Cooperative Layered Video Multicast using Randomized Distributed Space Time Codes

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

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

Abstract— **With the increased popularity of mobile multimedia services, efficient and robust video multicast strategies are of critical importance. In a conventional multicast system, the source station transmits at the base rate of the underlying network so that all the nodes can receive the data correctly. The performance of such a multicast system is limited by the node with the worst channel conditions, which usually corresponds to the nodes at the edge of the multicast coverage range. To overcome this problem, we propose a two-hop cooperative transmission scheme where in the first hop the source station transmits the packets and the nodes who receive the packets forward the packets simultaneously in the second hop using Randomized Distributed Space Time Codes (R-DSTC). We further integrate this randomized cooperative transmission with layered video coding to provide users different video quality based on their channel conditions. The performance of the system is evaluated and compared with a conventional multicast system. Our results show that the proposed cooperative system significantly improves the performance compared to conventional multicast.**

Index Terms: layered video coding, user cooperation, randomized distributed space time coding, wireless networks, video multicast

I. Introduction

Wireless video multicast is a bandwidth efficient method to deliver popular events to many wireless nodes. However, wireless channels suffer from path loss and fading, resulting in disparate channel qualities between the source and each node, hence making the wireless video multicast a challenging problem. Although rate adaptation is a standard feature in today's wireless networks, multicast/broadcast packets are transmitted using the base transmission rate of the system. The motivation for using the lowest transmission rate is to enable far away nodes to successfully receive and decode the transmitted packets. With such a conservative approach, all the multicast nodes see the same low video quality regardless of their channel conditions.

One effective technique to combat path loss and fading is to utilize user cooperation where terminals process and forward the overheard signal transmitted by other nodes to their intended destination [1]. Cooperation techniques can be used to provide spatial diversity [2] as well as reduction in source distortion (including video) by providing unequal error protection [3], [4]. Furthermore, cooperation can also be exploited at the MAC layer [6] or jointly at the physical and MAC layers [5].

The above mentioned studies consider a single relay case and a unicast (point-to-point) communication scenario. In general, there may be more than one node that can overhear the packet sent by the source. For unicast, an efficient way is for the nodes to relay simultaneously. Simultaneous transmission by multiple relays can be achieved 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 STC [12],[13]. However, in order to realize such a system, each relay participating in a DSTC needs to know exactly which antenna it will mimic in the underlying STC. Furthermore, based on the dimension of the underlying STC used, a fixed number of relays is chosen and even though there may be other nodes who decode the source information correctly, they are not allowed to transmit, thus forfeiting the potential diversity and coding gains. Finally, a DSTC requires tight constraints on the time synchronization of the nodes, putting a very heavy burden on the MAC and physical layers.

In order to circumvent these problems, Randomized DSTC (R-DSTC) [14] can be used where each relay transmits a random linear combination of antenna waveforms. Some initial results on the use of randomized coding in a wireless network for point-to-point transmission are described in [16], where the impact on the MAC layer performance is also discussed. A joint physical and MAC design point-to-point transmission using a randomized cooperative scheme [17] can enable robust cooperation under loose knowledge of the network topology. The results in [17] show that with a large number of nodes, up to 100% increase in throughput is achievable compared to a legacy non-cooperative network.

Cooperative transmission is especially 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, and hence, are free from the incentive and security concerns that may impact the deployment of cooperation for point-to-point communications. In our previous work, we considered cooperation in the MAC layer and studied a multi-hop multicast system where multiple relays transmit sequentially in time. We showed the benefits of such a scheme both numerically and experimentally [7],[8]. However, with such an approach, due to sequential transmission, the performance bottleneck becomes the number of relays. Similar to the unicast scenario, simultaneous transmission of relays using R-DSTC is a more efficient method in terms of spectral efficiency.

[1]This work is supported in part by National Science Foundation (NSF) under awards 0520054 and 0430885, 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), an NSF Industry/University Research Center at Polytechnic Institute of NYU.

The asymptotic behavior, in terms of successful reception probability, of a multi-stage randomized cooperative broadcasting system in a dense network has been studied in [9] where the authors considered the propagation of lossless information through the network. In [10], a multi-stage randomized cooperation scheme for multicasting lossy data such as multimedia signals (audio, image, and video) is studied and the expected end-to-end distortion of the multicast receivers in a certain coverage range is minimized under a delay constraint. Furthermore, in order to provide receivers with signals at different distortion levels commensurate with their channel conditions, layered cooperation is studied where different layers are transmitted sequentially in time. Although the results in [10] shed light on the multicast performance of randomized cooperation coupled with source layering, the dense network assumption does not necessarily hold in practice.

In this paper, we integrate layered coding with randomized cooperation to enable efficient video multicast in an IEEE 802.11g based WLAN. We discuss selection of transmission rates for single layer and layered cooperation that maximize the multicast performance. We analyze the proposed system and compare its performance with conventional multicast. Our results show that R-DSTC provides significant improvements. For single layer cooperation, each node in the system experiences more than four times higher video rate than the conventional multicast rate. For the layered case, closer nodes experience up to six times higher video rate as compared to conventional multicast, while the far away nodes experience the same or higher video rate than the conventional case.

This paper is organized as follows. We introduce the system model in Section II. Section III formulates the computation of bit and packet error rates for both direct transmission and R-DSTC. The computation of the video qualities at different nodes along with layered cooperation is addressed in Section IV. Section V analyzes the obtained results. We conclude the paper in Section VI.

II. System Model

We study an infrastructure-based wireless network and assume a source station (access point) is multicasting video to a total number of N_T uniformly distributed multicast nodes within its coverage range r_d. Although this paper considers an IEEE 802.11g as a case study, similar concepts are also applicable to cellular networks as well. All nodes in the network are equipped with one antenna and can transmit at different transmission rates supported by the underlying physical layer. Note that each physical layer transmission rate R, corresponds to a modulation level M, and channel code rate C. In accordance with IEEE 802.11g [11], we only consider square constellations. We assume that the channel between the source and each node, and among each pair of nodes experience independent slow fading that is constant over the transmission time of a single packet. This is reasonable for video communication as a typical video packet corresponds to a video frame or less and lasts for 33 - 100 ms. We also assume path loss with a path loss exponent α.

For the baseline direct transmission system, we assume the source station S, knows the average channel quality (in terms of the average received signal to noise ratio or SNR) between

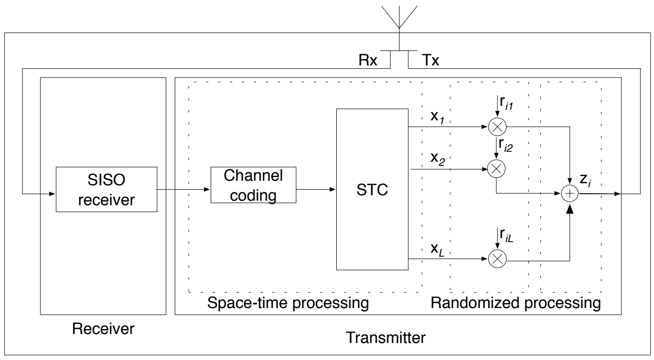


Fig. 1. Transmitter and receiver architecture at the nodes

itself and every node in the target coverage area. The source decides on a direct transmission rate R_d, such that all the nodes in the coverage range receive the packets with a PER of less than ϵ_T. We set ϵ_T to be sufficiently low (=0.5%) so that the effect of packet loss in the decoded video is negligible with effective error concealment in the video decoder.

The proposed cooperative system employs R-DSTC [14]. The main idea behind R-DSTC is that each relaying node will act as a virtual antenna of an antenna array. As illustrated in Figure 1, a single-antenna node employs a regular single-input and single output (SISO) decoder to decode the information sent by the source station in the first hop. The node checks the cyclic redundancy check (CRC) and relays the information when the packet is correctly received. To forward the information, the relay re-encodes the information bits and passes them through a space-time code (STC) encoder. The output from the STC encoder is in the form of L parallel streams where each stream corresponding to an antenna in a multiple input multiple output (MIMO) system with L transmit antennas. However, in contrast to a MIMO system, in a R-DSTC system, the relay transmits a random linear weighted combination of all L streams, where the weights are denoted by $\mathbf{r}_i = [r_{i1}\ r_{i2}\ \dots\ r_{iL}]$ where i denotes the index of each relay node.

For multicast with R-DSTC, the source station transmits a packet at a physical transmission rate of R_1. The nodes that receive the packet correctly form the relay set and are called the Hop-1 nodes as depicted in Figure 2 where a snapshot of the network for some fixed fading state is illustrated. Note that due to fading, the reception does not solely depend on the distance to the source station. Therefore, some of the nodes that are close to the source station experience a bad fading level and may not be able to receive the packet. On the other hand, there are some nodes who observe a good fading level and receive the packet even though they are far away from the source. Each node that can correctly receive a packet from the source re-encodes and transmits the packet simultaneously to other nodes at a physical transmission rate of R_2 using R-DSTC. The nodes who receive the packet in the second hop are called Hop-2 nodes. Note that due to the random nature of fading, a node can either be in Hop-1 or Hop-2 for a particular transmitted packet depending on whether the node can receive the packet correctly from the source.

For cooperative multicast, we assume that in addition to all

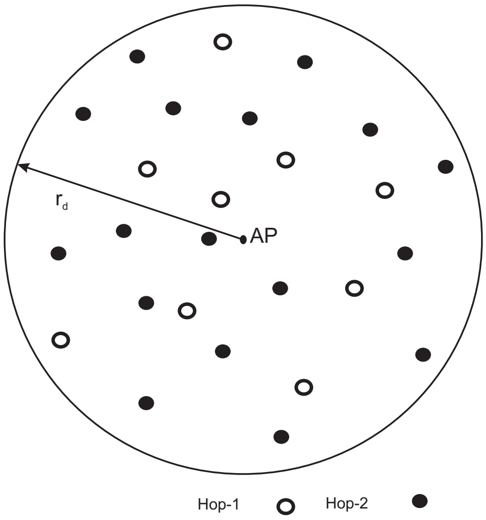


Fig. 2. Snapshot of the network.

the average channel qualities between source and all nodes, the source also knows the average channel qualities among every pair of nodes. The source computes all sustainable R_1 and R_2 such that all the nodes in the coverage range receive the packets with an average PER of less than ϵ_T after two hops. The source also decides on a suitable STC dimension L for the R-DSTC. Note that as we increase R_1, the number of relays or Hop-1 nodes that can decode the source packet and participate in the second hop, decreases. Therefore, the sustainable data rate for the second hop, R_2, is expected to be lower in order to cover all the nodes. On the other hand, if the first hop rate R_1 is lower, more nodes participate in the second hop transmission, and hence the second hop transmission rate R_2 can be higher. While this paper concentrates on a 2-hop system, the ideas can be easily generalized to multiple hops.

The system described so far considers single layer transmission of video. Note that we can code a video signal into multiple layers so that reception of more layers leads to better quality [15]. One advantage of using layered coding is that we can provide differentiated quality to different users based on their channel conditions. We assume the video is coded into a scalable stream of two layers (base and enhancement layers) with any desired base and enhancement layer bit rates, R_b and R_e, respectively. The source station transmits both base and enhancement layer packets using the same transmission rate R_1. Nodes who receive the base layer packets correctly forward these packets using R-DSTC at a transmission rate of R_2. Therefore, only the base layer packets go through two hop transmission, while the enhancement layer packets are transmitted by the sender only and go through one hop transmission. Any particular node, depending on its channel condition, receives the base and enhancement layer packets with different PER's, PER_b and PER_e. We choose the transmission rates R_1 and R_2 so that after two hop transmission all the nodes in the coverage range have a PER_b less than ϵ_T, and hence, receive a video at a quality Q_b corresponding to a base layer video rate of R_b. A certain percentage of users who have a PER_e less than ϵ_T after the first hop transmission receive a video quality Q_{b+e} corresponding to rate of $(R_b + R_e)$ where R_e is the enhancement layer rate.

III. Computation of the Bit and Packet Error Rates

In this section, we will discuss the computation of instantaneous BER and PER both for direct transmission and R-DSTC. In order to compute the PER, we first determine the instantaneous BER corresponding to a modulation level, M, for each fading level. We formulate the BER computation for a single link and R-DSTC in the following subsections. After the computation of the instantaneous BER, we find the packet error probability for the channel code rate, C. We use this probability to determine whether a packet is received or lost at a particular fading level. Then, at each node, we can compute the average packet error rate (PER) where the average is taken over all fading levels.

A. BER of Single Link

We assume that the source transmits $\mathbf{x}$ with a symbol energy of $E_{s,s}$ and k^{th} node experiences a channel gain of $\mathbf{h_k}$ from the source. Then the received signal at the k^{th} node can be written as:

$$y_k = \sqrt{E_{s,s}} h_k x + w_k \tag{1}$$

where w_k is additive white complex Gaussian noise with power spectrum density $N_0/2$. We can express the instantaneous received SNR at k^{th} node, SNR_k, as

$$SNR_k = \frac{E_{s,s} \|h_k\|^2}{N_0} \tag{2}$$

For a M-QAM square constellation, the symbol error rate can be computed as [18]:

$$P_{s,M(h_k)} = 1 - [1 - P_{\sqrt{M}}]^2 \tag{3}$$

with

$$P_{\sqrt{M}} = 2(1 - \frac{1}{\sqrt{M}})\ erf(\sqrt{\frac{3SNR_k}{(M-1)}}) \tag{4}$$

where the erf function is defined as:

$$erf(x) = \int_x^{\infty} \frac{1}{\sqrt{2\pi}} e^{-y^2/2} dy \tag{5}$$

With Gray coding, the bit error rate for the M-QAM can be approximated by,

$$P_{b,M(h_k)} \approx \frac{1}{\log_2 M} P_{s,M(h_k)} \tag{6}$$

B. BER for RDSTC

Note that the instantaneous BER computation for the first hop of R-DSTC is the same as the direct transmission. For the second hop, we assume N nodes receive the packets correctly and participate as relays. Each relay transmits its data with a symbol energy of $E_{s,r}$.

We consider a space-time code of size $L \times K$, where L is the number of antennas and K is the block length. We assume the underlying space-time code is based on real orthogonal designs [19]. For $L = 2, 4, 8$, the orthogonal design provides full rate for square QAM constellation [18],[19]. Using random weights represented by vector $\mathbf{r}_i$ for relay i, we can express the transmitted signal from the i^{th} relay at time m, as

$$z_i(m) = \sqrt{E_{s,r}} \mathbf{r}_i \mathbf{X}(m), \tag{7}$$

where $i = 1, 2, \cdots, N$ and $m = 1, 2, \cdots, K$. Here, $\mathbf{X}(m)$ is the m^{th} column of the STC. We assume that each element of $\mathbf{r}_i$ is an independent complex Gaussian random variable with zero mean and variance $\frac{1}{L}$ [14]. We denote the symbols sent by the STC as u_l, where $l = 1, 2, ..., L$.

The receiver architecture in Hop-2 is similar to a regular STC receiver with one antenna. The received signal at node k at the m^{th} symbol interval can be expressed as

$$y_k(m) = \mathbf{H_k Z}(m) + w_k(m) = \sqrt{E_{s,r}}\mathbf{H_k R X}(m) + w_k(m) \quad (8)$$

where $\mathbf{H_k}$ is the $1 \times N$ channel vector representing channel gain from each relay to the k^{th} node, $w(m)$ denotes additive white Gaussian noise with power spectrum density $N_0/2$. $\mathbf{Z(m)}$ and $\mathbf{R}$ can be written as, $\mathbf{Z(m)} = [z_1(m)\ z_2(m)\ \ldots\ z_N(m)]^T$, $\mathbf{R} = [\mathbf{r}_1\ \mathbf{r}_2\ \ldots\ \mathbf{r}_N]^T$.

Assuming the node estimates $\mathbf{H_k R}$ perfectly using pilot signals and using the orthogonality of the STC, an estimate of each symbol, $\widehat{u}_l$ at the input of the maximum likelihood detector can be expressed as [19]:

$$\widehat{u}_l = \sqrt{E_{s,r}\|\mathbf{H_k R}\|^2}u_l + \mathbf{H_k R}\breve{w}_l \quad (9)$$

where $\|\cdot\|$ represents for the Frobenius norm and $\breve{w}_l$ is Gaussian noise. Note that in the above formulation, the received SNR for u_l, $l = 1, 2, ..., L$, at node k is,

$$SNR_k = \frac{E_{s,r}\|\mathbf{H_k R}\|^2}{N_0} \quad (10)$$

Hence, we can model the effect of R-DSTC as an instantaneous received SNR given by (10). We can compute the instantaneous symbol error rate by inserting (10) in (4) and then use (6) to compute the instantaneous BER for different modulation schemes.

IV. Received Video Rates and Performance Evaluation

We assume that we can cover all the users in an area of radius r_d with a direct transmission rate of R_d. In a wireless network, multicast service usually uses a portion of the total available bandwidth. In order to account for this, we define the effective data ratio β, as the ratio of the bandwidth used to transmit multicast payload data (e.g. video data) to the total bandwidth. For example, if 5% of the bandwidth is utilized by the multicast service, $\beta = 0.05$. Then, with direct transmission all the users receive video at the same rate of $R_{v_d} = \beta R_d$.

We assume that we divide a video into segments of duration T seconds each. With direct transmission at a transmission rate of R_d bits/sec, the total bits received for each segment is $\beta R_d T$. For the cooperative scheme, the time T is shared between the first and second transmission hops. Let the sender transmit for T_1 seconds and the Hop-1 nodes transmit for the remaining $T - T_1$ seconds. Then the total number of bits received by the relays is $\beta R_1 T_1$, and that received by the remaining users is $\beta R_2(1-T_1)$. The equivalent received video rates at Hop-1 and Hop-2 nodes can be expressed as:

$$R_{v_1}(R_1, t_1) = \beta R_1 t_1 \quad (11)$$

$$R_{v_2}(R_2, t_1) = \beta R_2(1 - t_1) \quad (12)$$

where $t_1 = T_1/T$.

Note that if Hop-1 nodes forward all the packets they correctly received (e.g., single layer cooperation), for all the nodes to receive the video at the same video rate, we require $R_{v_1} = R_{v_2}$, which in turn requires $R_1 t_1 = R_2(1 - t_1)$, and the equivalent video rate is $R_{v_{eq}} = \beta R_1 R_2/(R_1 + R_2)$. In general, Hop-1 nodes can also differentiate between the base and enhancement layer packets (e.g. layered cooperation) and if we let these nodes only transmit the base layer packets, we have $R_{v_1} = R_b + R_e > R_{v_2} = R_b$. In this case, the nodes who have better average channel conditions experience better quality video than the nodes with poor channel conditions. Note that Hop-1 nodes change at each packet due to random fading. Hence, at different time instants different nodes may receive the enhancement layer packets. However, the nodes who receive the enhancement layer packets with an average PER lower than ϵ_T will be considered to receive the enhancement layer. Therefore, the percentage of the nodes who will receive the enhancement layer depends on R_1 and it is a design parameter.

Let $Q(R)$ be the quality-rate function for a given video, then, for a given video file if we know video rate R, we can compute Q. We define $Q_d(R_d) = Q(R_{v_d})$ as the average quality among all users in a coverage radius r_d with direct transmission. For the single layer case, $Q_{eq}(R_1, R_2) = Q(R_{v_{eq}})$ is the quality at all users and for the layered cooperation the base layer and enhancement layer qualities are denoted as $Q_{b+e}(R_1, t_1) = Q(R_{v_1})$ and $Q_b(R_2, t_1) = Q(Rv_2)$, respectively. We assume that the node distribution is fixed within each interval T. The number of users in Hop-1 and Hop-2 are N and $N_T - N$, respectively. In each interval lasting for T seconds, we choose the highest STC dimension L such that $L \leq N$.

In order to have a fair comparison with direct transmission, we only consider the nodes within the coverage range of direct transmission r_d. However, in general the coverage area can also be considered as a design parameter.

A. Single Layer Cooperation

For single layer cooperation, we require all the nodes to have the same quality, Q_{eq}. In other words, we find the optimum (R_1, R_2) that maximize:

$$Q_{eq}(R_1, R_2) = Q(R_{v_{eq}}) = Q(\beta \tfrac{R_1 R_2}{R_1 + R_2}). \quad (13)$$

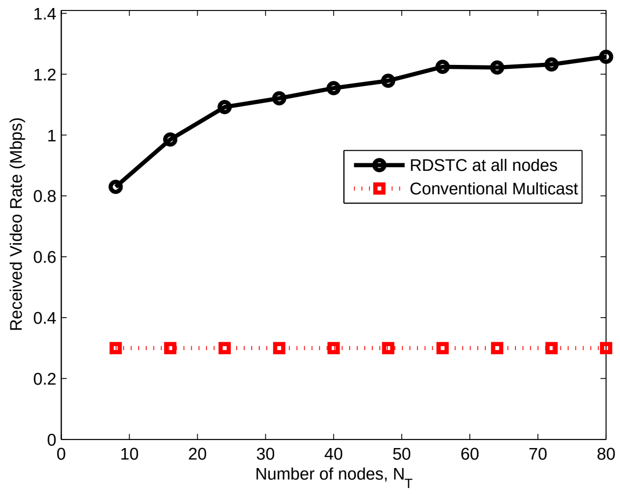
B. Layered Cooperation

In this case, for a given percentage of users to receive the enhancement layer, we find the optimum (R_1, R_2, t_1) that maximize the enhancement layer quality $Q_{b+e}(R_1, t_1) = Q(R_{v_1})$ while guaranteeing a base layer quality of $Q_b(R_2, t_1) = Q(R_{v_2}) = Q_{min} \geq Q_d(R_d)$.

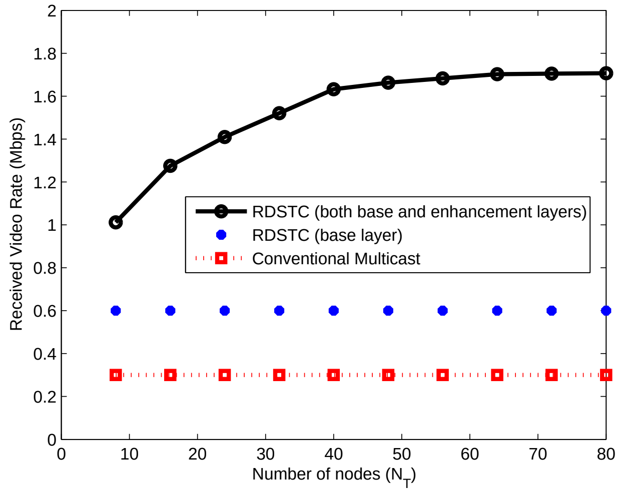
Note that maximizing the quality is equivalent to maximizing the received video rate due to the monotonic relation between video rate and quality. This is enabled since the transmission rates are chosen such that packet loss effects are negligible.

V. Results

We study a IEEE 802.11g based network and consider a coverage range of 100m radius, $r_d = 100m$, where the access point is at the center of the network and nodes are randomly



(a) Single Layer Cooperation



(b) Layered Cooperation

Fig. 3. Comparison of Single Layer and Layered Cooperation for different number of nodes.

independently located in this coverage range. In Table I, we list the physical transmission rates of IEEE 802.11g and their corresponding modulation and channel coding rates [11]. We choose the transmission power of the AP such that all nodes in the coverage range experience an average packet error rate of less than $\epsilon_T = 0.5\%$ using the base rate, $R_d = 6Mbps$. For R-DSTC, we consider only orthogonal STC with dimension $L = 2, 4, 8$. In order to have a fair comparison with direct transmission, we assume that the relay symbol energy is $E_{s,r} = E_{s,s}/N_T$. Note that with this assumption, since the number of relays is always smaller than the total number of nodes, the total energy consumption of all relays plus the sender energy in the R-DSTC system is always smaller than the total energy consumption of the sender with the conventional multicast system.

In our simulations, we consider different number of nodes in the system corresponding to different density networks and for each node density, we generate 100 different node distributions. In order to find the average packet error rate for each node distribution, we generate different independent fading levels for all node pairs. For each fading level, we first obtain the BER and compute the PER over different fading levels as discussed in Section III. For direct transmission, for each node distribution, we find the sustainable R_d such that each node experiences a packet error rate of less than $\epsilon_T = 0.5\%$. We then present the average received video rates and average video qualities averaged over different node distributions for the same total number of nodes. For the cooperative R-DSTC, we search through all possible (R_1, R_2) and find all sustainable (R_1, R_2)'s that satisfy the average packet loss threshold, ϵ_T, after two hop transmission for a given node distribution under the same node count. Then, we choose the optimum (R_1, R_2) that maximizes Q_{eq}. The presented results are averaged over different node distributions.

For layered R-DSTC, similar to the single layer case described above, we first find all sustainable (R_1, R_2). We find all sustainable (R_1, R_2) for a given percentage of nodes who receive both the base and enhancement layer. We then find the optimum (R_1, R_2, t_1) that maximize Q_{b+e} while guaranteeing $Q_b = Q_{min} \geq Q_d$.

In Figure 3, we illustrate the received video rates for different number of nodes. Here we set $\beta = 0.05$, hence, the received video rate with direct transmission is $R_{v_d} = \beta R_d = 300kbps$. For a fixed coverage range, $r_d = 100m$, we compare single layer and layered cooperation. The performance of single layer cooperation is depicted in Figure 3(a) for different number of nodes. As illustrated in the figure, the performance of the proposed scheme outperforms conventional multicast and for high density network ($N_T = 80$), we can support high transmission rates at both hops, hence, the supportable video rate of R-DSTC is more than four times higher compared to conventional multicast. In Figure 3(b), we illustrate the results for layered cooperation. In this set of simulations, we require 10% of all nodes receive both base and enhancement layer while the remaining nodes experience a video rate of ($R_{v_2} = 600kbps$) which is better than direct transmission's video rate of $300kbps$. Note that for different set of parameters, we can achieve different quality levels at Hop-1 and Hop-2.

In Figure 4, we illustrate the average percentage of user who participate in the second hop transmission. Note that as the number of nodes increases, since we can sustain higher transmission rates, the number of Hop-1 nodes reduces.

For a dense network (i.e. $N_T = 80$), we also consider the quality of the nodes in terms of average PSNR values for the Soccer video sequence. We assume the PER threshold is low enough so that the decoded video quality equals to the encoded video quality and depends on the video rate. Note that in practice, application layer FEC can be used to correct most of the packet losses. We use a H.264/SVC codec and encode 240 frames of the (352x288) Soccer video to determine the achievable PSNR for different video rates.

In Table II, we compare three systems in terms of the achievable system performance for optimal operating points. For single layer cooperation, we achieve 8.11 dB improvement at all users compared to conventional multicast. For the layered cooperation, we set $Q_{min} = Q_b = 34.51$ dB and we

Transmission Rates, R	6	9	12	18	24	36	48	54
Modulation, M	BPSK	BPSK	QPSK	QPSK	QAM-16	QAM-16	QAM-64	QAM-64
Channel Code Rate, C	1/2	3/4	1/2	3/4	1/2	3/4	2/3	3/4

TABLE I

TRANSMISSION RATES FOR IEEE 802.11G AND THEIR CORRESPONDING MODULATION SCHEMES AND CHANNEL CODES [11]

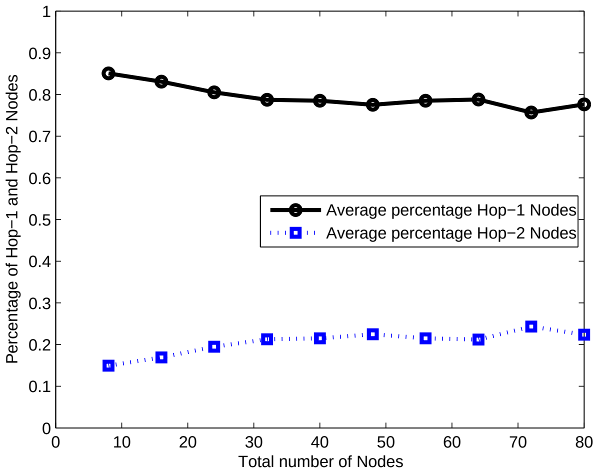


Fig. 4. The percentage of nodes at each hop for single layer cooperation

Direct Transmission	*Single Layer Cooperation*	*Layered Cooperation*
$R_d = 6$Mbps	avg. $R_1 = 52.32$Mbps avg. $R_2 = 48.72$Mbps	avg. $R_1 = 43.63$Mbps avg. $R_2 = 49.69$Mbps
$R_{v_d} = 300$kbps	$R_{v_{eq}} = 1260$kbps	$R_{v_1} = 1670$kbps $R_{v_2} = 600$kbps
$Q_d = 30.59$dB	$Q_{eq} = 38.70$dB	$Q_b = 34.51$dB $Q_{b+e} = 40.30$dB

TABLE II

COMPARISON OF SINGLE LAYER AND LAYERED COOPERATION FOR A HIGH DENSITY NETWORK ($N = 80$) WITH $\beta = 0.05$.

achieve a quality improvement of 9.71 dB for 10% of nodes compared to conventional multicast while also achieving a quality improvement of 3.92 dB for the remaining nodes as compared to the conventional case.

VI. CONCLUSION

In this paper, we propose a layered video multicasting scheme using randomized cooperative communications to enable efficient video multicast in infrastructure-based wireless networks. For single layer and layered cooperation, we determine the optimum transmission rates at both hops along with time scheduling. We show that randomized cooperative communication substantially improves the multicast system performance. Our results indicates that quality improvement of more than four times higher video rate and up to 8.11 dB in average PSNR are achievable compared to conventional multicast.

This paper assumes the source knows all the average channel conditions in the network and that the transmission rates are chosen such that the packet errors are negligible. Ongoing work includes investigating protocols that incorporate application layer forward error correction and reduce the channel state information at the source.

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 IT*, vol. 50, no. 12, p. 3062, December 2004.

[3] H. Y. Shutoy, D. Gunduz, E. Erkip and Y Wang, “Cooperative source and channel coding for wireless multimedia communications,” *IEEE Journal of Selected Topics In Signal Processing*, Vol. 1, Issue 2, p.295, Aug. 2007

[4] D. Gunduz and E. Erkip, “Source and channel coding for cooperative relaying,” *IEEE Transactions on Information Theory, Special Issue on Models, Theory, and Codes for Relaying and Cooperation in Communication Networks*, vol. 53, no. 10, pp. 3453-3475, October 2007

[5] P. Liu, Z. Tao, Z. Lin, E. Erkip, and S. Panwar, “ Cooperative wireless communications: A cross-layer approach,” *IEEE Wireless Communications*, 13(4):8492, August 2006.

[6] P. Liu, Z. Tao, S. Narayanan, T. Korakis, and S. Panwar, “CoopMAC: A cooperative MAC for wireless LANs,” *IEEE Journal of Selected Topics In Communications*, Volume 25, Issue 2,p.340, February 2007

[7] O. Alay, T. Korakis, Y. Wang, E. Erkip, S. Panwar, “Layered Wireless Video Multicast using Omni-directional Relays”, in *Proceedings of IEEE ICASSP*, 2008.

[8] O. Alay, Z. Xu, T. Korakis, Y. Wang, S. Panwar, “Implementing a Cooperative MAC Protocol for Wireless Video Multicast”, in *Proceedings of IEEE WCNC*, Budapest, Hungary, 2009, available at http://vision.poly.edu/∼ozgu/wcnc09.pdf

[9] B. Sirkeci-Mergen, A. Scaglione, and G. Mergen, “Asymptotic analysis of multi-stage cooperative broadcast in wireless networks”, *Joint special issue of IEEE Trans. on Information Theory and IEEE/ACM Trans. On Networking*, June 2006.

[10] O. Alay, R. Ding, E. Erkip, Y. Wang and A. Scaglione, “Layered randomized cooperation for multicast”, in *Proceedings of IEEE 42nd Annual Asilomar Conference on Signals, Systems and Computers*, Pacific Grove, CA, October 2008 (invited).

[11] LAN MAN Standards Committee of the IEEE Computer Society, ANSI/IEEE Std 802.11, “Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High-speed Physical Layer Extension in the 2.4 GHz Band,” IEEE 802.11 Standard, 1999.

[12] 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.

[13] 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.

[14] B. S. Mergen and A. Scaglione, “Randomized space-time coding for distributed cooperative communication”, *IEEE Transactions on Signal Processing*, pp. 50035017, October 2007.

[15] H. Schwarz, D. Marpe, T. Wiegand, “Overview of the Scalable Video Coding Extension of the H.264/AVC Standard”, *IEEE Transactions on Circuits and Systems for Video Technology*, pp. 11031120, September 2007.

[16] F. Verde, T. Korakis, E. Erkip, and A. Scaglione, “On avoiding collisions and promoting cooperation: Catching two birds with one stone”, in *Proceedings of IEEE SPAWC*, July 2008.

[17] 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*, New Orleans, Lousiana, November 2008.

[18] J. G. Proakis, “Digital Communications”, New York, McGraw-Hill, 2001.

[19] H. Jafarkhani, “Space-Time Coding: Theory and Practice”, Cambridge University Press, 2005

[20] Joint Scalable Video Model (JSVM), JSVM Software, Joint Video Team, Doc. JVT-X203, Geneva, Switzerland, June 2007