Performance Evaluation of ARQ Error Control Schemes in HiperLAN/2 Systems

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Abstract— **The ETSI BRAN HIPERLAN/2 is a Wireless Local Area Network (WLAN) standard that will operate in the 5 GHz frequency band and will provide high-speed (up to 54 Mbit/s) communications between portable computing devices attached to an IP, ATM or UMTS backbone network. WLAN are known to suffer from location-dependent, time-varying and burst errors. The usual way to deal with such problems is to implement forward error correction (FEC) and/or automatic repeat request (ARQ) in the physical and data link layer. In this paper we propose a multi-combining hybrid type-II ARQ scheme and evaluate it's performance in the data link layer and compare it with PRIME ARQ and SRPB ARQ. Simulation results verify that the proposed scheme works well over a time-varying fading channels.**

I. Introduction

Broadband wireless access to multimedia supporting backbone networks has been rapidly drawing attention toward ubiquitous communications scenario. Recently, a couple of standardizing bodies and research institutes have been actively working to establish high-speed Wireless Local Area Networks (WLANs). These standards will operate in the 5 GHz U-NII frequency bands. Both the HIPERLAN/2 [1] and IEEE 802.11a [2] is designed to provide high-speed communication, up to 54 Mbit/s, between portable devices attached to an IP, ATM or UMTS backbone network. Close cooperation between ETSI BRAN and IEEE has ensured that the physical layers of the two standards are harmonized to a large extend and they use Orthogonal Frequency Division Multiplexing (OFDM) as transmission scheme. The two standards mainly differs in the Medium Access Control (MAC) layer, HIPERLAN/2 uses TDD/TDMA and IEEE 802.11a uses CSMA/CA.

Wireless digital communication are strongly effected by errors caused by the effect of fading and multipath signal propagation. Most wireless systems have, therefore, adopted various error combating schemes in both the physical (PHY) layer and data link control (DLC) layer. This paper addresses the problem of using error-control coding in the DLC layer to achieve reliable communication over the wireless link. The two classical ways to implement such control are the Forward Error Correction (FEC) and the Automatic Repeat reQuest (ARQ) mechanisms. The choice for one of both methods is traditionally related with the kind of application in terms of delay tolerance, application error sensitivity and the availability of feedback channel. FEC does not adapt to the variable error control channel conditions; either a waste of bandwidth may occur when the radio channel is in good condition, or insufficient error protection may exist when the channel get bad. FEC is normally used for delay-constrained communications such as real-time audio and video services. ARQ is more suitable for delay-tolerable communications such as typical data services. ARQ is efficient when the channel condition is good, or moderately good, but as the channel condition gets poor, ARQ may suffer due to propagation time of retransmission and multiple NAK collision [3]. Since the channel is time varying the redundancy bits for error correction can be adapted to the channel condition and transmission of unnecessary redundancy bits can be avoided. This property provides a subset of hybrid schemes known as hybrid type-II ARQ schemes. Analysis of such schemes for binary symmetric channels and AWGN channels have been previously presented in numerous papers [4]-[6]. In H/2, the ARQ function is based on selective-repeat ARQ with partial bitmap [7].

In this paper we propose to use a Type-II/III hybrid ARQ with multiple copies combination in order to improve the system performance of H/2. We compare this proposed scheme with PRIME ARQ [8] and Selective Repeat ARQ with Partial Bitmap. We consider one cell with one access point and five mobile terminals. The radio channel is modelled by a Gilbert-Elliot model. We have evaluated the efficiency and system delay. The obtained results show that the proposed scheme increase the system performance by means of higher efficiency and lower delay.

This paper is organized as follows: The HIPERLAN/2 concept is briefly introduced in Section II. Section III discuss the different ARQ schemes and introduce the proposed scheme and in Section IV the radio channel is discussed. Section V gives numerical results. Conclusions and discussions are given in Section VI.

II. HIPERLAN/2 Overview

The HIPERLAN/2 standard is split into three layers: The physical layer and the data link control layer which are core network independent, and a set of Convergence Layers (CLs), which are network specific. The technical specifications define a radio access network that is able to operate at rates up to 54 Mbit/s, provides support for multimedia QoS parameters and, through the various CLs interconnect with various wired core networks.

A. Physical layer

The physical layer employs a transmission scheme called OFDM which has been selected due to its excellent performance to combat frequency selective fading in highly dispersive channels and randomizes the burst errors caused by the fading channel [9]. A key feature of the the physical layer is to provide several physical layer modes with different code rates and modulation schemes which are selected by link adaptation (see table 1). The modes are chosen such that the number of encoder output bits fits to an integer number of OFDM symbols.

B. Data Link Control layer

The DLC layer consists of a Radio Link Control (RLC) sublayer, an Error Control (EC) protocol and a Medium Access Control (MAC) protocol. The RLC provide a transport service to the DLC User Connection Control, the Radio Resource Control, and the Association Control Function. The EC is responsible for detection and recovery from transmission errors on the radio link. Moreover, it ensures in-sequence delivery of data packets. It is assumed that a dedicated EC instance is assigned to each DLC user connection. The medium access in based on a centralized TDMA/TDD approach based on a period of 2 ms. The allocation of resources is controlled by an AP or CC which informs the MT at which point in time in the MAC frame they are allowed to transmit their data. Time slots are allocated dynamically depending on the need of transmission resources. The MAC frame structure in figure 1, starts with a Broadcast CHannel (BCH) that contains some identifiers and information about transmission power. The BCH is followed Frame CHannel (FCH) and Access feedback CHannel (ACH). The FCH contains detailed information about the structure of the frame. The ACH informs about the result of the previous access attempts to the Random access CHannel (RCH). For BCH, FCH, ACH and RCH the most robust physical layer transmission mode is used. After the ACH follows the data transmission in downlink (DL), uplink (UL), and directlink (DiL) phases, which are allocated dynamically depending on the need for transmission resources. Downlink, uplink and directlink phases consists of two types of PDUs: long PDUs and short PDUs. The long PDUs have a size of 54 bytes and contain control or user data. The payload is 49.5 bytes and the remaining bytes are used for the PDU Type (2 bits) and then the fields for error control functions: 10 bit Sequence number field and the 24-bit Cyclic Redundancy Check (CRC-24) field. The SN field allows the identification and alignment of correctly received U-PDUs and is to be used in positive acknowledgment messages. Long PDUs are referred as the Long transport CHannel (LCH) Shorter ARQ acknowledgements and some other link control messages are mapped into a 9 octets transport format named Short transport CHannel (SCH). Note that one PDU burst per MT is allowed in each MAC frame.

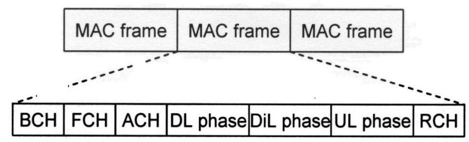

Fig. 1. HIPERLAN/2 MAC frame

C. Convergence layers

Several CL layers have been defined for interworking with IP transporting networks (Ethernet and PPP), ATM based network, 3^{rd} generation core network, and networks using IEEE 1394 protocols and applications. The CL layer have two main functions: Adapting service request from higher layers to service offered by the DLC and to convert the higher layer packets with fixed or variable size into a fixed-size SDU that is used within the DLC.

TABLE I
Physical layer modes of HIPERLAN/2

Mode	Modulation	Code rate	PHY layer bit rate
1	BPSK	1/2	6 Mbit/s
2	BPSK	3/4	9 Mbit/s
3	QPSK	1/2	12 Mbit/s
4	QPSK	3/4	18 Mbit/s
5	16QAM	9/16	27 Mbit/s
6	16QAM	3/4	36 Mbit/s
8	64QAM	3/4	54 Mbit/s

III. ARQ Schemes

To obtain high throughput in HIPERLAN/2, efficient retransmission, low overhead (for both retransmissions and acknowledgements) and low delay of acknowledgements are required. In order to fulfill these requirements we will discuss three different ARQ schemes: PRIME ARQ, SRPB and finally we propose a Type-II Hybrid ARQ.

A. PRIME ARQ

Partial selective Repeat superIMposED on Go-back-N (PRIME) ARQ was proposed by [8] and is a hybrid solution combining the advantages of Selective-Repeat (SR) ARQ and the simplicity of Go-back-N (GBN) ARQ. With this proposal the delay and overhead of acknowledgements are optimized. PRIME ARQ specifies a parameter which is referred as Management Sequence Number N_{MSN}. With N_{MSN} we mean how many U-PDUs are negative acknowledgement in an ARQ acknowledgement. If N_{MSN} is > 1, then the first N_{MSN}-1 erroneous PDUs in the acknowledgement are retransmitted with SR-ARQ, while the last U-PDU in the acknowledgement after that are retransmitted as GbN-ARQ. If $N_{MSN} = 1$, then the PRIME ARQ works like an GbN-ARQ.

B. Selective Repeat with Partial Bitmap (SRPB)

Beside the FEC on physical layer, *Selective Repeat ARQ with Partial Bitmap* (SRPB) is used on the DLC layer. To signal erroneous packets to the sending terminal partial-bitmap acknowledgements are used, i.e. correct and erroneous packets are acknowledged in form of a bitmap. An acknowledgement, also called *ARQ-feedback PDU*, contains three *Bit Map Blocks* (BMP). Each BMB consists of 8 bits, whereby a 0 bit indicates an error in the packet and a 1 bit a successful reception. Each packet is identified by the SN that is defined modulo 1024 (10 bit). The SNs to which the three BMBs refer are given by their *Bit Map Number* (BMN).

The transmitter(TX) and receiver (RX) windows of the SRPB protocol have a size of 512 and their indices are defined modulo that number. A bigger size could result in ambiguities among transmitter receiver due to the SN-space 1024. The transmitter can send packets until the TX window is full. Upon reception of an ARQ-feedback PDU (with so called*Cumulative Acknowledgement* bit is set to 1) the bottom of the TX window is shifted to the SN of the first 0 in the first BMB. This opens the TX window again and consequently a number of new packets corresponding to the size of the window shift can be transmitted. It is obvious that the probability of a closed TX window limits the maximum achievable throughput on the DLC layer. If the life time of a packet has expired after several unsuccessful transmissions, the transmitter discard it and inform the receiver about this with a DISCARD message. Upon acknowledgement of this message the TX window can be shifted.

C. Type-II/III Hybrid ARQ

Normally, Type-II and Type-III Hybrid ARQ use concatenated coding with half-rate outer code [5]. Codewords are computed on the data delivered from higher layers but, within each DLC U-PDU payload, only one of the parts (information and parity) is inserted. Type-II uses a correction code and a CRC for the outer and inner coding respectively. Type-III uses correction codes for both outer and inner coding. The main problem of the II/III HARQs is how to provide the receiver with the correct data, concerning the very important packet control information (SN and Info/Parity indication), when a received packet is detected as containing errors, the packet control information within it can not be considered reliable because the errors may have occurred exactly within that zone.

To efficiently use the available bandwidth we normally for the DLC U-PDUs use the LCH in the high bit rate physical modes but to the cost of higher vulnerability to errors. Short feedback messages, such as an ARQ positive acknowledgement containing a sequence numbers list, carry higher sensitive information. In this paper we use for each DLC connection, that information is condensed into a "forwarding direction packet list" and transported in one or more SCHs aside with the corresponding LCHs containing the U-PDUs. By using this method the packet control information has a significant increase in its protection, hence guaranteeing the normal operation of type-II/III hybrid ARQ.

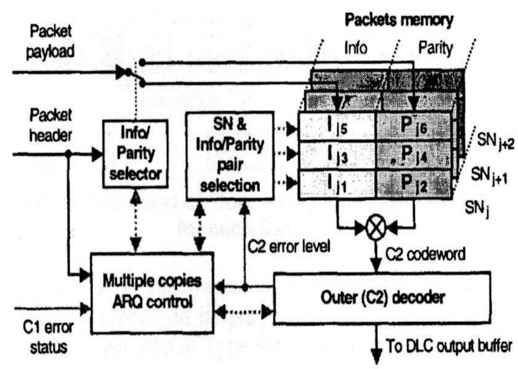

Fig. 2. Multiple copies combination for TYPE II/III HARQ Schemes

D. Type II/III Hybrid ARQ with Multiple Copies Combination

In this paper we propose some new improvements of Type-II/III HARQ schemes. One is in the receiver part, where we propose a new mechanism of combining to the (re)transmitted packet payload. For each packet (i.e., with the same SN), this mechanism enables the existence of multiple copies for the information and redundancy parts, guaranteeing the testing of more codewords for each copy arrival. The other improvement is the provision of a method that conveys the essential packet control information to the receiver in a safer way. This guarantees the fundamental condition for the operation of more powerful Type-II/III HARQ schemes, which is the correct knowledge of SN and "Info/Parity indication", even under a considerable number of errors in the main stream.

This new implementation is characterized by the existence of M (even) memories for each packet (packets with the same SN). M/2 memories are used to save "information" packets; the other M/2 memories are used to save "parity" check packets. The rationale behind this mechanism is that every received copy of a packet (even with unrecovered errors) contains large parts with correct information.

Hence, when the inner code states an unrecovered error, it passes the received packet payload to this second level of decoding. Having several copies memorized, it is possible to combine more "information" and "parity" parts. In this way, for each packet retransmission arrival, more codewords are put to the outer decoder, improving its success rate.

TABLE II

Multiple Copies Combination for TYPE II/III HARQ Scheme (M=6)

K-th arrival	Pair selection order
K=1 (I)	not applicable
K=2 (P)	$I_j1 - P_j2$
K=3 (I)	$I_j3 - P_j2$
K=4 (P)	$I_j3 - P_j4, I_j1 - P_j4$
K=5 (I)	$I_j5 - P_j4, I_j5 - P_j2$
K=6 (P)	$I_j5 - P_j6, I_j3 - P_j6, I_j1 - P_j6$
K=7 (I)	$I_j1 - P_j6, I_j1 - P_j4, I_j1 - P_j2$
K=8 (P)	$I_j1 - P_j2, I_j5 - P_j2, I_j3 - P_j2$
K=9 (I)	$I_j3 - P_j2, I_j3 - P_j6, I_j3 - P_j4$
K=10(P)	$I_j3 - P_j4, I_j1 - P_j4, I_j5 - P_j4$
K=11(I)	$I_j5 - P_j4, I_j5 - P_j2, I_j5 - P_j6$
K=12(P)	$I_j5 - P_j6, I_j3 - P_j6, I_j1 - P_j6$

IV. Channel Model

In this paper we will use a two state Markov model which have been extensively used in the literature to capture the bursty nature of the error sequences generated by a wireless channel [10]. Previous studies show that a first order Markov chain such as a two state Markov model provides a good approximation in the modelling the error process in fading channels as in Fig.3 [11].

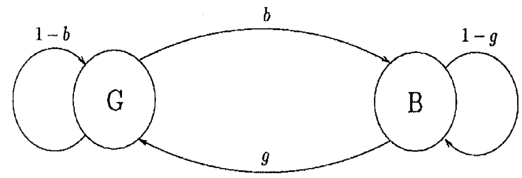

Fig. 3. Channel model

The channel state is either *good* or *bad* and can change on bit boundaries, that is, channel condition stays in a state during one bit duration. Following the widely accepted Rayleigh fading model, which corresponds to the case of no Line-Of-Sight (LOS) path between the sender and receiver, we can derive the transition probabilities g and b.

We define the *level-crossing rate* as the expected rate at which the Rayleigh fading envelope [12], normalized to the local rms signal level, crosses a specified level in a positive-going direction as:

$$N_R = \sqrt{2\pi} f_m \rho e^{-\rho^2}. \quad (1)$$

Furthermore, we define the *average fade duration* as the average period of time for which the received signal is below the threshold level R, is given by

$$\overline{\tau} = \frac{1}{N_R}[r \leq R] = \frac{e^{\rho^2} - 1}{\rho f_m \sqrt{2\pi}} \quad (2)$$

where $f_m = \frac{v}{\lambda}$ is the maximum Doppler frequency for the mobile speed v and the wavelength λ of the carrier and the normalized threshold fading envelope is given by $\rho = \frac{R}{R_{rms}}$. Average fade duration primarily depends upon the speed of the mobile, and decreases as f_m becomes large.

Assuming steady-state conditions and using above formulas, the probabilities μ_0 and μ_1 that the channel is in good state and bad states, respectively, are given by

$$\mu_0 = \frac{1/N_R - \overline{\tau}}{1/N_R}, \text{ and } \mu_1 = \frac{\overline{\tau}}{1/N_R}. \quad (3)$$

Finally, the state transition probabilities can be approximated by

$$b = \frac{N_R}{R_t^0}, \text{ and } g = \frac{N_R}{R_t^k} \quad (4)$$

where $R_t^k = R_t \mu_k$, and R_t is the symbol transmission rate.

Assuming that we are using binary phase shift keying (BPSK) modulation, we can calculate the bit error probabilities (BERs) $P_{b,0}$ and $P_{b,1}$ when the channel is in *good* and *bad* states, respectively, as [13]

$$P_{b,i} = \int_{\gamma_i}^{\gamma_{i-1}} P_{b|\gamma} f_i(\gamma) d\gamma \quad (5)$$

where BER for a given signal-to-noise ratio (SNR) γ is

$$P_{b|y} = Q(\sqrt{2\gamma}) \quad (6)$$

and the conditional distribution of the instantaneous SNR γ in a given state with mean SNR $\overline{\gamma}$ is

$$f_i(\gamma) = \frac{\frac{1}{\overline{\gamma}} e^{\gamma/\overline{\gamma}}}{e^{-\gamma_i/\overline{\gamma}} - e^{-\gamma_{i-1}/\overline{\gamma}}} \quad (7)$$

for $\gamma_i < \gamma < \gamma_{i-1}$ and the set $\{\gamma_{-1}, \gamma_0, \gamma_1\} = \{\infty, \rho^2\overline{\gamma}, 0\}$. Note that the mean SNR $\overline{\gamma}$ depends on the transmitted power, signal attenuation over the channel, and others.

V. Simulation Results

In order to properly compare the different ARQ protocols some simulations have been done to evaluate the performance. We consider a single cell with one AP and five MTs. The AP is connected with IP servers. The MTs have only client functions and send only acknowledgements to the servers. In the simulation we have not considered overhead from the physical layer. The scheduler assigns the capacity between the AP and MTs by first coming first served principle. When a sender in the AP gets opportunities for data transmission in the DL phase,

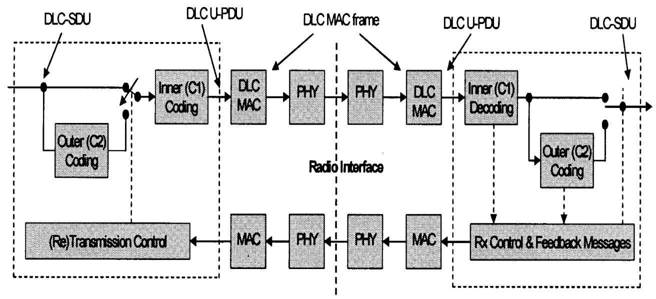

Fig. 4. Simulation model for the Type-II hybrid ARQ

the scheduler reserves a C-PDU to the corresponding MT in the UL phase for the transmission of ARQ acknowledgements. In this paper we have assumed that the PRIME ARQ can acknowledges 3 PDUs ($N_{MSN} = 3$) in a C-PDU. Furthermore, both the PHY- and DLC-layer follows the HIPERLAN/2 standard which means that in the PHY layer each OFDM symbol comprises 48 data-bearing and 4 pilot subcarriers, and modulation and demodulation can be implemented by means of 64 point Fast Fourier Transform (FFT) operation. The sampling rate is set to 20 MHz and the subcarrier spacing is 0.3125 MHz.

As the HIPERLAN/2 U-PDU contains 432 bits, and 24 of them are reserved for CRC function, a search for BCH (n,k) codes containing approximately the same number of information (k) and redundancy (n-k) bits was performed. For the Type II/III HARQ scheme we choose a BCH (432,405) code which acts as the DLC inner code and as outer code we choose a (790,395) code. In HIPERLAN/2 the size of payload is 396 bits. Checking of primitive BCH codes with more than 396 bits in the information part and an approximate size in the redundancy part leads to the BCH (1023,628) code with 395 redundant bits and a correction capability of $t = 43$. Shortening this code in 233 bits changes it to the required half rate format, more precisely a (790,395) code. Even though that the payload is not equal to this code (1 bit difference), it is enough to make the intended performance comparisons. We also try with smaller packet sizes and in Table III the parameters for the BCH code is shown.

Figure 6 shows the throughput as a function of system load. We observe that when the system starts to be heavy loaded the proposed scheme is superior the others mainly due to that less retransmissions are required. From figure 7 we can observe that when the channel conditions are good, all the different ARQ schemes performs almost equal but when the channel condition degrades the hybrid ARQ schemes with multiple copies combining are superior. The simulation results in figure 8 shows that the proposed scheme provides lower delay than SRPB ARQ and PRIME ARQ. The reasons that both the hybrid ARQ with multiple copies combining and SRPB ARQ provides higher throughput/efficiency and lower delay than PRIME ARQ is that the PRIME ARQ need more capacity than the other two schemes due to the Go-Back-N function in PRIME. If we then increase the N_{MSN} in PRIME ARQ the efficiency of retransmissions improve, because the PRIME makes more selective and less Go-Back-N retransmissions but to the cost of increased overhead. Furthermore, we can conclude from figure 8 that the 6-memory solution is best, but if memory saving is necessary the 4-memory appears to be a good compromise. From simulation it was also observed that the throughput efficiency was better for larger packets when the BER is small, but when the BER increases the efficiency drops since the larger user data are more likely to be corrupt. This phenomenon was also observed in [14], where an adaptive frame length control for WaveLAN was considered.

TABLE III
Packet lengths and respective BCH encoding (n, k, t)

Packet length	Inner code	Outer code
94	(94, 73, 3)	(126, 63, 10)
158	(158, 134, 3)	(248, 124, 18)
289	(289, 262, 3)	(504, 252, 30)
432	(432, 405, 3)	(790, 395, 43)

VI. Conclusion

In this paper we have evaluated different ARQ protocols suited for high performance wireless local area networks. It is obvious that a pure ARQ protocol is not sufficient enough to timely combat the errors introduced by the combined effects of channel fading and multipath propagation. These schemes require a considerable number of retransmissions almost proportional to the channel bit error rate.

In order to guarantee the normal operation of Type II/III HARQ schemes, it is now proposed to convey the important packet control information into more reliable physical modes. The packet control information is mainly composed of a "forwarding direction" SN packet list and in this way its protection is significantly increased.

Furthermore, we have proposed an M-memory packet copies combination associated with Type II/III HARQ schemes. This scheme outperforms both PRIME ARQ and SRPB ARQ in terms of better throughput efficiency and lower delay, but, to achieve this increasement in performance we have to pay in somewhat more complexity since the new scheme requires some buffers.

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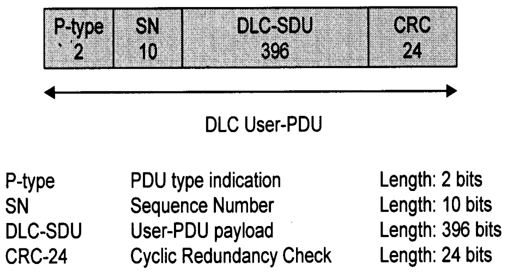

Fig. 5. HIPERLAN/2 U-PDU

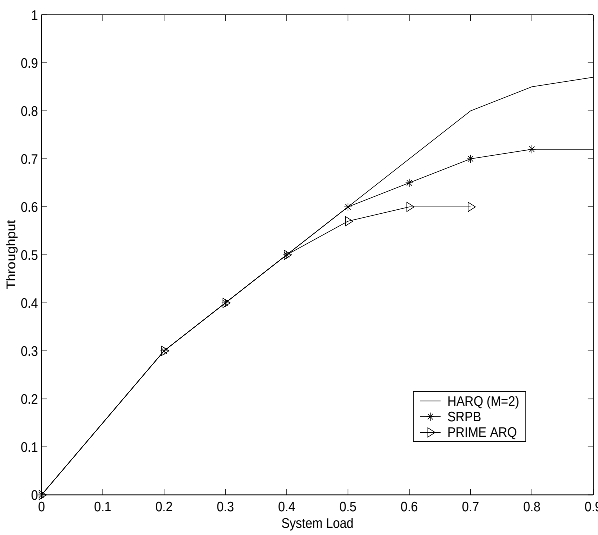

Fig. 6. Throughput of SRPB, PRIME ARQ and type II/III HARQ with multiple copies combination (M=2). Packet length is equal to 432 bits

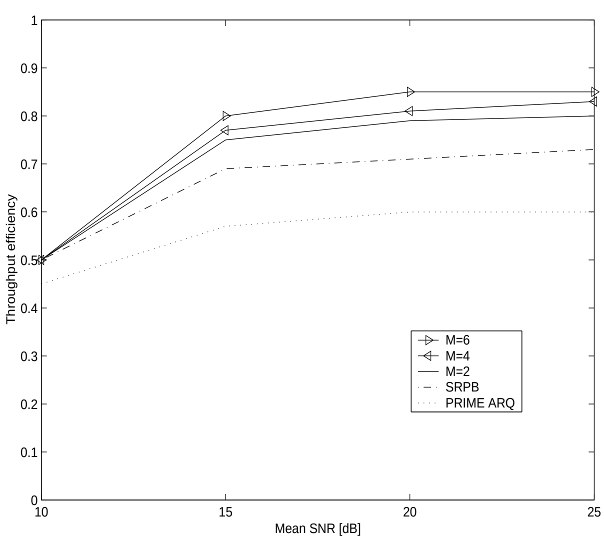

Fig. 7. Throughput efficiency versus mean SNR. Packet length is equal to 432 bits.

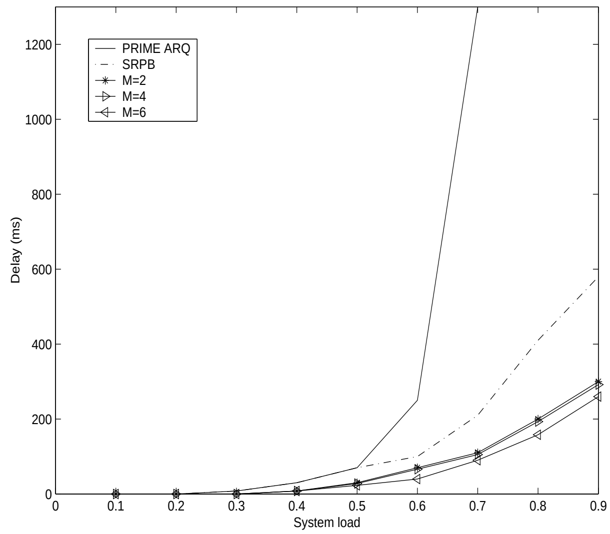

Fig. 8. Delay performance of SRPB ARQ, PRIME ARQ and the type II/III HARQ multiple copies combining scheme with different size of memory (M=2, 4, 6). Packet length is equal to 432 bits.

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