Error Resilient Video Multicast using Randomized Distributed Space Time Codes

Özgü Alay, Pei Liu, Yao Wang, Elza Erkip and Shivendra Panwar

Department of Electrical and Computer Engineering, Polytechnic Institute of NYU, Brooklyn, New York

***Abstract*—In this paper we study a two-hop cooperative transmission scheme where multiple relays forward the data simultaneously using Randomized Distributed Space Time Codes (R-DSTC). We propose to integrate this randomized cooperative transmission with layered video coding and packet level Forward Error Correction (FEC) to enable error resilient video multicast. Data rates in both hops as well as the FEC rate are adopted to maximize the video quality. Our results show that while rate-adaptive direct transmission provides better video quality than conventional multicast, randomized cooperative scheme outperforms both strategies significantly.**

Index Terms: forward error correction, layered video, randomized distributed space time coding, user cooperation, wireless video multicast

I. Introduction

Wireless video multicast enables delivery of popular events in a bandwidth efficient manner. However, variations in channel qualities between source and each receiver make wireless video multicast a challenging problem. One effective technique to combat channel variations that arise from fading is to utilize user cooperation where terminals process and forward the overheard signal transmitted by other nodes to their intended destination [1]. In general, there may be more than one node that can overhear the packet sent by the source. For unicast, if we let these nodes transmit cooperatively to the destination, significant diversity gains can be accomplished. A spectrally efficient way for the nodes to relay simultaneously is using a distributed space-time code (DSTC) [2]. The basic idea behind DSTC is to coordinate and synchronize the relays such that each relay acts as one antenna of a regular Space Time Code (STC) [3],[4]. However, DSTC requires tight coordination among the source and relays, leading to significant overhead at the MAC layer. Furthermore, DSTC works with a fixed number of relays and cannot exploit other nodes that receive the source information.

Randomized DSTC (R-DSTC) [5] circumvents some of these problems by having each relay transmit a random linear combination of antenna waveforms. R-DSTC not only loosens the coordination but also enables a variable number of relays. Node synchronization in R-DSTC is discussed in [12].

Cooperative transmission is suitable for multicast not only because of its ability to substantially reduce the packet losses, but also because the relays are part of the multicast group. R-DSTC is especially attractive for multicast since the nodes that receive the packets can act as relays and transmit simultaneously, hence there is no relay selection and scheduling. Recently, we considered randomized cooperation for video multicast in an IEEE 802.11g based WLAN [7].

In this paper, we extend the results in [7] by considering R-DSTC along with packet level FEC to enable error resilient video delivery to multicast nodes. For optimized performance, proper selection of STC dimension, transmission rates of the first and second hops as well as FEC rate is essential. In particular, adaptation of the FEC rate enables transmission at higher rates at both hops, thereby improving the video quality. We evaluate the performance of the proposed system and compare with rate adaptive direct transmission [8] and conventional multicast. We further consider layered coding to provide better video quality to nodes with better channel conditions. This is realized by letting the source transmit all the layers, and letting nodes that successfully receive the first hop transmission to forward only the base layer packets. Our results illustrate the benefits of FEC and rate adaptation as well as randomized cooperation. Furthermore, layered randomized cooperation integrated with FEC allows part of the users to get further improvements, while all users maintain video quality at least as good as rate adaptive direct transmission.

II. System model and Transmission Modes

We consider video multicast from a source (such as an access point) to nodes within its coverage range of radius, r_d. Nodes in the network have a single antenna and can transmit at different rates by adapting their modulation level and channel code rate. In accordance with IEEE 802.11g, we consider only square constellations. We assume independent slow Rayleigh fading among nodes that is constant over the duration of a single packet, a reasonable assumption for video communication. We also assume path loss with an exponent of α. Note that instantaneous Packet Error Rate (PER) depends on the modulation and channel coding as well as the fading level and the distance between the transmitter and the receiver, and can be computed for direct and randomized cooperative transmission as in [7].

For direct transmission, the source transmits packets at a physical layer transmission rate, R_d bits/sec. In order to correct packet errors, we employ packet level FEC at a rate of γ_d such that the residual loss rate at all nodes is less or equal to a target, ζ. We consider two different modes of transmission for direct transmission: conventional direct transmission and rate adaptive direct transmission. In conventional direct transmission, R_d and γ_d are fixed. On the other hand, for the rate adaptive

[1]This work is supported in part by National Science Foundation (NSF) under awards 0520054, 0430885, 0905446 and the New York State Center for Advanced Technology in Telecommunications (CATT). The work is also supported by Wireless Internet Center for Advanced Technology (WICAT).

direct transmission, R_d and γ_d are dynamically adjusted based on the feedback on the average PER of the nodes.

For multicast with R-DSTC, the source transmits a packet at a transmission rate of R_1 bits/sec. The nodes that receive the packet correctly form the relay set $\mathcal{R}$. Note that some close by nodes can experience a bad fading level and may not be able to receive the packet, while far away ones may receive the packet successfully. Each relay in $\mathcal{R}$ transmits the packet simultaneously to other nodes at a transmission rate of R_2 bits/sec. We assume R-DSTC is based on an underlying STC of dimension L and the minimum of the STC dimension and the number of relays determines the diversity gain in the second hop. In order to handle packet losses, the source employs packet level FEC of rate γ_s such that after two hop transmission, the residual loss rate at each node is equal or less than the target, ζ.

We also study a layered R-DSTC scheme where we consider two layers; base and enhancement layer, and assume each packet belongs to either the base or the enhancement layer. The source transmits packets from both layers in different time slots. The base layer packets go through two hop transmission, i.e. nodes receiving a base layer packet from the source will forward this packet in the second hop; whereas the enhancement layer packets go through only one hop transmission by the source. The FEC rate for the base layer, γ_b, is chosen based on the end-to-end PER after two hop transmission for the base layer; whereas the FEC rate for the enhancement layer, γ_e, is determined based on the PER after the first hop. We configure the transmission rates and FEC rates so that the nodes that receive both base layer and enhancement layers get much better quality than direct transmission, whereas other nodes still get quality better than or similar to direct transmission. In general the enhancement layer can also be relayed, but we only consider two-hop transmission of base layer for simplicity.

III. Packet Level FEC and Video Rate

In order to handle packet losses, we employ packet level FEC, which is a promising solution for error control in video multicast over wireless networks [9]-[10]. The basic idea of FEC is that redundant information is sent a-priori by the source, in order to be used by the receivers to correct errors/losses without contacting the source. It is assumed that each receiver, by using CRC, can identify the packets in error. The advantage of using packet level FEC for multicasting is that any parity packet can be used to correct independent single-packet losses among different nodes.

The lost packets can be viewed as erasures and an erasure code at the packet level can be used to recover the lost packets. Specifically, for every s source packets, we need at least m parity packets in order to recover all the source packets from the erasures e where $e \leq m$. The correction capability e depends on the code used. A perfect code (such as Reed Solomon) is a code that can correct up to m erasures, that is $e = m$. Assuming an average PER of ϵ, we choose the number of parity packets $m > n\epsilon$ to meet the target residual error rate, ζ. The resulting FEC rate is $\gamma(\epsilon) = s/(s+m)$.

With direct transmission, we assume that the maximum packet error rate among all users in the coverage area of radius r_d is ϵ_{max}, when the transmission rate is R_d. Then, the corresponding FEC rate is $\gamma_d(\epsilon_{max})$. We define the effective data ratio, β, as the ratio of the bit rate used to transmit multicast payload data (e.g. video data including the parity packets) to the total transmission rate. Then, with direct transmission all the nodes receive a video rate of:

$$R_{v_d} = \gamma_d \beta R_d \tag{1}$$

Note that the video rate depends on the transmission rate as well as the FEC rate, hence the PER. A rate is called *sustainable* if its corresponding average PER (without FEC) is less than ϵ_T. A higher sustainable transmission rate requires stronger FEC while a lower transmission rate has lower PER, so a weaker FEC. Therefore, unlike conventional multicast where transmission rate and FEC rate are fixed, we also consider a rate adaptive direct transmission mode as in [8], where the transmission rate and FEC rate are dynamically adjusted to improve the video rate. For cooperative multicast, we also optimize the video quality over different transmission rates and the corresponding FEC rates. We provide the details of the proposed protocols along with their video rate formulations in the next section.

IV. Optimization of Different Transmission Modes

We study two different transmission modes: direct transmission and cooperative multicast. For cooperative multicast, we consider single layer and layered cooperation.

A. Direct Transmission

1) Conventional Direct Transmission: We assume the source transmits at the base rate of the underlying network (e.g. R_d = 6Mbps for IEEE 802.11g) and employs packet level FEC at fixed rate γ_d chosen based on the PER of the node at the edge of the coverage range at the base transmission rate.

2) Rate Adaptive Direct Transmission: We assume the source knows the average channel quality (in terms of the average received SNR) between itself and every node in the target coverage area. This can be achieved by monitoring the channel periodically. Based on the average channel quality information, among all sustainable transmission rates, the source makes the decision on the direct transmission rate, R_d, and the corresponding FEC rate γ_d such that the video rate in (1) at all nodes is maximized.

B. Cooperative Multicast using R-DSTC

For randomized cooperation, we assume that the source knows all the average channel qualities between itself and all the nodes, as well as among the nodes. In order for source to know the average channel quality among the nodes, the nodes need to exchange control signals among themselves for measuring the average SNR and then transmit this information back to the source.

We assume that a video is divided into segments of duration T seconds each. For the cooperative scheme, the time T is shared between the first and second hops. Let the sender transmit for T_1 seconds and the relays transmit for T_2 seconds, where $T_1 + T_2 = T$. Then the total number of bits received by the Hop-1 and Hop-2 nodes are $B_1 = \beta R_1 T_1$ and $B_2 = \beta R_2 T_2$, respectively. We use this formulation to first discuss single layer cooperation and then generalize to layered cooperation.

1) Single layer Cooperation: For single layer cooperation, the relays will forward all the packets they receive without differentiating between the source and parity packets. The FEC rate γ_s depends on the maximum PER ϵ_{max} among all users after two hop transmission. Since we consider end-to-end packet level FEC, we compute the average PER experienced by each node in the multicast group using the formulation in [7]. Note that $\epsilon_{max}(R_1, R_2, L)$ depends on the transmission rates of both hops, R_1 and R_2 as well as R-DSTC dimension, L and the FEC rate γ_s depends on ϵ_{max}. Then the video rates at Hop-1 and Hop-2 nodes are $R_{v_1} = \gamma_s B_1/T = \gamma_s \beta R_1 t_1$ and $R_{v_2} = \gamma_s B_2/T = \gamma_s \beta R_2(1 - t_1)$, respectively where $t_1 = T_1/T$, $t_2 = T_2/T$ and $t_1 + t_2 = 1$.

We choose R_1, R_2, L, t_1 jointly so that Hop-1 and Hop-2 nodes receive the video at the same rate, i.e., $R_{v_s} = R_{v_1} = R_{v_2}$. This yields $t_1 = R_2/(R_1 + R_2)$, and the corresponding video rate for single layer cooperation is:

$$R_{v_s}(R_1, R_2, L, \beta) = \gamma_s \beta R_1 R_2/(R_1 + R_2) \tag{2}$$

Among all sustainable R_1, R_2, L's, the source chooses the optimum R_1, R_2, L and the corresponding γ_s that maximizes the video rate. Here, L is chosen as close as possible to the average number of relays N_{avg}. Note that, for large N, N_{avg} may be much larger than L due to practical L values. The robustness of R-DSTC ensures that even these parameters are chosen with partial channel information (for example only based on user count), the performance loss is negligible. This is argued for data unicast in [6], and will not be explored here due to space considerations.

2) Layered Cooperation : For layered cooperation, we define the FEC rates for base and enhancement layers as γ_b and γ_e respectively. Since base layer packets go through two-hop transmission, $\gamma_b(R_1, R_2, L)$ is chosen based on the packet error rate after two hops and depends on the transmission rates of both hops, R_1 and R_2 as well as L. However, $\gamma_e(R_1)$ is chosen based on the packet error after the first hop transmission and only depends on first hop transmission rate R_1. If we define μ as the ratio of the nodes that receive both base layer and enhancement layer to the total number of users, as γ_e decreases, the system can tolerate more packet errors, and we can provide both layers to more users, thus, increasing μ. On the other hand, the supportable video rate for enhancement layer become lower.

For layered cooperation, B_1, the total number of bits for Hop-1, is allocated among source and parity packets for base and enhancement layers. On the other hand, since Hop-2 nodes receive only the base layer, B_2 is allocated among source and parity packets for the base layer only. Hence, the video rate for Hop-2 nodes will be same as the single layer:

$$R_{v_2}(R_1, R_2, L, t_1, \beta) = \gamma_b \beta R_2(1 - t_1) \tag{3}$$

For Hop-1 nodes B_2 bits out of B_1 will be allocated for the base layer and the remaining $B_1 - B_2$ for the enhancement layer. The video rate for first hop nodes can be expressed as:

$$\begin{aligned} R_{v_1}(R_1, R_2, L, t_1, \beta) = \gamma_b \beta R_2(1 - t_1) \\ + \gamma_e \beta (R_1 t_1 - R_2(1 - t_1)) \end{aligned} \tag{4}$$

For layered cooperation, we set the video rate of base layer to a target rate R_b which is at least as good as the direct transmission video rate. Note that the percentage of the nodes, μ that will receive the enhancement layer depends on R_1 as well as the enhancement layer FEC, γ_e, and is a design parameter. For a given μ and R_b, among all sustainable R_1, R_2, L's, the source chooses the optimum R_1, R_2, L and the corresponding γ_b, γ_e, t_1 that maximizes the video rate for the nodes that receive both base and enhancement layers.

V. Results

We study a IEEE 802.11g based network and consider a coverage range of 100m radius, $r_d = 100m$, where the source is at the center of the network and nodes are randomly uniformly located in this coverage range. For R-DSTC, the underlying orthogonal STC can have dimensions among $L = 2, 4, 8$. For these STC dimensions, there exist real orthogonal designs which provides full rate for square constellations [11]. Therefore, the maximum L we consider is 8, even when the number of relays N_{avg} is much larger.

In our simulations, we consider different numbers of nodes corresponding to different density networks, and for each node density we generate 200 different node distributions. We choose the transmission power of the source at the base rate, $R_d = 6Mbps$, such that all nodes in the coverage range experience an average PER of 5%, which is a practical assumption for multicast in wireless networks. From our experimental work, we have found that a link becomes unreliable and the connection is often lost when the PER exceeds $\epsilon_T = 25\%$. Therefore, in our simulations, we only consider transmission rates which lead to $PER \leq \epsilon_T$.

In order to have comparable energy consumption with direct transmission, we assume that the relay energy per symbol is set to $E_r = E_s/N_{avg}$ where E_s is the symbol energy of the source and N_{avg} is the average number of Hop-1 nodes for a given node density and transmission rate. Note that due to the random nature of fading, we do not know the exact number of nodes that receive the packet at each fading realization of the network; that is why we compute the average number of relays based on simulations.

For the FEC computations, we use $s = 128$ and choose m such that the probability of the residual error after the erasure coding (or application layer FEC) meets $\zeta \leq 0.5\%$. We observe that when using an error-resilient video decoder, there is no observable quality degradation when the loss rate is equal or below this threshold.

We assume the video is pre-coded into a fine granularity scalable stream from which the sender can extract video bits up to the maximum supportable video rate of $R_{v_s} = R_{v_1} = R_{v_2}$ for the single layer cooperation. In layered cooperation, we assume the sender can extract up to the maximum supportable base layer rate R_{v_2} for the base layer, and extract additional bits up to the maximum supportable enhancement layer rate of $R_{v_1} - R_{v_2}$. We assume the base and enhancement layer bits are

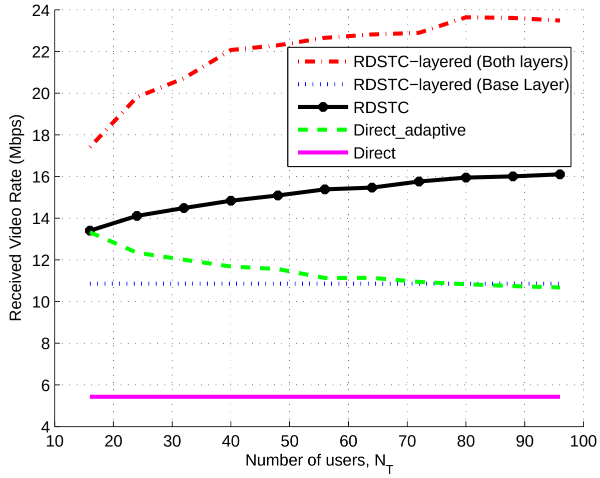

Fig. 1. Video Rates vs number of nodes ($\beta = 1$, μ=10%).

packetized separately and the layer information is embedded in the packet header.

For direct transmission, we use the base transmission rate $R_d = 6Mbps$ and since we assume an average PER of 5% in the coverage range, we apply a FEC rate of $\gamma_d = 0.905$. For the remaining modes, for each node distribution, we first find the optimal parameters numerically as discussed in Section IV and present the average video rates over different node distributions.

In Figure 1, we illustrate the performance of different modes as a function of different number of nodes in the network. For layered cooperation, we set $\mu = 10\%$ and the base layer video rate $R_b = 2R_{v_d}$. As illustrated in the figure, for direct transmission, the video rate does not change with number of nodes as transmission and FEC rates are fixed. For rate adaptive multicast, since the transmission and FEC rates are chosen based on the channel conditions, for a large number of nodes, there is a higher chance that there will be some node at the edge of the coverage range. These nodes have higher PER and hence the system must choose a lower FEC rate to guarantee these users residual loss rates are less than the target, yielding a lower video rate. For the cooperative multicast systems, as the number of nodes increases, more relays participate in the second hop transmission, making the end-to-end PER lower and hence the supportable video rate higher. The performance of the proposed scheme with single layer outperforms both direct transmission and rate-adaptive direct transmission, and layered cooperation provides further improvements and differentiated quality to different nodes.

We also consider the quality of the receivers in terms of average PSNR values for the Foreman and Bus video sequences and compare the performance of different transmission modes in Table I. We use a H.264/SVC codec with SNR scalability and encode CIF resolution (352x288) video sequences at the maximum video rates (assuming $\beta = 0.05$) supported by different transmission modes for a dense network (N_T=80). For both sequences, single layer cooperative multicast achieves 4dB and 2dB improvement compared to direct transmission and rate adaptive direct transmission, respectively. Such gains in PSNR lead to significant visual improvement.

	Direct	**Rate Adaptive Direct**	**Single Layer R-DSTC**	**Layered R-DSTC (Both Layers)**	**Layered R-DSTC (Base Layer)**
Foreman	30.12dB	32.52dB	34.38dB	36.55dB	32.53dB
Bus	23.04dB	25.40dB	27.09dB	29.27dB	25.41dB

TABLE I
VIDEO QUALITY FOR DIFFERENT TRANSMISSION MODES
$(\beta = 0.05, N_T = 80, \mu = 10\%)$

VI. CONCLUSION

In this paper, we propose a cooperative layered video multicasting scheme using R-DSTC along with packet level FEC to enable error resilient video delivery. We optimize the transmission rates of the first and second hops as well as the STC dimension, to maximize the supportable video rate at all nodes in the single layer system. In the layered case, we maximize the supportable video rate for the first hop while fixing the video rate for the second hop. We show that the proposed scheme with single layer outperforms both conventional multicast and rate-adaptive direct transmission, and layered cooperation provides further improvements and differentiated quality to different nodes.

In this paper, for a given transmission rate, we choose the FEC rate so that the residual loss rate is less than a target. One research direction is to consider joint optimization of transmission rate and FEC rate to minimize the end-to-end distortion or some other criterion.

REFERENCES

[1] A. Sendonaris, E. Erkip, and B. Aazhang, “User cooperation diversity-Part I and Part II ,” *IEEE Trans. Commun.*, vol. 51, pp. 1927-48, November 2003.
[2] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, “Cooperative diversity in wireless networks: Efficient protocols and outage behavior,” *IEEE Trans. on Information Theory*, vol. 50, no. 12, p. 3062, December 2004.
[3] V. Tarokh, H. Jafarkhani, and A. Calderbank,”Space-time block codes from orthogonal designs”, *IEEE Transactions on Information Theory*, vol. 45, no. 5, pp. 14561467, July 1999.
[4] S. Alamouti,”A simple transmit diversity technique for wireless communications”, *IEEE Journal on Selected Areas in Communications*, vol. 16, no. 8, pp. 14511458, October 1998.
[5] B. S. Mergen and A. Scaglione,”Randomized space-time coding for distributed cooperative communication”, *IEEE Transactions on Signal Processing*, pp. 50035017, October 2007.
[6] P. Liu, Y. Liu, T. Korakis, A. Scaglione, E. Erkip, S. Panwar,” Cooperative MAC for rate adaptive randomized distributed space-time coding”, in *Proceedings of IEEE GLOBECOM*, November 2008.
[7] O. Alay, P. Liu, Z. Guo, L. Wang, Y. Wang, E. Erkip, S. Panwar, “Cooperative Layered Video Multicast using Randomized Distributed Space-time Codes”, in *Proceedings of IEEE Infocom MOVID Workshop*, April, 2009.
[8] O. Alay, T. Korakis, Y. Wang, S. Panwar, ”Dynamic Rate and FEC Adaptation for Video Multicast in Multi-rate Wireless Networks”, to appear, *ACM/Springer Mobile Networks and Applications (MONET), Special Issue on Advances In Wireless Testbeds and Research Infrastructures.*
[9] 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.
[10] T. A. Lee, S. G. Chan, Q. Zhang, W. Zhu, and Y. Zhang, “Allocation of Layer Bandwidths and FECs for Video Multicast Over Wired and Wireless Networks,” *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 12, no. 12, December 2002. pp 1059-1070.
[11] J. G. Proakis, “Digital Communications”, NY, McGraw-Hill, 2001.
[12] M. Sharp, A. Scaglione and B. Sirkeci-Mergen, “Randomized Cooperation in Asynchronous Dispersive Links,” *IEEE Transactions on Communications*, vol. 57, no. 1, pp. 64-68, January 2009.