# Is Physical Layer Error Correction sufficient for Video Multicast over IEEE 802.11g Networks?

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***Abstract*— Wireless video multicast enables delivery of popular events to many mobile users in a bandwidth efficient manner. However, providing good and stable video quality to a large number of users with varying channel conditions remains elusive. A promising solution to this problem is the use of packet level Forward Error Correction (FEC) mechanisms. However, the adjustment of the FEC rate is not a trivial issue due to the dynamic wireless environment. This decision becomes more complicated if we consider the multi-rate capability of the existing wireless LAN technology that adjusts the transmission rates based on the channel conditions and the coverage range. In this paper, we explore the dynamics of Forward Error Correction (FEC) schemes in multi-rate wireless local area networks. We study the fundamental behavior of a 802.11g network which already has embedded error correction in physical layer, under unicast and broadcast modes in a real outdoor environment. We then explore the effectiveness of packet level FEC over wireless networks with multi-rate capability. In order to evaluate the system quantitatively, we implemented a prototype using open source drivers, and ran experiments. Based on the experimental results, we provide guidelines on how to efficiently use FEC for wireless multicast services in order to improve the overall system performance. We argue that even there is a physical layer error correction, using a higher transmission rate together with stronger FEC is more efficient than using a lower transmission rate with weaker FEC for multicast.**

**Index Terms**: Packet Error Rate (PER), IEEE 802.11g, wireless networks, multicast, Forward Error Correction (FEC)

## I. Introduction

In a wireless network, as the external environment changes, the channel error rate varies. In order to cope with errors, we need accurate channel-condition estimation and an effective error control mechanism. Video communication is fundamentally different from data communication, since interactive video applications are delay and loss sensitive. Unlike data packets, late arriving video packets are useless to the video decoder. Furthermore, due to bursty and location dependent errors, each user in a multicast system will most likely lose different packets. Therefore, a simple ARQ (Automatic Repeat reQuest) based scheme is not appropriate for video multicast services over wireless channels since it can cause a large number of retransmissions. A promising solution for error control in multicasting over wireless networks is the use of forward error correction (FEC), where redundant information is sent a-priori by the source station, in order to be used by the receivers to correct errors/losses without contacting the source. The advantage of using FEC for multicasting is that a single parity packet can be used to correct independent single-packet losses among different receivers.

The efficiency of FEC-based approaches for error correction in wireless multicasting, has been shown via simulations [1]-[4]. Although these simulation results provide some insights on the way FEC should be applied, they do not consider a wireless network with multi-rate capabilities. Villalon et al. [5] studied a cross-layer approach for adaptive video multicast considering the multi-rate capabilities of wireless networks. However, they did not consider error correction methods. Limited implementation approaches in the literature focus on specific algorithms, and therefore they do not present a thorough investigation of the various trade-offs. McKinley et al. [6] studied proxy-based adaptive FEC for reliable multicast in WLANs. They proposed an adaptive FEC mechanism where the number of parity packets transmitted is based on the current data loss rate with a feedback system. The same group extended their studies in [7] and show that combining forward and backward error control is an effective strategy for proxy-based video multicast. In both papers they evaluate the proposed schemes by implementing them in a real testbed. However, their studies considered only an indoor environment and fixed transmission rates (2 Mbps in [6] and 11 Mbps in [7]).

In our previous work [8], we studied a real wireless 802.11b network. We set up an experimental testbed and studied the behavior of the network in terms of packet error rates. We showed that using a higher transmission rate together with stronger FEC is more efficient than using a lower transmission rate with weaker FEC for video multicast in IEEE802.11b networks where there is no error correction mechanism in the physical layer.

In this paper, taking it one step further, we study the dynamics of FEC mechanisms for a real wireless IEEE802.11g network which already has a built in error correction mechanism in physical layer and we compare the results with a IEEE802.11b network. We set up an experimental testbed and study the behavior of the network in terms of packet error

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rates for different distances between the source and destination and different transmission rates. Based on the results of our experiments, we provide insights and guidelines on how to practically use FEC schemes for robust wireless multicast.

The paper is organized as follows. In Section II, the implementation effort is elaborated. We specify the primary configurations of the experiments in Section III. Section IV reports and analyzes the obtained results. We conclude the paper in Section V.

## II. Implementation Effort

Although rate adaptation is a standard feature in todays wireless networks, multicast/broadcast packets are always transmitted using the base transmission rate of the system (e.g., 1Mbps for IEEE 802.11b and 6Mbps for IEEE 802.11g). The motivation for using the lowest transmission rate is to enable far away receivers to successfully receive and decode the transmitted packets. In multicast, one cannot rely on retransmission to correct lost packets. Allowing the multicast server to retransmit lost packets to all receivers would dramatically increase the overhead on the network, since each receiver may ask for retransmission of different packets (due to the independent errors to different receivers). Without other error control mechanism, the server has to transmit at the lowest possible rate in order to accommodate users with poor channel conditions.

Forward error correction (FEC) at the application layer is a promising alternative for handling losses in multicast services. The basic idea of FEC is that redundant information is sent a-priori by the source station, in order to be used by the receivers to correct errors/losses without contacting the source. Since CRC-based error detection at the link layer results in the removal of the corrupted packets, many FEC-based protocols try to recover these packets [9]. However, such a scheme introduces overhead since extra parity packets are now transmitted by the source station. The level of the overhead depends on the packet error rates (PER) in the network. The higher the packet loss rate is, the more parity packets must be transmitted by the server, thus increasing the overhead and reducing the rate at which payload data can be transmitted.

From the above discussion, we conclude that it is important to have accurate estimate of the packet error rate, in order to decide on the number of FEC parity packets that should be applied. Considering now the fact that in wireless networks, different transmission rates give different PER, it is not clear how someone should define the combination of transmission rate and FEC rate in order to increase the efficiency of the network. It is true that the higher the transmission rate is, the higher the PER and therefore the more FEC parity packets should be transmitted. However, as the transmission rate increases, the more efficient the use of the medium becomes, leaving more room for extra FEC parity packets. Therefore, while designing a multicast system, we should consider transmission rate and FEC overhead jointly.

Inspired by the above considerations we decided to build a real system in order to study the effect of different transmission rates and packet sizes on the packet error rate of a wireless network and define the FEC rate that should be used. By understanding the interaction between different transmission rates, PER and FEC overhead we can define the guidelines on the way we should combine rate adaptation with FEC in order to improve the efficiency of multicast services over wireless networks.

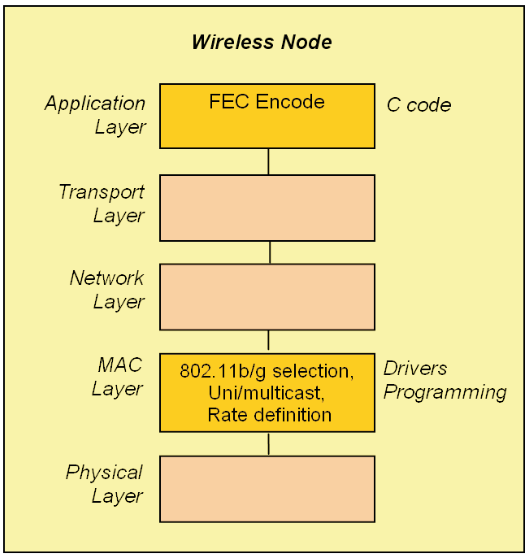



Fig. 1. Node Architecture

In order to implement the system in a way that we would be able to change different parameters and observe the behavior of different metrics, we changed the basic functionality of a wireless node in MAC layer as depicted in Figure 1.

For the implementation of the MAC layer we used open source drivers in a Linux platform. In particular we used the MadWifi driver [11] for the Atheros chipsets [12]. We modified the driver in order to be able to choose packet transmission in one of the two modes: unicast mode (i.e. with acknowledgment and retransmissions) and broadcast mode (i.e. no acknowledgment, no retransmissions). We can operate in either 802.11b mode or 802.11g mode. We utilize the results of 802.11b mode in order to compare the results with 802.11g. Additionally, we added a new feature in the driver that allowed us to choose the transmission rate that we would use. For 802.11g mode, there are eight different rates, however, in our experiments we choose to transmit at four different transmission rates: 6Mbps, 18Mbps, 36Mbps, 54Mbps. For 802.11b mode, we transmit at four different rates: 1Mbps, 2Mbps, 5.5Mbps, 11Mbps. For the control of the parameters we mentioned, we built a simple GUI that directly communicates with the driver and allows the user to set up the parameters in an easy way, through menus.

## III. Experimental Setup

### A. Testbed Configuration

The testbed used in the experiments consists of 2 Linux laptops with 802.11 wireless cards based on the Atheros chipset. In this experimental study, one station is used as a dedicated destination, which mimics the functionality of a receiver and the other station is an access point.

### B. Methodology

The experiments we conducted were composed of two parts. We first measured the Packet Error Rate (PER) using Iperf [13], which is a powerful tool for traffic generation and measurement. In our experimental setup, one of the stations runs an Iperf client to generate UDP traffic streams, while the other runs an Iperf server which receives the traffic and collects the statistics (e.g. PER). To remove any random effect and short-term fluctuation, we ran each experiment 10 times with each run lasting 1 minute. We then averaged the results.

After the computation of the average packet error rate, we calculate the amount of redundancy needed to correct the errors. We utilize $(n, k)$ RS codes since it is widely used in FEC schemes. An $(n, k)$ RS code contains $k$ source packets and $(n-k)$ parity packets. Together, they form a group of $n$ packets, such that any $k$ of the $n$ packets can be used to reconstruct the $k$ source packets [10]. More specifically, we use RS(n,64) ($k = 64$) and the number of parity packets ($m = n - 64$) needed to correct all the errors, on the average, is chosen based on the channel conditions (i.e. packet error rate $P_E$) as follows,

$$m = kP_E/(1 - P_E) \tag{1}$$

where $m$ is the number of parity packets and $P_E$ is the packet error rate. Using the above equation, we compute the FEC rate, $r_{FEC}$, as follows,

$$\begin{aligned} r_{FEC} &= k/(k+m) \\ &= 1 - P_E \end{aligned} \tag{2}$$

In order to cover the other overheads (e.g., headers, etc.), we define the effective data ratio, $\beta$, as the ratio of the time spent to transmit the actual payload data to the total transmission time, whose typical values will be presented in Section IV. Combining all, we then calculate the useful rate as,

$$R_{useful} = \beta\ r_{FEC}\ R \tag{3}$$

where $R$ is the transmission rate.

## IV. Results

In our experimental study we use an IEEE 802.11g based WLAN. In order to understand the behavior of such a network, we conducted experiments using both broadcast and unicast modes in an outdoor environment. As described in Section III, we first obtain PER curves for different physical transmission rates and various locations. We are mainly interested in the packet losses due to channel conditions rather than the traffic contention in the channel. Hence, in our experiments, we transmit for only 20% of the time in order to keep the traffic level low. In order to be fair for all transmission rates, we also consider the overhead introduced by MAC, IP and physical layer headers. Note that, MAC and IP headers are sent at the selected transmission rate, whereas the physical layer header is always sent at the base rate, 6Mbps. We also considered the effect of packet size, since the overhead due to headers also depends on the packet size. In Table I, we tabulate the time distribution among data and headers for different packet sizes for 54Mbps physical rate. In this table, for a transmission duration of 1 sec, the total airtime is 200msec. $T_{DATA}$, $T_{MAC+IP}$, $T_{PHY}$ denote the time spent for the data, MAC+IP header (including the UDP header) and physical layer header, respectively. $N$ denotes the number of packets that can be transmitted in 200msec and $Data$ illustrates how many bits you can transmit in $T_{DATA}$ msecs at a rate of 54Mbps. Finally, the last column shows the effective data ratio, $\beta$. We observe that as we increase the packet size, we reduce the overhead due to headers, hence there is more room for the actual data transmission. On the other hand, as the packet size is increased, the likelihood of reception of all the bytes in the packet decreases, hence the PER increases. We performed preliminary experiments to investigate the effect of the packet size on the useful rate. We observed that at higher packet sizes, even though we have a higher packet error rate, the useful rate is also higher. Hence, all the results reported in the remainder of this section are obtained for a packet size of 1470 Bytes in order to minimize the header overheads.

| $Packet$ $Size(B)$ | $N$ | $T_{DATA}$ $(msec)$ | $T_{MAC+IP}$ $(msec)$ | $T_{PHY}$ $(msec)$ | $Data$ $(Mb)$ | $\beta$ |
|---|---|---|---|---|---|---|
| 1470 | 808 | 176 | 7.42 | 17.24 | 9.504 | 0.176 |
| 1000 | 1120 | 166 | 10.29 | 23.90 | 8.964 | 0.166 |
| 500 | 1903 | 141 | 17.48 | 40.61 | 7.614 | 0.141 |
| 200 | 3341 | 99 | 30.69 | 71.28 | 5.346 | 0.099 |

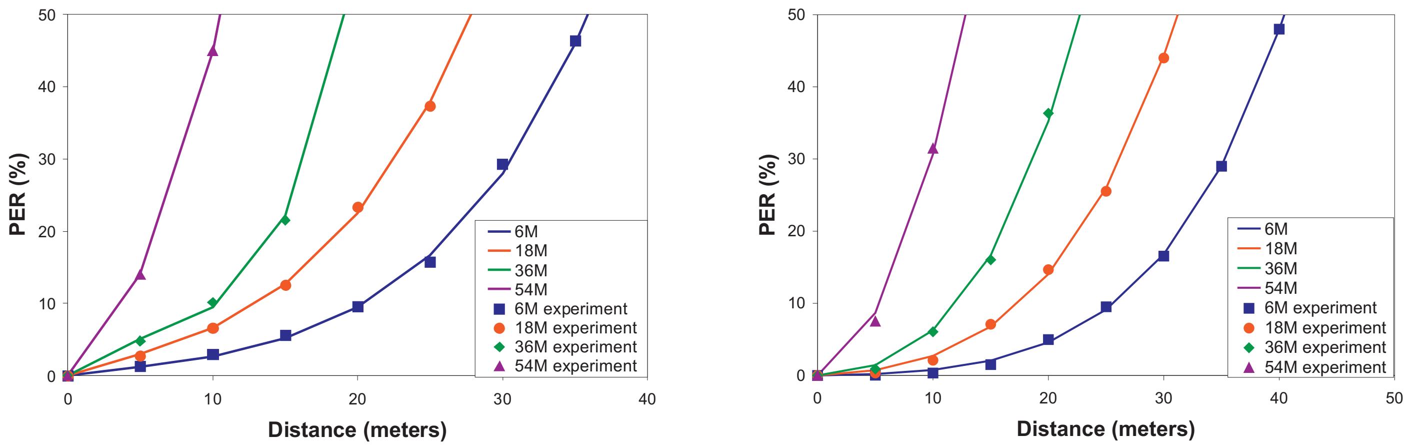
TABLE I

DISTRIBUTION AMONG DATA AND HEADERS FOR 54MBPS FOR DIFFERENT PACKET SIZES(MAC HEADER=34B, IP HEADER=28B (INCLUDING UDP HEADER), PHYSICAL LAYER HEADER=16B)

The outdoor experiments were conducted in Colombus Park, Brooklyn. We ran several experiments for different distances between the access point and the receiver. We varied the distance from 5 to 40 meters. The access point and the receiver are within line of sight. Figure 2(a) and Figure 2(b) illustrate the packet error rate versus distance curves for broadcast and unicast modes respectively. In these figures, the data points are the average loss rate derived from the experimental results whereas the curves show the exponentials fitted to these results. Here we only illustrate the results up to 50% PER since for PER higher than 50% we very often lost the connection due to bad channel conditions making the obtained PER values unreliable. The figures show the basic packet loss behavior of the IEEE802.11g wireless network. Based on these figures, we observe that,

- As the distance between the access point and the receiver increases, the packet error rate increases exponentially.
- For a target PER, the coverage area (defined as the distance at which the PER is less than the target) reduces significantly as the physical transmission rate increases.
- Due to the absence of ACK's and retransmissions in broadcast mode, the coverage area for the same PER reduces dramatically compared to the unicast case. For instance, for a PER of 30%, in unicast mode we can reach users up to 35 meters with 6Mbps transmission rate. However, using broadcast we can cover users up to only about 30meters.

Based on the PER's obtained, we compute the amount of




(a) Broadcast mode

(b) Unicast mode

Fig. 2. PER vs coverage area for IEEE 80211.g (outdoors)

| | 5m | 10m | 15m | 20m | 25m | 30m | 35m |
|---|---|---|---|---|---|---|---|
| **6Mbps** | 1 | 2 | 4 | 7 | 12 | 27 | 56 |
| **18Mbps** | 2 | 5 | 10 | 20 | 39 | - | - |
| **36Mbps** | 4 | 9 | 18 | 54 | - | - | - |
| **54Mbps** | 11 | 53 | - | - | - | - | - |

TABLE II
NUMBER OF PARITY PACKETS NEEDED FOR $k = 64$ SOURCE PACKETS IN BROADCAST MODE FOR IEEE 80211.G (PACKET SIZE IS 1470B)

packet level FEC to apply. We utilize RS(n,64). In Table II, we illustrate the amount of packet level FEC needed, on the average, to correct the errors for different coverage areas in broadcast mode. As seen in the table, for a target distance, as we increase the transmission rate, due to higher PER we need to send more FEC resulting in more overhead. On the other hand, since we are sending at a higher rate, the useful data rate is increased as illustrated in Figure 3(a) and Figure 3(b) for broadcast and unicast modes respectively.

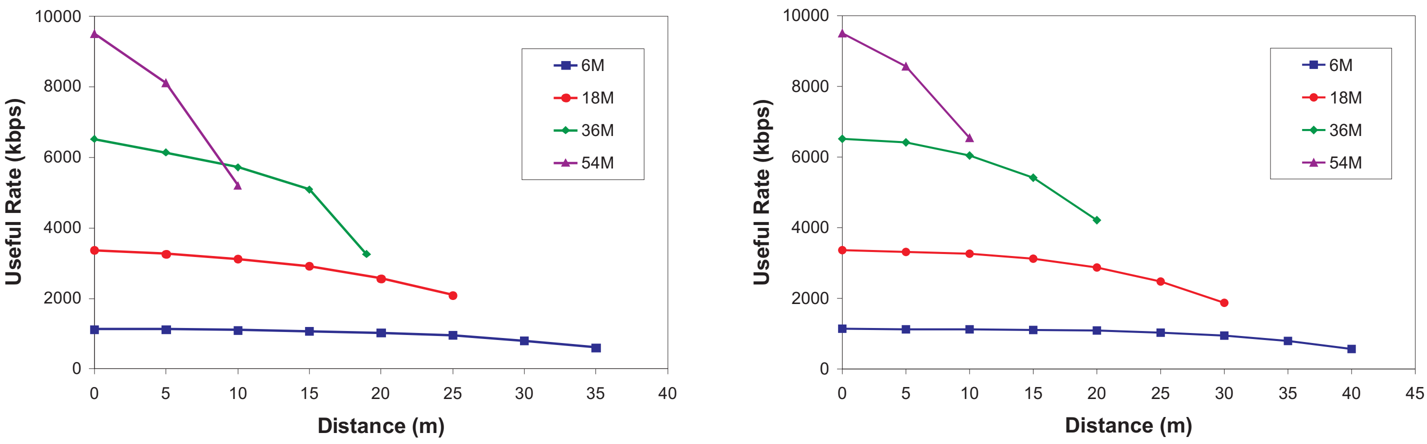
The results show that,

- For distances that are reachable with higher transmission rates, it is better to send at a higher rate with more error protection than to send at a lower rate with less error protection. For example, in Figure 4(b), if the target coverage area has a maximum distance of 10 m, and the data is transmitted at the base rate (6Mbps), you can only achieve a useful data transmission rate of 1105kbps. However if you chose to transmit at 54Mbps you can achieve a useful data transmission rate of 5198kbps for everyone in the coverage area.
- In order to extend the coverage range, we need to lower the transmission rate, with correspondingly lower useful data rate.

In order to compare IEEE802.11g system with IEEE802.11b, we conducted experiments using IEEE 802.11b. Note that IEEE 802.11b supports lower transmission rates and has no embedded error correction in physical layer. For IEEE 802.11b, we conducted outdoor experiments in Columbus Park. We varied the distance from 10 to 80 meters. In order to obtain the PER curves, we follow the same procedure described for IEEE 802.11g. Figure 4(a) illustrates the packet error rate versus distance curves for broadcast mode. Based on the PERs obtained, we compute the amount of packet level FEC to apply and the corresponding useful data rates for broadcast mode which we present in Figure 4(b). As we can see, the trends on IEEE 802.11b are similar to those of IEEE 802.11g in the sense that as the distance increases the PER increases exponentially. However, we observe that the coverage area for IEEE 802.11g system is smaller than the coverage area for IEEE 802.11b due to different modulation schemes and higher transmission rates. Furthermore, although we have embedded error correction in IEEE 802.11g, it is still better to apply application layer FEC at higher transmission rates to increase the useful rate.

## V. CONCLUSION

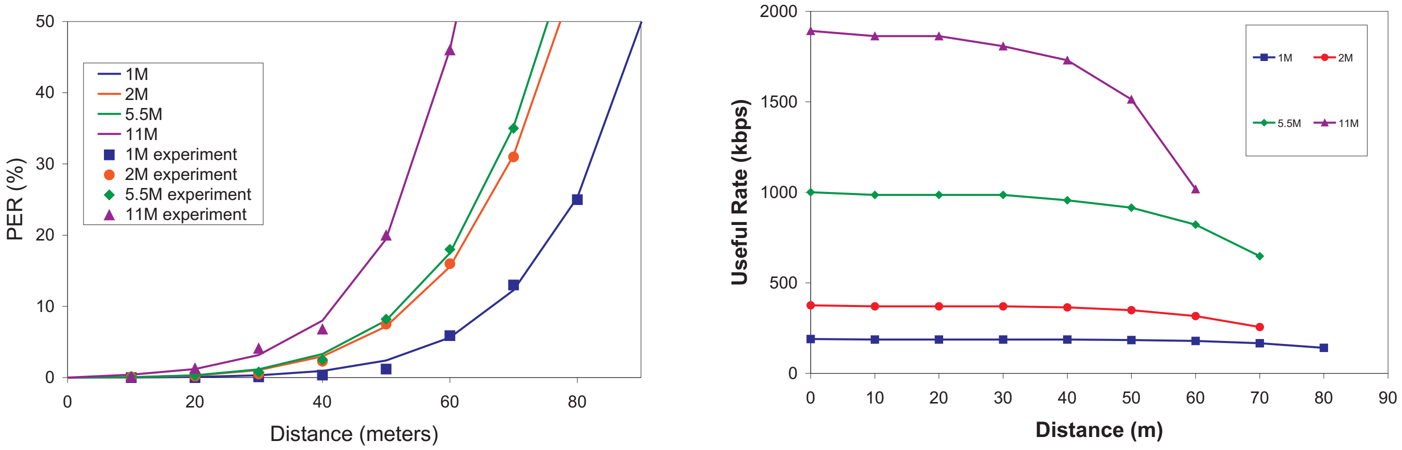
In this paper, we explore the dynamics of Forward Error Correction (FEC) schemes in multi-rate wireless local area networks which already have embedded error correction in physical layer. First we study the fundamental behavior of a 802.11g network under unicast and broadcast modes in a real outdoor environment. Then we explore the interaction between PER and FEC for different transmission rates. In order to evaluate the system quantitatively, we implemented a prototype using open source drivers, and ran experiments. We then compared the 802.11g network with 802.11b network which has no embedded error correction. Based on the results of these experiments, we argue that even though there is a physical layer error correction, using a higher transmission rate together with stronger FEC is more efficient than using a lower transmission rate with weaker FEC for multicast.




(a) Broadcast mode

(b) Unicast mode

Fig. 3. Useful rate vs coverage area for IEEE 80211.g (outdoors)




(a) PER vs coverage area

(b) Useful rate vs coverage area

Fig. 4. PER and useful rate vs coverage area for IEEE 80211.b (broadcast mode, outdoors)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## References


[1] A. Basalamah , H. Sugimoto and T. Sato, "Rate adaptive reliable multicast MAC protocol for WLANs," in *Proceedings of IEEE VTC*, 2006.

[2] C. Huang,J. H. David and C. Chang, "Congestion and Error Control for Layered Scalable Video Multicast over WiMAX," in *Proceedings of IEEE Mobile WiMAX Symposium*, 2007.

[3] I. Bajic, "Efficient Error Control for Wireless Video Multicast," in *Proceedings of IEEE MMSP*, 2006.

[4] H. Liu, M. Wu, D. Li, S. Mathur, K. Ramaswamy, L. Han and D. Raychaudhuri, "A Staggered FEC System for Seamless Handoff in Wireless LANs: Implementation Experience and Experimental Study," in *Proceedings of IEEE International Symposium on Multimedia*, 2007.

[5] J. Villalon, P. Cuenca, L. O. Barbosa, Y. Seok, and T. Turletti, "Cross-Layer Architecture for Adaptive Video Multicast Streaming Over Multirate Wireless LANs," *IEEE Transactions on Selected Areas in Communications*, vol. 25, no. 4, May 2007. pp 699-711.

[6] P. K. McKinley and A. P. Mani, "An experimental study of adaptive forward error correction for wireless collaborative computing", in *Proceedings of IEEE SAINT*, 2001.

[7] P. K. McKinley and A. P. Mani, "Experimental Evaluation of Error Control for Video Multicast", in *Proceedings of IEEE DCSW*, 2001.

[8] O. Alay, T. Korakis, Y. Wang, S. Panwar, "An Experimental Study of Packet Loss and Forward Error Correction in Video Multicast over IEEE 802.11b Network", in *Proceedings of IEEE CCNC*, 2009

[9] L. Rizzo, "Effective erasure codes for reliable computer communication protocols", in *ACM Computer Communication Review*, April 1997.

[10] A. J. McAuley, "Reliable broadband communications using burst erasure correcting code", in *Proceedings of ACM SIGCOMM*, September 1990.

[11] "MadWifi: Linux kernel drivers for Wireless LAN devices," http://madwifi.org/

[12] "Atheros: Chipsets for Wireless LAN devices," http://www.atheros.com/

[13] "Iperf: The TCP/UDP Bandwidth Measurement Tool," http://dast.nlanr.net/ Projects/Iperf/.