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Adaptive Packet Combining Scheme for Multi-path Wireless Sensor Networks

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Abstract

An adaptive packet combining (AdPC) scheme for multipath sensor network is proposed in this paper. The packet combining or packet merging techniques studied in the literature uses fixed number of copies of the packet received at the receiver, but in the harsh wireless communication environments, it is likely that one or more copies will be lost or missed due to sudden failure of some nodes, as a result some copies may not be received at the receiver. Thus to exploit the correct information present in the erroneous copies of the packet received at the receiver AdPC technique will adapt itself to the harsh wireless communication environment, and will combine two or more received erroneous copies of the packet in order to retrieve correct copy of the packet. The number of copies to be combined is based on the number of paths between transmitter and receiver. Receiver may receive single or double or triple or more erroneous copies of a single packet, accordingly the proposed technique will operate. Our simulation results show that the proposed technique show significant improvement over the traditional packet combining scheme interms of packet error rate and throughput.

Keywords: Wireless Sensor Network, Aggressive Packet Combining, ARQ protocols, Error Control.

Introduction

Wireless Sensor Networks are networks that consist of sensors which are distributed in an ad hoc manner. WSN mainly use broadcast communication paradigm [1-2] where a source transmits same copy of packet to more than one node and subsequently reaches sink via multiple paths (Fig. 1) or at different time slots. Thus multiple copies via multiple transmission links will be received for a single packet at sink. Thus packet combining techniques may be used in wireless sensor network when the multiple copies of same data are received from multiple paths. Several packet combining or packet merging techniques are studied in literature [3-9]. Ferriere et.al., [10] proposed Simple Packet Combining (SPaC) protocol for wireless sensor networks, which perform error correction by combining corrupted packets using HARQ[11]. SPaC buffers corrupted packet at the receiver and waits for retransmission. Rather than retransmitting the original packet, the sender transmits parity bits. Upon receiving the retransmitted packet, the receiver performs packet combining to retrieve the correct packet. In [12] authors have proposed packet combining scheme based on the use of CRC, which used improved packet merging (iPM) algorithm. iPM is an search algorithm suggested over PC combining scheme [4-5], it first tests all error candidates with a Hamming weight of one, then all those with a Hamming weight of two and so on until either a packet is found which produces the correct FCS or all candidates have been exhausted. Both the approaches SPaC and iPM, used only two copies of the same transmitted packet, but it is highly probable that more or less than two copies of the packet may be received by the receiver. The packet combining or packet merging techniques studied in the literature uses fixed number of copies of the packet received at the receiver, but in the harsh wireless communication environments, it is likely that one or more copies will be lost or missed due to sudden failure of some nodes, as a result some copies may not be received at the receiver. Thus to exploit the correct information present in the erroneous copies of the packet received at the receiver, we proposed adaptive packet combining (AdPC) scheme for multipath sensor network, which will adapt itself to the harsh wireless communication environment, and will combine two or more received copies of the packet in order to retrieve correct copy of the packet. The number of copies to be combined is based on the number of paths between transmitter and receiver. Receiver may receive single or double or triple or more erroneous copies of a single packet, accordingly the proposed technique will operate. The detail operation of the proposed technique is illustrated in the next section.

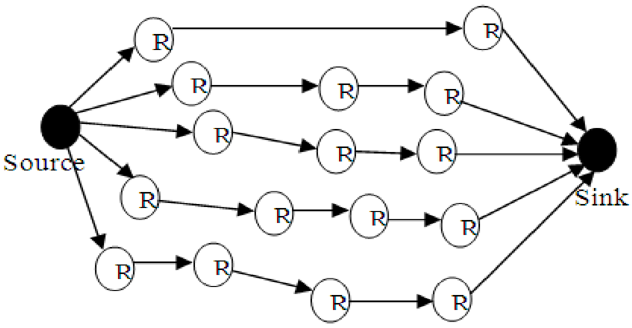

Fig. 1. Multiple possible routes to communicate from source to sink
● : Parent Node
○ : Relay Node

Proposed Technique: Adaptive Packet Combining Scheme

We refer to source node and destination node as the transmitter and the receiver respectively and proposed packet combining scheme will be implemented in receiver. The transmitter broadcast a copy of the packet and is transmitted by sensor nodes to the receiver via multiple paths as shown in Fig. 1. The prerequisite of the proposed scheme is that the receiver node will have memory to buffer received copies and it will be equipped with a processor to carry on basic computing. AdPC scheme will adapt itself based on the number of paths between transmitter and receiver. In multi-path sensor network, the paths are independent and will have different error syndrome. We assumed that α_i is the bit error rate of ith transmission path. The proposed AdPC scheme transmits (broadcast) single copy of the packet, which arrives through multiple transmission paths at the receiver. Thus in average in good channel condition (error-free transmission) only one copy is transmitted (broadcasted) for one packet, leading to high throughput for AdPC scheme. The throughput of AdPC scheme can be expressed as $\eta_i = \frac{1-PER}{i+PER} = \frac{1-PER}{1+PER}$, where PER is the probability of packet being in error.

A. A single path scenario: Protocol 1

When there exist a single path between transmitter and receiver, receiver will operate like in conventional packet combining scheme [4-5]. On receiving a single copy of the packet, receiver performs error detection on this received copy. In case of no error on received copy, receiver will accept this copy and will declare transmission successful. If this received copy is erroneous receiver will buffer this copy and will request for retransmission of the packet, if the retransmitted copy is again received erroneous. Receiver will XOR the erroneous copies [5-6] to find out the location of bit(s) in error, then it will choose one of the packet and invert the located bits as erroneous in order to retrieve correct copy of the packet. If errors are not corrected, receiver will request for retransmission. Say α is the aggregate bit error rate for the single path, then the probability that the packet is received with error is $PER = 1-(1-\alpha)^n$. If a correct copy of packet is retrieved by XORing two erroneous copies then, packet error rate is:

$$P_1 = (1-(1-\alpha)^n)\times(1-(1-\alpha)^n) = (1-(1-\alpha)^n)^2 \quad (1)$$

And the throughput of proposed protocol 1 can be expressed as:

$$\eta_1 = \frac{1-P_1}{2+P_1} \quad (2)$$

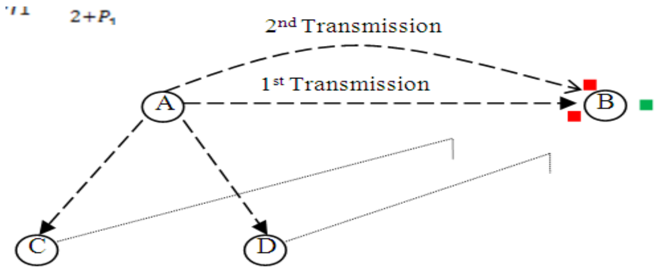

Fig. 2: Packet Combining in Single path
🟩 : Error-free packet
🟥 : Erroneous packet

B. Two path scenario: Protocol 2

Receiver on receiving two copies of the source packet via two independent paths with bit error rate as α_1 and α_2 respectively for path1 and path2, as shown in Fig. 3, will perform error detection on the received copies. If any of the packet is found with no detectable error(s), receiver will declare transmission as successful. But if both the copies of the packet are found to be erroneous, receiver will not discard the received erroneous copies, but will XOR the two erroneous copies to find out the location of bit(s) in error. Once the erroneous bits are located, receiver will choose one of the received erroneous copies and invert the located bits in order to retrieve correct copy of the packet. If errors are not corrected, receiver will request for retransmission. The packet error rate for packet size of '*n*' is:

$$P_2 = (1-(1-\alpha_1)^n)\times(1-(1-\alpha_2)^n) \quad (3)$$

Throughput of this protocol can be expressed as:

$$\eta_2 = \frac{1-P_2}{1+P_2} \quad (4)$$

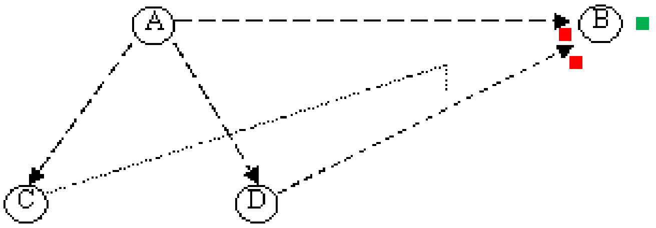

Fig. 3: Packet Combining in Two paths
🟩 : Error-free packet
🟥 : Erroneous packet

C. Three path scenario: Protocol 3

It is assumed that three copies of the packet are received at the receiver through three independent paths. Receiver will consider the three copies of the packet received from three independent paths. The receiver will perform error detection on each received copies, if atleast a copy is received with no detectable error the transmission is considered successful, else receiver will perform bit by bit majority voting on the received erroneous copies to produce a combined packet. If the combined packet is erroneous, then most unreliable bits are identified based on majority logic and receiver searches for correct bit pattern for the identified least reliable bits in order to retrieve correct copy of the source packet [6]. If errors are not corrected, receiver will request for retransmission. Say α_1, α_2 and α_3 respectively are the bit error rate of path 1, path 2 and path 3, then the probability of packet of size '*n*' being in error is:

$$P_3 = (1-(1-\alpha_1)^n)\times(1-(1-\alpha_2)^n)\times(1-(1-\alpha_3)^n) \quad (5)$$

Throughput of the proposed protocol 3 can be expressed as:

$$\eta_3 = \frac{1-P_3}{1+P_3} \quad (6)$$

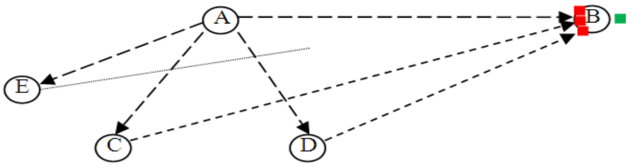

Fig. 4: Packet Combining in three paths
🟩: Error-free packet
🟥: Erroneous packet

D. Number of paths are more than three and are even: Protocol 4

Say receiver receives 'n' number of copies of the packet and say 'n' is more than three and is an even number. Receiver will choose any three copies of the packet received from different paths, and perform bit by bit majority voting on the received erroneous copies to produce a combined packet. If the combined packet is erroneous, then most unreliable bits are identified based on majority logic and receiver searches for correct bit pattern for the identified least reliable bits in order to retrieve correct copy of the source packet. If errors are not corrected, receiver will replace one or more copies of the packet with new copies of the packet received via different paths than before and again repeat the above operation. If still errors are not corrected, receiver request transmitter for re-transmission of the same packet and the procedure is repeated till the packet is retrieved error-free. Say '*k*' paths are used for successful transmission then the PER can be expressed as:

$$P_k = (1-(1-\alpha_1)^n)\times(1-(1-\alpha_2)^n)\times\ldots\times(1-(1-\alpha_k)^n) \quad (7)$$

Throughput of the proposed protocol 4 can be expressed as:

$$\eta_k = \frac{1-P_k}{1+P_k} \quad (8)$$

E. Number of paths are more than three and are odd: Protocol 5

Say receiver receives 'n' number of copies of the packet and say 'n' is more than three and is an odd number. Receiver will perform bit by bit majority voting on the received erroneous copies to produce a combined packet. If the combined packet is erroneous, then most unreliable bits are identified based on majority logic and receiver searches for correct bit pattern for the identified least reliable bits in order to retrieve correct copy of the source packet. If errors are not corrected, receiver will request for retransmission. Say '*m*' paths are used for successful transmission then the PER is:

$$P_m = (1-(1-\alpha_1)^n)\times(1-(1-\alpha_2)^n)\times\ldots\times(1-(1-\alpha_m)^n) \quad (9)$$

And the throughput can be expressed as:

$$\eta_m = \frac{1-P_m}{1+P_m} \quad (10)$$

Simulation

We have simulated the proposed protocols using MatLab in windows8 computer. The performance of proposed scheme is studied in terms of packet error rate (lower PER indicates better correction capability) and throughput. The range of bit error rate considered for simulation is from10^{-4} to 10^{-1}, with packet size 'n' 64 and 128. The simulation results are shown in Fig. 5 to Fig. 8. To study the performance of different protocols, we assumed that the probability of bit in error in all paths is equal. The packet error rate of protocol 1 & protocol 2 are equal as the bit error rate in all paths is assumed to be same. But the throughput of protocol 1 is much lesser than the throughput of protocol 2, as there is a need of retransmission in protocol 1, where as in other protocols the probability of re-transmission is much lesser. With the assumption that the bit error rate of all paths is equal, the PER of APC scheme will be same as that of protocol 3, but the throughput of PAC is lower than that of protocol 3 as seen in Fig 7 & Fig. 8. As observed from the Fig. 5 & Fig. 7, the probability that the packet is in error is lesser as the number of packets combined is higher. Fig. 6 & Fig. 8 show that the throughput of packet combining in multipath scenario is much higher than the single path. The results in simulation curves are in sync with our analysis that as retransmissions are lesser in multi-path scenario the throughput is higher. Simulation results (Fig. 6 & Fig. 8) show that a very high throughput can be achieved in highly error-prone wireless communication network.

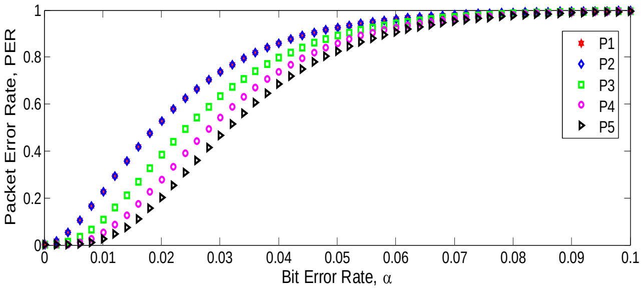

Fig.5: Packet Error Rate vs BER with packet size 64

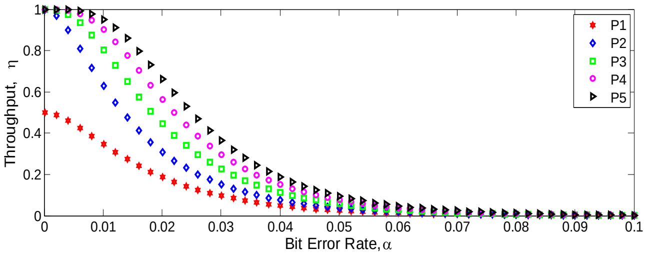

Fig. 6: Throughput vs BER with packet size 64

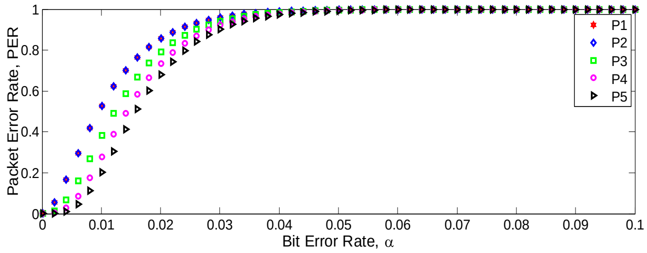

Fig. 7: PER vs BER with packet size 128

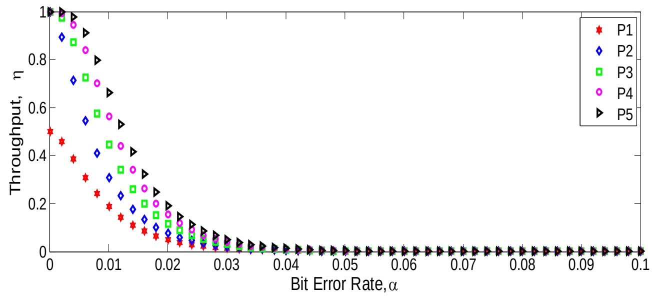

Fig. 8: Throughput vs BER with packet size 128

Conclusion

In this paper, we proposed a adaptive aggressive packet combining scheme for low power, low cost, resource constrained multipath sensor network. The proposed scheme adapts itself to the harsh wireless communication environment, and will combine two or more received copies of the packet in order to retrieve correct copy of the packet. The number of copies to be combined is based on the number of paths between transmitter and receiver. AdPC scheme unlike traditional packet combining scheme does not fixed the number of packets to be combined for which a fixed number of paths have to be established between source and sink nodes, neither will it discard received erroneous copies. It was shown that the AdPC scheme improves upon the PER and throughput of single path PC scheme (protocol 1) by upto 30% and 50% respectively.

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