Video Multicast through Cooperative Incremental Parity Packet Transmission

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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. Instead of sending source packets and parity packets through two hops using R-DSTC as proposed in our prior work, the new scheme delivers both source packets and parity packets using only one hop. The source station (access point, AP) first sends all the source packets, then the source as well as all nodes that have received all source packets together send the parity packets using R-DSTC. As more parity packets are transmitted, more nodes can decode all source packets and join the parity packet transmission. The process continues until all nodes acknowledge (through feedback) the receipt of enough packets for recovering the source packets. For each given node distribution, the optimum transmission rates for source and parity packets, are determined such that the video rate that can be sustained at all nodes is maximized. This new scheme can support significantly higher video rates (and correspondingly higher PSNR of decoded video) than the prior approaches. We further present two suboptimal approaches, which do not require full information about user distribution and feedback, and hence are more feasible in practice. The new scheme using only the node count information and without feedback still outperforms our prior approach that assumes full channel information and no feedback, when the node density is sufficiently high.

Categories and Subject Descriptors

H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems—*Video*; C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless Communication*

General Terms

Design, Performance, Theory

Keywords

user cooperation, randomized distributed space time coding, wireless networks, video multicast, incremental parity transmission

1. INTRODUCTION

Wireless video content delivery of popular events is emerging as a high demand service. Advantages in bandwidth efficiency makes wireless multicast an ideal way to deliver video content to many wireless nodes. However, variations in channel conditions between the source and each receiver make wireless video multicast a challenging problem. Cooperative communications effectively combats these variations in channel quality[1]. One way to enable multiple nodes to cooperate simultaneously is by using distributed space-time codes (DSTC)[2]. However, DSTC requires a predetermined and fixed number of relays, and requires tight coordination and synchronization among the relays. To relax these restrictions Randomized DSTC (R-DSTC)[3] lets each relay transmit a random linear combination of antenna waveforms, and enables all nodes to join in the relaying phase, without requiring strict coordination and synchronization.

Randomized cooperation for video multicast in an IEEE 802.11g based WLAN scheme is studied in [4], where the source (access point, or AP) transmits a video packet, and then all nodes receiving the packet forward simultaneously using R-DSTC. To combat packet losses, the source sends both the original video packets (called source packets) as well as parity packets needed by the receivers for recovering lost source packets. Each packet goes through two hops. The transmission rates of both hops and the FEC rate are chosen to maximize the video rates such that a large percentage of nodes can receive without errors. Throughout this paper, this scheme will be referred to *multicast-RDSTC*. With this scheme, the parity packets are generated at the AP and are transmitted over two hops.

An improved parity packet transmission scheme is proposed in [5], named *enhanced-multicast-RDSTC*. In this scheme, the AP, with the help of relays, first transmits all the source packets in two hops, as in the *multicast-RDSTC* scheme. Upon the completion of k source packet transmissions, the nodes that can recover all k source packets correctly generate parity packets and transmit them using R-DSTC. As more parity packets are transmitted, more relays join in parity packet transmission. Transmission rates at both hops for source packets, and the transmission rate for parity packets, are chosen to maximize the sustainable video rate at all nodes. Simulations showed that *enhanced-*

multicast-RDSTC can yield a significant increase in the video rate compared to *multicast-RDSTC*, by reducing the number of hops for parity packets.

In this paper, we propose an innovative way to implement source and parity packet transmissions to further enhance the performance of video multicast with R-DSTC. The AP will first transmit all source packets without using relays. After the source finishes the transmission of k source packets, the source will start to generate and transmit parity packets. Nodes which receive all k source packets will join in the transmission of the first parity packet. More nodes will join in the generation and transmission of additional parity packets as soon as they receive a total of k packets (source or parity), and can therefore decode all k source packets. The parity transmission will stop only after all nodes acknowledge reception of k packets. For each user distribution, we determine the optimal transmission rates for each phase to maximize the achievable video rate. We refer to this new scheme as *CIPT-multicast-RDSTC*, where CIPT stands for cooperative incremental parity transmission. Schemes that require less information about user distribution or no feedback are also considered.

The *CIPT-multicast-RDSTC* scheme assuming full channel information and feedback provides significant gains over the previous *multicast-RDSTC* scheme, increasing the achievable rate by 27% on average. Compared to the *enhanced-multicast-RDSTC*, which also requires feedback, it increases the rate by 16% on average. These increases in the video rate lead to gains of about 1dB and 0.6dB, respectively, in terms of the Peak Signal to Noise Ratio (PSNR), a metric commonly used to measure video quality. Even with only node count information and without feedback, when the node count in system is relatively large, the new scheme provides about 23% increase in rate over the previous *multicast-RDSTC* scheme that requires full channel information but no feedback.

This paper is organized as follows. We introduce the system model in Section 2. In Section 3, we discuss the optimization of different transmission schemes assuming full channel information and feedback. Optimization of system operating parameters under partial channel information and without feedback is addressed in Section 4. Section 5 analyzes the obtained results. We conclude the paper in Section 6.

2. SYSTEM MODEL AND DIFFERENT TRANSMISSION SCHEMES

We study video multicast within an infrastructure-based wireless network. The AP transmits the video to multicast nodes within its coverage range. We assume that the Rayleigh fading among nodes are independent, and that the fading level is constant over the duration of single packet transmission while the path loss exponent is α. Different transmission rates corresponding to different modulation and channel coding schemes are considered. Given the transmission rate, fading level and distance between transmitter and receiver, the instantaneous packet error rate (PER) for direct multicast as well as cooperative transmission is computed as in [4].

We consider direct multicast transmission as a baseline scheme 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. Note that R_d and γ_d are fixed for this baseline scheme. We call this scheme *direct-multicast*. As in [4], we assume that each receiver can identify packets in error by using CRC. We use the Reed-Solomon (RS) error correction code at the packet level to recover the lost packets. For every k source packets we generate m parity packets with a FEC rate of $\gamma = k/(k+m)$.

For *multicast-RDSTC*, the AP generates m parity packets for every block of k source packets and transmits each of these packets at a transmission rate of R_1 bits/sec. Nodes that receive each packet (either a source packet or a parity packet) correctly, relay this packet simultaneously using R-DSTC with STC dimension L to other nodes at a transmission rate of R_2 bits/sec. In order not to increase the total radiated power over the air, each relay transmits with a power that is equal to the transmission power of the AP divided by the average number of relays for a given node count (the number of users in the multicast session). We assume such information can be predetermined through presimulation. Note that for any given combination of (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 of the entire FEC block, the FEC decoding failure rate at each node is equal to or less than a target ζ as stated before for *direct-multicast*.

Note that there are only a few options for the STC dimension L due to the limited dimensions of practical STC codes. Each L has a corresponding STC code rate which will affect effective transmission rate. A full rate can be realized only when $L = 2$[4]. Therefore, in all results reported here, we use $L = 2$.

For *enhanced-multicast-RDSTC* scheme, the AP is only responsible for the transmission of the source packets. Source packets are transmitted by the AP at transmission rate of R_1 bits/sec and then relays forward these packets using R-DSTC at transmission rate R_2 bits/sec. After the completion of two-hop transmission of k source packets, nodes that receive all k source packets become *parity relays*. Parity relays then generate parity packets and transmit using R-DSTC at transmission rate R_p bits/sec. Note that, after each parity packet transmission, nodes that correctly receive k packets can become *parity relays* and join the parity transmission starting from the next packet transmission. Therefore, the number of *parity relays* increases in time. Each relay transmits with a power that is equal to the AP transmission power divided by the number of relays at each parity transmission time (known through the feedback described below). We assume that all nodes send feedback regarding whether they have received at least k packets (source or parity packets). The parity transmission stops when all nodes have received at least k packets.

In contrast to *multicast-RDSTC* and *enhanced-multicast-RDSTC*, for the *CIPT-multicast-RDSTC* scheme, the source packets will be sent only once from the AP at transmission rate R_s bits/sec and will not be relayed. Let us denote the source packets transmission as *phase 1*. After *phase 1* is completed, similar to *enhanced-multicast-RDSTC*, a group of *parity relays* will be composed by nodes that receive all k source packets. Unlike *enhanced-multicast-RDSTC*, the source also participates in parity transmission. At the beginning of *phase 2*, the phase for parity transmission, the AP and all parity relays will generate parity packets and transmit using R-DSTC together at transmission rate R_p bits/sec. As more parity packets are transmitted, more nodes join the parity relay group. Both the AP and the other parity relays transmit at a power that is equal to the AP transmission power for the source packet divided by the total number of parity relays plus one. Note that if there is no available *parity relay* at the beginning of *phase 2* (which will often be the case for systems with low user density), the AP will multicast parity packets by itself. With the previous *enhanced-multicast-RDSTC* scheme, because the AP does not join parity packet transmission, we had to use two-hop transmission for the source packets to ensure a sufficient number of parity relays after the completion of source packet transmission.

3. OPTIMIZATION OF TRANSMISSION RATES

In this section, we describe how to optimize the transmission rates of each scheme given full information about the channel state. The channel state information refers to the average channel SNR's of all the links between each receiving node and the AP, and between each pair of nodes. Without considering the shadow fading, they are determined by the user spatial distribution and an assumed path loss factor. For each possible channel state (which is simulated by a randomly generated user distribution), we find the optimal transmission rates for each scheme, through pre-simulations. We assume that, in practice, the optimal operating parameters for different channel states can be pre-computed and stored in a look-up table at the AP. In an actual multicast session, the AP periodically updates the channel state through feedback from users, and broadcasts the corresponding optimal relay transmission rates to all nodes. Note that the channel state information can be collected by exchanging control signals among nodes for measuring the average SNR's, and then transmitting this information back to the AP. Although the *multicast-RDSTC* and *enhanced-multicast-RDSTC* schemes were described in [4, 5], we review the main results for these two schemes for ease of comparison with the new scheme.

3.1 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 is chosen so that the FEC decoding failure rate is below a threshold ζ in all the nodes. Note that γ depends on the maximum PER among all users after two hop transmission, which in turn depends on the transmission rates R_1 and R_2. We compute the PER experienced by each node over multiple packet transmissions (under different independent fading realizations) using simulations as described in [4].

For any candidate set of R_1 and R_2, the video rate is [4]:

$$R_v(R_1, R_2) = \beta\gamma(R_1, R_2)\frac{R_1R_2}{R_1 + R_2} \qquad (1)$$

where β denotes the effective data ratio, defined as the ratio of the data rate used to transmit video data to the total sustainable rate. Among all candidates R_1,R_2, the source chooses the optimum R_1,R_2 and the corresponding γ that maximizes the video rate.

3.2 Enhanced-multicast-RDSTC

For the *enhanced-multicast-RDSTC* scheme, we assume that the nodes send feedback regarding whether they have received at least k packets. The number of parity packets transmitted for each FEC block, and hence the FEC rate γ depends on the fading levels experienced in each FEC block transmission, for a given set of transmission rate R_1,R_2 and R_p. Let γ denote the average FEC rate for a given set of (R_1, R_2 and R_p) over multiple FEC block transmissions, the video rate can be written as [5]:

$$R_v(R_1, R_2, R_p) = \frac{\beta\gamma R_1R_2R_p}{(1-\gamma)R_1R_2 + \gamma R_p(R_1 + R_2)} \qquad (2)$$

Among all sustainable rates R_1, R_2, R_p, the source chooses the optimum R_1, R_2, R_p and the corresponding γ that maximizes the video rate.

3.3 CIPT-multicast-RDSTC

For the proposed *CIPT-multicast-RDSTC* scheme, the number of parity packets m, and hence the FEC rate, also depends on both the source transmission rate R_s and the parity transmission rate R_p. Therefore, γ (or, m) is a function of (R_s, R_p).

Assume an average packet size of B. Then the transmission time for sending k source packets at transmission rate R_s is $T_s = kB/R_s$. Similarly, the transmission time for sending m parity packets at transmission rate R_p is $T_p = mB/R_p$. The video rate R_v is therefore:

$$R_v = \frac{\beta kB}{T_s + T_p} = \frac{\beta kR_sR_p}{kR_p + mR_s} = \frac{\beta\gamma R_sR_p}{\gamma R_p + (1-\gamma)R_s} \qquad (3)$$

Similar to the previous two schemes, for each user distribution, among all sustainable R_s,R_p, the source chooses the optimum R_s,R_p, and the corresponding γ that maximize the video rate. The optimal R_s and R_p for different channel states are stored in a lookup table. Note that m does not need to be stored in the look up table, as we use feedback to determine the necessary m for each particular realization of a FEC block transmission.

4. CHANNEL INFORMATION AND FEEDBACK

The optimization of the transmission rates for *CIPT-multicast-RDSTC* so far assumes that the system has full channel state information. As described earlier, to acquire such full channel information requires the exchange of control signaling, which can introduce overhead to the system and may not be practical. In [4], the authors considered how to optimize the operating parameters with partial channel information (for example only based on the node count, which is the number of users in the multicast session). Two different multicast R-DSTC schemes with partial channel information are studied in [4]. The robustness of R-DSTC ensures that the performance loss due to partial channel information is not significant.

In addition to requiring the full-channel information, the *CIPT-multicast-RDSTC* system also requires feedback from all nodes regarding whether they have received at least k packets. Because such feedback needs to be sent to all nodes, it can be delivered through the broadcast of short messages by each node. To further reduce the system complexity, we also evaluate the system performance when such feedback is not used.

In the following, we describe two simplified systems, both assuming only node-count information, with one requiring feedback and another not.

4.1 Node-count with feedback

In this case, we assume the AP only knows the node count. It still requires feedback from all nodes to determine when the parity transmission should be terminated for the transmission of each particular FEC block.

For each given node count, we generate multiple node placements. As with the node-count version in the *multicast-RDSTC* system [4], we remove the worst 5% of node placements in terms of maximum average PER. For each feasible set of (R_s, R_p), we find the maximum parity packet number m^* needed among all remaining node placements. By determining the achievable video rate using this m^*, we choose the set $(R_s^*,\ R_p^*)$ that maximize the average video rate R_v for 95% of the node placements for each node count.

In practice, a table of the system operating parameters $(R_s^*,\ R_p^*)$, for different node counts can be pre-computed and stored at the AP. Note that in the system operation, the necessary m for a particular node placement for each FEC block is determined based on the actual feedback, and is in most cases smaller than the one used for determining the optimal transmission rates. Also the relay transmission power is normalized by the actual number of parity relays at each transmission time, which is possible with the feedback.

4.2 Node-count without feedback

In this system, we assume there is no feedback among nodes and the AP to exchange information about whether a node has received enough packets. As with the previous case, we determine the optimal $(R_s^*,\ R_p^*)$ for each node count. But we also record the corresponding maximum number of parity packets m^* for the chosen $(R_s^*,\ R_p^*)$, as well as the average number of parity relay nodes as a function of the parity transmission time. This latter information is needed for normalizing the parity packet's transmission power. All this information will be precomputed and stored in a look-up table.

5. SIMULATION RESULTS

We study an IEEE 802.11g based network and consider a coverage range of 100m radius, where the AP is at the center of the network and nodes are randomly uniformly located in this coverage range. With this example network, there are only eight different transmission rates feasible, i.e., 6Mbps, 9Mbps, 12Mbps, 18Mbps, 24Mbps, 36Mbps, 48Mbps and 54Mbps.

In our simulations, we consider multicast sessions with different node counts, and for each given node count we generate 300 different node placements. For each node placement, we simulate the transmission of fifteen FEC blocks with independent identically distributed fading over each packet.

For the *direct-multicast* scheme, we set the transmission rate at $R_d = 6$Mbps. We further choose the transmission power such that the outer most nodes in the coverage range experience an average PER of 5%, which is a practical assumption for multicast in wireless networks.

For the *multicast-RDSTC* scheme[4], in order to have energy consumption comparable with direct transmission, the source transmits at the same power as the *direct-multicast* system. 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 (over multiple node placements) number of nodes that receive the packets correctly in the first hop for a given node count and transmission rate, R_1. N_{avg} is computed based on simulations. On the other hand, for the *enhanced-multicast-RDSTC* scheme[5], the relay energy per symbol is set to $E_r = E_s/N_{relay}$ where N_{relay} is the actual number of parity relays (which is assumed known through feedback). Note that since the number of parity relays changes from packet to packet, E_r also changes from packet to packet.

For the proposed *CIPT-multicast-RDSTC*, we set $E_r = E_s/(N_{relay} + 1)$ since the AP is serving in the parity packet transmission. As with enhanced-RDSTC, N_{relay} for each parity packet is known through feedback.

Figure 1 shows the average percentage of parity relays for different node counts. We can see that the trends of parity relay increases are different for different node counts. For $N = 16$, although in terms of percentage it has a much faster increasing rate, the total number of parity relays is still not enough to make every nodes in the system receive k packets quicker than when N is higher. There are some node placements in which some nodes are in bad locations and hence require a very large number of parity packets. On the other hand, for those cases with $N > 16$, the percentage of parity relay nodes increases almost linearly with time (before it reaches close to 1). This is a surprising result, and theoretical understanding of this needs further study.

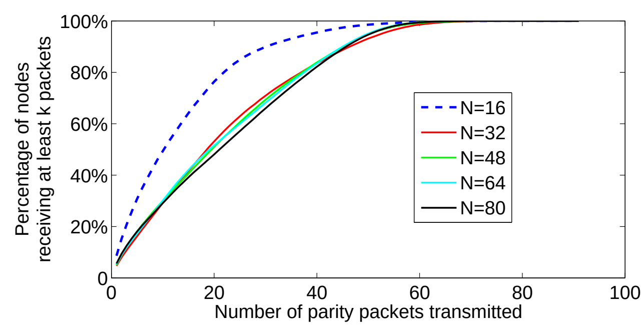

Figure 1: Percentage of nodes acting as parity relays as a function of time.

For FEC, for both *direct-multicast* and *multicast-RDSTC*, we use $k = 64$. For each node placement, we choose m such that the FEC decoding failure rate is less than $\zeta = 0.5\%$ over all nodes. We have observed 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[4]. The video rates reported are derived using the corresponding FEC rate. For direct transmission, we use the base transmission rate $R_d = 6$Mbps, 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 *multicast-RDSTC*, the necessary γ depends on the node placement.

For the *enhanced-multicast-RDSTC* scheme, and the new *CIPT-multicast-RDSTC* scheme, the number of parity packets m for each FEC block is determined so that all the nodes can correctly recover all source packets. To determine the video rate for each node placement, we use the average FEC rate over multiple FEC blocks.

In Figure 2, we present the average achievable video rate as a function of the node count in the network. The average is over multiple node placements under the same node count. We assume $\beta = 0.15$.

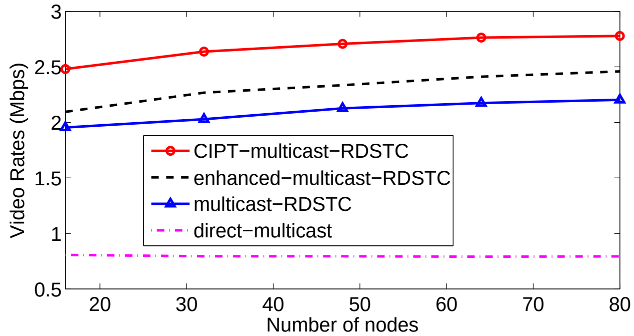

Figure 2: Video rates vs number of nodes for different transmission schemes.

Note that for *direct-multicast*, the video rate does not change with the number of nodes as the transmission rates and FEC rates are fixed. For *multicast-RDSTC*, as the number of nodes increases, more relays participate in the second hop transmission, providing higher supportable video rates. The *enhanced-multicast-RDSTC* scheme provides improvement in performance compared to *multicast-RDSTC* by foregoing the first hop transmission of parity packets. At the highest node count considered ($N = 80$), the video rate increased by 12%.

The proposed *CIPT-multicast-RDSTC* outperforms all other schemes. On average, over all node counts considered, *CIPT-multicast-RDSTC* provides 27% rate increase over *multicast-RDSTC*, and 16% rate increase over *enhanced-multicast-RDSTC*. Its improvement over the *enhanced-multicast-RDSTC* is enabled by letting the AP to join the parity transmissions while reducing the transmission time for the source packets.

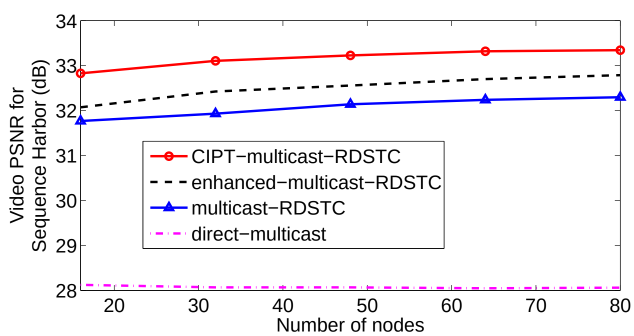

Figure 3: Achievable PSNR of Video Sequence Harbor vs number of nodes for different transmission schemes.

Figure 3 shows corresponding PSNR curves for the video sequence Harbor (SD resolution, 704×576, coded using the H.264 AVC encoder) at the video rates of Figure 2 for all different schemes. According to Figure 3, the proposed scheme has about 1.09dB average gain over *multicast-RDSTC*, and 0.66dB average gain over *enhanced-multicast-RDSTC*, in terms of PSNR.

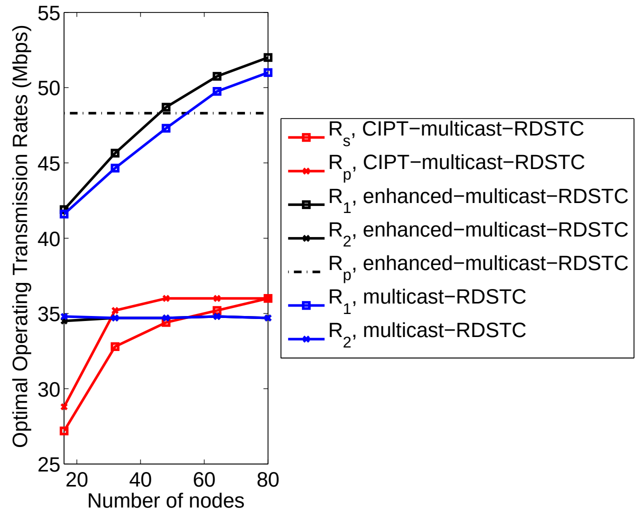

Figure 4: Average transmission rates vs number of nodes for different transmission schemes.

Figure 4 illustrates the optimal transmission rates for different schemes. We can see that R_1 and R_2 are very close for *multicast-RDSTC* and *enhanced-multicast-RDSTC*. But *enhanced-multicast-RDSTC* has a relatively high parity transmission R_p at relatively high node density; this together with the fact that it employs only one hop for the parity packets enable it to improve upon *multicast-RDSTC*.

For *CIPT-multicast-RDSTC*, R_s is significantly lower than R_1 for the other two schemes. This is to enable source packets be received by a sufficient number of nodes after one hop transmission. R_p is also lower than R_2 at low node-count, and significantly lower than R_p for *enhanced-multicast-RDSTC*. This is because, especially at the beginning of parity packet transmission, there are a limited number of relay nodes participating in the relay transmission. However, since both source and parity packets will be sent only once, the achievable video rate is still significantly higher.

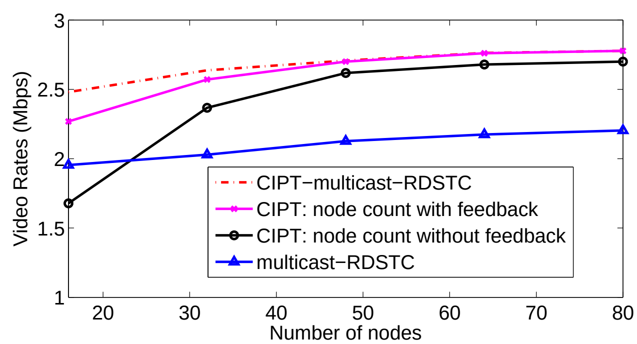

Figure 5: Video rates vs number of nodes for *CIPT-multicast-RDSTC* node count case with and without feedback, and comparison to *multiicast-RDSTC* (which does not require feedback).

In Figure 5, we compare the performance of the *CIPT-multicast-RDSTC* scheme assuming full channel information, and the more practical schemes discussed in Section 4. It can be observed from this figure that, when N is sufficiently large, the difference between *CIPT-multicast-RDSTC*, which requires full-channel information, and *node count with feedback* is negligible. This is because, when N is large, for any node placement, their performance should be close to the average. We could conclude that full channel information is not necessary for $N \geq 48$.

Regarding the necessity for feedback, when N is small, since there are substantial variations in terms of the number of parity packets required among different node placements, the scheme without feedback (where we choose m based on the worst case) will lead to very poor performance, compared to the scheme which has feedback mechanism. Note that the channel overhead for feedback will be limited if we employ it only for small N. But when N is large, the performance degradation is quite insignificant, with the video rate decreased by less than 3% for $N \geq 48$. Also, compared to the *multicast-RDSTC* (which does not require feedback but requires full channel information), the new scheme, with only the node count information and no feedback, still provides significant gain when the node count N is equal to or greater than 32. This demonstrates that the feedback that we introduced in *CIPT-multicast-RDSTC* is not the only significant reason for the improved performance.

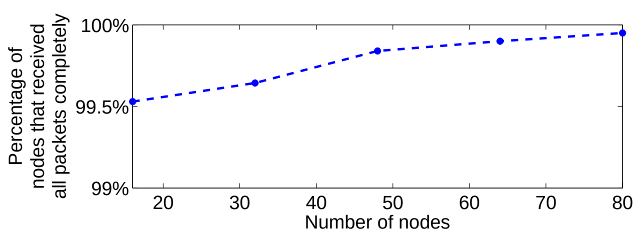

Figure 6: Percentage of nodes that receive all packets at all node placements versus number of nodes in the CIPT: node-count without feedback system.

Figure 6 shows the percentage of nodes that can correctly recover all source packets among all simulated node placements (including the worst 5%) for different numbers of nodes in the node-count system without feedback. As we can see from the figure, more than 99.5% of the users can successfully decode source packets regardless of the number of nodes in the system, in spite of the fact that we excluded the worst 5% node placements when determining the optimal transmission rates.

6. CONCLUSION

In this paper, a new approach is proposed for cooperative multicast using R-DSTC and packet level FEC. Instead of sending source and possibly parity packets through two hops as in our prior work, the proposed scheme transmits source packets and parity packets in only one hop. The source packet is sent by the AP, whereas the parity packets are sent by the AP as well as relays who have received source packets correctly. The proposed scheme provides substantially higher video rates over the *multicast-RDSTC* scheme in which both source and parity packets go through a two-hop transmission. It further improves over the *enhanced-multicast-RDSTC*, in which the parity packets are sent by relays, but the source packets still go through two hops. Furthermore, two suboptimal but more practical schemes are proposed, which only require the node count information, and one of them also does not require feedback from nodes. We showed that when the node count is large (over 48 users in a 100m radius), full channel information is not necessary. Feedback, on the other hand, very important when the node count is small.

There are multiple possible paths for future research. One is to further improve the performance of this proposed scheme by discontinuing relay packet transmissions from nodes after they have transmitted a certain times. This could be beneficial because these nodes may not be helpful any more, and yet by removing them from parity transmission, the remaining parity relays can transmit at a higher power. Another way to improve the performance is by dynamically increasing the relay transmission rate as more parity packets are sent. This is likely to be beneficial because, as more relays join parity transmission, higher transmission rates are sustainable. Another research direction is to adapt the proposed scheme to layered coded video, as done in [4]. This will deliver differentiated quality to different nodes.

7. ACKNOWLEDGMENTS

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