Diversity Combining and Packet Size Adaptation for Maximizing Throughput of ARQ Protocols in AWGN and Fading Channel

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***Abstract*—Multi-hop wireless network based on IEEE 802.11 WiFi technology has emerged as a cost effective solution for accessing cellular networks or the Internet from the remote rural areas of the developing countries. Such access networks, typically, have long distance links that span tens of kilometers. Because of the long distance nature of the links, bit error rate is significant. Hence, to make these networks a viable access technology, it is imperative to design schemes that combat noise and the fading effect and thereby improve the links' throughput. In this paper, we propose diversity combining along with packet size adaptation to maximize the throughput. We also show that the significant throughput improvement can be achieved by using Selective Repeat or Go-back-N ARQ instead of Stop-and-Wait ARQ, which is currently used in IEEE 802.11 WiFi.**

***Keywords*-packet size optimization, diversity combining, cross layer design**

I. INTRODUCTION

A. Motivation

The main motivation of our work stems from the need for developing technologies to access cellular networks or the Internet from the remote rural areas of the developing countries. Typically, the access technology will have to cover a large area with low population density. Hence, the traditional approaches like installing the base stations and connecting them to the rest of the network using optical fiber are not cost effective. Recently, significant amount of work has been done in the direction of designing cost-effective access technologies for the remote rural areas [1], [2], [3]. Most of the proposed solutions use multi-hop wireless network based on IEEE 802.11 WiFi technology [4] as it is capable of providing broad band access, and it can operate in unlicensed band. Some examples of the deployment of this access technology are: (i) Ashwini project in Andhra Pradesh, India [5], (ii) Akshaya deployment in Kerala, India [6], (iii) Digital Gangetic Plains testbed in Uttar Pradesh, India [3], (iv) DjurslandS.Net: a deployment in Denmark [7]. Here, the long distance IEEE 802.11 based links are used that span tens of kilometers. Because of the long distance nature of the links, the Bit Error Rate (BER) may be significant. Hence, for the effective use of this technology, it is imperative to design schemes that combat noise, and thereby reduce the BER.

To illustrate the key challenges that are involved in using the long distance link based on IEEE 802.11 technology, we state the following key observations that emerged from the experimental study in the Digital Gangetic Plains testbed [1].

1) The packet error rate as a function of received Signal to Noise Ratio (SNR) shows a threshold behavior, i.e., there exists an SNR value below which the error rate is almost 1, while above it the error rate drops steeply to 0. The packet is said to be in error if at least one bit is error.
2) For a given received SNR, the number of correctly delivered bits per unit time (*throughput*) depends on the packet size.
3) In IEEE 802.11, Stop-and-Wait (SW) Automatic Repeat reQuest (ARQ) protocol is used to ensure reliability of the Medium Access Control (MAC) layer. But, because of the significant propagation delay in the long distance link, SW ARQ protocol may waste considerable time waiting for the acknowledgment. This may further reduce the throughput.

Observation 1) shows that if we are allowed to boost the transmit power, then we can reduce the packet error rate close to 0. But, on account of the frequent power failures in the remote areas and the radiation constraints, increasing the transmit power may not be feasible. Thus, the packet error rate may be close to 1 due to insufficient received SNR. Hence, to use the system effectively, techniques for improving the BER performance for a given received SNR are required. We note that the ARQ protocols retransmit the packet in case of failure in the previous transmission. Generally, the erroneous copies are discarded. We propose to use various copies of the received packets along with diversity combining techniques [8] to reduce the error rate. These techniques are used at the physical layer.

Observation 2) illustrates the need for cross layer approach. Specifically, it demonstrates the need of choosing the optimal packet size at the MAC layer so as to maximize the throughput depending on the BER in the deployed physical layer technology. Here, since we use diversity combining at the physical layer, the packet size adaptation has to account for it.

Observation 3) shows that the SW ARQ may not be an ideal choice for the long distance link. Instead, ARQ protocols like Go-back-N (GBN) and Selective Repeat (SR) [9] may improve the throughput, as these protocols transmit other packets while waiting for the acknowledgements for the previous packets. But, to employ these protocols with diversity combining techniques, one needs to address some additional issues that are described in detail in Section II.

B. Related Work

Significant amount of work has been done on packet combining. The code and diversity combining has been described in [10]. In [11], the authors have used antenna diversity and packet combining to improve the throughput. In [12], packet retransmission diversity and power adjustment scheme has been proposed. However there is no packet size adaptation in this scheme. The authors of this paper have studied the effect of varying packet sizes on throughput efficiency of EARQ in [13]. Our scheme use MRC for diversity packet combining. In [14], authors have studied the performance of the packet combining scheme for the CDMA based wireless ATM network. The author did not consider packet size adaptation in his scheme. The chase combining has been described in [15]. In [8], the authors have proposed a technique for improving the throughput efficiency of ARQ system using Maximal Ratio Combining (MRC). In this scheme, they have proposed the time diversity reception of packets and MRC combining of the received packets. In this scheme, they have not considered the effect of packet size on throughput. This scheme is modified in [16] by employing finite number of transmissions of a packet. Here also, there is no packet size optimization and both these schemes employ SW ARQ.

The other approach for improving the throughput of wireless link is packet size adaptation. In [17], it has been shown that the throughput of a wireless link can be improved by packet size optimization based on the channel conditions. In [18], an expression for the optimum packet length that maximizes throughput, has been obtained.

However, both [17] and [18] have not considered packet combining. In [19], authors proposed link adaption scheme with optimal packet size and adaptive modulation and coding (AMC). Here the authors did not consider packet combining.

C. Our contributions

Our proposed schemes consider packet size adaptation along with packet combining, which has not been addressed previously. We also evaluate the performance of GBN and SR ARQ.

Specifically the key contributions are as follows: We first propose the ARQ schemes using packet size adaptation for maximizing throughput in presence of diversity combining at physical layer. Next we propose the extension of existing SW, GBN and Selective repeat ARQ to account for diversity combining. From our extensive simulation results, the proposed schemes demonstrate significant gain in throughput. We believe that our proposed schemes can be incorporated in the current system in a cost effective way.

The rest of the paper is organized as follows. In Section II, we discuss the system model and describe how diversity combining can be applied with ARQ protocols. In Section III, we discuss packet length optimization for varying BER. Fading channel model is given in Section IV. We describe the simulations and results in Section V. Finally, we conclude in Section VI.

II. SYSTEM MODEL

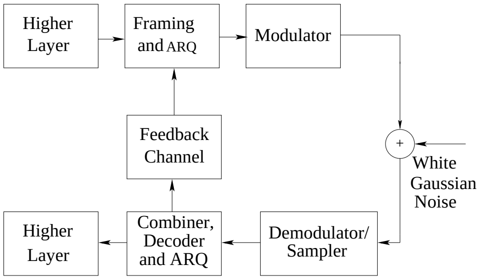

Fig. 1. Block diagram for the system under consideration

The block diagram of the system under consideration is shown in Fig. 1. We assume that the higher layers at the transmitter provide a bit sequence to be transmitted to the MAC layer. We assume the saturated case, i.e., the higher layers always have data to transmit. At MAC layer, the received bit sequence is partitioned into segments of appropriate size. Each segment is converted into a packet (packetization) by adding header, trailer (for packet identification) and cyclic redundancy check (CRC) bits for error detection. We assume that the packet header is also protected with a header CRC. This allows us to determine the packet sequence number, even when some data bits are received erroneously. Such assumption is also made in [21]. We assume that the CRC is perfect, i.e., it can detect any pattern of bit errors. After packetization, the MAC layer packet is given to the ARQ block, which chooses the next packet for transmission and provides it to the physical layer. The physical layer converts the bit sequence in the packet into baseband signal by assigning a pulse of amplitude +1 (-1, resp.) units for bit 1 (0, resp.). The width of the pulse is determined by the rate of transmission, which we assume to be fixed. Though, coding is not assumed, our proposed approach can be readily extended to account for any channel coding strategy. The baseband signal is then modulated and transmitted over Additive White Gaussian Noise (AWGN) channel. Fading is considered in Section IV.

At the receiver, the received signal is first demodulated to obtain the baseband signal (original baseband signal plus noise). The obtained baseband signal is then sampled for detection of the transmitted bits. We assume the maximum likelihood detector. In general, the sampled values are discarded after detection, and only the estimated bit sequence is provided to the MAC layer. We, however, consider a cross layer approach in which the sampled values are provided to the MAC layer. Thus, in our approach, the MAC layer is responsible for detection[1]. After detection, the sampled values (denoted by $\vec{C}$) are not immediately discarded as in the traditional approach, rather these may be retained for combining with the retransmission of the same packet in future, in case the current packet is received in error. Indeed, for each erroneously received packet, the average sample values (denoted by $\vec{A}$) are stored with two identifiers, namely, the packet sequence number (SN) and the retransmission count (r), i.e., a three tuple $(SN, r, \vec{A})$ is retained. The retransmission count keeps track of how many times the given packet is retransmitted, while average sample value is the average of the sample values that are observed in the previous retransmissions. Next, we explain in detail, how average sample values and the retransmission count is updated. First, after the detection based on the received sample values $\vec{C}$, the packet CRC is checked. If the CRC checks, then the packet is accepted as correct and ACK is sent to the transmitter. Moreover, any stored $(SN, r, \vec{A})$ data for the packet is discarded from the memory. Now, if the packet CRC does not check, the header CRC is checked. If the header CRC does not check, then packet is declared erroneous and NACK is sent. Also, $\vec{C}$ is discarded. Note that when the packet header is in error, it is not possible to identify the packet sequence number, and as a result it is not possible to know with which packet the current sample data should be combined. Hence, $\vec{C}$ is discarded immediately. Otherwise, i.e. if the header CRC checks, then we look for the average sample value data for the sequence number (say, sn) in the packet header. If $(sn, r, \vec{A})$ exists in memory, then it is updated as follows:

$$\begin{aligned} \vec{A} &\leftarrow \frac{r\vec{A}+\vec{C}}{r+1}, \\ r &\leftarrow r+1. \end{aligned}$$

After update, the detection is performed on $\vec{A}$, and then the packet CRC is checked. If CRC checks, then the packet is declared to be correct and ACK is sent, and $(sn, r, \vec{A})$ is discarded from the memory. Otherwise, NACK is sent to the transmitter. The pseudo code for the above procedure is provided in Algorithm 1.

At this point, we would like to mention that since the previous works [8], [16] that deal with the interaction of ARQ and diversity combining, consider SW ARQ, do not need such explicit procedure and data storage for combining. This is because in SW ARQ, the same packet is retransmitted until received correctly. We, however, allow for other ARQ protocols like GBN and SR as well. Thus, subsequent packets may arrive at the receiver even when the current packet is in error. As a result, the receiver may accumulate many erroneous packets before receiving their retransmissions. Thus, it becomes challenging to determine which packets should be combined together. We will show that though the detection procedure is more involved and additional storage is required for GBN and SR, the throughput gain of these protocols over SW is significant.

Algorithm 1 :Pseudo code for MRC combining and detection procedure at the receiver

```
Receive $\vec{C}$ (let the packet sequence number be $sn$)
Check packet CRC
if CRC checks then
    Frame accepted as correct
    Send ACK
    Discard $(sn, r, \vec{A})$
else
    Check header CRC
    if header CRC does not checks then
        Declare packet in error
        Send NACK
        Discard $\vec{C}$
    else
        Check $sn$
        if $(sn, r, \vec{A})$ exists in memory then
            $\vec{A} \leftarrow \frac{r\vec{A}+\vec{C}}{r+1}$
            $r \leftarrow r+1$
            Check packet CRC
            if CRC checks then
                Packet Correct
                Send ACK
                Discard $(sn, r, \vec{A})$
            else
                Send NACK
            end if
        end if
    end if
end if
```

We would also like to note that the proposed combining technique is adaptation of MRC technique for time diversity. Typically, MRC is employed for space diversity combining, where multiple copies of the same signal separated in space are combined. MRC is an optimal diversity combining technique that aligns the phase of the carriers in two receiver chains and provides gain in proportion to the individual receiver's signal amplitude and in inverse proportion to the individual receiver's noise power. The effects of fading are mitigated when independent fading paths are coherently combined. The output of the combiner is just a weighted sum of the different fading paths or branches [22], [23]. Different proportionality constants are used for each channel. MRC combiner is an optimal combiner for AWGN channel. Moreover, if the noise level is same on all the branches, then optimal weights used by the combiner are equal. In ARQ diversity combining (our case) different channels refer to different retransmissions separated over time. Since the noise process is stationary, all the proportionality constants reduce to 1. Thus, in our case, signal SNR increases linearly with each retransmission of the packet. Here onwards we refer to the proposed combining technique as MRC combining.

In the following section, we discuss how to choose appropriate packet size to maximize throughput.

III. PACKET LENGTH OPTIMIZATION

Here, our aim is to determine the optimal packet length. The packet length is considered optimal in the sense that it

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[1] For maximum likelihood estimator only a comparator logic is required for detection, which is simple to implement.

maximizes the throughput, where *throughput* is defined as the number of data bits delivered correctly to the receiver per unit time. Clearly, an optimal packet size has to be obtained by taking into consideration the combining technique and the ARQ protocol used. Typically, it is difficult to obtain the throughput of a general ARQ protocol. Hence, a popular metric used to get an approximate indication of the throughput performance is *Throughput Efficiency* [18].

Definition 1: Throughput Efficiency of the system is defined as the number of data bits delivered correctly to the receiver for each bit transmitted by the transmitter. Mathematically, let $T_b(t)$ and $R_b(t)$ denote the total number of bits transmitted by the transmitter and the total number of data bits received correctly at the receiver, respectively. Then, throughput efficiency η is given as

$$\eta = \lim_{t\to\infty}\inf \frac{R_b(t)}{T_b(t)}.$$

As our simulation results illustrate, the packet size that maximizes throughput efficiency achieves close to maximum throughput. Hence, from here onwards, optimal packet size refers to one that maximizes throughput efficiency.

Now, we compute the optimal packet size. For that, we first compute the BER for AWGN channel when MRC combining is used. Because of MRC combining, clearly, the BER is a function of the number of correct copies received. Now, due to AWGN and maximum likelihood estimator assumptions, BER is equal to the probability of detection error, as in AWGN channel with maximum likelihood estimator at the receiver, the detection errors are independent and identically distributed across transmitted bits. Moreover, the probabilities of detection error for bits 1 and 0 are the same. Thus, without loss of generality, let us consider that i copies of bit 1 are transmitted. Let us assume the perfect sampler, i.e., the sampled value is equal to the peak amplitude of the transmitted signal in absence of noise. In presence of noise, however, the sampled value of the j^{th} symbol is $1+n_j$ units, where n_j is a Gaussian random variable (r.v.) with mean 0 and variance σ^2. Note that σ^2 is the noise power spectral density. Thus, after combining i samples, we obtain the average sample value as $1+\frac{\sum_{j=1}^{i} n_j}{i}$, where $n_1,\ldots,n_i$ are i.i.d. Gaussian r.v.'s. Now, the maximum likelihood estimator makes detection error if $1+\frac{\sum_{j=1}^{i} n_j}{i} < 0$. Thus, BER after combining i received copies of the bit is

$$p_{bi} = Q\left(\frac{\sqrt{i}}{2\sigma}\right), \tag{1}$$

where $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-u^2/2}du$.

Now, using the BER computed above, we can obtain the packet error probability (probability that at least one bit is received in error) as follows. Let a packet containing L bits is transmitted i times, and these transmissions are MRC combined at the receiver. Then the probability of packet error after i transmission (p_i) is equal to $1-(1-p_{bi})^L$. Next using p_i's we obtain throughput efficiency. Let $L = l + h$, where l denotes the number of data bits (payload), while h denotes the number of redundant bits added for framing. Then, the throughput efficiency is given as

$$\eta = \left(\frac{l}{l+h}\right)\frac{1}{(1+p_1+p_1p_2+p_1p_2p_3+\cdots)}. \tag{2}$$

Here $(1+p_1+p_1p_2+p_1p_2p_3+\cdots)$ is the expected number of transmissions required to deliver the packet correctly. Thus, our optimization problem is to find $l^* \geq 0$ that maximizes η in (2). This problem is difficult to solve analytically. It is also difficult to solve using standard optimization algorithms as the packet error probability is different for different transmissions. Hence, we seek following approximations. We fix k and assume that $p_j = p_k$ for every $j \geq k$. We refer to this approximation as k-channel approximation. With k-channel approximation, (2) becomes

$$\eta = \left(\frac{l}{l+h}\right)\frac{1}{1+\sum_{u=1}^{k-2}\prod_{v=1}^{u} p_v + \frac{\prod_{v=1}^{k-1} p_v}{1-p_k}}. \tag{3}$$

Now, l^* that maximizes η in (3) is obtained by Newton-Raphson method [24]. Note that the approximation becomes more and more accurate as larger values of k is chosen (refer to Fig. 2).

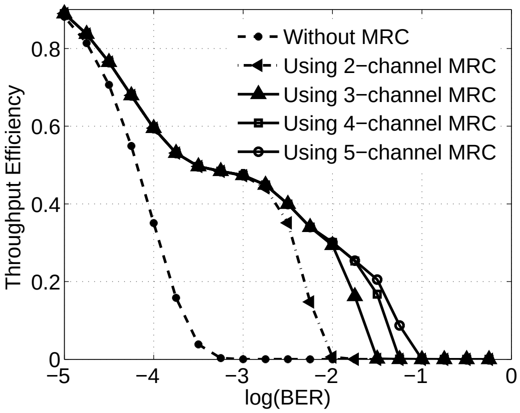

Fig. 2. Throughput vs BER with MRC

We only need the knowledge of BER for computing optimal packet size. If BER is not known a priori, then it can be easily estimated by sending pilot symbols periodically to the receiver. In this scheme, the receiver estimates BER and sends it to the transmitter. Alternatively, BER can also be estimated using packet error rate at the receiver. Information about the packet error rate at the receiver is also available at the transmitter because of the acknowledgements.

IV. FADING CHANNEL MODEL

Till now we have considered AWGN channel with i.i.d. bit errors. In actual practice the transmitted signal arrives the receiver via several paths and with different time delays. These multipath signals with random distributed amplitudes and phases combine at the receiver to give a resultant signal which fluctuates in time and space. This phenomenon of random fluctuations in the received signal level is termed as fading [22]. A baseband multipath fading channel can be modelled as a multiplicative fading component and a additive noise component. Rayleigh fading is a typical model for multiplicative component. Generally Rayleigh fading is often

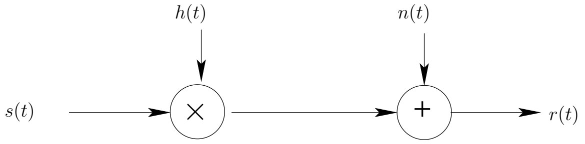

Fig. 3. Fading channel model

a good approximation of realistic channel conditions. But it is considered to be a worst case scenario of signal fading. If a wireless receiver works in a Rayleigh fading channel then it is likely to work in other types of channels.

As shown in the Fig. 3 the Rayleigh fading channel is modelled as

$$r(t) = h(t).s(t) + n(t)$$

where $r(t)$ is a received signal, $s(t)$ is the transmitted signal, $h(t)$ is multiplicative distortion of the transmitted signal $s(t)$ and $n(t)$ is the white gaussian noise. A received signal is the sum of signals with different phases caused by different paths. The amplitude of the received signal can be modelled as a random variable with Rayleigh distribution, whose pdf $f(r)$ is given by

$$f(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}; \quad r \geq 0.$$

Here $2\sigma^2$ is the pre detection mean power of the received signal. σ^2 is the variance of the two zero mean i.i.d. gaussian random variables. The simulations and results for AWGN and fading channel are discussed in Section V.

V. SIMULATION RESULTS AND DISCUSSION

A. Simulations and Results for AWGN channel

In the previous sections, we have discussed three factors that can potentially provide throughput gain in AWGN channel. These factors are: (a) MRC combining, (b) packet size adaptation, and (c) sophisticated ARQ protocols like GBN and SR. Here, using simulation, our aim is to quantify the throughput improvement because of each of these factors, and also because of their combinations. First, we describe our simulation setup.

We have simulated a point to point AWGN channel. The noise power spectral density is σ^2. We consider Binary Phase Shift Keying (BPSK) modulation scheme. We assume that the MAC layer packet contains 240 redundant bits, i.e., $h = 240\ bits$ as in IEEE 802.11. The window size for GBN and SR ARQ is assumed to be 8 packets (3 bits used to represent sequence number).

1) Effect of MRC Combining: Here, our aim is to quantify how much throughput gain is obtained through MRC combining alone. For this, we simulate all three ARQ protocols with and without MRC combining for various payload sizes (l) ranging from 10 bits to 18×10^3 bits and BER=10^{-3}. The results are shown in Fig. 4. Note that for all values of the packet sizes, the system with MRC combining provides significant throughput gain over the system without MRC for each of the ARQ protocols. In Fig. 5, we plot the throughput gain achieved by the system with MRC combining over that of the system without MRC combining as a function of BER. Under the specified ARQ protocol (say a), the throughput gain for a given BER (say b) (denoted by $G(a,b)$) is defined as follows:

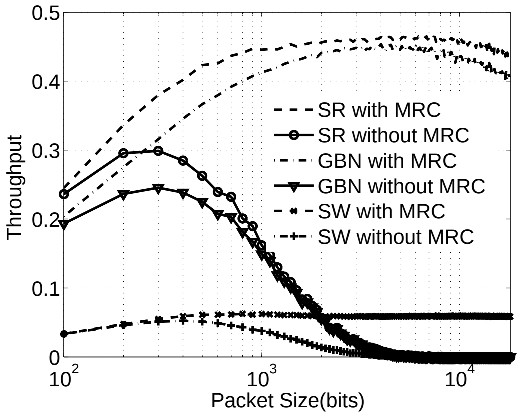

Fig. 4. Throughput performance of various ARQ protocols as a function of payload size in the systems with and without MRC

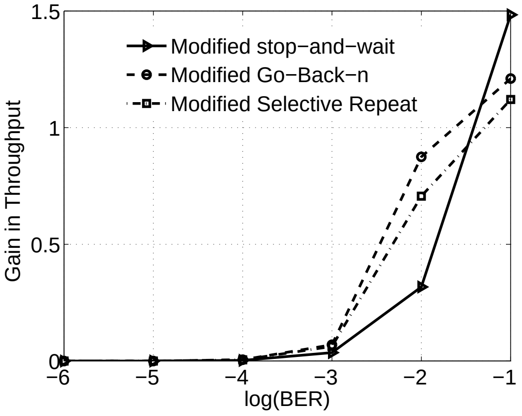

Fig. 5. Throughput gain under various ARQ protocols

$$G(a,b) = \frac{T^*_{MRC}(a,b) - T^*(a,b)}{T^*(a,b)},$$

where $T^*_{MRC}(a,b)$ and $T^*(a,b)$ are the maximum throughput values for BER b for a given ARQ protocol a, under the systems with and without MRC combining, respectively. Here, the throughput is maximized over all packet sizes; and the maximum value is obtained by performing simulations for various packet sizes, and then choosing the maximum value of throughput observed. We note that the throughput gain increases sharply for BER greater than 10^{-3}. Thus, MRC combining is much more effective in a low SNR region and packet size adaptation is the main reason for throughput improvement for the BER less than 10^{-3}.

2) Effect of Packet Size Adaptation: To capture the effect of packet size adaptation, we perform the following simulations

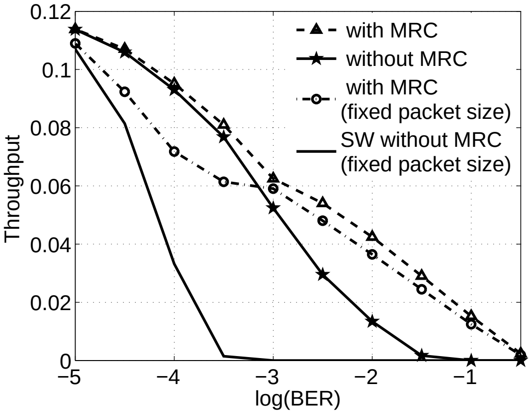

Fig. 6. Throughput improvement due to packet size adaptation as a function of $\log(BER)$ under SW ARQ in the systems with and without MRC

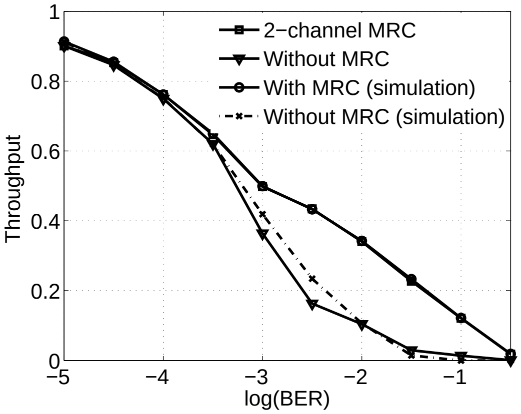

Fig. 7. Throughput comparison between the optimal throughput and the throughput obtained by using packet size computed with the analysis.

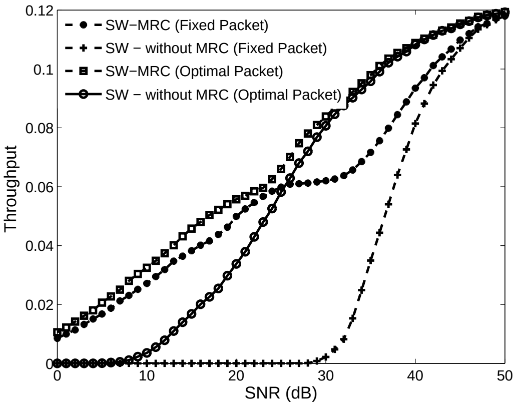

Fig. 8. Improvement in throughput of SW protocol in fading channel

in systems with and without MRC combining. First, we fix the packet size to 2347 bytes (maximum size for IEEE 802.11 system), and obtain the throughput for this packet size as a function of BER in the systems with and without MRC. Next, we compare the throughput values obtained above with $T^*_{MRC}(b)$ and $T^*(b)$ obtained for various BERs b. In all the cases above, the ARQ protocol is SW. The comparison is shown in Fig. 6. Note that the system with packet adaptation has significantly higher throughput than that in the system with fixed packet size (2347 bytes). The simulation results for other fixed packet sizes also yield the similar results.

3) Effect of ARQ Protocol: Here, using simulations, we quantify the effect of ARQ protocols on the throughput of the systems with and without MRC combining. Fig. 4 shows the throughput improvement achieved by SR and GBN ARQ over that of SW ARQ with and without MRC combining for various payload sizes. Here, we note that in the system without MRC combining the throughput gain of the SR and GBN ARQ over that of SW ARQ diminishes quickly as the packet size increases. However, with MRC combining, the throughput gain of the SR and GBN ARQ over that of SW ARQ is significant for the complete range of packet sizes considered. This throughput gain provides a strong case for replacing SW ARQ by either SR or GBN ARQ.

4) Comparison of Analysis and Simulation: In Section III, we have shown how optimal packet length can be obtained analytically. But, here, the packet length is chosen to maximize the throughput efficiency of the system. As Fig. 7 shows, the throughput obtained by using the packet size calculated by analysis is close to that of maximum throughput achieved in the system (ARQ protocol is SR) Thus, the analytic approach that we proposed works well in practice.

B. Simulations and Results for fading channel

Here throughput improvement is observed with our proposed ARQ scheme when the channel is i.i.d. fading with added gaussian noise. We assume that the channel fading doesn't change for the entire duration of packet transmission. We consider a point to point channel and BPSK modulation scheme. We assume that the MAC layer packet contains 240 header bits and a variable payload from 100 bits to 18000 bits. We consider Rayleigh fading channel. First the simulation is done for a SW protocol. Here we assume that the acknowledgement is received by the sender after a delay of 8 packets transmission time. Fig. 8 shows the improvement in throughput for this scenario.

Note that the throughput with MRC is higher than throughput with optimal packet size below SNR=26 dB whereas the throughput with optimal packet size is higher than throughput of MRC above SNR of 26 dB.

Next we investigate the throughput improvement in fading channel when GBN ARQ is employed. We consider the window size for GBN and SR to be 8 packets. Fig. 9 shows significant improvement in throughput of GBN ARQ when optimum packet length along with MRC combining is employed. When optimum packet size is used (without MRC) the throughput improvement over normal ARQ (without MRC -Fixed packet) can be observed at all SNRs. When only MRC combining is used the throughput is still higher than that of the normal ARQ but there are two crossover points with optimal packet scheme at SNR=19 dB and 32 dB. Between SNR= 19 dB to 32 dB the throughput of MRC scheme is higher than throughput with optimal packet length.

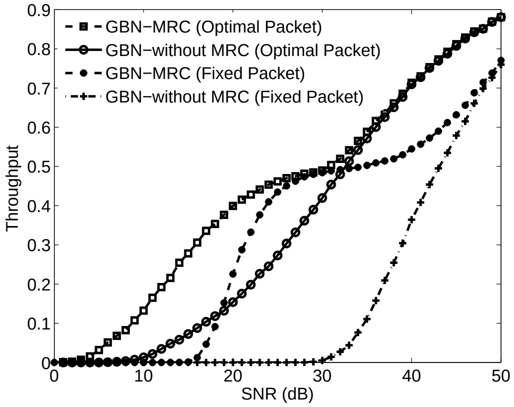

Fig. 9. Improvement in throughput of GBN protocol on fading channel

SR ARQ gives more throughput than GBN and SW ARQ. As shown in Fig. 10, The throughput of SR ARQ can be enhanced with optimal packet size alongwith MRC combining. Here as in GBN there are two crossover points of MRC-SR with optimal packet scheme at SNR of 19 dB and 29 dB. Between these points the throughput of MRC scheme is higher than that with optimal packet length.

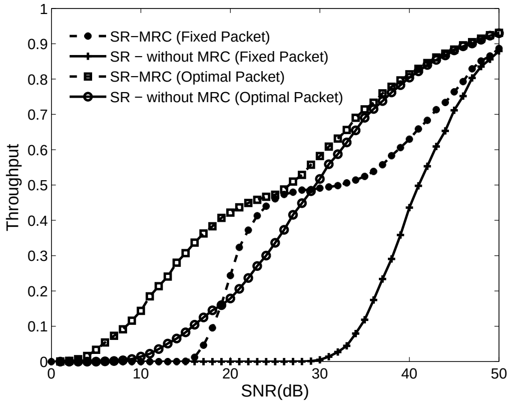

Fig. 10. Improvement in throughput of SR protocol on fading channel

VI. CONCLUSIONS

In this paper we have proposed the effective ARQ schemes for improving the throughput of SW, GBN and SR ARQ. The proposed ARQ protocols offer higher throughput than the conventional ARQ protocols. A novel method of packet size optimization (which is network layer technique) combined with the MRC applied on each bit of packet (which is a physical layer technique) is employed. We observe that for modified ARQ protocols, the improvement in throughput is significant at higher bit error rate, where throughput drops due to transmission errors.

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