Enhanced Parity Packet Transmission for Video Multicast using R-DSTC

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***Abstract*—In this paper, a cooperative multicast scheme that uses Randomized Distributed Space Time Codes (R-DSTC), along with packet level Forward Error Correction (FEC), is studied. For the source packets, two-hop transmission is considered, where a packet is transmitted first by the access point (AP), and then forwarded using R-DSTC by the nodes that receive the packet. On the other hand, parity packets are generated by the nodes that receive all the source packets correctly and are transmitted using R-DSTC. The optimum transmission rates for source and parity packets, as well as the number of parity packets required, are determined such that the video quality at all nodes is maximized. It is shown that this scheme can support a higher video rate than a previously developed R-DSTC based scheme where both source and parity packets go through a two-hop transmission, as well as non-cooperative direct transmission.**

I. Introduction

Wireless video multicast enables delivery of popular events in a bandwidth efficient manner. However, variations in channel quality between source and each receiver due to fading and path loss, make wireless video multicast a challenging problem. Cooperative communications effectively combats fading and path loss [1]. Significant diversity gains can be obtained by letting multiple nodes relay simultaneously using a distributed space-time code (DSTC) [2]. However, DSTC works with a fixed number of relays and requires tight coordination and synchronization. Randomized DSTC (R-DSTC) [3] relaxes these requirements [4] by letting each relay transmit a random linear combination of antenna waveforms. Furthermore, R-DSTC enables all decoding nodes to join in the relaying phase.

[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) an NSF Industry University Cooperative Research Center.

Cooperative transmission is suitable for multicast in two ways. First, user cooperation substantially reduces packet error rate (PER). Secondly, the relays are already part of the multicast group, hence are free from the incentive and security concerns of cooperative unicast communications. R-DSTC is especially attractive for multicast since there is no need for relay selection and scheduling.

Randomized cooperation for video multicast in an IEEE 802.11g based WLAN is considered in [6], where the AP transmits a video packet, and then all nodes receiving the packet forward simultaneously using R-DSTC. The transmission rates of both hops are chosen to maximize the supportable video rates while ensuring that all nodes receive the video with a negligible packet loss rate after two-hop transmission. To increase the supportable video rates, the packet-level FEC is considered in [7], and two-hop transmission rates and the FEC rate is chosen to maximize the supportable video rates. Throughout this paper, this scheme will be referred as *multicast-RDSTC*. 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. For *multicast-RDSTC*, the AP generates m parity packets for every k source packets. Then, the AP transmits each packet (either a source packet or a parity packet), and the nodes that receive the packet correctly transmit simultaneously using R-DSTC. With this scheme, the parity packets are generated at the AP and are transmitted over two hops.

In this paper, we propose a new way of parity packet transmission. For the proposed scheme, called *enhanced-*

978-1-4244-8015-9/10/$26.00 ©2010 IEEE

multicast-RDSTC, the AP first transmits all the source packets. Upon the completion of k source packet transmissions (each going through two-hops), the nodes that receive all k source packets correctly generate the parity packets and transmit them using R-DSTC. As more parity packets are transmitted, more relays decode and join in forwarding parity. We determine the optimum transmission rates at both hops for the source packets, the optimum transmission rate for the parity packets, the STC dimensions for both source and parity packets as well as the FEC rate that maximizes the video quality at all nodes. We evaluate the performance of the proposed *enhanced-multicast-RDSTC* scheme and compare it with the *multicast-RDSTC*, and non-cooperative direct transmission.

This paper is organized as follows. We introduce the system model in Section II. We discuss rate adaptation in Section III. In Section IV, we formulate the video rate for the proposed system and discuss the optimization of different transmission modes. Section V analyzes the obtained results. We conclude the paper in Section VI.

II. System model and Transmission Modes

In this paper, video multicast in infrastructure based networks is considered. The AP transmits the video to multicast nodes within its coverage range of radius r_d. We assume independent slow Rayleigh fading among nodes that is constant over the duration of a single packet and path loss with an exponent of α. We consider different transmission rates corresponding to different modulation and channel coding. For a given transmission rate, fading level and distance between the transmitter and the receiver, we compute the instantaneous PER for direct and randomized cooperative transmission as in [6].

As a baseline scheme, we consider direct transmission where the AP transmits packets at a physical layer transmission rate of R_d bits/sec and employs packet level FEC at a rate of γ_d such that the FEC decoding failure rate at all nodes is less or equal to a target ζ. We consider two different modes for direct transmission: conventional direct transmission (*Direct*) and rate adaptive direct transmission (*Rate-Adaptive*). In conventional direct transmission, R_d and γ_d are fixed. For the rate adaptive direct transmission, R_d and γ_d are dynamically adjusted based on the feedback on the average PER of the node with the worst channel conditions [8].

We also consider cooperative multicast using R-DSTC and study two schemes which differ in their parity packet transmission schemes. For the first scheme, *multicast-RDSTC*, the AP generates parity packets and transmits them along with the source packets at a transmission rate of R_1 bits/sec. The nodes that receive a packet (either a source packet or a parity packet) correctly, transmit 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. Note that for a given (R_1, R_2, L), there is a corresponding end-to-end PER for each node. The packet level FEC rate γ is chosen such that after two hop transmission, the FEC decoding failure rate at each node is equal or less than the target, ζ.

For the proposed *enhanced-multicast-RDSTC* scheme, the AP is only responsible for the transmission of the source packets. The AP transmits the source packets at a transmission rate of R_1 bits/sec and the relays forward these packets using R-DSTC with STC dimension of L at a rate R_2 bits/sec. After the completion of k source packet transmission, the nodes that receive all k source packets become *parity relays*. The parity relays generate parity packets and transmit using R-DSTC at a rate R_p bits/sec with STC of dimension L_p. Note that after each parity packet transmission, any node that receives a total of k packets out of all packets transmitted so far, can become a parity relay and then join the parity packet transmission. Therefore, the number of parity relays increases in time. Note that in *enhanced-multicast-RDSTC*, while it may seem that the source packets could be transmitted only in the first hop, due to the low diversity of the first hop transmission the number of nodes receiving all k packets after source transmission would be very small, leading to an insufficient number of parity relays. Therefore, the proposed scheme always uses two-hop transmission for the source packets.

The above cooperative multicast schemes require some modification at the transmitter and the receiver of the relay nodes as described [6]. However, for decoding R-DSTC, decoders already designed for space-time code reception can be directly used for both schemes [3].

III. FEC Rate and Rate Adaptation for Direct Transmission

We assume that each receiver, by using CRC, can identify the packets in error. We use an error correction code at the packet level to recover the lost packets. Specifically, we use Reed-Solomon (RS) codes, and generate m parity packets for every k source packets with a FEC rate of $\gamma = k/(k + m)$.

For direct transmission, we assume that the maximum PER among all users in the coverage area of radius r_d is ϵ_{max}, when the transmission rate is R_d. The FEC rate is chosen so that the FEC decoding failure rate is less than

(a) RDSTC scheme [7]

(b) Enhanced RDSTC scheme

Fig. 1. Transmission rates and time scheduling for RDSTC schemes

or equal to ζ. Since the FEC rate depends on ϵ_{max}, which in turn depends on R_d, we can also write the FEC rate as $\gamma_d(R_d)$. Then, with direct transmission, all the nodes receive the video at a rate of:

$$R_{v_d}(R_d) = \gamma_d(R_d)R_d. \tag{1}$$

Since the video rate depends on the transmission rate, R_d, besides conventional multicast where transmission rate and hence the FEC rate are fixed, we consider a rate adaptive direct transmission mode as in [8], where R_d and the FEC rate are adjusted for a given node placement to maximize the video rate.

IV. Optimization of Cooperative Transmission Schemes

The performance achieved by cooperative multicast scheme depends on the available channel information at the AP. If the AP knows all the average channel qualities between itself and all the nodes, as well as among the nodes, the highest cooperative multicast video rate can be achieved. This channel information can be collected by exchanging control signals among nodes for measuring the average SNR, and then transmitting this information back to the AP. Such an exchange of control signalling introduces overhead to the system and may not be practical. In [5], the authors considered a unicast model, where these parameters are chosen with partial channel information (for example only based on user count). The robustness of R-DSTC ensures that the performance loss due to partial channel information is negligible. Selection of operating parameters with partial channel information for multicast is subject of our ongoing research and will not be explored here due to space considerations. Hence, throughout this paper, we assume full statistical knowledge of all the links by the AP.

We assume that the compressed video is divided into segments of duration T seconds each. The total time T is shared between the first and second hops, and between the source and parity packet transmissions. We illustrate the time scheduling for R-DSTC schemes along with their transmission rates in Figure 1. Suppose the source packets are transmitted for fractions of time denoted by $t_{1,s}$ and $t_{2,s}$, by the AP and relays for the first and second hop, respectively. Similarly, the parity packets are transmitted by the AP and the relays for fractions of time $t_{1,p}$ and $t_{2,p}$, respectively. Here, the total time fraction for the first and second hops are $t_1 = t_{1,s} + t_{1,p}$ and $t_2 = t_{2,s} + t_{2,p}$, where $t_1 + t_2 = 1$. Note that, for the *enhanced-multicast-RDSTC*, since we forego the parity packet transmission at the first hop, we have $t_{1,p} = 0$, hence $t_1 = t_{1,s}$.

A. *Multicast-RDSTC*

For *multicast-RDSTC*, the relays will forward all the packets they receive without differentiating between the source and parity packets. The FEC rate γ depends on the maximum PER among all users after two hop transmission for a given pair of transmission rates R_1 and R_2. We compute the instantaneous PER experienced by each node in the multicast group using the formulation in [6]. Note that due to different node placements and randomization in the system, the mathematical analysis of PER is very difficult. Therefore, average end-to-end PER and the corresponding FEC is computed through simulations. The FEC rate γ, depends on the transmission rates of both hops, R_1 and R_2, as well as R-DSTC dimension, L. The video rates at both hops are $R_{v_1} = \gamma R_1 t_1$ and $R_{v_2} = \gamma R_2(1-t_1)$, where $t_1 + t_2 = 1$.

We choose R_1, R_2, L, t_1 jointly so that all the nodes receive the video at the same rate, i.e., $R_v = R_{v_1} = R_{v_2}$. This yields $t_1 = R_2/(R_1 + R_2)$, and the corresponding video rate is [7]:

$$R_v(R_1, R_2, L) = \gamma(R_1, R_2, L)\frac{R_1 R_2}{R_1 + R_2}. \tag{2}$$

Among all candidate R_1, R_2's, the source chooses the optimum R_1, R_2 and the corresponding γ, L that maximizes the video rate while keeping the FEC decoding failure rate below ζ. Here, L is chosen as close as possible to the average number of relays, N_{avg} for a given R_1. Note that, for a large number of nodes, N_{avg} may be much larger than L due to the limited dimensions of practical STC codes.

B. Enhanced-multicast-RDSTC

For the *enhanced-multicast-RDSTC* scheme, the FEC rate γ depends on a number of parameters. First, the maximum PER for the source packets among all users after two hop transmission is determined by the transmission rates of both hops (R_1, R_2) and the STC dimension L. Furthermore, since parity packets are only transmitted at the second hop, the number of parity packets required also depends on the PER of the second hop, which is determined by the parity transmission rate R_p as well as the parity transmission STC dimension L_p. Therefore, γ is a function of (R_1, R_2, L, R_p, L_p).

Assuming that the lost source packets are recovered using packet level FEC, the received rates for the source packets at each hop are $R_{v_1} = R_1 t_{1,s}$ and $R_{v_2} = R_2 t_{2,s}$, where $t_{1,s} + t_{2,s} + t_{2,p} = 1$. To ensure that all nodes receive video at the same rate, we have

$$R_v = R_{v_1} = R_{v_2} = R_1 t_{1,s} = R_2 t_{2,s}. \tag{3}$$

We can write $t_{1,s}$ as

$$t_{1,s} = R_2(1 - t_{2,p})/(R_1 + R_2). \tag{4}$$

Then, the received video rate can be expressed as:

$$R_v = (1 - t_{2,p}) \frac{R_1 R_2}{R_1 + R_2}. \tag{5}$$

To recover the lost packets, we need m parity packets. Assuming an average packet size of $B = R_1 t_{1,s}/k$, the time it takes to transmit m parity packets at a rate R_p is:

$$\begin{aligned} t_{2,p} &= mB/R_p = mR_1 t_{1,s}/kR_p \\ &= (1-\gamma) R_1 t_{1,s}/\gamma R_p, \end{aligned} \tag{6}$$

where $\gamma = k/(k+m)$ is the FEC rate.

Inserting (6) in (4) and rearranging the terms, we have:

$$t_{1,s} = \frac{\gamma R_2 R_p}{(1-\gamma) R_1 R_2 + \gamma R_p (R_1 + R_2)}. \tag{7}$$

Finally combining (3) and (7), we can derive R_v for the source packet transmission rates, R_1 and R_2, parity transmission rate R_p, and also for the R-DSTC dimension for both source and parity packets, L and L_p, as

$$\begin{aligned} R_v(R_1, R_2, R_p, L, L_p) &= \\ &\frac{\gamma R_1 R_2 R_p}{(1-\gamma) R_1 R_2 + \gamma R_p (R_1 + R_2)}. \end{aligned} \tag{8}$$

Among all sustainable R_1, R_2, R_p's, the source chooses the optimum R_1, R_2, R_p and the corresponding γ, L, L_p that maximize the video rate. Similar to the *multicast-RDSTC* case, L and L_p are chosen as close as possible to the average number of relays for given R_1, R_2.

V. Results

We study a IEEE 802.11g based network and consider a coverage range of 100m radius, $r_d = 100m$, where the AP 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 provide full rate for square constellations [9]. Therefore, the maximum L we consider is 8, even when the number of relays is much larger.

In our simulations, we consider multicast sessions with different numbers of nodes and for each number of nodes we generate 150 different node placements. We choose the transmission power of the AP 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 [8], we observe 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 $PER \leq \epsilon_T$.

For *multicast-RDSTC* scheme, 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 AP, and N_{avg} is the average number of nodes that receive the packets correctly at the first hop for a given number of nodes and transmission rate, R_1. The number N_{avg} is computed based on simulations. On the other hand, for the *enhanced-multicast-RDSTC* scheme, the relay energy per symbol is set to $E_r = E_s/N_{relay}$ where N_{relay} is the number of parity relays. Note that since the number of parity relays changes from packet to packet, E_r also changes from packet to packet. Through simulations, for

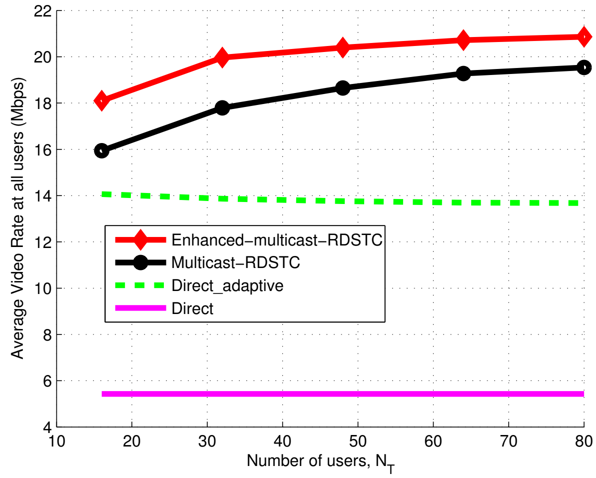

Fig. 2. Video rates vs number of nodes for different systems.

a given number of nodes, we estimate the number of parity relays and E_r for each packet numerically.

For the FEC computations, we use $k = 128$ and choose m such that the FEC decoding failure rate is less than $\zeta = 0.5\%$. We observe that when using an error-resilient video decoder, there is no observable quality degradation when the failure rate is equal to or below this threshold. For the *enhanced-multicast-RDSTC* scheme, for a given node placement, we first run multiple simulations with different fading levels and determine the minimum number of parity packets m that are sufficient to correct the missing packets for all fading levels. This m is used for the performance evaluation.

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 $\gamma_d = 0.905$ to satisfy the threshold ζ. For the remaining modes, for each node placement, we first find the optimal parameters numerically as discussed in Section IV and present the average video rates over different node placements.

In Figure 2, we illustrate the performance of different modes as a function of the number of nodes in the network. As shown in the figure, for *Direct* transmission, the video rate does not change with the number of nodes as the 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 larger number of nodes, there is a higher chance that there will be some node at the edge of the coverage range with a higher PER requiring a lower FEC rate, yielding a lower video rate. For cooperative multicast, as the number of nodes increases, more relays participate in the second hop transmission, providing higher supportable video rates. The proposed *enhanced-multicast-RDSTC* scheme provides further improvement in performance compared to *multicast-RDSTC* by foregoing the first hop transmission of parity packets.

In Figure 3, we present the optimum average transmission rates and FEC rates for all schemes. We observe that optimum transmission rates for source packets of *enhanced-multicast-RDSTC*, (R_1, R_2) are similar to the transmission rates of R-DSTC, (R_1, R_2). However, the transmission rate of parity packets is much higher than the transmission rate of source packets at the second hop. Therefore, the gains for the *enhanced-multicast-RDSTC* scheme, come from not only foregoing first hop transmission of parity packets, but also an increased second hop transmission rate.

VI. Conclusion

In this paper, we consider cooperative multicast using R-DSTC along with packet level FEC, and propose a new way of parity packet transmission where the parity packets are generated at the nodes that receive all the source packets, and are transmitted at the second hop using R-DSTC. We optimize the system parameters to maximize the supportable video rate at all nodes. We show that the proposed scheme outperforms the multicast R-DSTC scheme where both the source and parity packets go through a two-hop transmission, conventional multicast and rate-adaptive direct transmission.

In this paper, we assume the AP knows the average channel qualities between itself and all the nodes, as well as among the nodes. A future direction is to develop practical schemes where the optimization is done based on partial channel information, for example based on the node count. Another direction is to consider layered compression in order to provide differentiated quality to different nodes based on their channel conditions.

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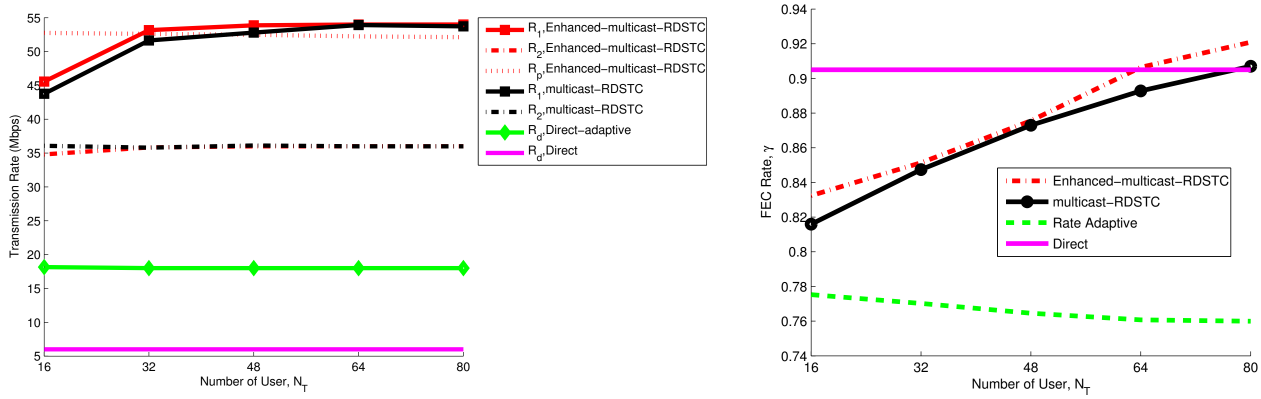

(a) Average optimum transmission rates

(b) Average optimum FEC rates

Fig. 3. Optimum transmission rates and FEC rates for different systems

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