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Title: Comparison of Hybrid ARQ Types I and II-III for TDD

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A performance analysis of ARQ Types I and II-III for NRT services based on simulations is presented. In this paper, we emphasise differences between Types I and II and consider Types II and III as minor variants of the same scheme which we will call "Type II-III" for the purpose at hand. For this contribution, a subset of the Layer 2 protocol for UTRA TDD mode is simulated for a single cell. Both user traffic and signalling messages suffer from path-loss, fading, and interference in the model. Interference due to traffic in neighbouring cells is also taken into account through the "actual value interface". Results are presented for downlink traffic in Micro and Pico environments for various code-rates and interleaving schemes. It is concluded that the Hybrid ARQ Type II greatly outperforms Type I for "UDD 2048 Pico" and "UDD 384 Micro".

1. Introduction

Various Hybrid ARQ types are described in [1]. At present, it is difficult to assess the relative merits of adopting either Type I, II, or III for UTRA in TDD mode. The inter-action of time-varying carrier-to-interference ratio (CIR), power control algorithms, and resource allocation methods on various ARQ schemes is not yet well understood. Performance critically depends on selected PDU sizes, coding rates, and interleaving among other system parameters.

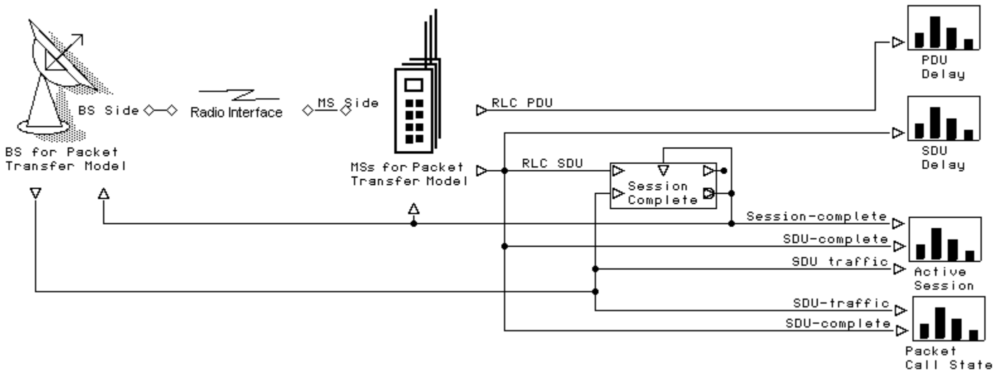
If there are significant areas in a cell with high CIR and if there is sufficient interleaving for low FEC overhead then Type I is capable of high throughput. However, when few islands of high CIR exist then Type II-III might offer major improvements relative to Type I. Whilst Type II-III may offer a throughput that is not dissimilar to Type I, it may offer some advantage on cell borders, where CIR may be poor, because of the ability to combine copies of a PDU rather than decode each copy independently.

Performance comparisons for various schemes can be found in the literature. Analytical results for Type II on Gaussian and Rayleigh channels are found e.g. in [9]. In Ref. [10], the throughput of Type III is analytically calculated. Results for different types of adaptive coding rate (ACR) and adaptive incremental redundancy (AIR) ARQ schemes are given in [8]. Simulations dealing with Hybrid ARQ can be found in [12]. Analytical expressions and simulation results for the performance of a set of Type II methods in Rayleigh fading channels can be found in [2]. In Ref. [11], Hybrid Types II and III are compared against ARQ *without* FEC through simulations for Rayleigh fading environments. The last paper shows that there is no substantial difference in performance for Types II and III.

2. Simulator Architecture and Working Assumptions

The simulator is implemented using an event-driven data transfer paradigm. The behaviour of the first two layers of the OSI protocol stack is modelled using messages that are exchanged between building blocks. All traffic (user data and signalling) over the radio interface is corrupted by random errors.
Random errors cause *Block Erasure Rates (BLER)* for user data and *signalling message erasures* on the radio interface. As a general guideline, the "UMTS 30.03 Document" [5] was adopted and implemented as closely as possible whenever appropriate. User entities in the simulated cell are created according to the traffic model described in [5]. Handover issues are neglected because layer 3 is not part of the model.

The top-level system model is implemented with BONeS Designer (see Error! Unknown switch argument.**).** The base-station (BS) is shown on the left. It communicates with an ensemble of mobile stations (MS) exclusively through the radio interface. The building blocks to the right of the MSs are used to analyse the performance and create output plots.



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In the following, the protocol simulation assumptions are described in detail. A single BS and several mobile stations are modelled operating in UTRA TDD mode with a single switching point between up- and downlink. This working assumption was adopted for the simulations presented here. UDD traffic is implemented in downlink direction according to the requirements in [5]. The associated signalling messages on the FACH in the downlink (resource allocation messages from the BS to the MS) and Signalling DCH in the uplink (ACK and NACK messages from the MS to the BS) are secured by FEC and interleaving. They are transmitted through the radio interface along with channel-coded user data on the DCH. Transmission errors on the radio interface are modelled using the actual value interface with maximum-ratio combining according to [7] which was first presented in [4]. The effect of FEC is incorporated through an interface to link-level simulations. The Signalling DCH always uses interleaving 1 whereas the FACH is implemented with interleaving 2. The DCH is implemented with interleaving factors 1 or 2 depending on parameter settings. Working assumptions about message formats on the FACH and Signalling DCH are explained in Section 5.2. Inter-cell interference is incorporated through an interface to system-level simulations [7]. Finally, a simple scheduler in the BS was implemented which does not optimise cell capacity.

3. Simulated Retransmission Schemes

Type I and II-III simulations were carried out with varying parameter settings. This section summarises selected parameter combinations for which results are shown in the following sections. The following table displays parameter combinations chosen for Type I simulations presented here.

Code-Rate R	Interleaving factor I	Naming convention in plots
1/1	1	ARQ **I** (R, I = 1)
2/3	1	ARQ **I** (R = $^2/_3$, I = 1)
1/2	2	ARQ **I** (R = ½, I = 2)

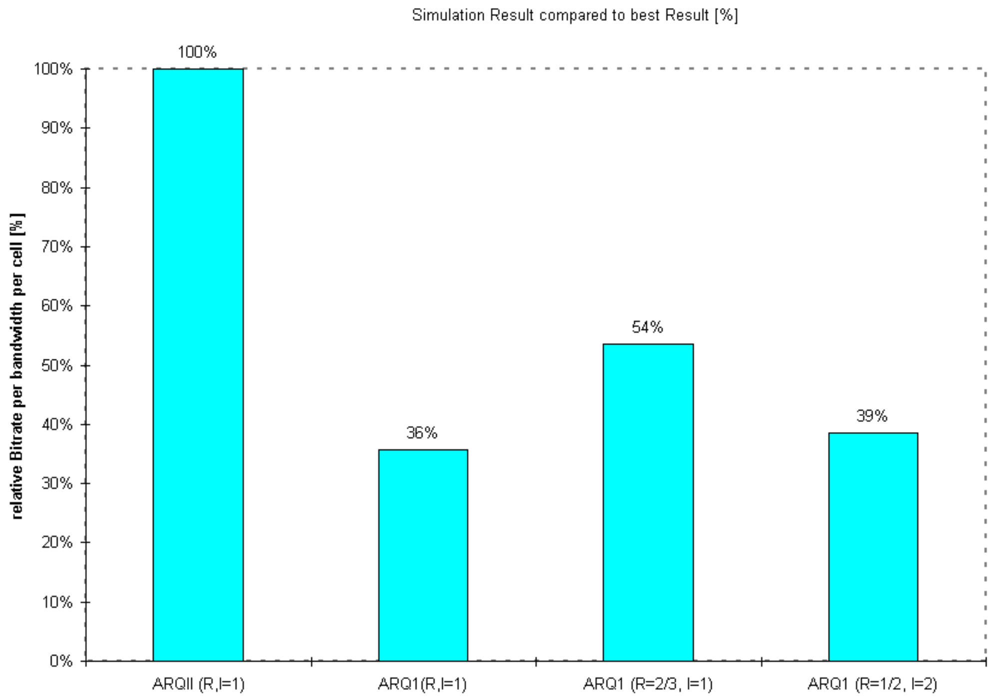
Interleaving factor 3 was also examined for Type I, but did not yield significant performance.

For Type II-III, the interleaving factor I = 1 was chosen to be constant and the joint code-rate changes for the retransmissions. Here, a scheme was chosen where the initial transmission is almost uncoded ($R_1 \approx 1$) and all subsequent retransmission have the smaller joint code-rate R_2 = ½. Beginning with the 3rd transmission (i.e. the 2nd retransmission), the burst with weakest CIR is repeated and maximum-ratio combined with the previously received corrupted copy.

Code-Rates R_1,R_2	Interleaving factor I	Naming convention in plots
1/1, 1/2	1	ARQ II (R, I = 1)

4. Relative Capacity Results

The following bar graph in Error! Unknown switch argument. compares capacities (bitrates per bandwidth per cell) relative to the maximum obtained capacity for various ARQ schemes implementing the UDD 2048 service in the Pico environment. The bars give percentages of capacity. This approach was adopted for avoiding confusion with results presented in [7] which are not easily comparable. We have optimised over code-rate/interleaving parameters for Hybrid ARQ Type II-III and show the best obtained result in the left bar of Error! Unknown switch argument.**.** The three other bars show highest capacity results for Hybrid ARQ Type I with various combinations of code rate *R* and interleaving factor *I.* We have not found any parameter combination for Type I that can seriously compete with Type II-III: Type II outperforms Type I by a bold factor of 2.



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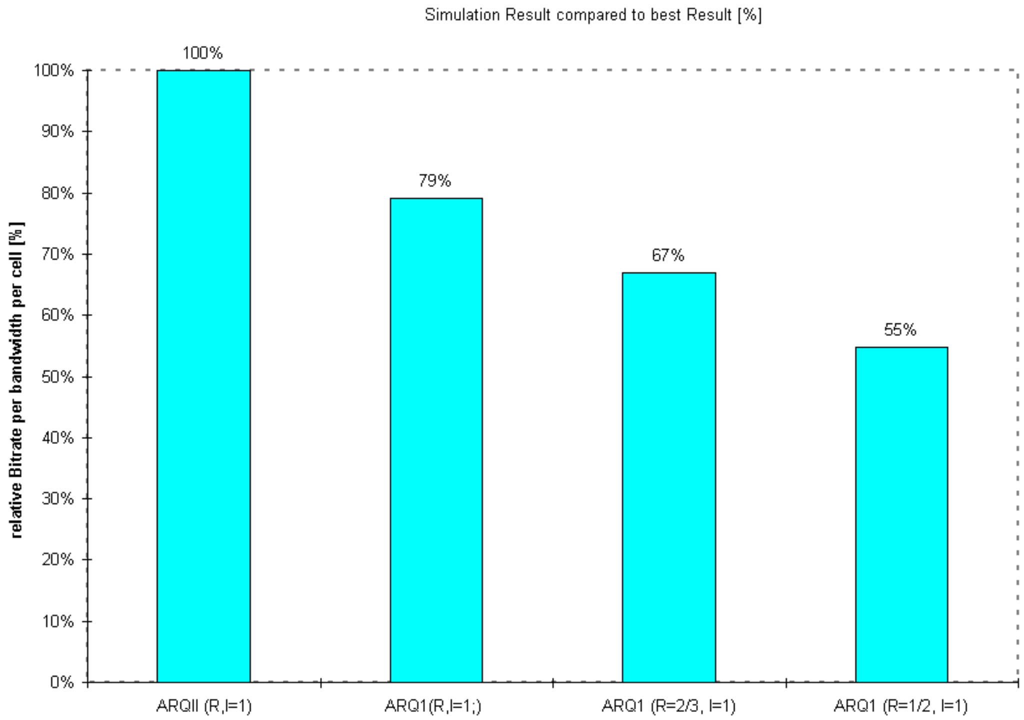
Similarly, Error! Unknown switch argument. compares capacities for various ARQ schemes implementing the UDD 384 service in the Micro environment. We have optimised over parameters for Hybrid ARQ Type II-III (see left bar). The three other bars show capacity results for Hybrid ARQ Type I for various combinations of code rate *R* and interleaving factor *I.* It is noted that the Type I scheme performs quite well for the parameter setting *R,I*=1 at the expense of a large number of retransmissions (cf. Error! Unknown switch argument. and the discussion in Section **Error! Unknown switch argument.**). We have not found any parameter combination for Type I that can compete with Type II-III.



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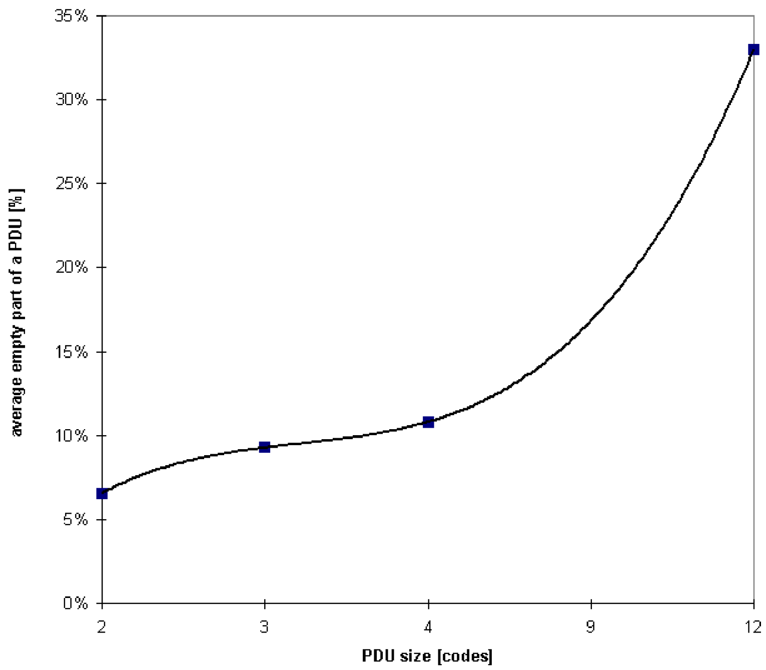
It is observed that the improvement in capacity from using Type II-III (instead of Type I) for "UDD 384 Micro" is not as high as for "UDD 2048 Pico" although the improvement is still significant.

5. Overhead

Transmission overhead is due to four factors: signalling information, coding, allocation granularity, and retransmission of corrupted data/signalling packets. Also, since signalling information on the radio interface suffers from noise and fading too, corrupted signalling messages must be repeated. This gives rise to additional overhead.

Error! Unknown switch argument. shows overhead due to allocation granularity. The PDU size (measured in the number of codes per time-slot that is allocated per request) is shown on the horizontal axis. The plot shows the mean percentage of the PDU that is unused as a function of PDU size. This result is based on the downlink burst with short midamble carrying 268 channel bits [7]. The mean empty percentage stays around 10% for granularities up to 4 codes and starts rising drastically for higher PDU sizes.



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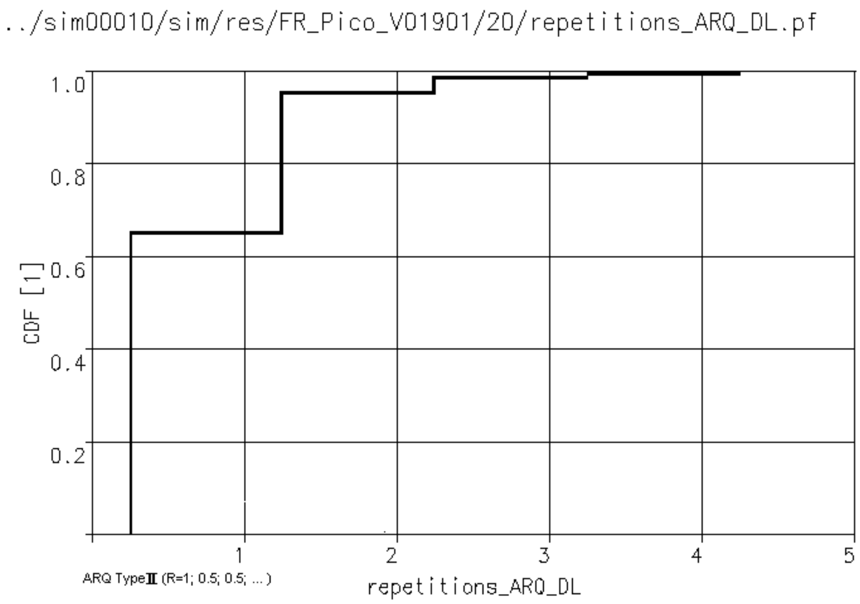
5.1 Number of Retransmissions

The **Error! Unknown switch argument.** and Error! Unknown switch argument. depict exemplary cumulative distribution functions (CDF) of transmission numbers for UDD 2048 Pico. The result for Type II-III for an initial code rate 1 and subsequent code rates ½ is shown in Error! Unknown switch argument.. The rate of success at initial transmission is relatively low (slightly above 60%). However, the gain from the switch in code-rate at the second transmission is very high. As can be seen from the figure, only around 4% of the PDUs need more than two transmissions. At the third transmission, the weakest burst is repeated and maximum-ratio combined with the previous copy resulting in yet another boost in gain. The cumulative distribution shows a steep rise and the resulting number of average retransmissions is very low showing little standard deviation.



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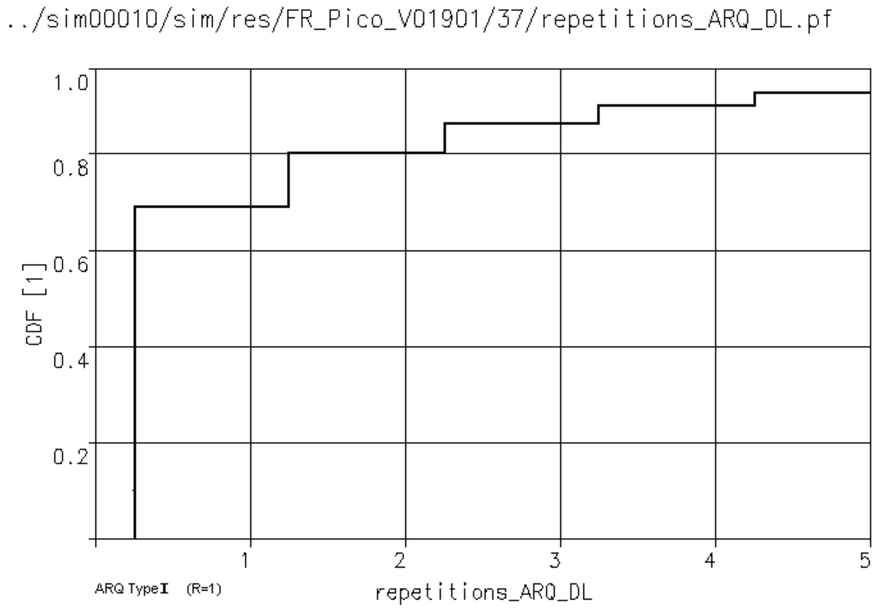
Error! Unknown switch argument. shows the Type I result with code-rate 1. The initial success-rate is comparable to the one in the previous case (but slightly higher due to a difference in system-load as compared to Error! Unknown switch argument.). The rise of the cumulative distribution is ***significantly flatter*** than in the previous figure. The gain from retransmissions is clearly much lower here. More than two transmissions are required for 20% of the PDUs. This leads to a heavy-tailed distribution of retransmission count and significantly higher delays.



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This is interpreted as follows: Type I suffers from correlation in fading statistics and interference levels due to low mobility between subsequent (re-)transmissions of a PDU. Thus, if a PDU is not successfully transmitted at the first try, there is a high failure probability in the following transmissions also. On the other hand, maximum-ratio combining in Type II schemes *increases* the effective joint CIR from try to try.

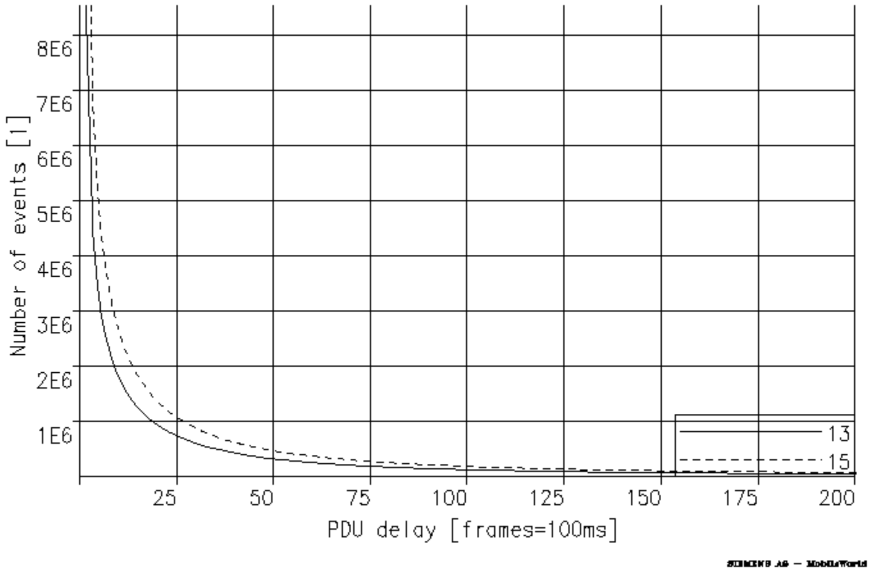
5.2 Amount in Signalling

The Type II-III resource allocation message on the FACH needs more bits than the corresponding message for Type I because it needs to specify the PDU number. Thus the amount of signalling messages for both types of ARQ must be weighted by a factor α to achieve a fair comparison (if *n* bits are needed for a Type I message then αn bits are required for the corresponding Type II-III message). Some signalling schemes have been investigated resulting in $1 \leq \alpha \leq 2$. The following table gives the signalling overhead per PDU, i.e. the *average amount* of resource allocation messages on the FACH per successfully transmitted PDU.

UDD Service [kb/s]	Environment	ARQ Type	α=1	α=1.5	α=2
2048	Pico	**I**	2.0	2.0	2.0
2048	Pico	**II-III**	1.4	2.1	2.8

6. PDU Delay

The essence of ARQ schemes are repetitions which combat random errors through diversity at the expense of some delay. The following histogram plot in Error! Unknown switch argument. shows a comparison of PDU delay histograms for Types I and II-III, for the case "UDD 384 Micro". The upper curve (dashed line) shows the behaviour of Type I, whereas the lower curve (full line) describes Type II-III. The curves do not intersect anywhere. At low delays the Type II-III curve shows a very steep decay visualising the benefit from maximum-ratio combining in contrast to the Type I scheme. Finally, observe that the delay distribution for Type I is heavy-tailed, increasing both the mean delay and its variance.



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7 Conclusions

Protocol simulations have been presented for downlink packet transfer focusing on various ARQ schemes. It is shown that Hybrid ARQ **Type II-III greatly outperforms Type I** for the cases "UDD 2048 Pico" and "UDD 384 Micro" in terms of capacity and PDU delay. However, the performance merits of both types at lower bit-rates need to be clarified being now under study.

Further simulations will be performed with other bearer types and cell environments to better estimate the respective advantages of both ARQ types.

The TDD Layer 2 signalling protocol has to be developed for supporting both Hybrid ARQ Type **I** and Type **II-III** protocols.

8 References

This document was submitted to SMG2 UMTS-L23 before as Tdoc 298y486.

[1] ARQ error control techniques, Tdoc SMG2 UMTS-L23 307/98 (s298y307.doc).

[2] S. Falahati and A. Svenson: *Hybrid type-II ARQ schemes for Rayleigh fading channels*; to be published in ICT'98.

[3] TDD System Description v 0.2.1, SMG2 UMTS L1, 274/98.

[4] Seppo Hämäläinen, Peter Slanina, Magnus Hartman, Antti Lappeteläinen, Harri Holma, Oscar Salonaho, *A Novel Interface Between Link and System Level Simulations,* Acts Mobile Communications Summit '97, pp. 599-604, Aalborg/Denmark, Oct 7-10, 1997.

[5] ETSI TR 101 112, *Selection procedures for the choice of radio transmission technologies of the Universal Mobile Telecommunications System UMTS* (UMTS 30.03), version 3.2.0, April 1998.

[6] Tdoc SMG2 165/98, Object: *Hybrid ARQ*, Source: Nortel, Helsinki, Sep 1-4, 1998.

[7] Tdoc SMG2 306/98*, UTRA TDD Link Level and System Level Simulation Results for ITU Submission*, Source: Siemens, Helsinki, Sep 8-11, 1998.

[8] S. Kallel and Samir: *Efficient hybrid ARQ protocols with adaptive forward error correction*, IEEE Trans. Comm., vol. 42, No. 2/3/4, pp. 281-289, Feb/Mar/Apr 1994.

[9] Joachim Hagenauer: *Rate-compatible punctured convolutional codes (RCPC Codes) and their applications*, IEEE Trans. Comm., vol. 38, pp. 389-400, Nov 1988.

[10] S. Kallel: *Complementary punctured convolutional (CPC) codes and their applications*, IEEE Trans. Comm., vol. 43, No. 6, pp. 2005-2009, Jun 1995.

[11] H. Lou and A.S. Cheung: *Performance of punctured channel codes with ARQ for multimedia transmission in Rayleigh fading channels*, 46^{th} IEEE Vehicle Technology Conf., 1996.

[12] H. Liu and M. El Zarki: *Performance of H.263 video transmission over wireless channels using hybrid ARQ,* IEEE J. Sel. Ar. Comm., vol. 15, pp. 1775-1786, Dec 1997.