TYPE-II HYBRID ARQ SCHEME IN A DS-CDMA PACKET TRANSMISSION NETWORK

Jordi Pérez, Ramón Agustí, Oriol Sallent
Dept. Signal Theory and Communications.Polytechnic University of Catalonia (UPC)
C/ Jordi Girona, 1-3, Campus Nord - Edifici D4 08034 Barcelona-Spain
e-mail: [jorperez,oriol,ramon]@tsc.upc.es

Abstract **-** In this study a type-II hybrid ARQ strategy is analyzed in a DS-CDMA packet transmission network. A comparison is performed with other strategies such as simple ARQ and type-I hybrid ARQ, resulting in a better performance for ARQ-II in terms of capacity, although the delay becomes worse compared to ARQ-I. The main advantage of ARQ-II over ARQ-I is that it deals with channel errors by sending the required redundancy only when it is strictly necessary and as a result it can send information bits in those bits where ARQ-I working with the same packet length sends redundancy bits. Only when channel errors become present redundancy is sent, thus reducing the useful information rate but maintaining the channel bit rate. This idea suggests that ARQ-II can be regarded as a strategy that performs an information rate adaptation at the DLC (Data Link Control) layer, and consequently it can be compared with other multi-rate strategies that perform this adaptation at the MAC (Medium Access Control) level by varying the channel bit rate.

I. INTRODUCTION. ARQ STRATEGIES.

Next generation mobile communications systems will be mainly focused in the provision of different kinds of integrated multimedia services. In such a scenario, packet switching becomes an interesting alternative for those services not requiring the transmission of a continuous information flow, as it would be the case of bursty data transmission or high speed Internet access. Furthermore, for its inherent flexibility and ability to integrate different kinds of traffic sources, DS-CDMA (Direct Sequence – Code Division Multiple Access) is emerging as the predominant multiple access scheme to be used in third generation mobile communications systems, particularly in proposals such as UTRA (UMTS Terrestrial Radio Access) [1] or cdma2000 [2]. Then, assuming DS-CDMA as the radio access scheme, transmission reliability needs to be guaranteed at the DLC (Data Link Control) sub-layer, which constitutes the main task of ARQ (Automatic Repeat reQuest) strategies that are the subject of the present study.

Hybrid ARQ strategies are a set of techniques whose main objective is to enhance the performance of transmission so that information at the link level is delivered without errors. They are located in an intermediate position between ARQ (packets are retransmitted in case of error) and FEC (no retransmissions are carried out and the added redundancy should correct errors at the receiver side) schemes and they try to combine the best of these two techniques. Basically there are two hybrid ARQ strategies: type-I hybrid ARQ (from now on referred as ARQ-I), which makes use of channel coding to protect the information (as the FEC strategy) but which also makes use of retransmissions whenever the code is not able to correct all the errors in the received packet, and type-II hybrid ARQ (from now on referred as ARQ-II) where an information packet with only error detecting capability is firstly sent and, whenever a retransmission is required, redundancy is transmitted instead of repeating the same packet. As a result, the receiver will make use of this redundancy together with the previous data packet to perform error correction [3,4,5].

With respect to ARQ-II strategy, some special kinds of channel codes are required: in general, they are half rate invertible block codes in order that whenever the redundancy is received error free, information can be decoded without making use of the first packet. Such a kind of codes can be obtained from cyclic codes C(n,k) with n-$k \leq k$ just by removing the last ($2k$-n) bits and obtaining a ($2(n$-$k)$,n-k) code with the same minimum distance and therefore the same correcting capability as the original one [3,4].

Not much effort has been devoted so far in the open literature to assess the hybrid ARQ strategies when combined with the multiple access scheme DS-CDMA. In [7] ARQ-I is considered in a slotted DS-CDMA network in the presence of jamming, while in [8,9] a comprehensive analytical model is introduced to evaluate the packet transmission performance in the framework of the combined DS-CDMA-ARQ-II technique. However, this model is too cumbersome and unable to cope with the presence of even moderate buffer sizes, which are required in the transmitter site. In [6] a simpler Markov model is presented. Additionally, this model considers a more realistic message-based instead of a packet-based analysis. In this context, a message is considered to be composed by a variable number of fixed length packets. Based on this framework, this paper is organized as follows: in section

This research was supported by CICYT project TIC 98-684.

2, description of ARQ-II scheme in a slotted DS-CDMA packet transmission network is presented on a message basis, while in section 3 a comparison is carried out between ARQ-I and ARQ-II Finally, and considering that sending redundancy can be seen as a kind of adaptation in the useful information rate with respect to the case where no redundancy is required, in the last section ARQ-II is presented as an alternative to those techniques that perform adaptive changes in the bit transmission rate of a DS-CDMA environment [10].

II. ARQ-II IN A DS-CDMA NETWORK

In order to study the performance of ARQ-II in a slotted DS-CDMA packet transmission environment, a number of users U that transmit L-bit packets in the different time slots in the uplink is considered. They make use of a previously assigned spreading code, and the number of spreading codes is assumed to be, at least, equal to the number of admitted users in the system. Then, a perfect power control is assumed to counteract the channel fading. Under these circumstances, we can make use of the gaussian approach to model interference [11] and thus obtain the expression for the bit error probability given by

$$p_e = Q\left(\sqrt{\frac{3S_f}{n_a - 1}}\right) \tag{1}$$

S_f being the spreading factor and n_a the number of users that simultaneously transmit a packet in a given slot. The effects of thermal noise are neglected and the system is considered to be interference limited.

Data traffic is modelled according to a Poisson statistic where each user generates messages with arrival rate λ messages/slot. Their length is exponentially distributed with a mean ($1/\mu$) bits. These messages are divided into K-bit packets which are stored in a buffer. An error detecting code $C_o(L,K)$ is applied to each packet thus obtaining L-bit packets that will be transmitted. A half rate invertible code $C_1(2L,L)$ with error correcting capability t is also applied to each packet and, as a result, an L-bit packet redundancy is obtained. Whenever the feedback information in the downlink indicates that the first L bits contain errors, the second L bits are transmitted in the next slot and then the receiver can make use of these two packets to decode the information based on C_1. In the case when there are more than t errors within these two packets, a retransmission of the first L bits is required, and then correction is performed again based on the last received set of $2L$ bits. If it is still necessary, the redundancy will be sent again and alternatively original L-bit packet and redundancy will be retransmitted until the information can be decoded successfully. When it is not possible to correct the packet even with the redundancy, retransmissions will be made with probability p_b in the successive slots, which allows to reduce the number of simultaneous users in the system and thus the interference level. Finally, after the packet has been correctly received, normal transmission continues with the rest of packets in the buffer. Figure 1 summarises the process explained above.

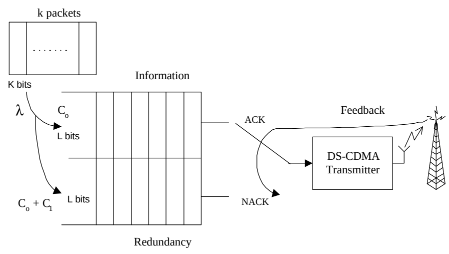

Figure 1 Type-II hybrid ARQ DS-CDMA system model

Stop & Wait technique is considered, and it is assumed the ideal situation where the feedback information in the downlink is received error free and instantaneously, so each user will know exactly whether a new packet or a redundancy must be transmitted in the next slot.

III. COMPARISON BETWEEN ARQ, ARQ-I AND ARQ-II STRATEGIES.

ARQ-II strategy described before has been compared with ARQ-I and simple ARQ both employing the same bandwidth in a DS-CDMA environment. The same conditions regarding on message arrivals and multiple access protocol have been considered, and hence the difference relays only on how packets are coded and transmitted. Then, simple ARQ just consists on sending L-bit packets without error correcting capability and whenever errors are detected retransmissions are performed with probability p_b. If we consider simple ARQ with the same S_f as the described ARQ-II, both strategies will employ the same bandwidth because in both cases packets of the same length are sent. On the other hand, ARQ-I consists on sending $2L$-bit packets corresponding to L data bits and L redundancy bits according to code $C_1(2L,L)$ with the same error correcting capability t as ARQ-II. Whenever the received packet contains more errors than the maximum number that can be corrected, retransmissions are performed with probability p_b. As this strategy sends $2L$ bits/slot, it works with twice the bit rate of ARQ-II; consequently, in order to occupy the same bandwidth it is necessary to work with half the spreading factor, $S_f/2$, and as a result the robustness to multiuser interference is poorer.

First of all, a comparison between strategies has been performed by considering a fixed arrival rate per user λ and by making variable the total number of users U. System parameters that have been assumed are: packet length L=500 bits, code C_1 (1000,500) achieved by shortening the BCH code (1023,523) with correcting capability t=54 errors, S_f=63, p_b=0.1, λ=1/150 messages/slot and *$(1/\mu)$*=4000 bits. Buffer length is assumed to be long enough to avoid message losses.

Results regarding message delay are depicted in figure 2. It can be observed that, as expected, both strategies ARQ-I and ARQ-II perform better than simple ARQ thanks to their correcting capability: since the ARQ system is not able to correct any error, as soon as interference is such that almost all the received packets contain errors, the delay increases indefinitely. On the other hand, when comparing ARQ-II against ARQ-I, three regions can be distinguished: first of all, when the number of users is low, which means that a low interference level is generated and hence received packets contain very few errors, both ARQ-II and ARQ-I have the same performance, which is also the same as for simple ARQ. Moreover, when increasing the number of users up to a level where almost all the transmitted packets contain some errors, the receiver working with ARQ-I can make use of the correcting capability to decode each packet in a single slot. On the opposite, when working with ARQ-II the receiver must wait for an additional slot to get the redundancy and decode the packet; and hence two slots are required to complete the transmission of each packet. Therefore, the delay for ARQ-II becomes approximately twice the delay for ARQ-I. Finally, when the number of users is high and interference grows, retransmissions are required for the ARQ-I system and as a result the message delay increases. When such a situation arises, the ARQ-II scheme is still able to recover packets by making use of the redundancy thanks to the higher protection against interference provided by the higher spreading factor. Consequently, in this situation, a system working with ARQ-II allows a higher number of users than a system working with the ARQ-I strategy.

For both ARQ-I and ARQ-II, the total delay of a given message is mainly the sum of two factors: firstly, the number of packets of the message times the transmission time of a single packet and, secondly, the queueing waiting time, which is the number of existing packets in the buffer when the message arrives times the transmission time of a single packet. Previous results have been obtained with a high mean time between arrivals $(1/\lambda)$=150 slots, and therefore message arrivals mainly found empty buffers, so the main contribution to the delay was the first factor. However, for a complete comparison it is necessary to take λ (or in general the offered load per user) into account.

As a matter of fact, when reducing the interarrival time, the second factor in the total message delay must be considered. In this case, it must be noted that its effect over ARQ-I and over ARQ-II is slightly different: this is due to the fact that, when the required packet transmission time for ARQ-II is two slots while packets in ARQ-I are transmitted in a single slot, there will be more packets in the ARQ-II buffer than in the ARQ-I one and therefore the message delay will be higher than in the previous comparison (the ratio ΔD shown in figure 2 will be higher than 2). Consequently the individual offered load plays an important role when comparing ARQ-II against ARQ-I: depending on the specific value for this load, the poorer behavior of ARQ-II in terms of delay can become more significant and thus the advantage of using ARQ-II in terms of capacity can be less important.

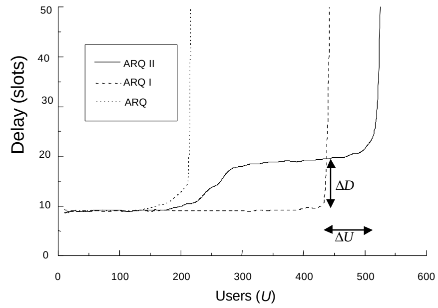

Figure 2 Message delay as a function of the number of users.

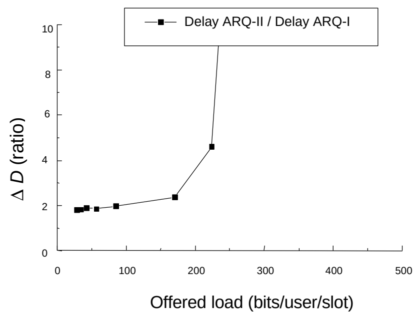

Figure 3 Relationship between the delay of ARQ-II and ARQ-I at the point where ARQ-I reaches the maximum throughput

This result is better explained in figure 3 where the relationship between the delay of ARQ-II and the delay of ARQ-I at the point where the last reaches the maximum throughput (the ratio ΔD in figure 2) is shown as a function of the offered load per user. Moreover, in figure 4 the increment in maximum number of allowed users (the ratio ΔU in figure 2) for the two strategies is presented. As it can be observed, for low offered loads, ARQ-II allows almost 20% more users in the system with a delay that is approximately twice the delay of ARQ-I, which corresponds to the result obtained in figure 2. Nonetheless, when the offered load increases, not only the delay of ARQ-II becomes worst due to an increase in the queueing waiting time, but also the difference in the maximum number of allowed users becomes smaller. Finally, there exists a maximum offered load that bounds the region where ARQ-II is better than ARQ-I: it corresponds to *$L/2$* bits/user/slot. Last result is logical if we consider that when redundancy becomes necessary, two slots are required to transmit *L* information bits, and hence the maximum information rate that ARQ-II can accept will be *$L/2$*

bits/slot. When approaching this maximum load, the delay for the system using ARQ-II increases abruptly.

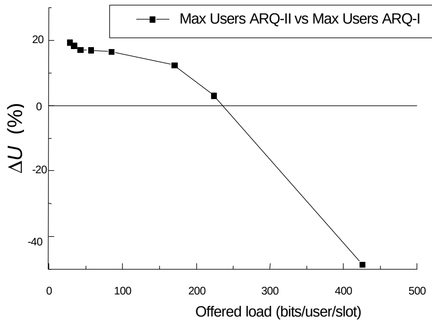

Figure 4 Increment in the maximum number of users allowed by ARQ-II and ARQ-I for different values of the offered load.

IV. ARQ-II AS AN ALTERNATIVE TO MULTIRATE ALGORITHMS

In the previous section the comparison of ARQ-II against ARQ-I with the same correcting code and half the spreading factor has been performed. In particular, we have shown that at low interference levels, when no retransmissions are required, performance is the same for both techniques: the delay is the same and in both cases L information bits per slot are sent, although in ARQ-I the total amount of transmitted bits is $2L$. However, when interference increases and redundancy is required, the information transmission rate for ARQ-II reduces down to $L/2$ bits/slot. This suggests that in this case the behavior can be similar to the case of a system working with ARQ-I and the same spreading factor, that would transmit L-bit packets with another channel code $C_1(L,L/2)$. The correcting capability of such a code would hardly depend on the specific code to be used, but by making use of shortened BCH codes, this capability can be approximately $t/2$ [3]. As such a technique would have the same spreading factor and the same correcting capability ($t/2$ errors in each set of L bits) as the considered ARQ-II, both strategies are supposed to behave quite similarly under high interference conditions. System parameters for the considered schemes are presented in table I.

The effect explained above is shown in figure 5, where the delay of ARQ-II working with S_f=31, and L=1000 bits is shown versus the delay of ARQ-I working with $S_f/2$=15 and S_f=31, for the same message arrival conditions as in the last section. It can be regarded that, as it has been previously discussed, for low interference levels, ARQ-II performs as ARQ-I with $S_f/2$ while for high interference levels, it behaves as ARQ-I with spreading factor S_f. Therefore, ARQ-II behaves as an adaptive technique that would change transmission rates according to the erroneous transmissions such as the one presented in [10].

Nevertheless, there exist some differences between ARQ-II and such an adaptive multi-rate technique. First of all, when errors occur in ARQ-II and redundancy is required to be transmitted, the delay is increased by a factor of two, while for the same interference level, in ARQ-I at $S_f/2$ retransmissions are not required and then the delay can be maintained at the same low level. Rate adaptation in this case is performed in a softer way: as soon as packets at the highest rate are not correctly decoded, mobile users will progressively change their rate, thus approaching to the case where all of them transmit with the lowest rate. Then, the resulting message delay curve will follow approximately the envelope of the curves for the S_f and the $S_f/2$ cases. This means that the resulting delay in any case will be lower than the required by the ARQ-II scheme.

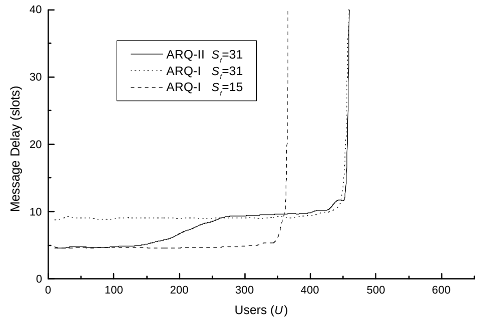

Figure 5 Comparison between ARQ II and ARQ I with two different bit rates

Something advantageous for ARQ-II would be the fact that the change in transmission rate is made at the DLC level in an independent way from the MAC level. This consideration would allow to perform rate adaptation even when it is not allowed by the MAC level: particularly, it is interesting to note that the ARQ-II scheme performs adaptation by adding redundancy bits, which implies that the total number of bits per slot remains always the same and consequently neither the spreading factor nor the spreading code nor the transmitted power need to be changed. The main point is that while an adaptive ARQ-I scheme performs adaptation by varying the channel bit rate, an ARQ-II technique maintains the channel bit rate and changes the useful bit rate by sending redundancy only when it is necessary, thus being able to use as information bits those bits that a system working with ARQ-I would waste in sending not required redundancy.

Furthermore, the additional overhead that a transmission rate adaptive algorithm would require must be considered. In particular, mobile users should indicate in some way to the base station which is the current rate that is being used for each packet. On the opposite, the ARQ-II strategy wouldn't require this information because the bit rate remains always the same, and thus no overhead is needed. Just by decoding each packet and knowing the result of the last transmitted packet, the base station would have enough information to know whether the current packet corresponds to a new transmission or to a redundancy packet.

In figure 6 the comparison between the performance in terms of message delay for the ARQ-II strategy and the adaptive transmission rate algorithm MS proposed in [10] is presented. Basically, this algorithm consists on increasing or reducing the bit rate according to the number of consecutive correct transmissions or the number of consecutive erroneous transmissions, respectively. It can be observed how the performance in terms of maximum allowed number of users is similar for both techniques and how the main difference relays basically on the higher delay for the ARQ-II technique.

Strategy	**Spreading factor**	**Channel bit rate**	**Packet length**	**Correcting capability (errors/bit)**
ARQ-II	S_f	R_b	L	$t/(2L)$
ARQ-I	S_f	R_b	L	$(t/2)/L$
ARQ-I	$S_f/2$	$2R_b$	$2L$	$t/(2L)$

Table I System parameters for the considered strategies.

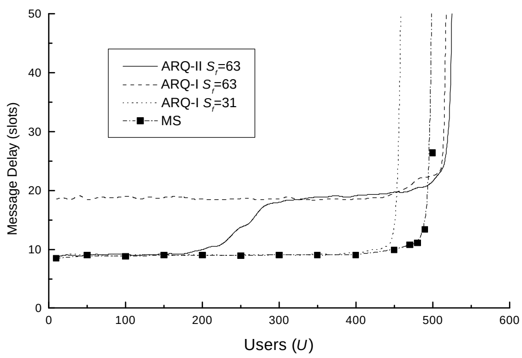

Figure 6 Comparison of ARQ-II with an adaptive multirate algorithm

V. CONCLUSIONS

ARQ-II strategy has been studied in a DS-CDMA packet transmission environment. This strategy has been compared with other techniques such as simple ARQ and ARQ-I. It has been shown that ARQ-II performs better than ARQ-I in terms of capacity although it has to tolerate a poorer delay. When the offered load per user is low, delay for ARQ-II is as maximum twice the delay for ARQ-I, and a system working with ARQ-II allows 20% more users, but for higher loads, the relationship between delays increases and at the same time the increment in number of users becomes smaller. Moreover, it has been found that there exists a region where ARQ-I scheme performs better than ARQ-II, which corresponds to the region with offered loads higher than $L/2$ bits/user/slot, being L the packet length.

Finally, it has been shown that ARQ-II working with L-bit packets and spreading factor S_f behaves for low interference levels as ARQ-I with $2L$-bit packets and spreading factor $S_f/2$, while for higher interference levels it performs as ARQ-I with L-bit packets and spreading factor S_f. This has suggested the idea that ARQ-II behaves in the same manner as an adaptive multi-rate technique but with changes in the useful information rate and not in the channel bit rate, and thus the spreading factor and the spreading sequence to be used can be maintained. Then, the change of rate is performed at the DLC level and not at the MAC level, as it would be the case for an ARQ-I scheme with a change in the spreading factor.

REFERENCES

[1] E. Dahlman, B. Gudmundson, M. Nilson, J. Sköld, “UMTS/IMT-2000 based on Wideband CDMA”, IEEE Communications Magazine, Vol 36, nº 9, pp 70 - 80, September 1998.

[2] D. N. Knisely, S. Kumar, S. Laha, S. Nanda, “Evolution of Wireless Data Services: IS-95 to cdma2000”, IEEE Communications Magazine, Vol 36, nº 10, pp 140 - 149, October 1998.

[3] S. Lin, D.J. Costello, *Error Control Coding: fundamentals and applications*, Prentice-Hall, 1983

[4] S. Lin, P.S. Yu, “ A hybrid ARQ scheme with parity retransmission for error control of satellite channels”, IEEE Trans. On. Comm., vol 30, nº7, pp1701-1719, July 1982

[5] Y.M. Wang, S. Lin, “ A Modified Selective-Repeat Type-II Hybrid ARQ System and its Performance Analysis”, IEEE Trans. On Comm, vol. 31, nº5, pp 593-607, May 1983

[6] J.Pérez, R. Agustí, O. Sallent, “Analysis of a type-II Hybrid ARQ Strategy in a DS-CDMA Packet Transmission Environment”, Submitted to IEEE Trans. On Comm., March 1999.

[7] J. M. Hanratty, G.L. Stüber, “Performance Analysis of Hybrid ARQ Protocols in a Slotted Direct Sequence Code-Division Multiple-Access Network: Jamming Analysis”, IEEE Journal On Selected Areas in Communications, vol 8, nº4, pp.562-579, May 1990

[8] Q. Zhang, T.F. Wong, J.S. Lehnert, “Performance of a Type-II Hybrid ARQ Protocol in Slotted DS-SSMA Packet Radio Systems”, IEEE Trans. On Comm, vol. 47, nº2, pp 281-290, February 1999

[9] Q. Zhang, T.F. Wong, J.S. Lehnert, “Stability of a Type-II Hybrid ARQ Protocol for Slotted DS-SSMA Packet Radio Systems”, Proc. IEEE INFOCOM’98, vol.3, pp1301-1308, San Francisco, April 1998.

[10] O.Sallent, R.Agustí, “A Proposal for an Adaptive S-ALOHA Access system for a Mobile CDMA Environment”, IEEE Trans. On Vehic. Techn. , Vol 47, nº3, pp 977-986, August 1998.

[11] M.B. Pursley, “Performance Evaluation for Phase-Coded Spread – Spectrum Multiple – Access Communication – Part I: System Analysis”, IEEE Trans. On Comm, Vol-Com 25, nº8, pp 795-799, August, 1977.