

# NETWORK EMBEDDED FEC (NEF) FOR VIDEO MULTICAST IN PRESENCE OF PACKET LOSS CORRELATION

*Shirish Karande, Mingquan Wu, Hayder Radha*

ECE Department, Michigan State University, East Lansing, MI –48824, USA

## ABSTRACT

Network Embedded Forward Error Correction (NEF) framework is a paradigm shift from a conventional approach of providing Forward Error Correction (FEC) only on an end-to-end basis. Previous work on NEF has shown promise in greatly improving the decodable probability, message throughput and video quality available to the end receiver. However the utility of NEF for video applications in presence of packet loss correlation has not been evaluated as yet. In practice, packet losses are often correlated and occur in bursts. The distortion in video can be sensitive to the bursty nature of the losses. Thus in this paper we analyze the performance of NEF within random multicast distribution trees that exhibit losses-with-memory over their branches. We utilized the Gilbert model for packet losses over each link. We quantify the performance improvement of NEF over conventional end-to-end FEC in terms of improvement in video quality in presence of packet loss correlation. Embedding NEF codecs can impact the sensitivity of video quality to packet loss correlation. We explicitly evaluate as to how NEF can alter the dependence of video quality on packet loss burstiness. Finally we show that in addition to an average improvement in video quality, NEF can improve the performance in terms of quality guarantees also.

## 1. INTRODUCTION

Traditionally, FEC has been employed on an end-to-end basis over multicast trees. Hence, those nodes that are far away from the source suffer high packet losses and may not be able to receive enough packets to recover the original FEC blocks. In [1], we introduced a network embedded FEC (NEF) framework for overlay and P2P multicast networks. In NEF, FEC codecs are placed optimally in the intermediate nodes of a network. Analysis and simulations [1][2] have shown that NEF outperforms end-to-end FEC dramatically in terms of decodable probability, message goodput and video quality. However, analysis in [1][2] is based on the assumption that packet losses follow a binomial distribution. In practice though,

packet losses are correlated and often occur in bursts [5][6]. It is well known that the length of packet loss burst has a significant impact on the performance of FEC and thus subsequently also on the quality of Video.

In [1] we proposed a greedy algorithm that embeds Reed-Solomon (RS) based  $(n, k)$  codecs in a tree in an optimal manner. This greedy algorithm can be completely described in terms of  $P_{v|v-1}(i, j)$  (the probability that a node  $v$  receives  $i$  packets given that its parent  $v-1$  sends  $j$  packets). For links with memory-less losses as described in [1], this probability is simply a binomial distribution. However deducing a similar expression when the Gilbert model governs each link is a challenging problem.

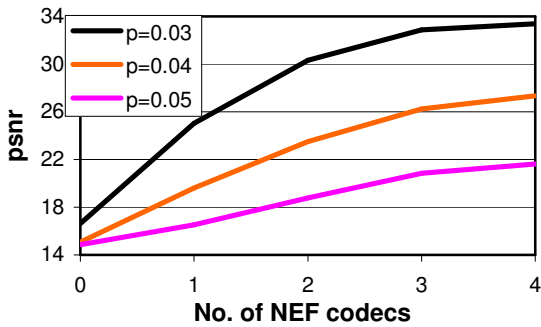
In [3] we evaluated the desired probability measure for the Gilbert model. This was achieved by constructing a Markov process obtained by extending the two-state Gilbert model using the number of correctly received packets as the indexes for the states of the extended Markov process. Using the flow-graph of such a Markov process we obtained a closed form expression for  $P_{v|v-1}(i, j)$ , for nodes in a multi-hop (but single path) wireless network. Thus in [3] we proposed a greedy algorithm that placed NEF codecs in an optimal manner in a multi-hop network governed by the Gilbert model. In [4] this greedy algorithm was extended from a network consisting of a single path to a tree-topology. Details of a greedy algorithm that embeds RS-codecs in an optimal manner, in a network with packet loss correlation can be found in [3][4]. In this paper, our primary focus is to evaluate the video quality performance facilitated by the greedy algorithm proposed in [3][4].

As the performance of a FEC scheme can be significantly affected by presence of channel memory, it is important to re-establish the performance gains that can be obtained by NEF schemes when the links are not memoryless. Thus in section 2 we re-evaluate the utility of NEF relative to end-to-end FEC. We show that under variety of channel conditions NEF can provide significantly improved performance when compared with end-to-end FEC. Once we clearly establish the utility of

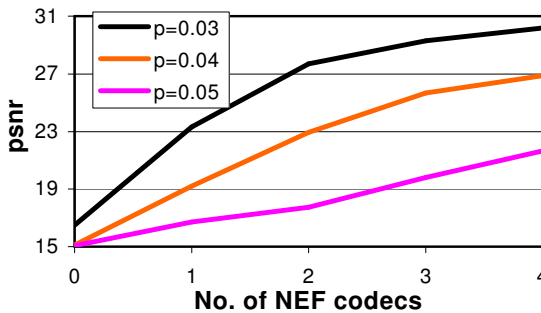
NEF even in presence of memory, in section 4 we have a closer look on the performance dependence of NEF purely on packet loss correlation. In section we illustrate the improvement in quality guarantees on account of NEF. Finally we summarize our key conclusions in section 5.

Before we proceed further it is worth noting that though 2- state channels can be characterized in a variety of ways we find that the parameters  $p$  (average packet loss probability) and  $\rho$  (packet erasure correlation) provide a more intuitive, insightful, and broad characterization. The packet erasure correlation  $\rho$  provides an average measure of how the states of two consecutive packets are correlated to each other. In particular, when  $\rho = 0$ , the loss process reduces to the special case of a memory-less Binary Erasure Channel (BEC). On the other hand, as the value of  $\rho$  increases, then the states of two consecutive packets become more and more correlated. Thus from this point onwards all the results and analysis in this paper are presented in terms of  $p$  and  $\rho$ .

## 2. IMPROVEMENT IN VIDEO QUALITY DUE TO EMBEDDING NEF CODECS

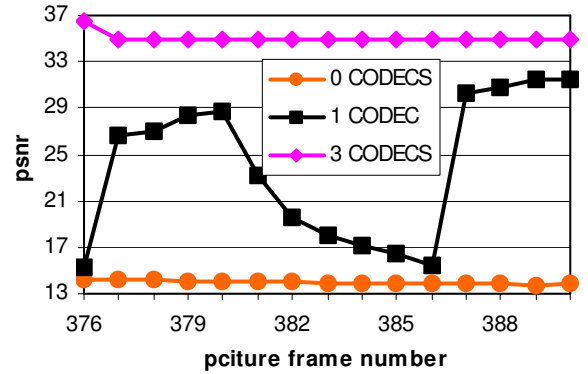


(a)



(b)

**Figure 1** Video quality in terms of average psnr as a function of the number of NEF codecs embedded in a multicast tree. (a)  $\rho = 0.1$  (b)  $\rho = 0.5$



**Figure 2** Temporal Comparison showing the impact of embedding NEF codecs on video quality. Each link satisfies parameter values  $p = 0.03$  and  $\rho = 0.05$ .



**Figure 3** Comparison of picture frames (frame no. 377 corresponding to Figure ) left: 0 codecs, right: 1 codec for subjective evaluation

The results in this section are based on implementing the greedy algorithm on ten random trees of 100 nodes generated using the popular Georgia Tech gt-itm [1] network topology generator. The average loss rate per-link is set to 3%, 4% and 5% respectively. The FEC code we use here is  $RS(223,255)$ . The video test sequence used for all simulations is the “Stefan” sequence with a “cif” resolution and frame frequency of 30fps. The video is compressed in a robust fashion (i.e. RD optimised for packet losses) using the H.264 standard with a constant quantisation of  $QP=16$  which translates into a bitrate of 1.8Mbps. Figure 1 (a) exhibits performance for low packet loss correlation (almost memoryless) while (b) exhibits psnr performance for channel with increased memory. It can be clearly observed that embedding only a few NEF codecs can improve video quality by over 10-15 dbs when compared with end-to-end FEC; irrespective of the amount of packet-loss correlation or the average packet loss rate.

Figure 2 provides further evidence on the utility of embedding NEF codecs. The temporal snapshot represents a scenario where embedding 3 codecs allows an end receiver to recover all the message packets associated with a GOP in a loss-less manner. Embedding only 1 codec is

not sufficient to facilitate such a complete recovery. Nevertheless, embedding a single codec facilitates enough local recovery at an intermediate node, so as to significantly reduce the distortion. Finally in Figure 3 we provide actual picture frames to facilitate a subjective evaluation. It should be noted that embedding 3 codecs allows us to recover the video without any block-distortion or motion discontinuity. On the contrary both these artifacts are clearly observed when only end-to-end FEC is used.

#### 4. IMPACT OF PACKET LOSS CORRELATION

In this section we specifically investigate the impact that packet loss correlation has on FEC and NEF performance. For FEC codes, we are often concerned about the probability that a node can receive enough packets to decode an FEC block.

Figure 4 plots the average decodable probability of a

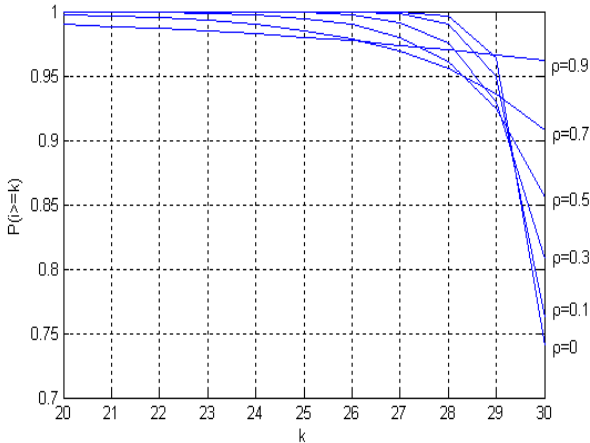


Figure 4 Decodable probability for a receiver when sender sends a  $(n,k)$  FEC block

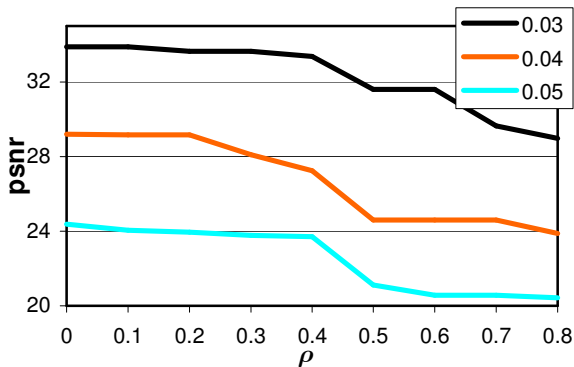


Figure 5 PSNR performance dependence on packet loss correlation (Results based on embedding of 4 codecs)

receiver when the sender sends FEC blocks through a Gilbert channel. The block size  $n$  is set at 30, the number of message packets in a FEC block  $k$  is changed from 20 to 30;  $p=1\%$  and  $\rho$  is changed from 0 to 0.9. The FEC code rate equals  $k/n$ .

From Figure 4 we can observe that if the coding rate is reasonably lower than channel capacity, the decodable probability is inversely proportional to correlation. However as the coding rate increases, this relationship changes and the decodable probability becomes proportional to correlation. This phenomenon can be explained as follows. In the Gilbert model, as  $\rho$  increases, the packet loss burst length increases. For FEC codes with high coding rate, any FEC block that suffers even a few packet losses may not remain decodable. However, for a given average loss rate, longer loss bursts means fewer FEC blocks suffer from packet loss; this may result in an average higher decodable probability.

In a NEF framework, as we employ data recovery at intermediate nodes, the impact of a large number of FEC blocks suffering packet losses is diminished. As against that if a particular FEC block is very severely affected then even embedding codecs at intermediate nodes is of no use. Thus in general it should be expected that in a NEF framework, the decodable probability has an inverse relationship with packet loss correlation. Consequently in Figure 5 it can be observed that the video quality in a NEF framework always deteriorates as packet loss correlation increases

#### 5. VIDEO QUALITY GUARANTEE

Till this point most of the results presented in this paper are based on the averages over the users and nodes. In certain video applications the minimum quality received by a user may be a more important performance parameter than average video quality. It is worth noting that it is possible to obtain a high average throughput even when some users do not receive any video at all. In fact in an end-end FEC scheme optimizing average throughput could often lead to providing poor video quality to some users. Thus it is important to establish that the average improvement in quality seen in a NEF framework is on account of improvement in quality of video for almost all receivers and not just because of large improvement in quality among a small select set of receivers.

Thus in this section we show that in a NEF framework not only is the average throughput improved, but the variance in the throughput available to different users also reduces as the number of codecs are increased. In other words we show that as the codecs are increased a larger set of receivers get improved video quality with

increased probability (guarantee). We evaluate the improvement in performance by monitoring the reduction factors. A reduction factor corresponding to  $m$  codecs is the ratio of the performance measure variance in the absence of a codec to performance measure variance in presence of  $m$  codecs. Thus we can define reduction factors for performance measures throughput and decodable probability.

**Table 1 Variance Reduction Factors**

Number of NEF codecs	Throughput Variance	Decodable Probability Variance
0	1	1
1	1.23	1.03
2	1.56	1.03
3	2.56	1.67
4	4.35	1.88
5	7.33	2.54

The above table provides reduction factors for an arbitrarily chosen graph. Similar performance was observed for all graphs. It can be seen that as the number of codecs are increased the variance in performance reduces. Thus the greedy algorithm embeds the NEF codecs in such a way that the more needy receivers get helped more. Thus a NEF framework improves the overall throughput guarantee provided to the receivers.

**Table 2 Reduction factors as a function of correlation**

Packet loss correlation	Variance reduction factor	
	Throughput	Decodable probability
0	15.92	6
0.5	6.827	2.39
0.9	1.73	1.19

Above table shows reduction factors when 5 NEF codecs are embedded. It can be seen that as the packet loss correlation increases the variance in performance increases. Nevertheless NEF codecs continue to significantly reduce the variance in quality of the received data. However as the channel gets bursty, higher number of codecs are required to provide identical service quality to all receivers

We can further evaluate the ability of the NEF framework to reduce the variance in performance by monitoring the performance of the best and the worst node in the graph. Note that as we embed codecs in a greedy manner the actual choice of best and worst node will alter with each new codec. When the channel conditions are

severe, the video quality can be affected more by motion jerkiness than block distortion. Thus while comparing the performance of the best and the worst node, we shall consider a motion discontinuity reduction factor, which is defined as the ratio of the picture frames received by the best node to the picture frames received by the worst node. It was observed that for packet loss correlation of 0, the motion discontinuity factor was reduced from 5.95 for 0 codecs to 2.21 for 5 codecs. There was absolutely no improvement in performance for the best node, but performance of the worst node improved significantly. Similarly for packet loss correlation of 0.9 it was observed that the motion discontinuity factor is reduced from 1.56 for 0 codecs to 1.31 for 5 codecs. Thus it was observed that NEF codecs help improve the performance guarantees in the network.

## 6. CONCLUSIONS

In this paper we evaluated the impact of packet correlation on the video quality performance of NEF over random multicast trees that consists of erasure channels with memory. Results show that NEF is very effective even in environments where packet losses have a strong correlation. NEF framework improves the average as well as a worst-case guarantee based video quality performance. It was observed that addition of codecs reduces the sensitivity of video quality to channel burstiness.

## 6. REFERENCES

- [1] H. Radha and M. Wu, "Overlay and Peer-to-Peer Multimedia Multicast with Network-Embedded FEC," IEEE International Conference on Image Processing (ICIP), September 2004.
- [2] M. Wu, S. Karande, and H. Radha, "Network-Embedded Channel Coding for Optimum Throughput of Multicast Packet Video," International Packet Video Workshop (PV), December 2004.
- [3] M. Wu and H. Radha, "Network-Embedded FEC (NEF) Performance for Multi-Hop Wireless Channels with Memory," IEEE International Conference on Communications (ICC), May 2005.
- [4] M. Wu and H. Radha, "Network Embedded FEC for Overlay and P2P Multicast over Channels with Memory," Conference on Information Sciences and Systems (CISS), March 2005.
- [5] W. Jian "QoS measurement and Management for Internet real-time multimedia services", Ph.D thesis, Department of Computer Science, Columbia University, 200M. Yajnik, J. Kurose, D. Towsley, "Packet Loss Correlation in the Mbone Multicast Network," IEEE Global Internet Conference, London, November 1996.
- [6] E. W. Zegura, "GT-ITM: Georgia tech internetwork topology models (software)," <http://www.cc.gatech.edu/fac/Ellen.Zegura/gt-itm/gt-itm.tar.gz>, 1996.