IMPROVING WLAN PERFORMANCE WITH ENHANCED MAC, NODE COOPERATION AND TWO-STAGE FEC SCHEME

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ABSTRACT

Signal interference, route disruption, congestion and fluctuations cause several consecutive bits arriving at the receiver in error. The error handling method in tradition communication protocols is error detection and retransmission. This method is inappropriate for distributed multimedia systems for two reasons: It introduces variable delay unacceptable for isochronous streams, and it is very inefficient and difficult to use in the multicast environment typical for many multimedia applications. We propose Enhanced MAC Node Cooperation with Two-Stage Forward Error Correction Scheme to be used on WLANs. The proposed scheme enables the joint optimization of protection strategies across the protocol stack. Node cooperation technique improves networks' overall system throughput and reliability, reduces the cost of retransmission and energy consumption. In stage 1 of FEC, packet-level FEC is added across packets at the application layer to correct packet losses due to congestion and route disruption. In stage 2, bit-level FEC is processed within both application packets and stage 1 FEC packets to recover from bit errors in the MAC/PHY layer. Thus, we add FEC at the application layer to correct both application layer packet errors and MAC/PHY layer bit errors. MAC is enhanced to support node cooperation and header CRC.

1. INTRODUCTION

Transmitted signal suffers harsh impairments such as interference, congestion, route disruption and signal fluctuation. Received signal is rapidly fluctuating due to the mobility of the mobile terminal causing changes in multiple signal components via different paths. This rapid fluctuation of the signal amplitude is referred to as small-scale fading, and is the result of movement of the transmitter, the receiver, or objects surrounding them. Two effects contribute to rapid fluctuations of the signal amplitude. The first, caused by the movement of the mobile terminal toward or away from the base station/transmitter, is called Doppler. The second, caused by the addition of signals arriving via different paths, is referred to as multipath fading. Other harsh environment which causes signal fluctuation is interference, routing disruption and routing congestion. All these effects cause several consecutive bits to arrive at the receiver in error.

Two different approaches can be used to correct transmission errors in computer networks: error detection and retransmission of damaged packet (ARQ – Automatic Repeat Request) or correction of bit errors by means of redundant information (FEC – Forward Error Correction). Tradition network protocols (HDLC, ISO/OSI-TP4, TCP/IP) all work with error correction by retransmission, because of the following reasons:

- Error detecting codes require less redundancy than error correcting codes thus save bandwidth.
- Error detecting codes require less computational effort.
- Retransmission is implemented in order to recover from loss of complete packets.

Advantage of FEC is maintenance of isochronous flow. Retransmission of damaged packets introduces considerable delay jitter; the computational overhead for FEC is the same for damaged as for undamaged packets. IEEE 802.11 wireless LANs are designed for reliable data transmission, they treat classical data flows and multimedia flows alike, even though these two kinds of flows have deferent demands. The wireless physical (PHY) and media access control (MAC) layers are designed to be as reliable as possible, so that one bit error in a packet could result in the whole packet being dropped. However, due to the error resilience features of many multimedia CODECs and the utilization of error correction strategies at the application layer, packets with errors are still useful for multimedia applications; therefore, mechanisms are needed to efficiently support multimedia data transmission over wireless networks. Packet losses in a wireless channel there are in two categories: packets dropped due to routing disruption, interference, and congestion in the intermediate nodes and packets discarded in the MAC/PHY layers due to internal bit errors. To protect data from losses/errors in a wireless environment, two thoughts are taken into consideration, protocol layer in which protection scheme is located and how protection strategies are deployed. The simplest strategy is to add protection mechanisms at each protocol layer, as in 802.11 protocols. We argue that the layered protocol protection strategy does not always result in efficient performance of delivering multimedia data, due to independency of each protocol layer.

Here, we propose Enhanced MAC Node Cooperation with two-stage FEC scheme to efficiently support multimedia data transmission over wireless LANs. Since only the application knows the characteristics of the multimedia data, the proposed scheme enables joint optimization of protection strategies across the protocol stack, packets with errors are delivered to the application layer for correction or drop. The reason we choose to study proposed scheme for video error recovery is to reduce re-transmissions and increase effective throughput on WLAN since retransmission result in unpredictable delay and jitter at the application layer. We enhance the MAC/PHY layers to efficiently support multimedia flows by using both header CRC and FEC. MAC is modified so that it can support node cooperation technique to improve overall system throughput and reliability, and to reduce the cost of retransmission and energy consumption. We also slightly modified the protocol stack so that it can deliver packets with errors from the MAC layer to the application layer, instead of just dropping them. For the two-stage FEC, we add FEC only at the application layer, but can correct both application layer packet drops and MAC/PHY layer bit errors. Packet-level FEC (Stage 1) is added across packets at the application layer to correct packet losses due to congestion and route disruption. Bit-level FEC (Stage 2) is processed within both application packets and stage 1 FEC packets to recover bit errors from the MAC/PHY layers. Proposed scheme has the following characteristics: Network efficiency: enhanced MAC protocol using header CRC and FEC improves application layer effective throughput; all useful informations are delivered to the application layer. Cooperating nodes decode the received packets and participate in the transmission of the error-free packets. If one node received the packet with no error, then the packet is successfully received. Protection efficiency: unequal error protection is easily deployable, since we only process FEC at the application layer. Furthermore, the proposed scheme combines bit-level protection codes and symbol level codes to correct both bit errors at MAC/PHY layers and packet losses at the application layer.

The remainder of this paper is organized as follows: In Section II, we give a detailed description and analysis of our proposed Enhanced MAC and Two-Stage FEC scheme protocol with node cooperation support. In Section III, simulation results are provided, followed by conclusions in Section IV.

2. SYSTEM OVERVIEW

To efficiently support multimedia applications, we modify the protocol stack so that it can deliver packets with errors to the application layer. This can be achieved by turning off the CRC checksum function in the MAC/PHY layers. The TCP with adaptive forward error correction (TCP-AFEC) protocol should be used at transport layer to match the enhanced MAC protocol and improve TCP performance over wireless networks. To ensure better delivery, we enhance the MAC/PHY layer by modifying the 802.11 packet CRC mechanism to check only the header part possibly also with bit-level FEC for the header part at the same time to support node cooperation. The proposed system diagram is shown at Figure below.

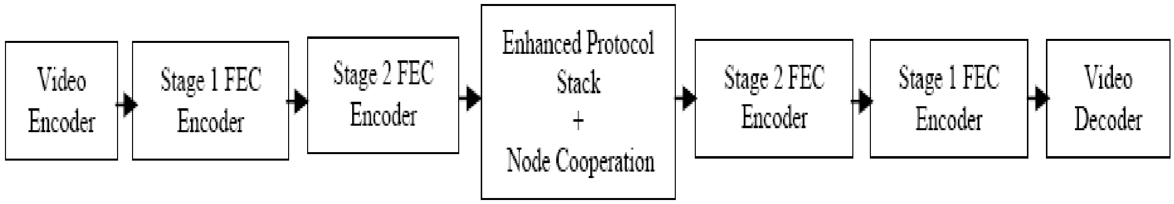

Fig. 1 Enhanced MAC Node Cooperation and Two-Stage FEC scheme System diagram

At the application layer, two-stage FEC is applied to the encoded video bit stream based on network conditions. In stage 1, packet level FEC is added across application layer packets to correct packet drops due to congestion or route disruption. Stage 2 is processed within each application packet; a small amount of bit level FEC is added to recover bit errors from the MAC/PHY layers at each packet. Cooperating nodes decode the received packets and participate in the cooperative transmission of the error-free packets. At the receiver side, we first process the bit-level FEC; the bit errors from the MAC/PHY layers can be recovered. Then we pass the bit stream to the stage 1 FEC decoder for further correction. Here, we choose Reed-Solomon (RS) codes for packet-level protection (stage 1) and BCH codes for bit-level protection (stage 2).

3. ENHANCED MAC LAYER AND NODE COOPERATION

In tradition communication network, we assume that the uplink and downlink have the same BER p_b, the probability of successfully transmitting a packet P_{suc} is give by:

$$p_{suc} = \left(1-p_e(L)\right)\left(1-p_e\left(s_{ACK}\right)\right) = \left(1-p_b\right)^{8\left(L+S_{ACK}\right)} \quad (1)$$

Where, L and S_{ACK} are the size of MAC packet and ACK packet in byte, respectively. Given a physical layer bandwidth B_{PH}, the effective application layer throughput B_{AP} is given by:

$$B_{AP} = B_{PH} * p_{suc} * r \quad (2)$$

Where r is the ratio defined as r = application packet size/MAC packet size.

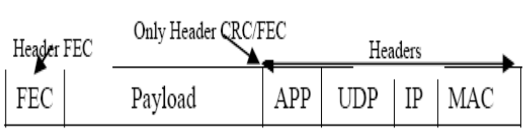

Figure 2 Enhanced MAC/PHY protocol using header CRC and header FEC

Header CRC and header FEC have been used to enhance the MAC/PHY layers. 802.11 MAC/PHY layer packet CRC mechanisms modified to check if there is error within the header part. The packet is dropped if the header CRC fails. With this header CRC mechanism, the probability of successful transmission of a packet P_{sucH} is given by

$$p_{sucH} = \left(1-p_b\right)^{8\left(S_{header}+S_{ACK}\right)} \quad (3)$$

Where, S_{header} is the size of all header bytes. Since S_{header} is much smaller than the packet itself, the probability of successful transmitting a packet using header CRC is larger than when using whole-packet CRC. It results in a larger application layer effective throughput according to Equation 2. Similarly to header CRC, a bit-level FEC can be added to the header part to combat bit errors in the header and further reduce the probability of header errors.

Node cooperation techniques have been widely used in Ad hoc and Sensor networks. Here we propose node cooperation to be used in WLAN. The node cooperation can be implemented in two steps depending on the quality of the link: *Stage 1: Cluster head decides if cooperation is necessary*. The nodes with the error free packet send their status to the cluster head using a low bit rate message. The cluster head chooses one of the nodes with the error free packet to forward that packet to the next cluster. *Stage 2:FEC*. If no node receives the packet successfully, the packet with no head errors is sent to application layer for error correction. If the reconstruction is unsuccessful the master node sends an ARQ to the previous cluster for the packet retransmission.

4. Two-Stage FEC with Node Cooperation

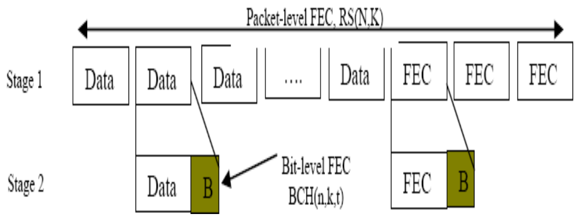

Figure 3 Detailed two-stage FEC scheme

In stage 1, packet level FEC is added across application layer packets to correct packet drops due to congestion or route disruption. We use RS codes for stage 1 FEC.
In stage 2, FEC is processed within each application packet, and a very small amount of bit-level FEC is added to recover any bit errors from the MAC/PHY layers. We use BCH codes for stage 2 FEC. Considering headers CRC and not taking into account ACK packet, the probability of a packet loss p_{loss} is give by:

$$p_{loss} = p_{drop} + 1 - \left(1 - p_b\right)^{8\left(S_{header}\right)}$$

(4)

Where, p_b is bit-error rate and p_{drop} is the probability of a packet being dropped at the sender due to congestion, with channel physical bandwidth B_{PH}.

Bit-level FEC is added within each packet to correct bit errors. Given a BCH (n,k,t) code, number of bit errors larger than *t* in a codeword cannot be corrected, so the probability of not correctly decoding the codeword $P_{BCH}(E)$ is

$$P_{BCH}(E) = \sum_{j=t+1}^{n} \binom{n}{j} p_b^j \left(1 - p_b\right)^{n-j}$$

(5)

Packets with errors are passed to the packet level FEC RS(N,K) for further correction. After BCH decoder correction, the residual bit-error rate p_{rb} is given by

$$p_{rb} = p_b p_{BCH}(E) \qquad (6)$$

The RS correction failure $P_{RS}(E)$ in the proposed two-stage FEC is

$$p_{RS}(E) = P\{R(E) \mid B(C)\} p_B + P\{R(E) \mid B(E)\} p_B(E)$$

(7)

Where, $P_B(E)$ is the probability of BCH decoding error, $P_B(C)$ is the probability of BCH decoding success, *R(E)* is the event of RS decoder correction failure, *B(E)* is the event of BCH decoder correction failure and *B(C)* is the event of BCH decoder successful correction. If BCH can successfully correct the bit errors inside packets, the conditional probability of RS error decoding is an erasure correction problem as

$$P\{R(E) \mid B(C)\} = \sum_{i=d_{\min}}^{n} \binom{N}{i} p_{syc}^{i} \left(1 - p_{syc}\right)^{N-i}$$

(8)

Where the probability of symbol erasure is $p_{syc} = p_{loss}$, and $d_{min} = N - K + 1$.
If the BCH code fails to correct the bit errors inside the packets, then the conditional probability of RS error correction is a mixed erasure and error correction problem is given by

$$P\{R(E) \mid B(E)\} = \sum_{i=\lceil (N-K)/2 \rceil + 1}^{N} \binom{N}{i} p_{syc}^{i} \left(1 - p_{syc}\right)^{N-i}$$

(9)

Where the probability of symbol error is a combination of packet loss and packet error, can be calculated as

$$p_{syc} = p_{loss} + 1 - \left(1 - p_b\right)^m \qquad (10)$$

Where *m* is the symbol size of *RS(N,K)* code. After both BCH code correction and RS code correction, the residual bit error rate can be reduced to

$$p_{rsrb} = p_{rb} P_{RS}(E) = p_b P_{BCH}(E) P_{RS}(E)$$

(11)

For header FEC, we can have a similar analysis, but using a residual bit-error rate after header FEC decoding to calculate p_{loss} at equation 4.

FEC principle of packet loss states that, two packets p_1 and p_2 are to be sent, and redundancy of 100% is taken into account, two additional packets may be generated. These additional packets are to be sent together with original packets. In the event of packet loss, original packets p_1 and p_2 must be restored from remaining packets. In this case two operations are necessary with their help the redundant packets can be generated.
Consider transmission of *n* packets $P = \{p_1, p_2, p_3 \cdots p_n \in B_j\}$. A total of *n* + *m* packets will be transmitted $Q = \{q_1, q_2, q_3 \cdots q_{n+m} \in B_j\}$ such that upon arrival of at least *n* packets out of *Q* all packets of the set *P* can be restored. Under node cooperation

there is high probability of receiving large number of Q packets, therefore probability of successful correcting errors is higher. In equation 4, p_{drop} is highly reduced by node cooperation technique, therefore probability of a packet loss under node cooperation p_{nloss} is reduced to big extent and given by

$$p_{nloss} = p_{ndrop} + 1 - \left(1 - p_b\right)^{8\left(S_{header}\right)} \quad \text{Since} \quad p_{ndrop} \ll p_{drop} \therefore p_{nloss} \ll p_{loss} \qquad (12)$$

Where, p_{ndrop} is the probability of a packet being dropped at the sender due to congestion, under node cooperation scheme. Probability of symbol error p_{nsyc} under node cooperation technique is also highly reduced due to reduction of p_{nloss} as shown in equation below

$$p_{nsyc} = p_{nloss} + 1 - \left(1 - p_b\right)^{m} \quad \text{Since} \quad p_{nloss} \ll p_{loss} \therefore p_{nsyc} \ll p_{syc} \qquad (13)$$

These will lead to better effective application layer throughput, therefore better network performance.

5. EFFECTIVE APPLICATION-LAYER THROUGHPUT

Here, we define the effective throughput as the throughput of error free traffic. We compare four protection schemes: 802.11 ARQ, application-layer FEC using Reed-Solomon codes, two-stage FEC with header CRC, and two-stage FEC with header FEC, we also consider the effect of Node Cooperation on both two-stage FEC schemes. For 802.11, the application layer throughput B_{AP} *(802)* is give by

$$B_{AP}(802) = r B_{PH} \left(1 - p_b\right)^{8\left(L + S_{header} + S_{ACK}\right)} \left(1 - p_{loss}\right) \qquad (14)$$

In our application-layer scheme, RS(N,K) packet-level FEC scheme is applied across packets with code rate $C_{RS} = K/N$. Here p_{rbrs} is the residual bit error rate after RS decoding and $p_{rbrs} = p_b P_{RSO}(E)$. $P_{RSO}(E)$ can be calculated from equation 9 and equation 10. After the RS code correction, the effective application-layer throughput is

$$B_{AP}(RS) = r B_{PH} \left(1 - p_{rbrs}\right)^{8L/C_{RS}} \left(1 - p_{loss}\right) C_{RS} \qquad (15)$$

At receiver BCH decoder first decodes the received packet. No matter BCH decoder can fully correct the bit errors or not, it passes the packets to RS decoder for further burst-loss and packet-loss correction. The effective throughput is then given by

$$B_{AP}(our) = r B_{PH} \left(1 - p_{rsrb}\right)^{8L/C_{our}} \left(1 - p_{loss}\right)^{C_{our}} \qquad (16)$$

Where, C_{our} is the combined code rate of two-stage FEC scheme. Equation 16 can be used for header CRC and header FEC, using different p_{loss} and p_{nloss} under node cooperation. $p_{loss/}$ p_{nloss} can be calculated from equation 4 if header CRC is used. For header FEC, we still use equation 4 but replace of p_b with p_{rb} from equation 6.

Comparison of throughput of four mentioned methods shows that at very low bit-error rate, 802.11 offer the highest effective throughput, since SW-ARQ requires less overhead than fixed FEC protection. If an adaptive FEC scheme is used, we can expect similar results to those of our proposed scheme at low bit-error rates. As bit-error rate goes higher, performance varies dramatically. For 802.11, probability of retransmission and packet drops goes very high at high bit-error rates, and it quickly reduces effective throughput. Due to the characteristic of RS codes, RS-only protection method is even worse than 802.11 at high bit-error rates with the FEC overhead. On the other hand, our proposed scheme effectively joins the advantages of both bit-level protection and packet-level protection. The performance is better than both 802.11 and RS-only.

6. SCALABLE VIDEO CODING AND FEC DESIGN AND ADAPTATION

Here, we use fully scalable coder MC-EZBC. Advantage of scalable encoded bit stream is it can be chopped at any point to match with bandwidth varying channel. MD-FEC is used in stage 1 FEC to protect MC-EZBC video bitstream. MD-FEC transforms this unequally important bitstream into one of equally important packets using erasure correcting RS codes. Packetization scheme provides the property: if *n* packets are received, decoding is guaranteed up to n^{th} section. MD-FEC can generate a certain rate encoded bitstream in a GOP and send it to the channel. At receiver, the decoder only needs to decode received part to n^{th} section. The benefit of using MD-FEC as stage 1 is we can at least decode to a certain rate if any part of bitstream is received.

FEC design should try to recover all random errors at low protocol levels. Given needed bit-level FEC bandwidth B_{bit} and available bandwidth B_{avail}, R_{max} can be calculated by $R_{\max} = B_{val} - B_{bit}$.

To efficiently protect packets from losses and to match the available sending rate, adaptation is needed for FEC design. The receiver estimates the loss behavior of the channel and feeds back the result to the sender. Two types of loss information are sent back to the sender. The packet loss information is fed back regarding stage 1 FEC design for each GOP. Since bit errors in packet can dramatically affect application layer loss rate, stage 2 bit-level FEC uses a Step-Increase-Step-Decrease (SISD) method. A NACK packet is sent back to sender in case of FEC decoder failure. Then sender encodes bit-level FEC with a step higher FEC code, eg. from BCH(n, k, t) to BCH(n, k, t+1). If errors inside a packet can be corrected, receiver should know how many bit errors are inside the packet. If the correction capability is much higher than bit errors, for instance, correction capability is twice higher than the number of errors, receiver also feeds back an ACK for bit-level FEC to step decrease one level from BCH(n, k, t) to BCH(n, k, t - 1).

7. SIMULATION

MATLAB simulation performed to compare the application layer bandwidth efficiency of using header CRC, header FEC and packet CRC. Here, we assume that the application layer packet payload size is 1000 bytes, the CRC header size is 60 bytes (UDP 8 bytes, IP 20 bytes, MAC header 24 bytes, application layer header 4 bytes) and the ACK packet size 14 bytes. Physical layer bandwidth is set to 2 Mbps

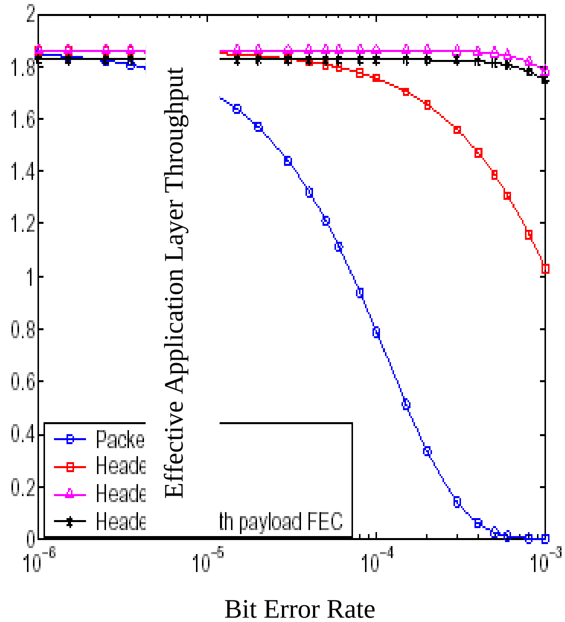

Figure 4 Application layer bandwidth efficiency vs BER

In Fig. 4, we use the same method as the current 802.11 does for MAC layer packet CRC, any bit error inside a packet results in the whole packet being dropped. For header CRC, only the header part is checked at the receiver side, if anything is wrong within the header part, the whole packet is dropped. Even if only the header part is checked, the performance degrades a lot at high bit-error rates, and this is due to the large number of header check errors. So, we further added a BCH(511, 502, 1) code to protect the header part from bit errors. The performance then became good even at high bit-error rates and the bandwidth overhead added by the header FEC is only 0.1%. Header CRC/FEC results in a better application layer throughput, but the received packet may have errors in it. To protect the packet payload from errors, a BCH(8191, 8000, 14) code is applied to each packet, and therefore, any 14 bit errors out of the 8191 codeword bits can be corrected. While fixed FEC adds overhead at low bit rates, it performs quite well at high bit error rates. In Fig. 4, a plot of header FEC with payload FEC has lower throughput compared with header FEC alone. This is because of overhead in payload FEC and we artificially drop the packet if payload FEC cannot correct the errors. This is comparable to 802.11 packets CRC with error free delivery. Here, we define a FEC decoding failure if FEC cannot correct all errors in a codeword. To identify a decoding failure is an engineering problem. If combined with CRC, the FEC decoder first decodes the codeword, then makes a CRC check of the decoded codeword, if the CRC is ok, then decode, otherwise, declare a decode failure.

8. CONCLUSION

In this paper, we propose a Enhanced MAC Node Cooperation with Two-Stage FEC scheme to support multimedia data transmission over wireless LANs. The proposed scheme enables joint optimization of protection strategies across protocol stack. Two-stage FEC combines bit-level protection codes and symbol level codes to correct both bit errors in the MAC/PHY layers and packet losses in application layer. Cooperation architecture effectively improves link performance and reduces energy consumption. Simulations show that the proposed scheme outperforms conventional IEEE 802.11. Future work will focus on joint source and network coding for video streaming over a mobile multihop network and then evaluate these schemes under more realistic conditions using ns-2 simulator.

REFERENCES:

[1]. Su Yi, Babak Azimi-Sadjadi, Shivkumar Kalyanaraman and Vijaynarayanan Subramanian. Error Control Code Combining Techniques in Cluster-based Cooperative Wireless Networks. In ICC-Camera-2005.

[2]. Yufeng Shan, Su Yi, Shivkumar Kalyanaraman, and John W. Woods. Two-Stage FEC Scheme for Scalable Video Transmission over Wireless Networks.

[3]. B. Lamparter, Otto Bohrer, W. Effelsberg and V. Turau. Adaptable Forward Error Correction for Multimedia Data Stream. TR-93-009.

[4]. Thinh Nguyen and Avideh Zakhor. Path Diversity with Forward Error Correction (PDF) System for Packet Switched Networks.

[5]. Mark Felegyhazi_ and Jean-Pierre Hubaux. Cooperative Packet Forwarding in Multi-Domain Sensor Networks.

[6]. Naouel Ben Salem, Levente Butty´an, Jean-Pierre Hubaux, Markus Jakobsson. Node Cooperation in Hybrid Ad hoc Networks. Online TMCO3 February 14, 2005.

[7]. Vikram Srinivasan†, Pavan Nuggehalli†, Carla F. Chiasserini‡, Ramesh R. Rao. Cooperation in Wireless Ad Hoc Networks. INFOMCOM 2003.

[8]. Kaveh Pahlavan and Prashant Krishnamurthy. Principles of Wireless Network: A Unified Approach. Science Press and Pearson Education North Asia Limited. 2003.

[9]. William Stallings. Wireless communications and Networks. Pearson Education 01- 2003-6860.

[10]. Theodore S. Rappaport. Wireless Principles and Practice Second Edition. Pearson Education Asia Limited 2004.

[11]. Andrew W. Davis Forward Error Correction. TechOnline. Dec. 6, 1998.

[12]. http://www.cs.uml.edu/~bliu/pub/wireless TCP.pdf