An Approach for Using Adaptive Error Control Schemes in Wireless LAN with CSMA/CA MAC protocol

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Abstract— **Communication in high-speed wireless local area networks such as IEEE 802.11a are known to suffer from location-dependent, time-varying, and burst errors. It is usual to implement Forward Error Correction and Automatic Repeat reQuest mechanisms in the physical and data link layer to combat this errors. In this paper we evaluate the system performance of a WLAN with CSMA/MAC protocol with different ARQ protocols. We have implement three different schemes 1) Selective repeat ARQ, 2) ARQ with majority voting and 3) Type II Hybrid ARQ. The simulation results show that all three scheme performs well when the channel is in good condition but when the bit error rate (BER) increases the type II hybrid ARQ is superior the other two schemes**

I. Introduction

RECENTLY , Wireless Local Area Networks (WLANs) has become more popular since a rapidly attention towards broadband wireless access has grown in the wireless society and the demand for higher data rates and mobility for future multimedia services is one of the driving forces. In the last years a couple of standardization bodies and research institutes have been actively working to establish high-speed WLANs [1]-[3]. The IEEE 802.11a is one of these standards and it will operate in the 5 GHz U-NII bands. Both IEEE 802.11a and HIPERLAN/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 IEEE and ETSI has ensured that the physical layers of the two standards are harmonized to a large extend and they use Orthogonal Frequency Division Multiplex (OFDM) as transmission scheme. The two standards differ primarily in the Medium Access Control (MAC) layer, IEEE 802.11 uses CSMA/CA and HIPERLAN/2 uses TDD/TDMA.

Wireless mobile digital communication are strongly affected 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 layer and in the data link layer. This paper considers the problem of using error-control coding in the data link layer to achieve reliable communication over a wireless link. Generally speaking there is two types of error control methods used: Forward Error Correction (FEC) and Automatic Repeat reQuest (ARQ). FEC does not adapt to variable error control channel conditions; either a waste of bandwidth may occur when the radio channel is in a good condition, or insufficient error protection may exist when its get bad. ARQ is efficient when the channel condition is good, or moderately good, but as the channel condition gets deterioated, ARQ may suffer due to the propagation time of retransmission and multiple NAK collision [4]. 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 (BSC) and AWGN channels have been previously presented [5]-[7]. The authors in [8] introduced a simple packet combining scheme in WLAN to improve the system throughput.

In this paper, we consider a WLAN quite similar to the IEEE 802.11a with CSMA/CA MAC protocol and evaluating the system performance by using different error control methods; 1) A Selective Repeat (SR) ARQ scheme is considered, 2) ARQ with majority voting; and 3) type-II hybrid ARQ. Simulation results show that all three error control schemes improving the system performance of the WLAN. It is observed that when the channel is good the SR ARQ performs best but when the channel becomes poor the type II hybrid ARQ scheme outperforms the other two schemes. But this scheme adds some extra complexity to the system.

The paper is organized as follows. Section II gives a brief introduction to the IEEE 802.11a PHY and MAC-layers. Section III introduces the channel model. In Section IV we discuss the proposed schemes. In Section V we discuss the simulation results and finally we conclude the work in Section VI.

II. 802.11 overview

The 802.11 standard support two topologies: ad hoc topology which is a fully meshed network where stations

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communicate directly with each other and infrastructure topology where each Basic Service Set (BSS) has an Access Point (AP) acting as gateway for the Mobile Terminals (MT's) to the outside world analogous to the base station in a cellular communications network. The 802.11 MAC sublayer provides fairly controlled access to the shared wireless medium through two different access mechanisms, called the Distributed Coordination Function (DCF), and the Point Coordination Function (PCF).

TABLE I
PHYSICAL LAYER MODES OF IEEE 802.11A

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	1/2	24 Mbit/s
6	16QAM	3/4	36 Mbit/s
7	64QAM	2/3	48 Mbit/s
8	64QAM	3/4	54 Mbit/s

A. 802.11a physical layer

In the physical layer, IEEE 802.11a employs a transmission scheme called Orthogonal Frequency Division Multiplex (OFDM) which has been selected due 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 PHY-layer is to provide several modes with different coding and modulation schemes (see Table I) which are selected by link adaption. It enables the system to match the physical layer mode to the required radio link quality in order to reach desired QoS.

B. Media Access Controll in IEEE 802.11

The fundamental access method in IEEE 802.11 MAC is called DCF and is the random access protocol based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) with random back off. The DCF is implemented in all MT's and AP's. A station that is ready to transmit a frame senses the medium, and if the medium is busy, the MT will wait until the end of the correct transmission. The station will then wait for a predetermined time period denoted as DCF Inter-Frame Space (DIFS), and select a random time slot within a contention window to transmit its frame. If there are no other transmissions before the selected time slot arrives, the station starts transmitting its frame when the time slot arrives. However, if there are transmissions by other stations during this time period, known as the back off time, the station freezes its counter and then resumes the count where it left off, after the other station has completed its frame transmission and after a DIFS. Thus, collisions can occur only when two or

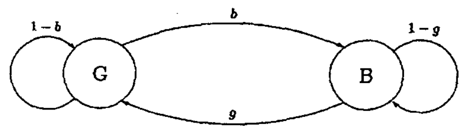

Fig. 1. Two-state Markov channel model

more stations select the same slot in which they transmit their data frames. In the event of a collision, the source detects the collision based on the abscence of a positive acknowledgement (ACK) from the destination or the receipt of an explicit negative acknowledgement (NAK) from the destination.

The process of partitioning an MSDU into smaller MAC frames is called *fragmentation*. Fragmentation creates MPDUs smaller than the original MSDU length to improve reliability, by increasing the probability of successful fragment transmissions. Each fragment is sent as an independent transmission and is acknowledged separately. Once a station has contended for the medium, it shall continue to send fragments with Short Inter-Frame Space (SIFS) gap between the ACK reception and the start of the subsequent fragment transmission until either all the fragments of a single MSDU have been sent, or an ACK frame is not received.

III. 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], [11]. 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.1 [12].

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 [13].

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

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 [14]

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

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 [15]

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

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.

IV. Description of ARQ Schemes

This section discuss three different types of ARQ schemes. A selective repeat is assumed, i.e, the transmitter only resends (or repeat) those packets that are negative acknowledged. The detection of lost packet is achieved by an ACK timeout.The ARQ concept is of the IEEE 802.11 standard is integrated with the MAC layer, which determines the ARQ relevant round trip delay by specifying the inter frame space. The ARQ can be adapted to the channel conditions by a fragmentation - defragmentation procedure, which transmits larger MAC layer service data units (MSDU) in smaller MAC layer protocol data units (MPDU).

A. ARQ with Majority Voting

When a decoded packet is deemed erroneous at the receiver, the bit decisions of the decoder are stored and a retransmission is requested. If the i^{th} transmission of a packet is detected in error, the corresponding bit decisions $\tilde{d}_0^i, \tilde{d}_1^i, ..., \tilde{d}_N^i$ are stored, where $\tilde{d}_j^i \in [0, 1]$, corresponds to the decision on the j^{th} bit during the i^{th} transmission and N is the length of the data packet including the CRC bits. When the packet is detected in error during the third subsequent transmissions ($i \geq 3$), a bit-by-bit majority voting is performed using the rule

$$\hat{d}_j = \begin{cases} 1 & \text{if } \sum_{i-2}^{1} \tilde{d}_j^i \leq 2 \\ 0 & \text{Otherwise} \end{cases} \quad (8)$$

Then the new decisions $\tilde{d}_0, \tilde{d}_1, ..., \tilde{d}_N$ are checked for errors using the CRC check. If the packet is still erroneous a retransmission is requested. If the packet has not been accepted after five retransmissions it is declared as a decoding failure and the transmitter proceeds with next packet.

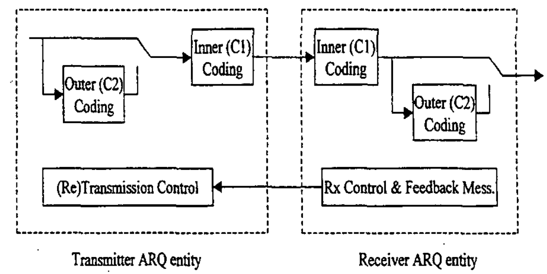

Fig. 2. Transmitter-receiver setup for the type II hybrid ARQ scheme

B. Type II Hybrid ARQ

We assume that there is an error-free feedback channel from the receiver back to the transmitter is immediately acknowledged after each packet transmission. We consider two block codes C_0 and C_1. Let C_0 be an $(n-k)$ high-rate BCH code for error detection, and C_1 be an $(2n, n)$ invertible code for error detection. For the invertible code, the n-bit information block can be obtained by uniquely from the n-bit parity check block by a simple inverting algorithm. An invertible BCH code can be designed by shortening a regular BCH code [5].

Let the k-bit information sequence I be encoded first into a n-bit codeword, denoted $J = (I, Q)$, in the (n, k) code C_0. Then the n-bit parity block $P(J)$ corresponding to J us formed based on J and the $(2n, n)$ invertible code C_1. $(J, P(J))$ is a codeword in C_1. J is first transmitted and $P(J)$ is saved in the transmitter for possible transmission at a later time. Let $\tilde{J}$ be the received version of J at the receiver. The syndrome of $\tilde{J}$ based on C_0 is checked. Is the syndrome is zero, $\tilde{J}$ is assumed to be error free and is accepted as the original information data by the receiver (n-k parity bits removed). An ACK is sent to the transmitter. If the syndrome is not zero, the presence of errors in $\tilde{J}$ is detected. $\tilde{J}$ is then stored in the receiver buffer for reprocessing at a later time and no ACK is sent. At the transmitter, if an ACK is received before the timer expires, the transmitter knows that the first transmission was successful and it discards the parity block $P(J)$. If not, it assumes that errors occurred in the first transmitted packet and it sends the parity block $P(J)$ to the receiver.

Let $\tilde{P}(J)$ be the received parity block. After $\tilde{P}(J)$ is received, the receiver first takes the inverse of $\tilde{P}(J)$, denoted $\tilde{J}(P)$, based on C_1. Since C_1 is invertible, $J(\tilde{P})$ should be the original data block J and be a code word in C_0 if $\tilde{P}(J)$ is error free. After $J(\tilde{P})$ has been obtained, the receiver computes its syndrome based on C_0. If the syndrome is not zero, the received parity block $\tilde{P}(J)$ is combined with the erroneous data block $\tilde{J}$ in the receiver buffer to form a $(2n, n)$ error correction code. Error correction is then performed and the decoded message is delivered to the receiver.

The process that recover the information from $\tilde{P}(J)$ itself through inversion increase the system reliability. For example, if the first received packet $\tilde{J}$ contains a lot of errors and the second received packet $\tilde{P}(J)$ is error free, the decoding process based on the rate 1/2 BCH code would not be able to recover the message I. However, the message I can be recovered from $\tilde{P}(J)$ through a simple inversion algorithm. This is very important for time varying wireless channels, where a burst of errors might wipe out most of the first transmission yet leave the retransmission relatively error free. This reduces the ARQ delay and makes decoding simple when the channel is good. Furthermore, every transmitted packet has the same length and contains the same number of information bits so that this scheme can use fairly straightforward buffer management and network interface techniques

TABLE II

SIMULATION PARAMETERS

Characteristics	Value	Comments
SlotTime	$9\mu s$	Slot Time
SIFSTime	$19\mu s$	SIFS Time
DIFSTime	$34\mu s$	SIFSTime + 2 x SlotTime
CWmin	15	min contention window size
CWmax	1023	max contention window size
Symbol	$4\mu s$	OFDM symbol interval

V. Simulation and Results

We have simulated a Wireless LAN with CSMA/CA MAC protocol in a radio cell where one MT and one AP is operating. In the simulations we have assumed that the station is moving with speed of 5 km/h (1.4 m/s). The transmission mode on the physical layer is set to 6 Mbps. The threshold SNR (Good ↔ Bad) for the GE-model was set to 20 dB and the mean of the receiver SNR $\rho = 20.5\ dB$. Other related characteristics for the 802.11a PHY are listed in Table II. According to the IEEE 802.11 standard, the length of an MSDU must be less or equal to 2034 octets. In this paper we have assumed a packet length of 512 bits, with 32 of them reserved for the CRC function. Furthermore a search for BCH (n, k) codes containing approximately the same number of information (n) and redundancy $(n-k)$ bits was performed. We use a BCH (511, 485) as code C_0 and for C_1 we use a BCH (970,485) code.

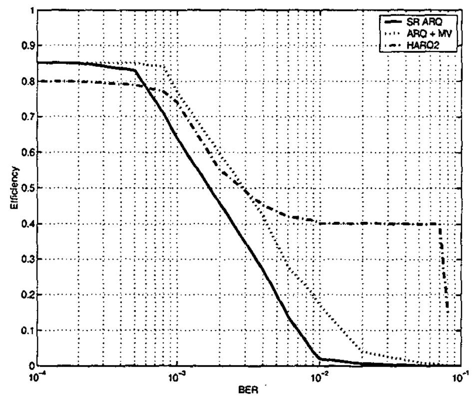

Fig. 3. Throughput efficiency η versus BER

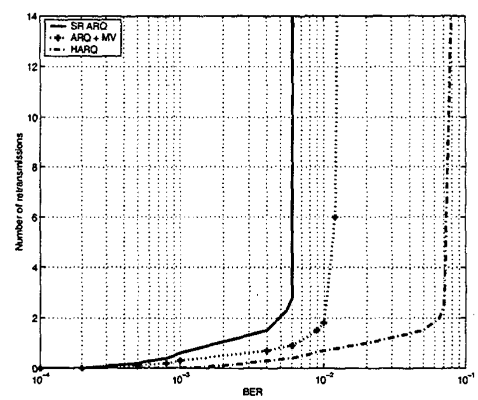

Fig. 4. Number of retransmission vs BER

Figure 3 shows the efficiency η as a function of BER. It is observed that when the channel condition is good, the SR ARQ scheme performs better then the type II hybrid ARQ, this due to the fact that the total code rate is the product of the code rates of the error correcting code and the error detecting code, but when the channel deterioates, the efficiency of the SR ARQ drops rapidly while the error correction provided by the half rate code C_1 will maintain a high efficiency for the type II hybrid ARQ. The ARQ with majority voting scheme performs slightly better then the original ARQ scheme, especially when the channel condition gets poor.

In figure 4 we see the number of retransmissions as a function of BER. In good channel conditions all schemes

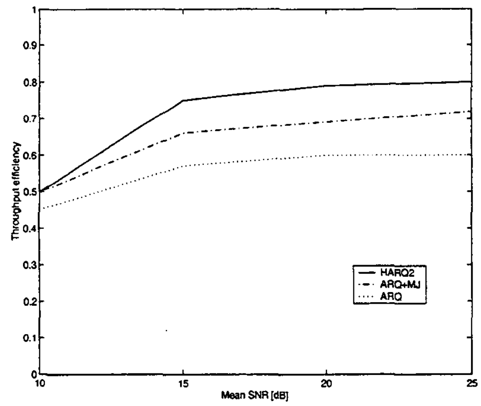

Fig. 5. Mean SNR (dB) vs throughput

performs equally but for poor channel conditions the type II hybrid ARQ is superior the other two schemes. For a BER value of 10^{-2} we only need one retransmission in the case of a type II hybrid ARQ scheme. Figure 5 shows the system throughput as a function of the mean SNR. Here one can observe that for a mean SNR of 20 dB the type II hybrid ARQ has an throughput of almost 80% while the ARQ with majority voting has a throughput of 73% and worst is the SR ARQ scheme with just 60% throughput. From simulations it was also observed that the efficiency is better for large packet when the BER is small, but then the BER increases the efficiency decreases rapidly since the the larger user data are more likely to be corrupt. This phenomenon was also observed in [16], where an adaptive frame length control for WaveLAN was considered.

VI. Conclusion

In this paper, we have evaluated different error control schemes in the data link layer for reliable communication over wireless links which suffer from time-varying and burst errors. We have considered three different error-control schemes and analyst their performance by means of efficiency and delay. Simulation results show that for good channel conditions the selective repeat ARQ performs slightly better than the others, but when the channel gets poor the type II hybrid ARQ scheme is superior the other schemes. It was also observed that a better efficiency was achieved when smaller packet sizes was used. In perspective of complexity, both the ARQ with majority voting and the type II Hybrid ARQ are more complex than the selective repeat ARQ.

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