AGGRESSIVE PACKET COMBINING SCHEME IN MULTIPATH ROUTING TO ACHIEVE HIGHER THROUGHPUT AND ERROR CORRECTION RATES

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Abstract- In this paper the performance of Aggressive Packet Combining (APC) technique for multipath routing has been studied and analyzed. In this technique the transmitter transmits a single copy of the packet which will be received by the receiver through multiple paths. While receiving multiple copies of the packet through different transmission links it is highly unlikely that the same error pattern will appear in all the received copies. The receiver executes Aggressive Packet Combining (APC) technique on the received copies to detect and correct the errors. The simulation result shows that multipath routing offers better correction capability and higher throughput than conventional APC.

Keyword- Aggressive Packet Combining (APC), Multipath Routing, Throughput, Error Control

I. INTRODUCTION

It has been indeed a challenge to the scientists and researchers for many years to faithfully transmit data or information from a source to a destination. For this purpose Forward Error Correction (FEC) and Backward Error Correction (BEC) are the two techniques that are being extensively used. FEC is used in wireless communication and BEC has found its application in wired communication. For being cost effective many researchers are trying to implement BEC in wireless transmission of data. Chakraborty [1,2] proposed a simple yet elegant technique called Packet Combining (PC) scheme in which the information present in the erroneous copy of a packet is explored to obtain the correct packet rather than discarding the erroneous packet. In PC scheme, two erroneous copies of a packet are XORed bitwise to obtain the location of bits in error, then the located erroneous bits are invert by brute force method to retrieve the correct copy of the packet. However PC scheme cannot correct multiple errors and errors present at the same bit location.

In order to improve performance and error correction capability Leung [3] proposed Aggressive Packet Combining (APC) scheme. In APC three copies of the packet are sent from transmitter to receiver via a single transmission link. The receiver applies bit wise majority logic on the received erroneous copies to obtain a combined packet [4-8]. If the combined packet is without any detectable error, it is accepted as correct copy of the packet, but if the combined packet is found to be erroneous then receiver will obtain the least reliable bits and search for correct bit pattern to retrieve the correct copy of the packet. It has been well established and proved that APC offers significantly better performance with low latency, so it is important for wireless networks[9-13]. But APC too has many flaws. The major limitation of APC is firstly its inability to correct errors when errors are present at the same bit location of two or more copies and secondly that APC suffers from low throughput because in APC three erroneous copies are required to correct a single packet.

The aim to investigate APC in multipath routing scheme is to improve the throughput efficiency of APC as well as to increase the error correction capability. In multipath routing technique multiple alternative paths are used to transmit the data which eventually results in variety of advantages and benefits which include fault tolerance, bandwidth optimization, error correction, enhanced security etc. [14-25]. Although extensive research is being done on the domain of multipath routing but this is not being practically implemented on a large scale. The aim of this work is to make a significant contribution in the field of error control by implementing APC in multipath routing for reliable transport of data. With this in mind the following contributions has been made in this paper.

- By implementing APC in multipath routing a highly efficient system for reliable data transmission is developed and proposed. The efficiency is measured in terms of throughput performance and error correction capability.
- A detail analysis and experiment is carried out to access the superiority of the proposed scheme over conventional APC and the results are depicted at the later part of this paper.
- The simulation results clearly reflects that the proposed scheme indeed offers much better throughput efficiency and improved error correction capability.

The throughput in conventional APC scheme is very low which nearly equals to 33%. It is so because we are transmitting three copies of the packet through a single transmission medium. While in multipath routing scheme we transmit multiple copies of the packet via multiple paths i.e. only a single copy through a single path. This significantly results in higher throughput and better error correction capability as all the paths will not have the same error probability. So similar error patterns will not appear at the received copies. From the experimental results shown at the later part of this paper we have found that multipath APC indeed provides better throughput and error correction capability than the conventional APC.

1.1. Paper Organization

The next section reviews the conventional APC scheme in which three copies of the packet are sent via a single transmission link. Section 3 then illustrates the APC scheme for multipath routing and Section 4 carries out a detail analysis of different scenario or cases in multipath routing depending upon the number of paths. Section 5 explains the advantages of multipath APC over conventional APC by carrying out numerical analysis. Section 6 carries out experiments to obtain the throughput and the PER curves for conventional and multipath APC and thereby establishing that multipath APC provides better throughput and error correction capability. Finally section 7 concludes the paper.

II. REVIEW OF CONVENTIONAL APC SCHEME

Aggressive Packet Combining (APC) scheme is a modified form of Majority Packet Combining (MjPC) scheme [23]. Say that an original packet '00101100' is to be transmitted from a transmitter to a receiver. In APC three copies of each packet are sent via a single transmission link between a source and a destination. Say the three copies are received with errors by the receiver (The bits in error are marked in bold).
At the receiver, the received copies are:

First Copy: 0010110**1**
Second Copy: 001011**1**0
Third Copy: 00101**0**00

Majority Logic: 00101100

The combined packet obtained by bitwise majority voting of the erroneous copies is '00101100', which is correct copy of the packet so the combined packet is accepted as the correct copy.

Let us consider another example, say that an original packet '00101100' is to be transmitted from a transmitter to a receiver. At the receiver, say the received copies are:

First Copy: 0010110**1**
Second Copy: 0010110**1**
Third Copy: 00101**0**0**1**

Majority Logic: 00101101

The combined packet obtained by bit-wise majority voting is '00101101', which is still erroneous. The receiver then identifies least reliable bit(s) using majority consensus on the received erroneous copies. The receiver identifies 6th bit from left as the least reliable bit, but receiver fails to detect the error located on the 8th bit. Thus, the receiver request retransmission in which the transmitter resend three copies of the packet. So in such case, six or even more copies of a packet are required to obtain correct copy of a packet.

III. APC SCHEME FOR MULTIPATH ROUTING

The APC scheme for multipath routing (mAPC) deals with transmitting the copies of a single packet through multiple paths, instead of transmitting multiple copies via single transmission link. The receiver while receiving multiple copies of the packet applies the bitwise majority logic on the received copies to generate and obtain a combined packet. If the combined packet is found to be erroneous, the least reliable bits are identified and errors are corrected through brute force method.

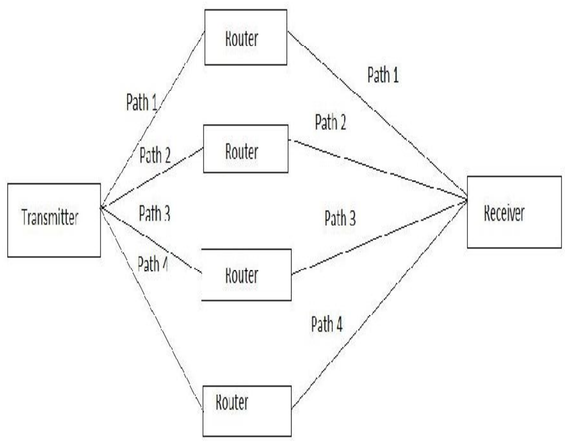

Fig. 1 Multipath routing scheme

IV. DIFFERENT SCENARIOS IN THE PROPOSED SCHEME

In the multipath routing scheme the transmitter broadcast its data, and multiple copies of a single packet arrive at the receiver via different transmission paths. The receiver upon receiving the multiple copies of the packet applies the error detection scheme to generate the correct packet. Depending upon the number of paths (n) the following scenarios may arise.

4.1 Scenario 1: When the number of paths is three

In this scenario, we have considered that the receiver receives erroneous copies from three distinct independent paths, i.e., n=3. In this case the receiver applies bit by bit majority voting on the received erroneous copies to obtain the combined packet. For example, say the original packet '00101111' is to be transmitted from transmitter to receiver. And it is assumed that erroneous copies arrive at the receiver via three distinct paths, thus it is highly probable that distinct paths will have distinct link error syndrome. Receiver performs bit by bit majority voting on the received copies as:

First Copy: 0010111**0**
Second Copy: 001011**0**1
Third Copy: 00101**0**11

Majority Logic: 00101111

The combined packet obtained using bitwise majority logic is found to be without detectable errors and thus it is accepted by receiver.

4.2 Scenario 2: When the number of paths is more than three and odd

In the multi path scenario where receiver receives multiple copies of a packet via multiple paths, number of paths may vary. Say the receiver receives multiple copies via multiple paths, and the number of paths is odd but greater than 3 such as 5, 7, 9 etc, the receiver will perform bitwise majority voting onto all the erroneous copies received. If the combined packet is found to be erroneous then the receiver will identify the least reliable bits and will search the correct bit pattern for the identified least reliable bits. Say the original copy '10101010' is broadcasted by the transmitter and is received by the receiver via five distinct, independent paths. Receiver perform bit-wise majority voting on the received five erroneous copies as:

First Copy: 1010101**1**
Second Copy: 101010**0**0
Third Copy: 1**1**101010
Fourth Copy: 1010**0**010
Fifth Copy: **0**0101010

Majority Logic: 10101010
The combine packet obtained is correct.

4.3 Scenario 3: When the number of paths is more than three and even

In scenarios where the packet broadcasted by transmitter arrives at the receiver via 'n' number of distinct independent paths, where 'n' is greater than three and an even number. In such case the receiver will perform bit by bit majority voting on first three erroneous packets. If the receiver fails to detect and correct the errors, then it applies the same procedure to second, third and fourth copy and so on.

Let us assume that the original copy, '00101110' is transmitted and receiver receives four erroneous copies of the packet as: 001**1**1110, 0010111**1,** 001011**0**0 and 0**1**101110. Receiver will perform bit by bit majority voting on the first, second and third copy as:

First Copy: 001**1**1110
Second Copy: 0010111**1**
Third Copy: 001011**0**0

Majority voting: 00101110

After applying the majority logic to the first three erroneous copies the bit stream generated is 00101110 which is the correct packet. Therefore the fourth erroneous copy is discarded in this case as the correct copy is obtained from the first three packets. Had combined packet being erroneous, receiver will perform majority voting on second, third and fourth copies.

V. ADVANTAGES OF MULTIPATH ROUTING OVER CONVENTIONAL APC

If α is the bit error rate, the probability that the 'k' bit packet is erroneous is given by $P = 1 - (1 - \alpha)^k$ [5]. The paths are assumed to be distinct and independent, with distinct bit error rate in the individual channels, that is, P_1, P_2, …, P_n are not equal, where P_1, P_2,…, P_n are the probabilities that a packet is in error while traversing on first path, second path and n[th] path respectively. Thus $P_1 = 1 - (1 - \alpha_1)^k$ $P_2 = 1 - (1 - \alpha_2)^k$ and $P_n = 1 - (1 - \alpha_n)^k$. In the multipath routing APC scheme, multiple copies of the packet are used to form a combined packet, but these packets are received from different transmission links. Therefore it is very unlikely that the links will have the same link error syndrome. For the conventional APC scheme if the transmission path is in bad state i.e. the transmission link have low probability of transmitting bit correctly, the Packet Error Rate(PER) may be higher leading to low error detection and correction rate. But in the multipath routing scheme, if one link is in the bad state , it is likely that the other paths is in good or better state thus leading to better error detection and correction rate than conventional APC. The PER for 'k' bits 'n' paths multipath APC is:

$$P_{mAPC} = (1 - (1 - \alpha_1)^k) \times (1 - (1 - \alpha_2)^k) \times \dots \times (1 - (1 - \alpha_n)^k)$$

In the conventional APC scheme three copies of the packet are always transmitted through a single link. This leads to low throughput of $\frac{1}{3} \times 100\% = 33.33\%$ for conventional APC scheme. Also if the link is in bad state i.e. the transmission link has low probability of transmitting bits correctly, the probability of error being not detected and corrected is quite high. On the other hand the APC scheme for multipath routing broadcasts a single copy of the packet through multiple transmission paths to the receiver. Thus in average in good channel condition (error-free transmission) only one copy is transmitted for one packet, leading to high throughput efficiency of multipath routing APC scheme. The throughput efficiency of APC scheme is given by $\eta_{APC}= [(1-P_{apc})/ (3+P_{apc})]$ [5]. The throughput efficiency of multipath routing APC scheme is given by $\eta_{mapc}= [(1-P_{mapc})/ (1+P_{mapc})]$.

In the multipath routing scheme the transmitter transmits a single copy of the packet to its surrounding nodes. But in the APC scheme three copies of the packet is transmitted over a single link. Thus the energy consumed by the transmitter in transmission in APC scheme will be higher than the multipath APC scheme, as multiple copies are being transmitted in APC scheme. If the transmission link is in the bad state, energy consumption in the APC scheme will be much higher than the mAPC scheme. Not only mAPC saves energy, but will also improves the latency in APC as the extra overhead of sending multiple copies of a packet is removed in mAPC.

VI. SIMULATION RESULTS

The typical Bit Error Rate (BER) for wireless channel is as high as 10^{-2} to 10^{-4}. The performances of proposed mAPC scheme and APC scheme is compared in terms of Packet Error Rate (lower PER indicates better correction capability) and throughput efficiency. We did experiment with packet size n=128 and simulated the result on MATLAB simulator. We study the performance of APC and mAPC scheme over BER from 10^{-2} to 10^{-4} and portrayed the results in Fig. 2.1, Fig. 2.2, Fig. 3.1 and Fig. 3.2. We see that the proposed mAPC scheme has achieved significantly better performance than the conventional APC scheme. When the BER is 0.004, the throughput efficiency of mAPC and conventional APC is 90% and 33% respectively as shown in Fig 2.2. Thus the proposed multipath APC scheme is more bandwidth efficient than conventional APC.

In the conventional APC scheme, packets are transmitted over a single link. In the multipath APC scheme, multiple copies of the packet are received from multiple paths. For our simulation, we have considered three different paths 1, 2 and 3 for mAPC and all the paths are independent and have distinct link error probability. The following two cases have been considered for our experiment.

Case 1: In the first case we assumed that both path 1 and 2 have same bit error probability as that of conventional APC but path 3 has lesser bit error probability, the simulation result is depicted in Fig 2.1 and Fig. 2.2.

Case 2: In the second case we have considered that only one path of mAPC has the same bit error probability as that of APC scheme and the other paths of mAPC has lower bit error probability than that of APC scheme, this result is depicted in Fig 3.1 and Fig. 3.2. In both the cases we have observed that the packet error rate in mAPC is lower than that of APC that indicates that the correction capability of mAPC is superior as compared to APC.

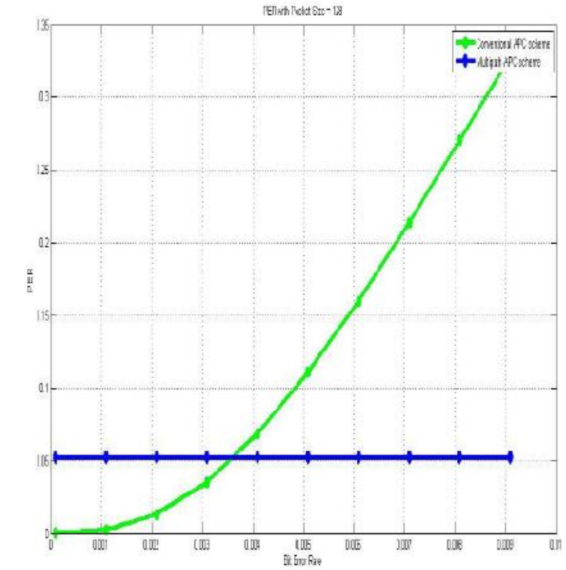

Fig 2.1 Comparision of PER in Case 1

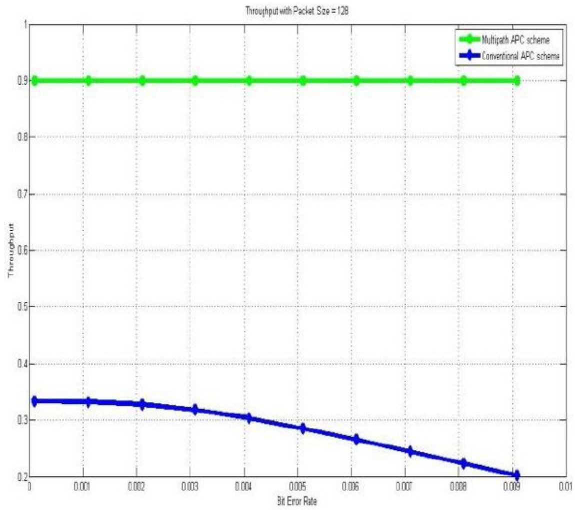

Fig 2.2 Comparision of throughput in Case 1

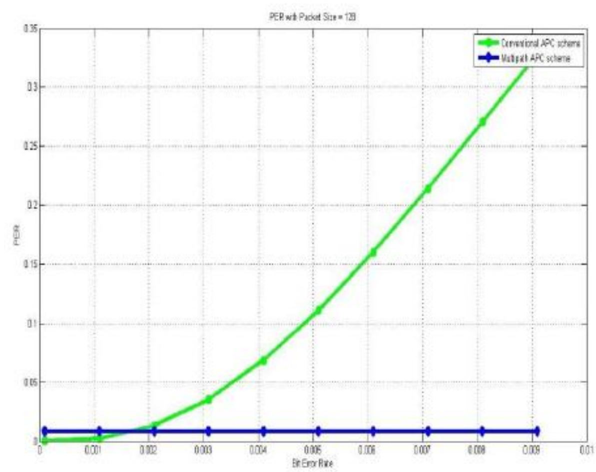

Fig 2.3 Comparision of PER in Case 2

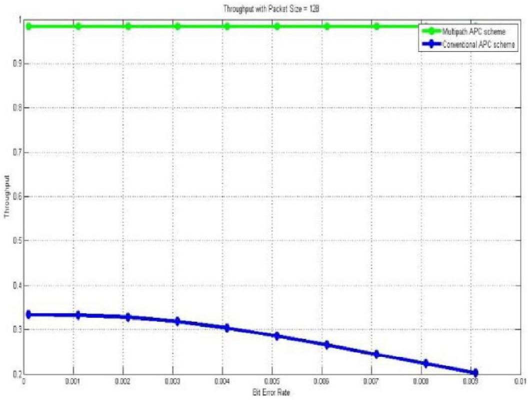

Fig 2.2 Comparision of throughput in Case 2

CONCLUSION

In this paper we proposed to implement APC scheme for multipath routing. The proposed scheme is more bandwidth efficient than the conventional APC scheme. The proposed scheme does not add additional bits to the packet and hence does not consume extra bandwidth in the wireless channel. The proposed scheme has better correction capability than the conventional APC scheme.

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