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ORIGINAL CONTRIBUTION

Adaptive Packet Combining Scheme in Three State Channel Model

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Abstract The two popular techniques of packet combining based error correction schemes are: Packet Combining (PC) scheme and Aggressive Packet Combining (APC) scheme. PC scheme and APC scheme have their own merits and demerits; PC scheme has better throughput than APC scheme, but suffers from higher packet error rate than APC scheme. The wireless channel state changes all the time. Because of this random and time varying nature of wireless channel, individual application of SR ARQ scheme, PC scheme and APC scheme can't give desired levels of throughput. Better throughput can be achieved if appropriate transmission scheme is used based on the condition of channel. Based on this approach, adaptive packet combining scheme has been proposed to achieve better throughput. The proposed scheme adapts to the channel condition to carry out transmission using PC scheme, APC scheme and SR ARQ scheme to achieve better throughput. Experimentally, it was observed that the error correction capability and throughput of the proposed scheme was significantly better than that of SR ARQ scheme, PC scheme and APC scheme.

Keywords Packet combining · Aggressive packet combining · Automatic repeat request · Markov chain · Throughput

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Introduction

Automatic Repeat reQuest (ARQ) scheme is one of the basic error control techniques used in wireless communication system. In ARQ scheme, a packet is retransmitted if it gets corrupted due to transmission errors caused by the channel. Because of too many expensive retransmissions, ARQ suffers from very low throughput in wireless network. In order to achieve desirable levels of error correction capability and throughput, in wireless channels with high bit error rate, several improvements of basic ARQ scheme are found in literature [1–7]. In ARQ scheme, on receiving an erroneous packet, the receiver discards it and immediately requests for retransmission of the packet by sending Negative AcKnowledgment (NAK) to the transmitter. However, the erroneous packet received by the receiver contains correct bits in addition to erroneous bits. The erroneous packets can be buffered at the receiver and the erroneous and the correct bits of these packets can be combined to extract useful information for error detection and correction at the receiver. This approach eliminates the expensive transmission of NAK and retransmissions of the packet; which in turn contributes to improve the throughput of a wireless communication system. This technique has been used in Packet Combining (PC) scheme [8] and Aggressive Packet Combining (APC) scheme [9].

In PC scheme [8, 10], the receiver on receiving an erroneous packet buffers it and requests for retransmission of the packet by sending NAK to the transmitter. On receiving NAK, the transmitter retransmits a copy of the packet to the receiver; on receiving the retransmitted copy the receiver checks for errors in the retransmitted copy of the packet. If the retransmitted copy is again found to be erroneous, the receiver does not immediately send NAK to the transmitter, instead the receiver uses the second erroneous copy of the packet to perform XOR operation with the first, buffered, copy of the packet to obtain an error vector that contains the probable bit positions of the erroneous bits. A bit 1 in the error vector indicates a possibility of occurrence of an error in the location of bit 1, and a bit 0 in the error vector indicates no error in the location of bit 0. If the number of bit 1 in the error vector exceeds N_{max}, where N_{max} is the maximum number of erroneous bits that can be corrected using PC scheme, the receiver requests for retransmission of the packet by sending NAK to the transmitter. But if the number of bit 1 in the error vector does not exceeds N_{max}, the receiver bit inverts the located erroneous bits, in the received erroneous copies, using brute force method to retrieve the correct copy of the packet. If the correct copy of the packet is retrieved, the receiver discards the buffered erroneous copies and it sends ACKnowledgment (ACK) to the transmitter for transmission of the next packet, otherwise, the receiver buffers the erroneous copies of the packet and requests for retransmission of the packet by sending NAK to the transmitter. If the retransmitted copy of the packet is again received with errors, the receiver performs XOR operation, using the current received erroneous copy and one out of the two buffered erroneous copies, and bit inverts the located erroneous bits; the above mentioned procedure of error detection and correction is repeated with all possible pairs of erroneous copies of the packet in an attempt to retrieve the correct copy of the packet. And this process is repeated till the correct copy of the packet is obtained or till the specified maximum number of retransmission of the transmitter is reached, in which case the transmission of the packet is aborted.

PC scheme fails to address double errors that occur at the same bit position in both the erroneously received copies of the packet. PC scheme also fails to handle when number of erroneous bits exceeds N_{max}, where N_{max} is the maximum number of erroneous bits that can be corrected using PC scheme.

However, due to poor error correction capability of PC scheme, the number of retransmission increases with increase in channel error rate which in turn deteriorates the packet throughput of PC scheme. Further, every retransmission is associated with two unavoidable propagation delays, one for NAK and the other for retransmission; this increases latency i.e., delay in the delivery of the packet to the receiver. With increase in number of retransmissions, consumption of scarce resources like communication bandwidth and transmission energy increases. In order to address the above mentioned limitations of PC scheme, APC scheme was proposed by Leung [9].

In APC scheme, the receiver on receiving an erroneous copy of the packet transmitted by the transmitter buffers it and requests for retransmission of the packet by sending NAK to the transmitter. The transmitter on receiving NAK message from the receiver re-transmits two copies instead of one copy of the packet. The transmission of the second redundant copy facilitates better error correction. The receiver on receiving the retransmitted copies of the packet checks for errors using each received packet separately; if both the retransmitted copies are also found to be erroneous, the receiver performs bitwise majority voting using the received three erroneous copies to obtain a combined packet. The receiver checks for errors in the combined packet; if the combined packet is found to be erroneous, it obtains the least reliable bits in the combined packet, using bit-by-bit majority voting, and searches for the correct bit pattern for the identified least reliable bits in the combined packet to retrieve the correct copy of the packet. In case, if APC scheme fails again, the above mentioned procedure is repeated. In case, if correct copy of the packet is retrieved or received successfully, the receiver discard the erroneous copies of the packet and sends ACK to the transmitter for transmission of the next packet. However, APC scheme fails when at least an error occurs in the same bit position of all received erroneous copies of the packet. For a successful transmission, APC scheme uses at least three erroneous copies of the packet due to which APC scheme suffers from low packet throughput and low throughput [11].

In comparison to PC scheme, APC scheme has better error correction capability with reduced latency, but PC scheme offers better throughput than APC scheme. However, the throughput of the PC scheme drastically deteriorates with increasing Bit Error Rate (BER) of the wireless channel. Thus, PC scheme is suited for channels with low BER, while APC scheme for channels with high BER.

Wireless channels exhibit random and time varying characteristics, due to factors such as multi-path fading, shadowing, interference and noise [12]. Therefore wireless channels do not remain in the same channel condition all time [13].

Several researches attempted to model wireless channels [14–17] with a goal to accurately describe the random and time varying characteristics of wireless channels. The two basic categories of wireless channel models are: single state model and multi state model. Single state model considers single channel environment, whereas multi state model considers different channel environment, and it is more realistic. In [16], a three-state Markov chain based channel model is proposed, that describes wireless channel in three states, namely, good state, moderate state and bad state. Good state refers to channel condition in which the received signal strength of a wireless radio device is strong; Bad state refers to channel condition in which the received signal strength of the wireless radio device is the weakest and moderate state lies between good state and bad state.

The state transition model based on the three state Markov chain is shown in Fig. 1. Since the wireless channel conditions change dynamically, therefore, logically there is neither any reason of assuming that error syndrome of channel remains same, nor any reason to apply same scheme for error correction for all conditions of channel, particularly when throughput is a measure of performance of any scheme. Thus, there is a need of a packet combining scheme which would adapt itself to the time varying characteristics of wireless channels.

In order to meet the desirable values of throughput and error correcting capability in random and time-varying wireless channel, an adaptive packet combining scheme, that uses PC scheme and APC scheme, is proposed and is discussed next.

Adaptive Packet Combining Scheme

Generally, Selective Repeat (SR) ARQ scheme is used in good state, where the probability of packet being delivered successfully is very high; PC scheme is used in moderate state, where the BER of channel is neither high nor low; and APC scheme is used in bad state, where the BER of channel is very high.

The operation of the proposed AdPC scheme is shown in Fig. 2. Assuming that initially the channel is in good state, the transmitter transmits a copy of a packet, *packet1_copy1*, using SR ARQ protocol. The receiver performs error detection on the received copy, *packet1_copy1*, and if no errors are detected, it sends ACK to the transmitter for transmission of next packet. The transmitter, on receiving ACK, assumes that the channel is in good state and it transmits a copy of the next packet, *packet2_copy1*. If the received packet, *packet2_copy1*, is found to be erroneous, the receiver buffers the received erroneous copy, *packet2_copy1*, and it requests for retransmission of the packet, *packet2*, by sending NAK to the transmitter. The transmitter, on receiving NAK, assumes that the channel has moved to moderate state, and it re-transmits

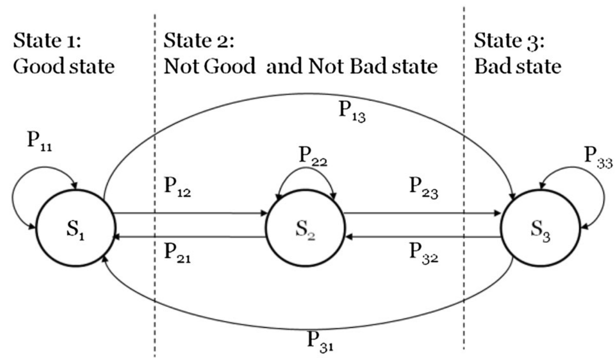

Fig. 1 Three state Markov chain

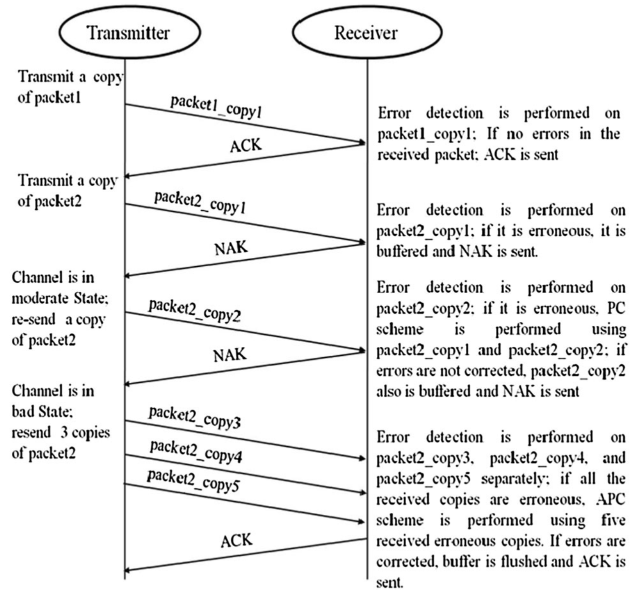

Fig. 2 Transmission model of adaptive packet combining scheme

another copy of the packet, *packet2_copy2*. The receiver, on receiving retransmitted copy, *packet2_copy2*, checks for errors on it, if it is found to be erroneous, the receiver applies PC scheme using *packet2_copy1* and *packet2_copy2* as mentioned above. If correct copy is not retrieved, the receiver buffers both the received erroneous copies of the packet, *packet2_copy1* and *packet2_copy2*, and requests for retransmission of the packet by sending NAK to the transmitter. On receiving consecutive NAKs, the transmitter, assumes that the channel has moved to bad state and re-transmits three copies of the packet, *packet2_copy3*, *packet2_copy4* and *packet2_copy5*. The receiver on receiving the three retransmitted copies, *packet2_copy3*, *packet2_copy4* and *packet2_copy5*, performs error detection on these three copies of the packet separately. If at least a copy is detected without error, that copy is accepted as the correct copy of the packet and the receiver, discards the erroneous copies including the previously buffered copies and sends ACK to the transmitter for transmission of the next packet. But, if *packet2_copy3*, *packet2_copy4* and *packet2_copy5* are all found to be erroneous, APC scheme is performed on *packet2_copy3*, *packet2_copy4* and *packet2_copy5*. If APC scheme using these three erroneous copies, *packet2_copy3*, *packet2_copy4* and *packet2_copy5*, fails to correct the errors, the receiver re-performs APC scheme using five erroneous copies: *packet2_copy1*, *packet2_copy2*, *packet2_copy3*, *packet2_copy4* and *packet2_copy5*. The APC scheme using five copies is illustrated in Fig. 3. If APC scheme using five erroneous copies, *packet2_copy1*, *packet2_copy2*, *packet2_copy3*, *packet2_copy4* and *packet2_copy5*, successfully retrieve the correct copy, the receiver sends ACK to the transmitter for transmission of the next packet. But if APC scheme fails, the receiver sends NAK to

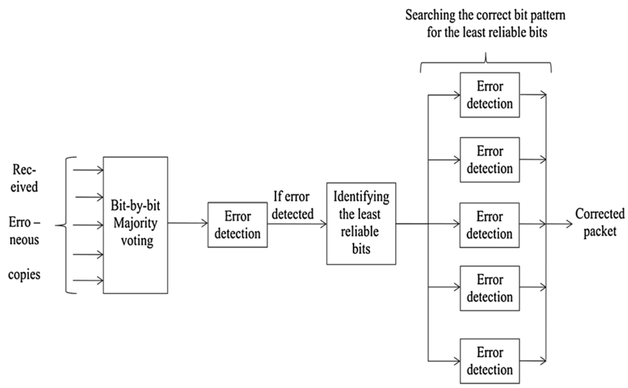

Fig. 3 APC scheme with 5 packets

the transmitter for retransmission of the packet. The transmitter, on receiving the third NAK for the packet, retransmits another two copies of the packet. If these two retransmitted copies are found to be erroneous, the receiver performs APC scheme using seven erroneous copies of the packet, and the above described procedure is repeated.

Further, the proposed scheme of Adaptive Packet Combining (AdPC) scheme could be adopted when the initial state of channel is moderate or bad state, say when a radio device is powered on in a low signal strength area. The operation of AdPC scheme in moderate state is shown in Fig. 4. The transmission model of AdPC scheme when the initial state is bad is shown in Fig. 5.

Throughput Analysis

AdPC scheme is analyzed considering binary symmetric channel with BER α and packet size of n bits, with a negligible round trip delay and an error-free feedback path, in three state Markov model. Further, it is assumed that error detection works perfectly.

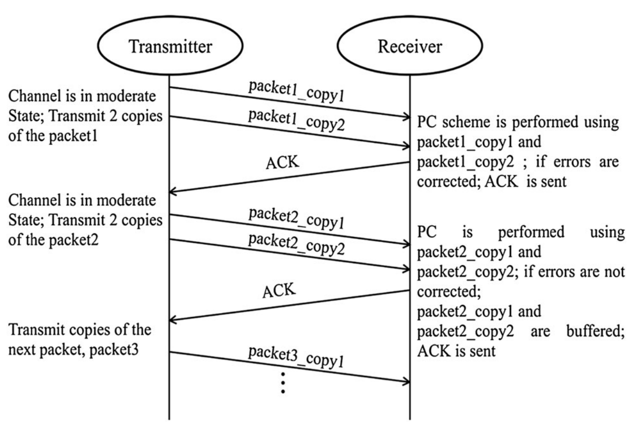

Fig. 4 Transmission model of AdPC scheme when the initial channel state is moderate

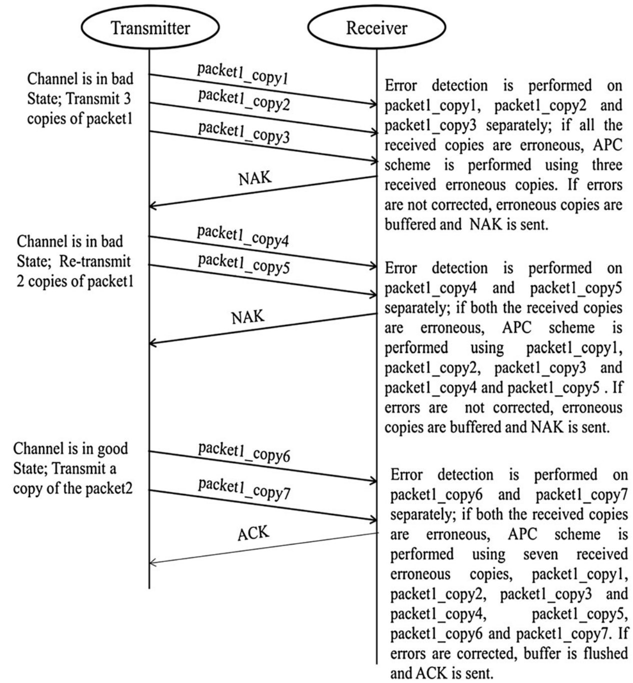

Fig. 5 Transmission model for AdPC scheme when the initial channel state is bad

The probability of packet being in error [18] in good state employing SR ARQ scheme is:

$$P_g = 1 - (1 - \alpha)^n \tag{1}$$

The packet throughput in good state using SR ARQ scheme is:

$$T_g = 1 - P_g \tag{2}$$

PC scheme is used in moderate channel state. PC scheme fails when there is a double error in the same bit position of both the received erroneous copies; but it can correct errors which do not occur in the same bit position of both the received erroneous copies if the number of bits in error does not exceeds N_{max}. Assuming N_{max} to be infinite, the probability of errors which do not occur in the same bit position of both the received erroneous copies is $\left(\binom{2}{1}\alpha(1-\alpha)\right)^n$. Thus, the probability of packet being in error in moderate state using PC scheme is:

$$P_m = \left(1 - (1 - \alpha)^n\right)^2 - \left(\binom{2}{1}\alpha(1-\alpha)\right)^n \tag{3}$$

Thus the packet throughput in moderate state which uses PC scheme is:

$$T_m = 1 - P_m \tag{4}$$

APC scheme is used when channel state is bad, it fails when triple error occur in the same bit position of all the received three erroneous copies; the probability of triple error in a n bit packet is $\left(\binom{3}{3}\cdot\alpha^3\right)^n$. APC scheme can correct errors which occur only in one out of three erroneous copies of the packet and double errors that occur in the same bit position of received two out of three erroneous copies of the packet. The probability of error occurring only in one copy out of three erroneous copies of the packet is $\left(\binom{3}{1}\cdot\alpha\cdot(1-\alpha)^2\right)^n$ and the probability of double error in three copies is $\left(\binom{3}{2}\cdot\alpha^2\cdot(1-\alpha)\right)^n$. Therefore, the probability of packet being in error in bad channel state using APC scheme is:

$$P_b = (1-(1-\alpha)^n)^3 - \left(\binom{3}{1}\cdot\alpha\cdot(1-\alpha)^2\right)^n - \left(\binom{3}{2}\cdot\alpha^2\cdot(1-\alpha)\right)^n \tag{5}$$

The packet throughput in bad state using APC scheme is:

$$T_b = 1 - P_b \tag{6}$$

It is known that $P_g + P_m + P_b = 1$ by probability theorem. The probability of packet being in error in proposed AdPC scheme is:

$$P_H = P_g \times P_m \times P_b \tag{7}$$

Throughput of the proposed AdPC scheme is:

$$T_H = 1 - P_H \tag{8}$$

Simulation Result

The proposed AdPC scheme was simulated using MATLAB R2012b in a windows-8 environment on an Intel based 1.70 GHz PC having 4 GB RAM. Initially, experiments were conducted to compare the performances of SR ARQ scheme, PC scheme, APC scheme and AdPC scheme in terms of packet error rate. Packet error rate indicates the reliability of an error correction scheme. Lower the packet error rate of a scheme better is its reliability. The packet error rates of SR ARQ scheme, PC scheme, APC scheme and AdPC scheme, for packet size $n = 128$ and BER ranging from 10^{-8} to 0.03, were plotted and are shown in Fig. 6. It can be observed that the performances of SR ARQ scheme, PC scheme, APC scheme and AdPC scheme deteriorates with increasing BER. However, the proposed AdPC scheme had better packet error rate than other schemes for increasing BER. The better performance of AdPC scheme could be attributed due to adaptive error correction being employed accordingly to the condition of channel.

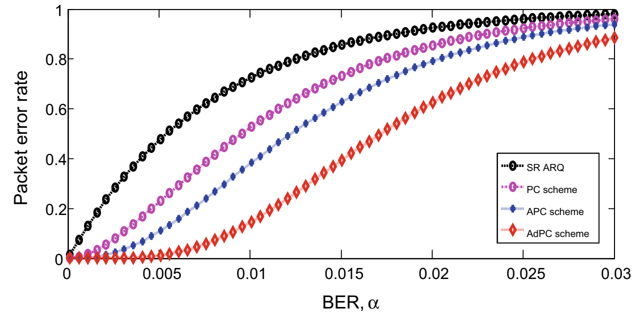

Fig. 6 PER comparison of AdPC scheme with SR ARQ scheme, PC scheme and APC scheme with n = 128

Next, experiments were conducted to compare the performances of SR ARQ scheme, PC scheme, APC scheme and AdPC scheme in terms of packet throughput. Higher value of packet throughput is desirable as it implies better bandwidth and energy efficiency. The packet throughput of SR ARQ scheme, PC scheme, APC scheme and AdPC scheme, for packet size $n = 128$ and BER ranging from 10^{-8} to 0.03, were plotted and are shown in Fig. 7. It can be observed that the packet throughput of AdPC scheme is better than that of PC scheme and APC scheme and SR ARQ scheme. The superior performance of AdPC scheme can be attributed to the adaptive transmission approach incorporated in it.

Conclusion

An attempt was made to adaptively transmit data packets, using SR ARQ scheme, PC scheme and APC scheme, based on the channel condition of wireless channel to improve the throughput of a wireless communication system. Accordingly, AdPC scheme was proposed by using three state Markov model. When the channel condition is good, AdPC scheme uses SR ARQ scheme for transmission. If the channel condition transitions to moderate state, AdPC scheme employs PC scheme. Further, if the channel condition deteriorates to bad state, AdPC scheme uses APC scheme for transmission. Experimentally, it was observed

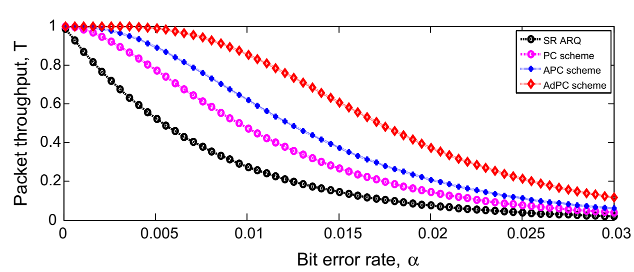

Fig. 7 Packet throughput comparison of AdPC scheme with SR ARQ scheme, PC scheme and APC scheme with n = 128

that the error correction capability of AdPC scheme was significantly better than SR ARQ scheme, PC scheme and APC scheme. Also, the throughput of AdPC scheme was better than SR ARQ scheme, PC scheme and APC scheme.

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