Layered Randomized Cooperative Multicast for Lossy Data: A Superposition Approach

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***Abstract*—In this paper, we consider randomized distributed cooperation for multicasting a source signal with end-to-end distortion used as a performance metric. In order to provide differentiated quality to users with different channel strengths, we study layered cooperation where layers are transmitted simultaneously using superposition coding. We first formulate the problem and investigate the effect of power allocation of different layers on the distribution of end-to-end quality of users under a real-time delivery requirement. We then compare the proposed scheme with sequential layered transmission in which the layers are transmitted sequentially in time. Our results show that layered cooperation with superimposed layers outperforms sequential layered cooperation and provides a good alternative for multicast applications.**

Index Terms: randomized distributed cooperation, superposition coding, wireless networks, lossy source, layering

I. Introduction

Wireless video multicast is a bandwidth efficient method to deliver popular events to many wireless users. However, sensitivity of the video to packet losses coupled with time varying and error prone nature of the wireless channels make video multicast over wireless networks a challenging problem.

Cooperative communication techniques at the physical layer have been extensively studied as a means to provide spatial diversity starting with [1], [2]. Our previous work on point-to-point source transmission suggests that cooperation of users significantly improves the end-to-end source distortion by providing an alternate means of unequal error protection [3]-[6]. 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.

Randomized distributed cooperation is an effective method for multi-stage broadcasting where a transmitter node initiates the broadcast by transmitting a packet and every node who can hear the source with sufficient signal-to-noise ratio (SNR), decodes and forwards the same packet using randomized distributed space time coding. Each group excites a new group of nodes and the retransmissions continue until every node who hears the others with sufficient SNR, forwards once. The asymptotic behavior in terms of successful reception probability of such a system in a dense network has been studied in [7] where the authors considered the propagation of lossless information through the network.

In our previous work [8], we studied a multi-stage randomized cooperation scheme for multicasting lossy data such as multimedia signals (audio, image, and video). We minimized the end-to-end distortion of the multicast receivers in a certain coverage range under a delay constraint and we investigated the effect of decoding SNR threshold, number of hops and the diversity level of the underlying space time code (STC) on the end-to-end distortion of the multicast users. In order to provide receivers with signals at different distortion levels commensurate with their channel conditions, we considered layered cooperation where we transmit different layers sequentially in time and illustrated the benefits.

The transmission of layers can also be done simultaneously by superposition coding. Superposition of source layers has been considered in [3],[9] where the authors show the benefits of superposition in minimizing end-to-end distortion for point-to-point channels over sequential transmission and over single layer transmission.

In this paper, we consider layered compression for multicast of lossy data where different source layers are transmitted simultaneously. For a fixed coverage area and a real-time delivery constraint, we investigate the effect of power allocation, decoding SNR threshold and the diversity level of the underlying space time code (STC) for different layers on the distribution of the end-to-end distortion of the multicast users. We carry out our analysis using an i.i.d. Gaussian source and make use of the well-known rate distortion function and the successive refinability [10] to determine the encoding-induced distortion at different source rates. We compare the simultaneous transmission scheme with sequential transmission in time [8] and show the benefits of using superposition of layers.

This paper is organized as follows. We introduce the system model in Section II. We first formulate the single layer expected end-to-end distortion in Section III. We then study

[1]This work is supported in part by National Science Foundation (NSF) under award 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.

layered cooperation where different layers are transmitted simultaneously by superposition coding and formulate the expected end-to-end distortion in Section IV. In Section V, we present the results. We conclude the paper in Section VI.

II. System Model

We study a network in which the node locations are randomly and uniformly distributed over a fixed coverage area. Specifically, we consider a dense network and use the continuum approach following the model [7], where the total relay power density at each hop is fixed. We denote the source power and relay power density as P_s and $\tilde{P}_r$, respectively. We assume independent Rayleigh fading channels between nodes and unit variance additive white complex Gaussian noise. We use a path-loss model, *l(d)*, with

$$l(d) = \begin{cases} 1/d^2 & \text{if} \quad d > d_0 \\ 1/d_0^2 & \text{if} \quad d \leq d_0 \end{cases} \tag{1}$$

where d is the distance between the transmitter and the receiver. In general the path loss model $l(d) = 1/d^2$ arises from the free-space attenuation of electromagnetic waves, and it does not hold when d is very small leading to the model in (1).

We assume that the broadcast transmission is initiated by the source node by transmitting a packet. Appropriate channel coding is used so that the information is correctly received as long as the received SNR is above the decoding SNR threshold, τ. Every node who hears the source with a signal-to-noise ratio above the threshold, τ, will be able to decode the packet and will forward. Each node only transmits at most once. A training preamble in the message helps nodes detect the presence of the packets, estimate the received power, and synchronize the relay transmissions. The relays use a STC of dimension L and the relay transmissions are done simultaneously, even though they may not be symbol synchronized. The first group excites a second group of nodes and they will activate the next group nodes. The subsequent groups of nodes that are activated are referred to as hops. Since the nodes only use the locally available received SNR information to make transmission decisions, the network can operate in a distributed fashion. Note that the transmission rate is R bits per channel use at each hop where the rate depends on the SNR threshold, τ, as

$$R = \log(1 + \tau) \tag{2}$$

In our analysis, we consider two different STC dimensions. In one extreme, we assume a high diversity regime where the relays transmit in orthogonal channels obtained by using a space time code of dimension, $L = \infty$ (orthogonal). In another extreme, we consider a low diversity transmission scheme using a space time code of dimension $L = 1$ (non-orthogonal). Note that the analysis can be extended to arbitrary L using [11].

We define a channel frame as a block of n channel uses and assume the fading amplitudes are constant during each channel frame. We have k source samples to be transmitted in one channel frame leading to a bandwidth ratio of $b = n/k$ channel uses per sample. Typically the bandwidth ratio b is dictated by the application and the channel bandwidth. For example, a channel bandwidth of W Hz suggests that we have W channel uses per second. If the source is sampled at a rate of f_s samples per second and due to the real-time constraints, needs to be sent at the sampling rate, the bandwidth ratio can be expressed as $b = W/f_s$ channel uses per sample. Hence, in this paper, we use b to characterize the real-time delivery requirement. A bandwidth ratio of b corresponds to transmission of bR bits for each source sample. For a real i.i.d Gaussian source with unit variance, the resulting distortion per source sample becomes:

$$D = 2^{-2bR} \tag{3}$$

In the case of N hops, to send k source samples, each hop can use n/N channel uses, leading to a bandwidth ratio of $\frac{n}{kN} = \frac{b}{N}$ per hop. The resulting distortion then becomes

$$D(\tau, b, N) = 2^{-2bR/N} \tag{4}$$

Equation (2) and (4) indicate that the distortion depends on the decoding SNR threshold, bandwidth ratio and the number hops.

The end-to-end distortion at a particular location depends not only on the distortion induced by the source code, but also on the packet loss probability at that location. Section III illustrates the end-to-end distortion for single layer transmission and Section IV investigates the end-to-end distortion for layered compression where the source layers are transmitted simultaneously using superposition coding.

III. Single Layer Transmission

In this section we discuss non-layered (or single layer) randomized distributed cooperation. We first revisit the probability of a node at (x, y) receiving the data at the j^{th} hop for a random network [7]. Then we formulate the expected distortion considering the number of hops, N, and the bandwidth ratio, b.

Let $P_j(x, y)$ denote the probability that the user at location (x,y) receives either the source or relay transmission correctly at j^{th} hop. For the first hop (i.e., source transmission), the probability can be expressed as

$$P_1(x, y) = Pr\{\|h_1(x, y)\|^2 \geq \tau\} \tag{5}$$

where $\|h_1(x, y)\|^2 = P_s\|h(x, y)\|^2$ is the received SNR for a source transmission power of P_s and instant fading level of $h(x, y)$ at location (x,y). The SNR threshold to be exceeded for the relay node to decode is τ.

For the j^{th} hop ($j > 1$), we only consider the users who did not receive the information in the previous hops. All users who receive the information in the previous hop (i.e. $(j-1)^{th}$ hop) will forward. The probability of successful reception for the j^{th} hop can be expressed as,

$$P_j(x, y) = Pr\{\|h_j(x, y)\|^2 \geq \tau\}[1 - \sum_{i=1}^{j-1} P_i] \tag{6}$$

where $h_j(x,y)$ is the equivalent channel gain at location (x,y) given by

$$h_j(x,y) \sim N_c(0, \sigma_j^2(x,y)), \text{L=1 (non-orthogonal)} \quad (7)$$

$$\|h_j(x,y)\|^2 = \sigma_j^2(x,y), \text{L=}\infty \text{ (orthogonal)} \quad (8)$$

where

$$\sigma_j^2(x,y) = \int\int \tilde{P}_r P_{j-1}(x',y') l(x-x', y-y') dx'dy' \quad (9)$$

Note that $\sigma_j^2(x,y)$ is the sum of signal powers from all nodes who successfully received the information from the previous hop at location (x,y). Due to the continuum model assumption [7], $P_j(x,y)$ and $\sigma_j^2(x,y)$ are only functions of $r = \sqrt{x^2+y^2}$. Therefore, the above equations are one dimensional functions.

We define $P(x,y;N)$ as the probability of successful reception after N hop transmission which can be expressed as

$$P(x,y;N) = \sum_{i=1}^{N} P_i(x,y) \quad (10)$$

Therefore, the expected distortion at location (x,y), $D_{exp}(x,y)$, after N hops is

$$D_{exp}(x,y) = P(x,y;N)D(\tau,b,N) + (1 - P(x,y;N)) \quad (11)$$

Note that since we consider a unit variance Gaussian source, when data is lost, we observe the maximum distortion, D_{max}=1.

IV. Superimposed Transmission of Multiple Layers

In this section, we discuss layered cooperation to provide differentiated quality for the multicast receivers based on their channel conditions. In our previous work, we studied a layered cooperation scheme where the layers are transmitted sequentially in time [8]. In this paper, we consider the simultaneous transmission of layers using superposition coding due to its potential benefits over sequential transmission [3],[9]. We only consider two layers, base and enhancement layer, to illustrate the main idea. We assume that we have two SNR thresholds: base layer threshold τ_b and enhancement layer threshold τ_e. We apply channel coding and transmit the base and the enhancement layers simultaneously using superposition coding. We use β proportion of the total power for the base layer transmission and $1-\beta$ proportion of the power for the enhancement layer and assume that the same proportionality is applied at the source and at all the relays. At a given node, we first decode the base layer treating the enhancement layer as noise. Then, enhancement layer is extracted by re-encoding and subtracting the base layer from the received signal. Note that, reception of the enhancement layer requires the reception of the base layer. Hence, we need to choose τ_b, τ_e, β such that the reception of base layer is guaranteed for reception of the enhancement layer.

We next derive a general expected distortion formulation considering $(\tau_b, \tau_e, P_s, \tilde{P}_r, \beta)$ for N hop transmission and then evaluate the effect of these parameters on the performance.

The expected distortion at location (x,y) can be expressed as,

$$\begin{aligned} D_{exp}(x,y) &= P_{b+e}(x,y;N)D_{b+e}(\tau_b,\tau_e,N,b) \\ &\quad +(P_b(x,y;N) - P_{b+e}(x,y;N))D_b(\tau_b,N,b) \\ &\quad +(1 - P_b(x,y;N)) \end{aligned} \quad (12)$$

where D_{b+e} is the distortion when both base and enhancement layers are received and D_b is the distortion when only base layer received. For Gaussian sources with unit variance, using (4), we can compute these distortion values as:

$$D_{b+e} = 2^{-2b(R_b+R_e)/N} \text{ and } D_b = 2^{-2bR_b/N} \quad (13)$$

where $R_b = \log(1+\tau_b)$ and $R_e = \log(1+\tau_e)$.

In (12), $P_b(x,y;N)$ and $P_{b+e}(x,y;N)$ denote the probability of success after N hop transmission for base and both base and enhancement layers, respectively, and they are expressed as follows:

$$P_b(x,y;N) = \sum_{j=1}^{N} P_j^b(x,y) \quad (14)$$

$$P_{b+e}(x,y;N) = \sum_{j=1}^{N} P_j^{b+e}(x,y) \quad (15)$$

where $P_j^b(x,y)$ denotes the probability that the user at location (x,y) receives either the source's base layer transmission or relay's base layer transmission from the previous hop correctly at j^{th} hop. Similarly, the probability of successful reception of both base and enhancement layers is defined as $P_j^{b+e}(x,y)$ for the j^{th} hop.

For the first hop (i.e., source transmission), received signal at a node a node at location (x,y) is given by:

$$\begin{aligned} r(x,y) &= \sqrt{\beta P_s} h(x,y) S_b \\ &\quad + \sqrt{(1-\beta)P_s} h(x,y) S_e + n(x,y) \end{aligned} \quad (16)$$

where S_b and S_e represents base and enhancement layer signals and $n(x,y)$ is the additive white Gaussian noise. Then, the probability of receiving the base layer can be expressed as

$$P_1^b(x,y) = Pr\{\frac{\|h_1^b(x,y)\|^2}{1+\|h_1^e(x,y)\|^2} > \tau_b\} \quad (17)$$

where $\|h_1^b(x,y)\|^2 = \beta P_s \|h(x,y)\|^2$ is the received SNR at location (x,y) for the base layer and $\|h_1^e(x,y)\|^2 = (1-\beta)P_s\|h(x,y)\|^2$ is the received SNR for the enhancement layer. In (17), the base layer is decoded treating the enhancement layer as noise [13]. We can express (17) as,

$$\begin{aligned} P_1^b(x,y) &= Pr\{\frac{\beta P_s \|h(x,y)\|^2}{1+(1-\beta)P_s\|h(x,y)\|^2} > \tau_b\} \quad (18) \\ &= Pr\{\|h(x,y)\|^2 > \frac{\tau_b}{\beta P_s - (1-\beta)P_s\tau_b}\} \end{aligned}$$

The probability of receiving the enhancement layer depends on the base layer. Given the base layer is decoded correctly and removed from the received signal, the probability of receiving the enhancement layer can be expressed as

$$P_1^{e|b}(x,y) = Pr\{\|h_1^e(x,y)\|^2 > \tau_e\} \quad (19)$$

Note that we can express (19) as,

$$P_1^{e|b}(x,y) = Pr\{\|h(x,y)\|^2 > \frac{\tau_e}{(1-\beta)P_s}\} \quad (20)$$

Recall that, for (19) to be valid, the base layer has to be decoded and subtracted from the received signal. This can be guaranteed under the constraint,

$$\frac{\tau_b}{\beta-(1-\beta)\tau_b} < \frac{\tau_e}{(1-\beta)} \quad (21)$$

Under (21), $P_1^{e|b}(x,y)$ can be considered as the probability of receiving both the base and enhancement layers leading to

$$P_1^{b+e}(x,y) = P_1^{e|b}(x,y) \quad (22)$$

For the j^{th} hop ($j>1$), we only consider the users who did not receive the information in the previous hops. All users who receive either the base layer or both base and enhancement layers in the previous hop (i.e. $(j-1)^{th}$ hop) will forward. Also, if a node receives the base layer, it will stop listening to subsequent hops even though it does not have the enhancement layer. We assume that if a node only receives base layer, it will use all its power to transmit only the base layer. If it also receives the enhancement layer, it will allocate its total power among the base and enhancement layers according to the proportionality constant, β. For the j^{th} hop, the probability of successful reception for the base layer and the probability of receiving both layers, can be expressed as,

$$P_j^b(x,y) = Pr\{\frac{\|h_j^b(x,y)\|^2}{1+\|h_j^e(x,y)\|^2}) > \tau_b\} \cdot [1-\sum_{i=1}^{j-1} P_i^b] \quad (23)$$

$$P_j^{b+e}(x,y) = Pr\{ \|h_j^e(x,y)\|^2 > \tau_e, \frac{\|h_j^b(x,y)\|^2}{1+\|h_j^e(x,y)\|^2}) > \tau_b\} \cdot [1-\sum_{i=1}^{j-1} P_i^b] \quad (24)$$

where $h_j^b(x,y)$ and $h_j^e(x,y)$ are the equivalent channel gains at location (x,y) for the base and enhancement layers, respectively, given by,

$$\begin{array}{l} h_j^b(x,y) \sim N_c(0, {\sigma_j^b}^2(x,y)) \\ h_j^e(x,y) \sim N_c(0, {\sigma_j^e}^2(x,y)) \end{array}, \quad \text{L=1 (non-orthogonal)} \quad (25)$$

$$\begin{array}{l} \|h_j^b(x,y)\|^2 = {\sigma_j^b}^2(x,y) \\ \|h_j^e(x,y)\|^2 = {\sigma_j^e}^2(x,y) \end{array}, \quad \text{L=}\infty \text{ (orthogonal)} \quad (26)$$

where

$${\sigma_j^b}^2(x,y) = \int\int [\tilde{P}_r(P_{j-1}^b(x',y') - P_{j-1}^{b+e}(x',y')) + \beta\tilde{P}_r P_{j-1}^{b+e}(x',y')] \cdot l(x-x', y-y')dx'dy' \quad (27)$$

$${\sigma_j^e}^2(x,y) = \int\int [(1-\beta)\tilde{P}_r P_{j-1}^{b+e}(x',y')] \cdot l(x-x', y-y')dx'dy' \quad (28)$$

In the above formulation which can be derived similar to [7], ${\sigma_j^b}^2(x,y)$ represents the sum of signal powers at location (x,y) from all nodes who successfully received the base layer information from the previous hop. Similarly, ${\sigma_j^e}^2(x,y)$ represents the sum of signal powers at location (x,y) from all nodes who successfully received the base and enhancement layers from the previous hop. Recall that from (21), the nodes who receive the enhancement layer also receive the base layer. In other words, we can think of the nodes who receive the enhancement layer as a subset of the nodes who receive the base layer. Hence, $h_j^b(x,y)$ and $h_j^e(x,y)$ are dependent and can be related as $h_j^b(x,y) = \eta h_j^e(x,y) + h_j^n(x,y)$ where $h_j^n(x,y)$ is the equivalent channel gain representing nodes that transmit the base layer when the enhancement layer is not received. Note that $\eta = \sqrt{\beta/(1-\beta)}$. Since $h_j^n(x,y)$ and $h_j^e(x,y)$ are independent, we can show that $h_j^b(x,y)$ and $h_j^e(x,y)$ have the correlation coefficient $\rho = \eta\sigma_j^e/\sigma_j^b$. We can express ${\sigma_j^b}^2(x,y)$ as

$${\sigma_j^b}^2(x,y) = \eta^2 {\sigma_j^e}^2(x,y) + {\sigma_j^n}^2(x,y) \quad (29)$$

where

$${\sigma_j^n}^2(x,y) = \int\int [\tilde{P}_r(P_{j-1}^b(x',y') - P_{j-1}^{b+e}(x',y'))] \cdot l(x-x', y-y')dx'dy' \quad (30)$$

For orthogonal relay transmission, we can compute (23) and (24) by substituting in (26). For nonorthogonal relay transmission, note that we can write the former part of (23) as

$$Pr\{\frac{\|h_j^b(x,y)\|^2}{1+\|h_j^e(x,y)\|^2}) > \tau_b\} = Pr\{\|h_j^b(x,y)\|^2 - \tau_b\|h_j^e(x,y)\|^2 > \tau_b\} \quad (31)$$

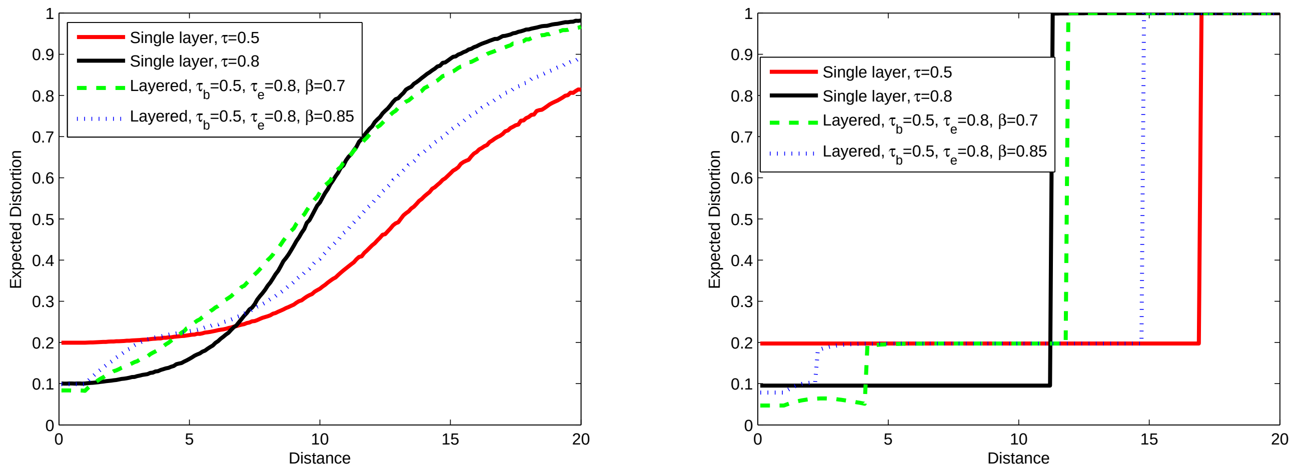
In order to compute the above probability, we need to find the probability distribution function of the difference of two correlated chi-square distributed random variables, $\|h_j^b(x,y)\|^2$ and $\|h_j^e(x,y)\|^2$. Let h_1 and h_2 be two dependent zero-mean complex Gaussian variables with correlation coefficient ρ and variances σ_1 and σ_2, respectively. Then, $u = \|h_1\|^2 - \|h_2\|^2$ is a dependent central chi-square difference with a probability distribution function [12], given by,

$$p(u) = \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}} \exp(-\frac{(\alpha^+ - \gamma^-)u}{4}) K_0(\frac{\gamma^-|u|}{4}) \quad (32)$$

where $K_0(u)$ is the modified Bessel function of the second kind and

$$\gamma^- = \frac{[(\sigma_2^2-\sigma_1^2)^2 + 4\sigma_1^2\sigma_2^2(1-\rho^2)]^{\frac{1}{2}}}{\sigma_1^2\sigma_2^2(1-\rho^2)} \quad (33)$$

$$\alpha^{\pm} = \gamma^- \pm \frac{\sigma_2^2-\sigma_1^2}{\sigma_1^2\sigma_2^2(1-\rho^2)} \quad (34)$$



(a) Nonorthogonal(L=1)

(b) Orthogonal (L=∞)

Fig. 1. The effect of β on the expected distortion as a function of distance for $P_s = 10$, $\tilde{P}_r = 2$, $N = 2$, $b = 4$. The 'layered' plot illustrates simultaneous transmission of layers by superposition.

Hence, (31) can be computed using (32) with $\sigma_1^2 = {\sigma_j^b}^2$, $\sigma_2^2 = \tau_b {\sigma_j^e}^2$ and $\rho = \eta \sigma_j^e / \sigma_j^b$.

The computation of former part of (24) requires the consideration of the above derived joint distribution of $\|h_j^b(x,y)\|^2$ and $\|h_j^e(x,y)\|^2$ and we evaluate this probability numerically.

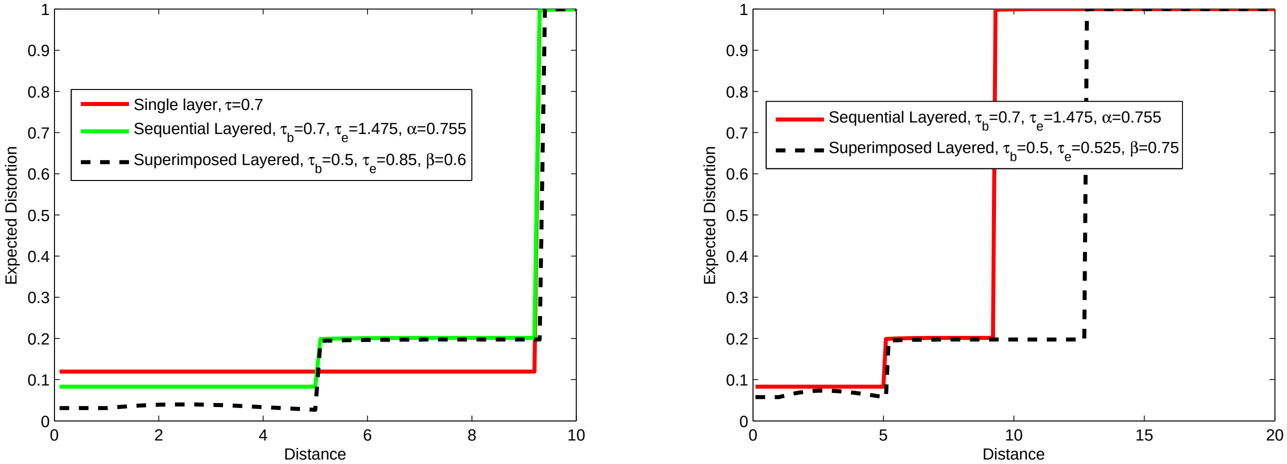
V. Results

We first evaluate the effect of the power allocation, β, on the distribution of the distortion. In Figure 1(a) and Figure 1(b), for a fixed $P_s, \tilde{P}_r, b, N$ we present the expected distortion as a function of distance from the source for two different β's for nonorthogonal and orthogonal relay transmissions, respectively. We also plot the single layer performance for comparison. Note that as we increase β, since we allocate more power to base layer and less power to enhancement layer, base layer propagates more at the expense of enhancement layer propagation. However, the base layer can not propagate as far as the single layer, since in the single layer case all the power is utilized to transmit the same layer. The benefit of layered cooperation is to provide lower distortion to nearby users than the single layer transmission at the expense of coverage range. By choosing β, we can adjust the base and enhancement layer coverage ranges. Note that by choosing $\tau_b = \tau$, the base layer quality match with single layer quality and the nearby users achieve better quality than that of single layer at an expense of reduced coverage range. On the other hand by choosing $\tau_e = \tau$, nearby user quality matches with single layer quality, with reduced enhancement layer coverage range, but base layer reaches farther than that of single layer.

In Figure 2, we compare the performance of single layer randomized cooperation, sequential layered randomized cooperation [8] and superimposed layered randomized cooperation. Since the notion of coverage range is more clearly defined for orthogonal transmission, we show the results for $L = \infty$. For the single layer case, we find the optimum τ which minimizes the distortion at a target coverage range, $r_{cov} = 9.3$ [8]. For the layered case, we find the optimum parameters such that, all the receivers in a target coverage range observe a certain expected quality, say D_1, while the close-by receivers observe better quality, D_2. we fix the coverage range same as the single layer case that is $r_{cov} = 9.3$ and the maximum distortion in the coverage range to $D_1 = 0.2$. Finally, in order to have a fair comparison between sequential layered cooperation and superimposed layered cooperation, we also fix the coverage range of the users who will receive both the base and the enhancement layers ($r_{cov}^{b+e} = 5$ in the figure). We find the optimum parameters for each case which minimize the distortion, D_2, in the coverage range of r_{cov}^{b+e}. For the sequential layered transmission α refers to proportion of the base layer transmission time to the all transmission time. As illustrated in Figure 2(a), layered cooperation with superimposed layered cooperation improves the quality significantly compared to the sequential case. In a multicast system, the coverage range can also be a design parameter. We also compare the sequential and superimposed layered cooperation in terms of coverage range. We fix the maximum distortion in the coverage range to $D_1 = 0.2$ and the coverage range of the users who will receive both the base and the enhancement layers ($r_{cov}^{b+e} = 5$). We then set D_2 of superimposed cooperation equal to that of sequential transmission and compare the coverage ranges. In Figure 2(b), we show that superimposed layered cooperation improves the coverage range of the system from the $r_{cov} = 9.3$ to $r_{cov} = 12.7$ compared to the sequential transmission.

VI. Conclusion and Future Work

This paper considers a randomized distributed cooperation scheme for multicasting a source signal. We study layered cooperation where layers are transmitted simultaneously by



(a) Quality improvement at closer receivers (b) Coverage range extension

Fig. 2. Comparison of expected distortion for single layer randomized cooperation, sequential layered randomized cooperation [8] and superimposed layered randomized cooperation with $P_s = 10$, $\tilde{P}_r = 2$, $N = 2$, $b = 4$ (L=∞)

using superposition coding to provide differentiated quality to users with different channel strengths. We consider the end-to-end (or expected) distortion as a performance metric and formulate the expected distortion as a function of distance to the source. We then investigate the effect of power allocation of different layers on the distribution of end-to-end quality of users under a real-time delivery requirement. We compare the proposed scheme with sequential layered transmission and show that layered cooperation with superimposed layers outperforms sequential layered cooperation.

In this paper, we considered only specific diversity levels (L=1, L=∞). A future direction is to consider the effect of different diversity levels on the performance of the multicast system. Furthermore, while we assumed both base and enhancement layers use the same underlying STC, it is possible to use different STC's for different layers in order to provide unequal error protection to different layers. This paper only presented results for 2 hop transmission. Another research direction is to investigate larger number of hops and different real-time delivery requirements. Finally, our model assumes that once a node receives the base layer, it stops listening to subsequent transmissions. By extending the model to enable such nodes to listen until they also receive the enhancement layer, we could further improve the performance of superimposed layered cooperation.

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