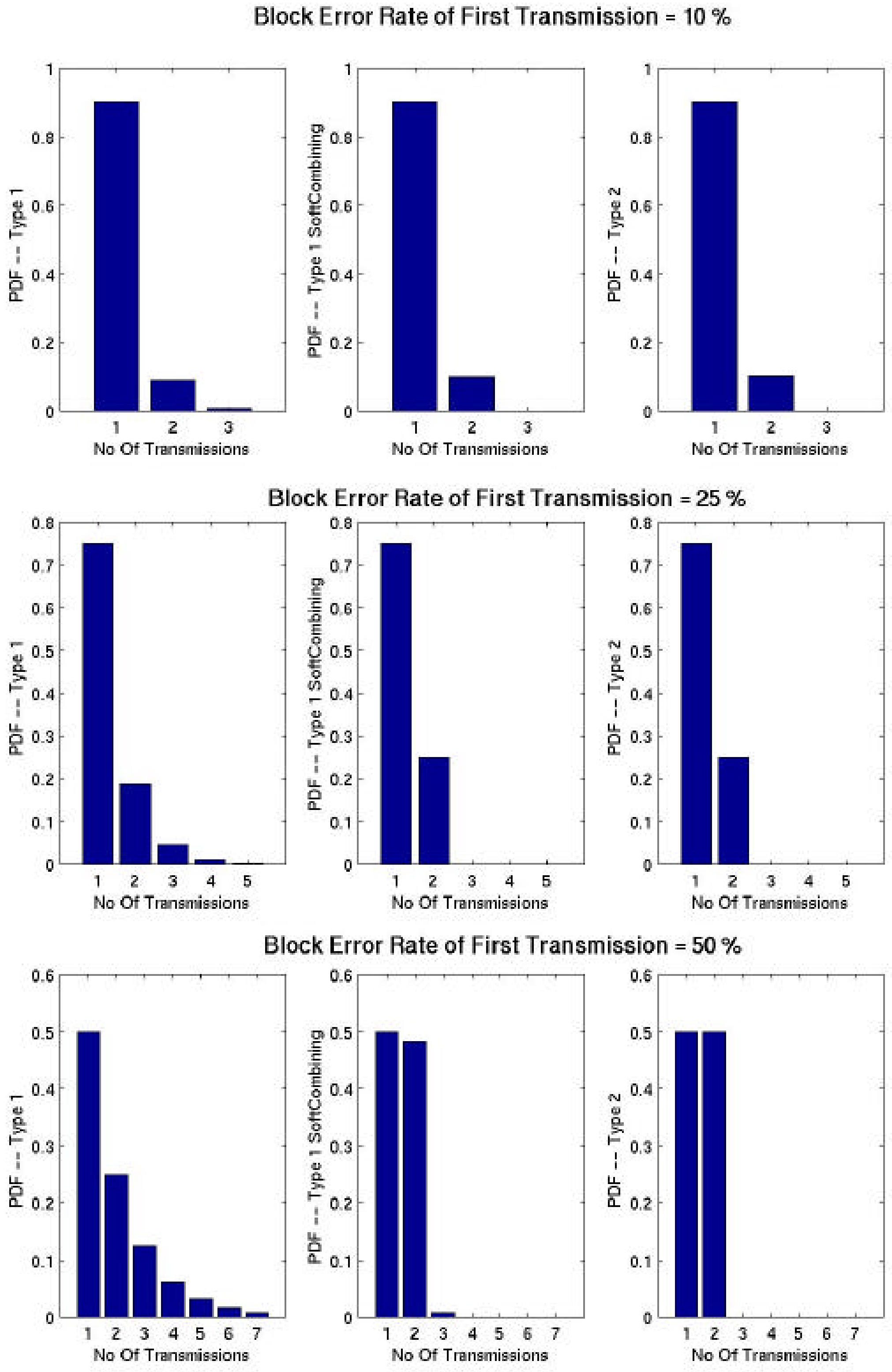


Figure 2.4.3.2-3 Cell Capacity



Block Error Rate of First Transmission = 10 %

Block Error Rate of First Transmission = 25 %

Block Error Rate of First Transmission = 50 %

Figure 2.4.3.2-4 PDF Vs Number Of Transmissions

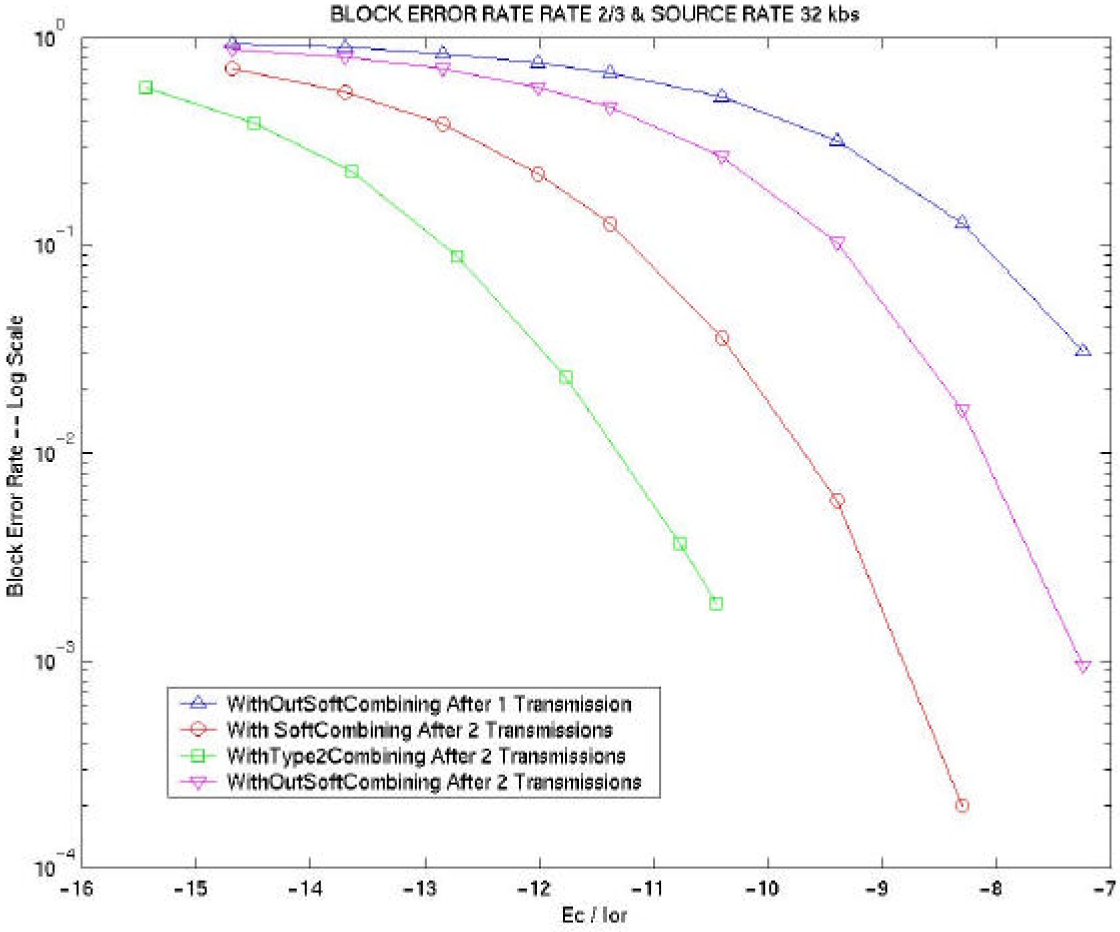


Figure 2.4.3.2-5 Block Error Rates

The simulation plots show that the transmission efficiency and the system capacity for Type II scheme is better than that of Type I scheme with soft combining. The maximum capacity of both Type I with Soft Combining as well as Type II schemes occurs when the block error rate is more than 50 %. The capacity of both Type I with Soft Combining and Type II schemes are almost the same when block error rate is less than 50 %. Fig 2.4.3.2-4 shows the delay distribution of the transmitted packets. When the Block Error Rate of the first transmission is high, the delay for Type I scheme with out Soft Combining can be very high, whereas for packet combining schemes the delay is considerably less. There is no significant difference in delay between Type I Hybrid ARQ with Soft Combining and Type II Hybrid ARQ when the BLER of first Transmission is less than 60%. This result indicates that packet combining schemes can be used for delay sensitive applications.

2.4.3.3 A Comparison of Type II Hybrid ARQ with Type I Hybrid ARQ With Soft Combining

The simulation results in this section shows the comparison between the Type I Hybrid ARQ with soft combining (Rate 1/3) and Type II Hybrid ARQ (Rate 2/3, 1/3). The simulations were done for an input data rate of 8 kbit/s. The simulation results were plotted for 5 different cases

1. WithOut SoftCombining (Rate 2/3)
2. With SoftCombining (Rate 2/3)
3. With Type II Combining (Rate 2/3).

4. WithOut SoftCombining (Rate 1/3)
5. With SoftCombining (Rate 1/3).

The rates indicated in the braces are for the first transmission. The retransmission also uses the same rate code. The packet length for the first transmission and the retransmission are same in all the cases. So for the cases 2 and 3 the code rate decreases to 1/3 after the first retransmission, whereas for the case 5 the code rate decreases to 1/6 after the first retransmission.

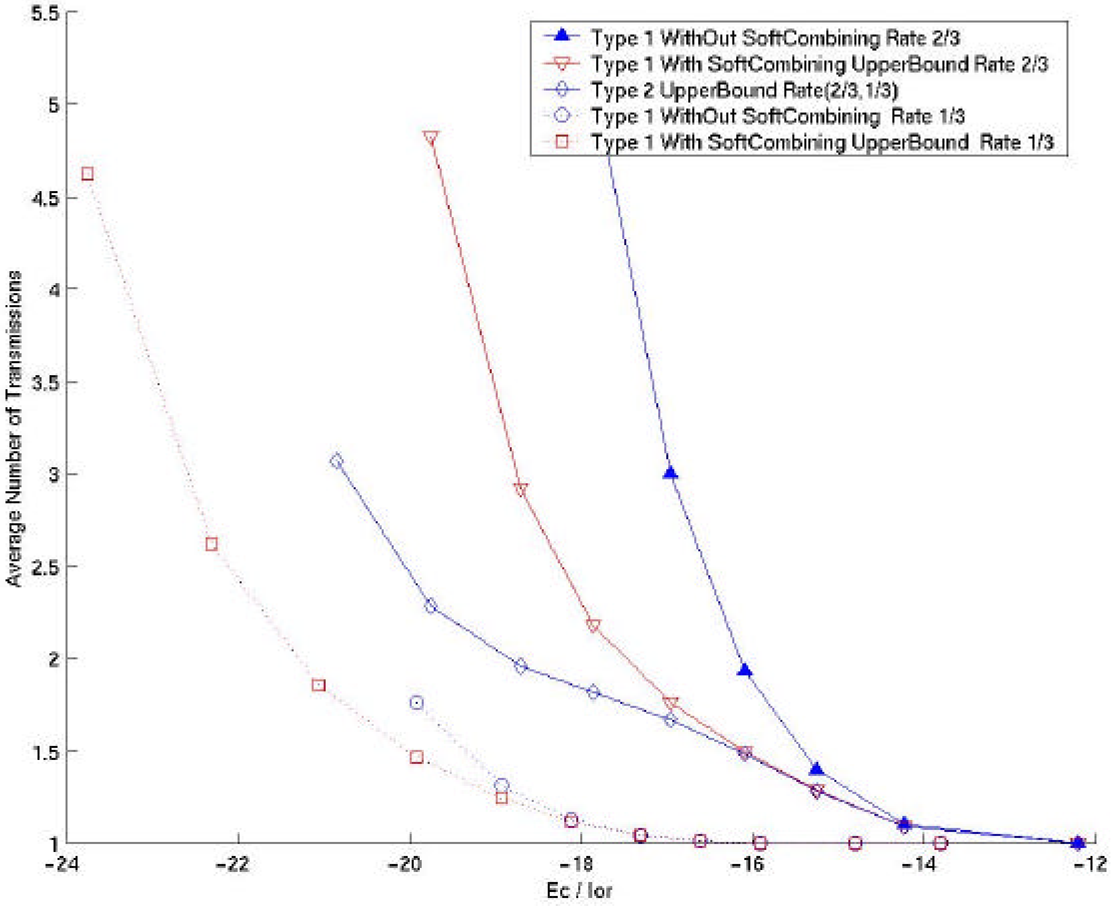


Figure 2.4.3.3-1 Average Number of Transmissions

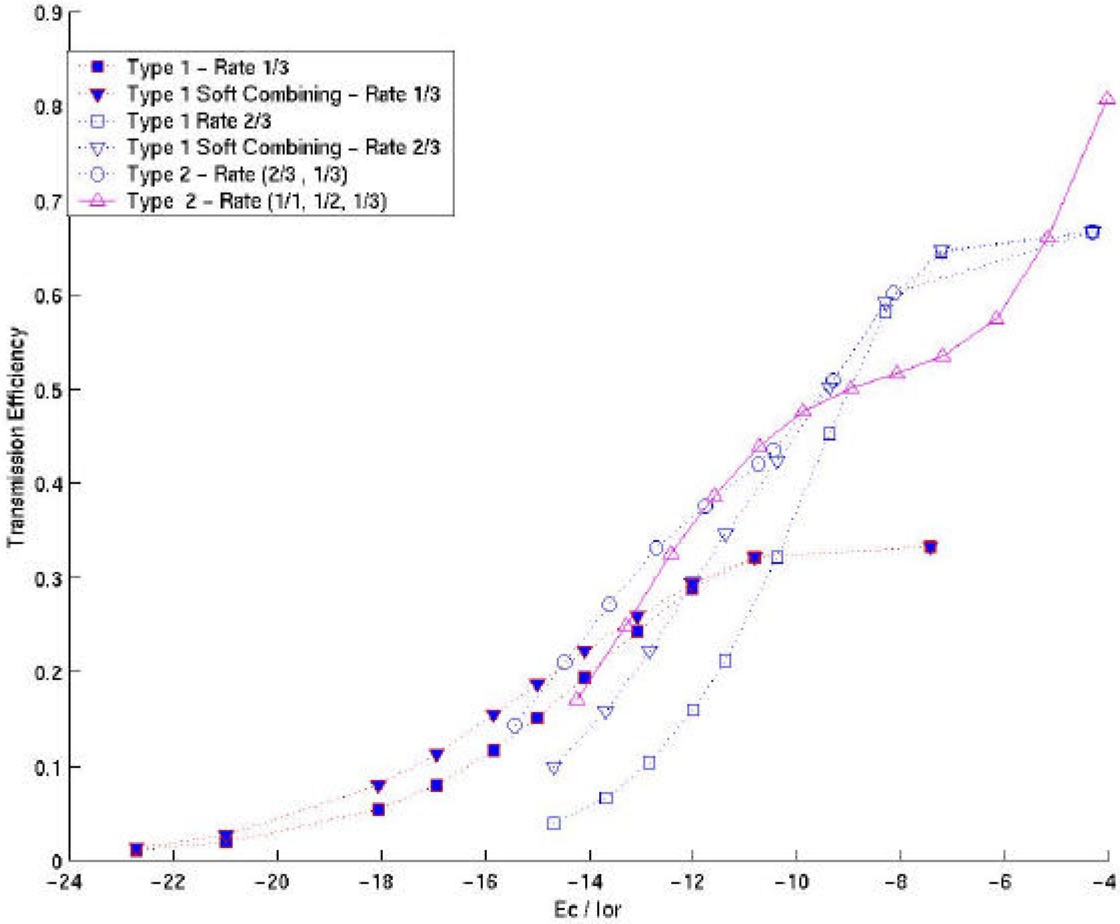


Figure 2.4.3.3-2Transmission Efficiency

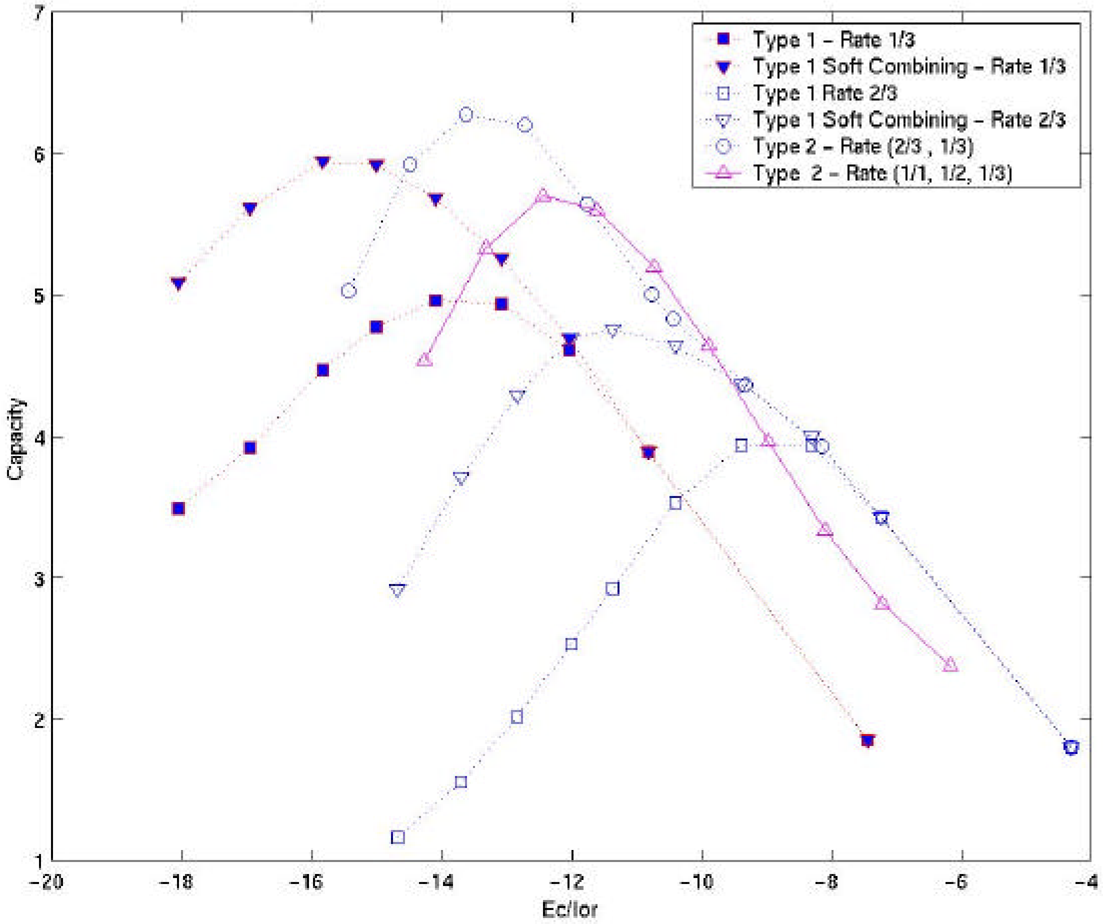


Figure 2.4.3.3-3 Cell Capacity

The simulation plots show that the cell capacity of Type II Scheme (Rate 2/3, 1/3) is comparable to Type I Scheme with soft combining (Rate 1/3).

2.4.3.4 A Comparison of System Capacity & Delay Vs Frame Error Rate

The simulation results in this section examines the relationship between cell capacity and the Block Error Rate (of first transmission) for different Hybrid ARQ Schemes The simulations were conducted for an input data rate of 8 kbits/s.

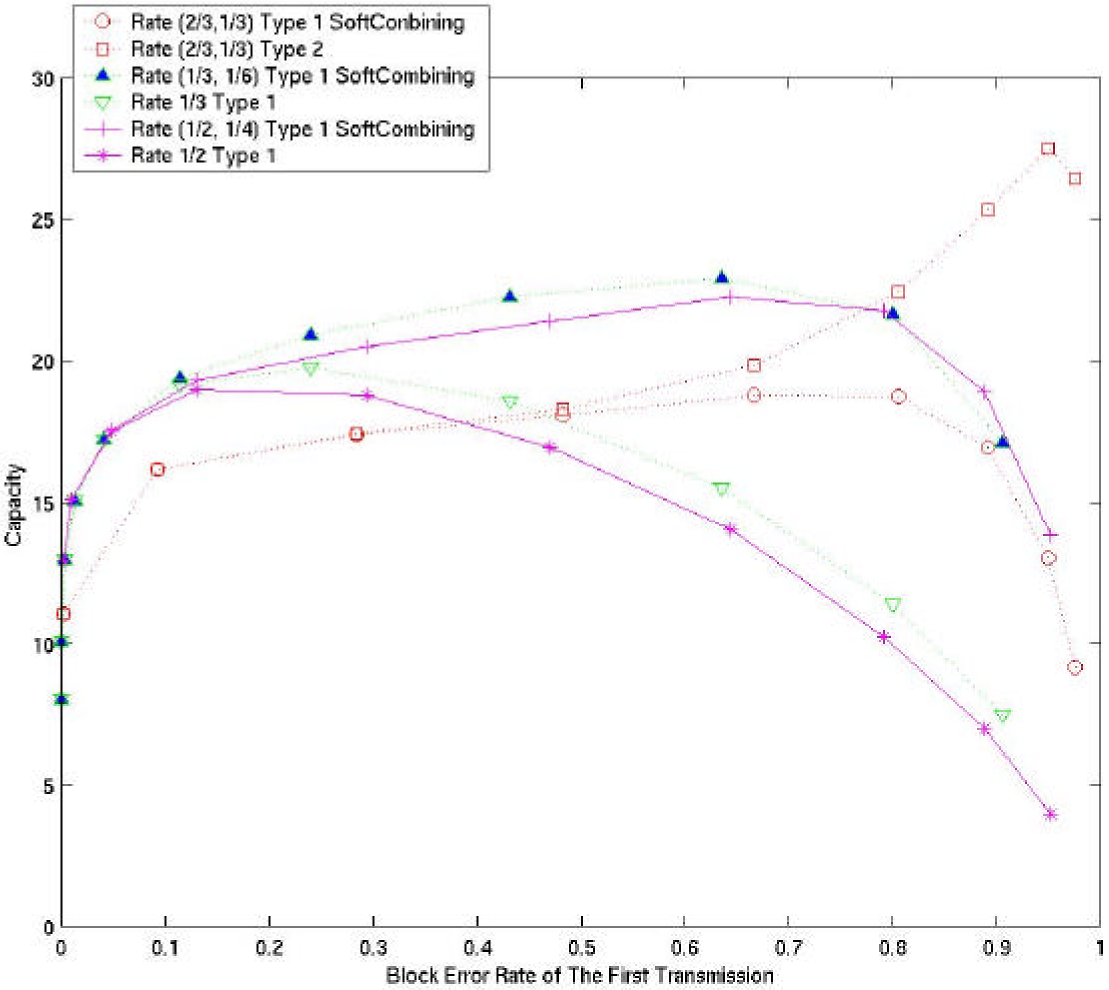


Figure 2.4.3.4-1 Block Error Rate of First Transmission Vs Cell Capacity

The cell capacity is maximized with soft combining type I hybrid ARQ schemes at BLER up to 80%, above that type II hybrid ARQ schemes maximize the capacity.

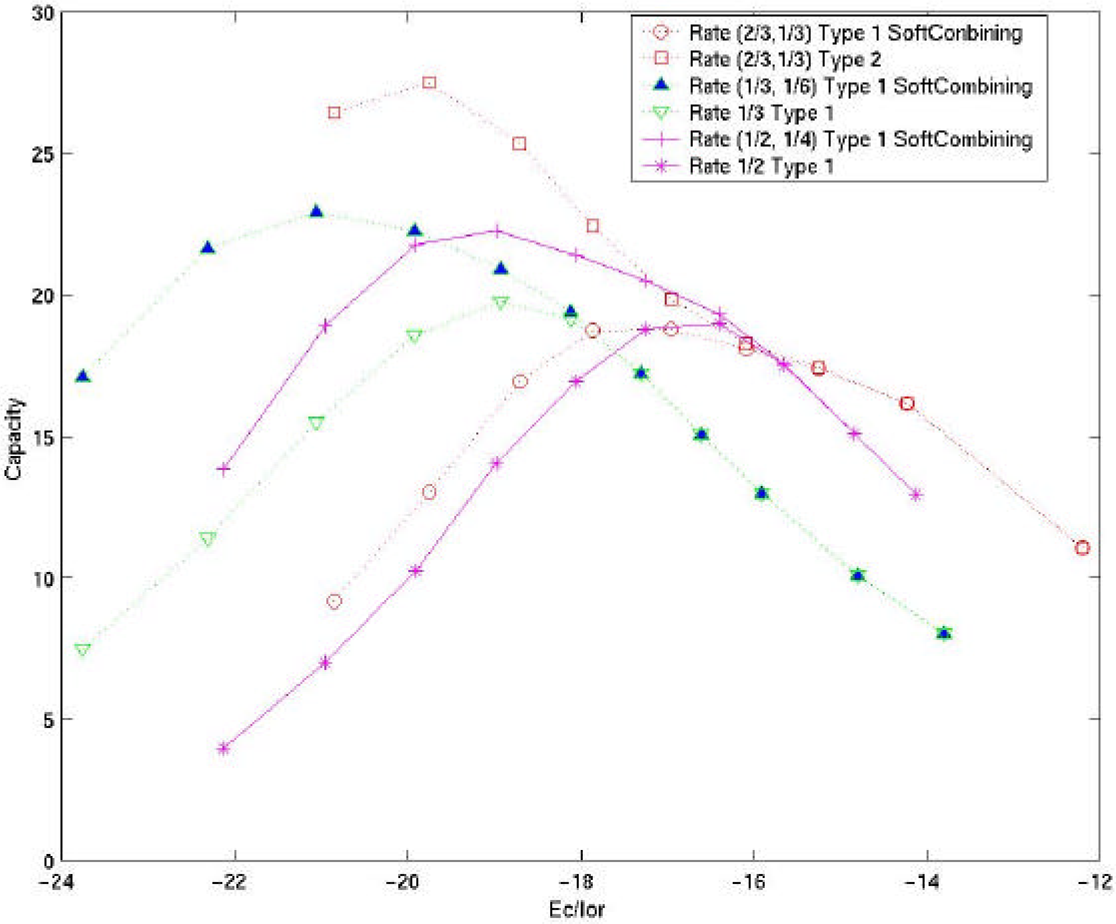


Figure 2.4.3.4-2 Cell Capacity Vs Ec/Ior

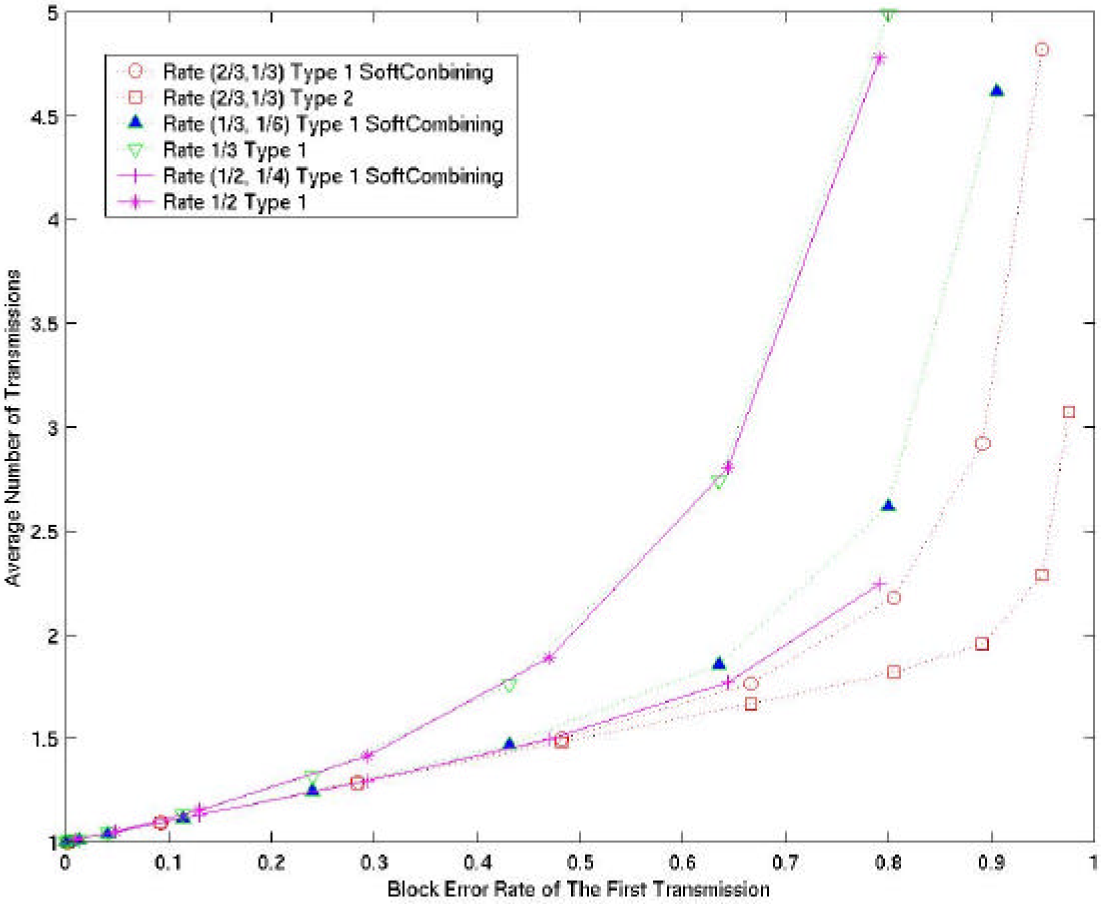


Figure 2.4.3.4-3 Block Error Rate of First Transmission Vs Average Number of Transmissions

The average number of transmission as a function of BLER of the first transmission is depicted above. This shows that type II hybrid ARQ is slightly better than type I hybrid ARQ with soft combining but only at high BLER.

3 Discussion

3.1 Performance

Hybrid ARQ does bring some capacity gain and it may be an attractive option in some cases. Soft combining makes the system capacity curve flatter which implies that the system can be operated over a larger range of FER. At higher BLERs the delay properties of ARQ transmission are also made more robust by HARQ.

In practical cases the air interface may have difficulty operating at very high block error rates due to L2/L3 considerations. ARQ without combining reaches highest capacity when BLER is 10%. When BLER of 50% is assumed, type I HARQ with soft combining gives about 10-15% capacity increase over the current scheme of no combining. Type II HARQ can achieve higher capacity gain (starting code rate R=2/3) but this would require that BLER during the first transmitted frame is very high (around 90%). This would not probably be acceptable to higher layers. The simulations presented in this document were made with floating point processing so no quantization inaccuracies were considered in the receiver. In practical cases we can expect the capacity gain to be somewhat smaller.

3.2 Complexity

3.2.1 UE complexity

Another important aspect to consider is the complexity of introducing HARQ into Release -00. When considering specification changes, the easy way to create HARQ functionality would be to add it on top of the existing RLC ARQ protocol. In this case ACKs are communicated between UE and RNC RLCs, and soft combining is done on L1. However, RLC level round trip delay (ca 120 ms) and polling period (ca 80 ms) for ACKs makes the buffer memory requirement in UE L1 considerable.

The number of symbols to be buffered in L1 receiver can be estimated roughly as follows:

$$buffer = \left(coded\ bits_{RCL\ PDU} \times failed\ PDUs\ in\ TTI \times (latency_{retransmit} + latency_{NACK}) \right)$$

where it is assumed for the sake of clarity that an integer number of RLC PDUs fit into one L1 TTI. The latencies are also considered as multiples of a TTI. For HARQ with soft combining all retransmissions are combined and stored in the same location as the first transmitted symbol, so the number of retransmissions does not directly reflect on the buffering need. Type II HARQ is sending smaller blocks than type I, but in practice one has to reserve room for a whole symbol in the receiver for assembling the incremental information; thus type I and type II buffering does not differ a lot if the lowest encoding rate is the same.

In practical cases, with a total latency around 200 ms, there is a need to buffer several tens of ksymbols of soft symbol decisions in the receiver. Depending on how many bits are used to represent a soft symbol in the decoding stage this memory requirement becomes a multiple of the soft symbol memory usage.

3.2.2 Other considerations

Even though it is not directly related to WG1 work one should also keep in mind what takes place in the network side with Hybrid ARQ. Assuming that the HARQ protocol runs at RLC level the retransmissions are transmitted over the Iub interface from RNC to Node B. With high block error rates needed for any marked capacity improvement from HARQ the traffic over Iub is also increasing considerably. With BLER of 50% the traffic over Iub also grows by 50% for the particular service. How this impacts other services using the Iub interface at the same time needs to be considered.

3.3 Conclusion

Means of decreasing UE buffer memory usage would be very desirable. RLC level HARQ implies currently such a big impact on memory use in the receiver that it is not an attractive choice for Release –00. HARQ protocol terminated in Node B as proposed in [1] would reduce memory requirements but is as such a very big change to Release –99 status. These two means of applying HARQ protocol should be considered together in order to generate a good solution.

Thus, as a conclusion:

1) Type I HARQ brings little capacity gain with soft combining: 10-15% at FER = 50%. Type II provides more capacity gain but the initial transmission frame should be at FER = 90%

2) Complexity problem must be solved before HARQ can be considered a feasible addition to Release 2000.

3) HARQ should be considered in relation to the improved downlink performance work such that a desirable overall solution is reached

4 References

[1] TSGR1#12(00) 0556, "Feasibility study of Advanced techniques for High Speed Downlink Packet Access", Motorola.