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Cooperative Multimedia Communications: Joint Source Coding and Collaboration

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Abstract— **Cooperative diversity exploits the broadcast nature of wireless channels by allowing users to relay information for each other so as to create multiple signal paths. This paper analyzes what is the best strategy from the viewpoint of a resource allocation protocol, to match source coding with cooperation diversity for conversational multimedia communications by studying the distortion performance for different schemes. The results show that the best performance is obtained when all layers of a layered-coded source are sent with user cooperation (using decode-and-forward in most cases) if the source-destination channel is bad, and with no user cooperation, if the source-destination channel is good. The results also show that the gains from cooperative diversity outweigh the loss due to the sacrifice in overall bandwidth and that cooperation performance is sensitive to the proportion of communication capacity allocated for cooperation.**

I. INTRODUCTION

Future wireless communications will need to support conversational multimedia traffic with good quality of service while operating at reduced power levels in environments impaired by signal fading. One effective way in overcoming this challenge is the use of diversity techniques. In spatial diversity copies of a signal are transmitted through different (ideally undergoing mutually independent fading) paths by using multiple physically-separated antennas at the transmitter, the receiver or both. Although spatial diversity provides useful performance gain, its practical implementation is limited by the size of mobile terminals. This limitation can be overcome by making multiple users collaborate during communication by relaying information for each other so as to create multiple signal paths that are combined at the receiver, a technique known as cooperation diversity [1]. Cooperation diversity builds upon early studies on the relay channel [2]. While [1] introduced the idea of cooperation through "decode and forward" (DF), in [3] the authors introduced the idea of implementing cooperation through "amplify and forward" (AF) and further studied the achievable capacity of user-cooperation schemes. Diversity through coded cooperation was studied in [4].

Diversity can be exploited in a cross-layer approach when the physical layer presents multiple communications paths to upper layers. Multiple Description Coding is a form of source coding diversity [5] that had been studied as an error resiliency tool [6]. Here, different coded descriptions are sent through different paths. At the receiver, each description can be decoded independently or, if possible, combined together to reconstruct the source at a lower distortion [7]. Layered source coding [8] is a technique that allows matching the source coder to the channel, where the source coded representation is segmented into a hierarchy of layers. The first layer (the "base layer") provides the lowest bit rate representation of the source. To gradually refine the source representation, each of the successive layers needs to be orderly combined with the preceding ones.

Cooperative diversity can be combined with channel-matched source codecs to further improve performance. Our goal in this paper is to study what is the best strategy in matching source coding with cooperation diversity for multimedia communications. The solution to this problem does not appear readily due to the challenges involved in real-time multimedia communications. In [9], the authors considered in a capacity achieving case, AF cooperation combined with refinable single description coding where only the base layer is transmitted using cooperation. Our work goes further by considering that delay constraints typical of conversational traffic precludes from using capacity achieving codes. Also, we consider that multimedia sources allow for some channel errors, thus we study the end-to-end distortion performance as a balance between channel errors and source coding rate. Even more, for layered coding, we study performance with AF or DF cooperation as a function of the number of layers and number of them sent using cooperation. Also, we compare the performance of single and multiple description source coding with coded cooperation to AF and DF cooperation. Finally, we study the effect on performance when the proportion of communication capacity allocated to cooperation is reduced. This aims at studying the balance between overall bandwidth utilization and cooperative diversity in multimedia systems.

Our results show that layered coding when all layers use cooperative diversity provides the best performance of all source encoding methods. We also conclude that the best overall performance is obtained when the mobile switches between cooperative and non-cooperative operation depending on the channel conditions. We also remark that in most cases DF cooperation shields the best performance among cooperative techniques, with coded cooperation being outperformed by AF. In addition, we see that the gains from cooperative diversity outweigh the loss due to the sacrifice in bandwidth and that cooperation performance is sensitive to the proportion of communication capacity allocated to cooperation. Thus, it is important to design efficient protocols that can meet the optimal proportion of cooperation for each call and that can motivate collaboration to users with good channels.

II. SYSTEM MODEL

We consider a wireless network shared between users by allocating to each call an orthogonal channel with fixed communication capacity F channel code symbols per transmission period. We focus on a source node transmitting conversational multimedia traffic to a destination node. At the source node, a block of N input signal samples (each modeled as a memoryless, zero-mean, unit-variance Gaussian source) are first compressed at a source encoder and then error-protected for transmission over a channel with fading that remains constant for the duration of each transmission period.

A *Single Description* (SD) source encoder generates one coded representation of the source (a single bit stream) at a rate R_S bits per source sample. The performance of source codecs can be measured through its achievable distortion rate (D-R) function. If the input block length is long enough and distortion is measured through the minimum mean-squared error, the D-R function for the SD source codec is [10],

$$D_S(R_S) = 2^{-2R_S}. \tag{1}$$

A *Multiple Description* (MD) source codec encodes the source into multiple (two in this paper) bit streams at a combined rate of R_M bits per source sample. In each bit stream, the source is encoded at a rate $R_{D1} = \alpha R_M$ and $R_{D2} = \beta R_M$ bits per source sample. Here α and $\beta = 1 - \alpha$, are parameters taking values between 0 and 1 that control the proportion of total coding rate allocated to each stream. The achievable D-R function of any one of the two descriptions follows the same performance as in SD coding, i.e.

$$D_{D1}(R_{D1}) = 2^{-2R_{D1}}, \text{ and } D_{D2}(R_{D2}) = 2^{-2R_{D2}}. \tag{2}$$

When the two descriptions are combined and decoded together, the achievable D-R function becomes [7]

$$D_M(R_{D1}, R_{D2}) = \frac{2^{-2(R_{D1}+R_{D2})}}{1 - \sqrt{\left(1 - 2^{-2R_{D1}}\right)\left(1 - 2^{-2R_{D2}}\right)}}. \tag{3}$$

After source encoding, the source-encoded bits are protected against transmission errors through a channel code. We assume that the delay constraint exclude the use of capacity-achieving codes and we consider Reed-Solomon block codes with parameters (n, k), i.e. it operates at a rate $r = k/n$, encoding k b-bits symbols into n-symbols codeword. Also, we assume that the receiver discards channel-decoded frames containing codewords with errors. This is common practice in conversational communications due to the strict delay constraints. If a channel frame contains L codewords, the probability of having a frame with errors is $\widetilde{P}(\gamma, L) = 1 - \big(1 - q(\gamma)\big)^L$, where γ is the channel signal to noise ratio (SNR) and $q(\gamma)$ is the probability of channel decoder failure when using a bounded distance decoder [11]. For the case of Reed-Solomon codes we have this probability approximated as

$$\begin{aligned} q(\gamma) &= P\Big[\text{erred symbols in codeword} > \lfloor \frac{n-k}{2} \rfloor\Big] \\ &= \sum_{j=t}^{n} \binom{n}{j} P_s(\gamma)^j (1 - P_s(\gamma))^{n-j}, \end{aligned} \tag{4}$$

where $t = 1 + \lfloor \frac{n-k}{2} \rfloor$ and P_s is the probability of a symbol error. For b-bits symbols, $P_s(\gamma) = 1 - \big(1 - P_b(\gamma)\big)^b$, where P_b is the bit error probability, which depends on the modulation scheme and the channel conditions. In this work we will assume BPSK modulation over AWGN channel with coherence detection and maximum-likelihood decoding.

Communication may be carried on using or not user cooperation. In a cooperative scheme a third node, the *relay node*, is associated with the source node to achieve user-cooperation diversity. Communication in a cooperative setup takes place in two phases, which share the fixed communication capacity F due to our requirements for orthogonal channels. In phase 1, a source node sends information to its destination node that is also overheard by the relay node (which is likely in a wireless network). In phase 2, the relay cooperates by forwarding to the destination the overheard information. At the receiver the signals received from the source and the relay are combined and the transmitted message detected. We assume that a Maximum Ratio Combiner (MRC) is used to combine the symbols arriving through different paths. We will see that the different user-cooperation strategies differ in what channel code symbols from a codeword are sent during each phase and what is the channel SNR 'seen' by each symbol. In our setup we will assume a symmetric setting, with reciprocal source-relay channels and where the source cooperates with the relay and vice versa (during phase 2 the source relays the information sent by the relay).

It is also important to control the proportion of overall communication capacity allocated to the cooperative phase. This is important for cooperation management protocols so as to find a balance between the performance gains from user cooperation diversity and the reduction in communication capacity to allow transmission during phase 2. For this purpose, when $n_1 < n$ symbols are sent through a channel with SNR γ_1 and the rest are sent through a channel with SNR γ_2, (4) becomes

$$\begin{aligned} q = \sum_{j=t}^{n} \sum_{i=a}^{b} \binom{n_1}{i} \binom{n-n_1}{j-i} P_s(\gamma_1)^{n_1-i} \big(1 - P_s(\gamma_1)\big)^{n_1-i} \\ P_s(\gamma_2)^{j-i} \big(1 - P_s(\gamma_2)\big)^{n-n_1-j+i}, \end{aligned} \tag{5}$$

where $a = \max[0, j - n + n_1]$ and $b = \min[j, n_1]$.

We will consider three schemes that implement cooperation. In *amplify-and-forward* (AF), the relay retransmits the source's signal without further processing. In general, the total communication capacity is split evenly between phase 1 and 2, but we will consider a general setup where $n_1 \le n$ channel code symbols are sent during phase 2. It can be shown, [12], that for these symbols the SNR at the receiver after the MRC is

$$\gamma_A = \gamma_{sd} + \frac{\gamma_{sr}\gamma_{rd}}{1 + \gamma_{sr} + \gamma_{rd}}. \tag{6}$$

where γ_{sd} is the source-destination channel SNR, γ_{sr} is the source-relay channel SNR and γ_{rd} is the relay-destination channel SNR. The probability of having a frame with errors will be $\widetilde{P_A}(\gamma_A, \gamma_{sd}, L) = 1 - \big(1 - q\big)^L$, with q as in (5) with $\gamma_1 = \gamma_A$ and $\gamma_2 = \gamma_{sd}$.

In *decode-and-forward* (DF), the relay first decodes the message from the source. If the decoded message has no errors, the relay re-encodes it and transmits a copy. When the relay fails to decode the source message, it switches to a non-cooperative mode and sends during phase 2 a copy of its own signal. Here, again, we will consider a more general implementation than the usual one where $n_1 \le n$ channel code symbols are sent during phase 2. It can be shown, [12], that for these symbols the SNR at the receiver after the MRC is $\gamma_D = 2\gamma_{sd}$ if source and relay fail decoding, $\gamma_D = \gamma_{sd} + \gamma_{rd}$ if source and relay succeed, $\gamma_D = \gamma_{sd}$ if source succeeds and relay fails and $\gamma_D = 2\gamma_{sd} + \gamma_{rd}$ if source fails and relay succeeds. The probability of having a frame with errors is

$$\begin{aligned}\widetilde{P_D}(\gamma_D, L) &= \widetilde{P}_{sfrf}\widetilde{P}_{sr}^2 + \widetilde{P}_{ssrs}(1-\widetilde{P}_{sr})^2 + \\ &\quad + \big[\widetilde{P}_{ssrf} + \widetilde{P}_{sfrs}\big]\widetilde{P}_{sr}(1-\widetilde{P}_{sr}), \qquad (7)\end{aligned}$$

where $\widetilde{P}_{sr}$ and $\widetilde{P}_{ssrf}$ are computed using (4) with $\gamma = \gamma_{sr}$ and $\gamma = \gamma_{sd}$, respectively, and an (n, k) code. $\widetilde{P}_{sfrf}$, $\widetilde{P}_{ssrs}$ and $\widetilde{P}_{sfrs}$ are all computed using (5) with $\gamma_1 = 2\gamma_{sd}$, $\gamma_1 = \gamma_{sd} + \gamma_{rd}$, and $\gamma_1 = 2\gamma_{sd} + \gamma_{rd}$, respectively, and $\gamma_2 = \gamma_{sd}$.

In *coded cooperation*, during phase 1 the source sends data using an (n_p, k) channel code, punctured from an (n, k) mother code (usually following a rate-compatibility rule). During phase 2 the relay decodes the received message and, if successful, re-encodes the data using the lower rate (mother) channel code and sends to the destination the previously punctured parity bits so as to create a stronger code at the receiver. If decoding fails, the relay does not cooperate and sends the punctured bits from to its own data.

In coded cooperation, the parity symbols sent during phase 2 depend on the outcome of the source-relay and relay-source communication. We denote the frame error probability linked to this event $P_{(n_p,k)}(\gamma_{sr}, L_c)$ which follows from (4) with $\gamma = \gamma_{sr}$ and channel code (n_p, k). When the source and the relay fail in decoding each other's message, both revert to a non-cooperative operation by sending its own extra redundancy. We denote the frame error probability linked to this event $\widetilde{P}_{(n,k)}(\gamma_{sd}, L_c)$, which follows from (4) with $\gamma = \gamma_{sd}$ and channel code (n, k). When the relay fails but the source succeeds in decoding each other's message, only the source cooperates, i.e. there is no extra parity sent for the source during phase 2. We denote the frame error probability linked to this event $\widetilde{P}_{(n_p,k)}(\gamma_{sd}, L_c)$, which follows from (4) with $\gamma = \gamma_{sd}$ and channel code (n_p, k). When the relay and the source successfully decode each other's message, the relay sends during phase 2 extra redundancy for the source. We denote the corresponding frame error probability $\widetilde{P_{sr}}(L_c)$, which follows from (5) with $n_1 = n_p$, $\gamma_1 = \gamma_{sd}$ and $\gamma_2 = \gamma_{rd}$. Finally, when only the relay succeeds in decoding the source's message, both the source and the relay transmit the extra redundancy for the source node. We denote the corresponding frame error probability $\widetilde{P_r}(L_c)$, which follows from (5) with $n_1 = n_p$, $\gamma_1 = \gamma_{sd}$ and $\gamma_2 = \gamma_{rd} + \gamma_{sd}$. Combining all outcomes, the overall frame error probability is

$$\begin{aligned}\widetilde{P}_c(L_C) &= \widetilde{P_{sr}}(L_c)\Big(1 - \widetilde{P}_{(n_p,k)}(\gamma_{sr}, L_c)\Big)^2 + \\ &\quad + \widetilde{P}_{(n,k)}(\gamma_{sd}, L_c)\widetilde{P}_{(n_p,k)}(\gamma_{sr}, L_c)^2 + \\ &\quad + \Big[\widetilde{P_r}(L_c) + \widetilde{P}_{(n_p,k)}(\gamma_{sd}, L_c)\Big] \\ &\qquad \widetilde{P}_{(n_p,k)}(\gamma_{sr}, L_c)\Big(1 - \widetilde{P}_{(n_p,k)}(\gamma_{sr}, L_c)\Big). \qquad (8)\end{aligned}$$

III. CROSS-LAYER DIVERSITY

In this section we study how to combine source coding with cooperation diversity and we study distortion as a function of the source-destination channel SNR (the D-SNR performance).

A. Single Description Source Coding:

With no cooperation, there is a direct communication between source and destination through a channel with SNR γ_{sd}. If each of the N source samples are source encoded using R_{SN} bits and error protected with a (n, k) code there are $L = NR_{SN}/(bk)$ codewords per frame. With $F = Ln$, we have $R_{SN} = bkF/(nN)$ and

$$D_{SN} = \min_{n,k}\Big\{D_F\widetilde{P}(\gamma_{sd}, L) + D_S(R_{SN})\Big(1 - \widetilde{P}(\gamma_{sd}, L)\Big)\Big\} \qquad (9)$$

where D_F is the distortion when the frame is received with errors ($D_F = 1$ for our source model and distortion measure).

Using cooperation with source coding rate R_{sc} and channel code (n, k), we have in one frame $L_{sc} = NR_{sc}/(bk)$ codewords. These codewords are mapped into $F = (n + n_1)L_{sc}$ channel code symbols when using AF or DF cooperation. It follows that $R_{SC} = bkF/((n+n_1)N)$. When using coded cooperation, the codewords are mapped into $F = nL_{SC}$ channel code symbols, thus $R_{SC} = bkF/(nN)$. The D-SNR performances are as in (9) with $\widetilde{P}(\gamma_{sd}, L) = \widetilde{P_D}(\gamma_D, L_{SC})$, from (7), when using DF cooperation, $\widetilde{P}(\gamma_{sd}, L) = \widetilde{P_A}(\gamma_A, \gamma_{sd}, L)$ when using AF cooperation and $\widetilde{P}(\gamma_{sd}, L) = \widetilde{P}_c(L_C)$, from (8), when using coded cooperation. In this last case n_p is an extra design variable, along with n and k.

B. Multiple Description Source Coding:

With no cooperation, both descriptions are sent over the same channel, in the same frame using an aggregate communication capacity of F. This corresponds to the case of source coding diversity only. Let each descriptions be source encoded at rate $R_{D1} = \alpha R_{MN}$ and $R_{D2} = \beta R_{MN}$ bits per sample and protected with codes (n_1, k_1) and (n_2, k_2), respectively. Thus, each frame will contain $L_1 = N\alpha R_{MN}/(bk_1)$ codewords from the first description and $L_2 = N\beta R_{MN}/(bk_2)$ from the second, $F = L_1n_1 + L_2n_2$ and

$$R_{MN} = \frac{bF}{N}\left(\frac{\alpha n_1}{k_1} + \frac{\beta n_2}{k_2}\right)^{-1}. \qquad (10)$$

For this setup the D-R performance becomes

$$\begin{aligned}D_{MN} &= \min_{n_1,k_1,n_2,k_2,\alpha}\Big\{D_F\widetilde{P}(\gamma_{sd}, L_1)\widetilde{P}(\gamma_{sd}, L_2) \\ &\quad + D_{D1}(R_{D1})\widetilde{P}(\gamma_{sd}, L_2)\Big(1 - \widetilde{P}(\gamma_{sd}, L_1)\Big) \\ &\quad + D_{D2}(R_{D2})\widetilde{P}(\gamma_{sd}, L_1)\Big(1 - \widetilde{P}(\gamma_{sd}, L_2)\Big) \\ &\quad + D_M(R_{D1}, R_{D2})\Big(1 - \widetilde{P}(\gamma_{sd}, L_1)\Big) \\ &\qquad \Big(1 - \widetilde{P}(\gamma_{sd}, L_2)\Big)\Big\}, \qquad (11)\end{aligned}$$

where D_{D1}, D_{D2}, and D_{MN} are as in (2) and (3). There are four different outcomes in terms of success or failure in receiving each of the two descriptions. Each outcome accounts for one term in (11).

When using cooperative diversity, we meet the need to send each description through a different channel by transmitting description 1 through a non-cooperative scheme and description 2 using coded cooperation as was discussed for a single description codec. We will study the use of coded cooperation only, AF and DF cooperation were considered in [13].

By adapting α and β we are able to control each description source coding rate and the proportion of resources used for cooperation. Let each descriptions be source coded at rate $R_{D1} = \alpha R_{MC}$ and $R_{D2} = \beta R_{MC}$, and protected with codes (n_1, k_1) and (n_2, k_2), respectively. Then, the design equations are the same as for the case with no cooperation, considering that the source coding rate is now R_{MC} and that the (n_2, k_2) code is punctured to n_{p2} symbols during transmission in phase 1 of description 2. The D-SNR performance follows the same expression as Equation (11) with R_{MN} replaced by R_{MC} and $\widetilde{P}(\gamma_{sd}, L_2)$ by $\widetilde{P}_c(L_2)$, from (8). Note that the minimization variables are now n_1, k_1, n_2, k_2, α, *and* n_{p2}.

C. Layered Single Description Source Coding:

Since we assumed a Gaussian source with squared error distortion measure, the source is successively refinable [8]. Let Q be the number of coding layers and R_T be the overall source coding rate. Each layer coding rate is defined as $R_i = \alpha_i R_T$, $\sum_{i=1}^{Q} \alpha_i = 1$. In our setup we consider that each layer is protected with a different channel code (n_i, k_i), which corresponds to an implementation of unequal error protection (UEP). Thus each layer accounts for $L_i = NR_T\alpha_i/(bk_i)$ codewords per frame. Let $\mathbb{C}$ be the set of layers that are transmitted using cooperation. Considering AF and DF cooperation with $n = n_1$ (even cooperation),

$$F = \frac{NR_T}{b}\left(\sum\nolimits_{i\in\mathbb{C}}\frac{2\alpha_i n_i}{k_i} + \sum\nolimits_{i\notin\mathbb{C}}\frac{\alpha_i n_i}{k_i}\right). \qquad (12)$$

Because all layers following the first one with errors cannot be used to refine the source representation, the D-SNR performance is

$$D = \min_{\alpha_i, n_i, k_i}\left\{\sum_{j=0}^{Q} 2^{-2(R_T\sum_{i=0}^{j}\alpha_i)}\widetilde{P}_{j+1}\prod_{i=0}^{j}(1-\widetilde{P}_i)\right\}, \qquad (13)$$

where R_T is derived from (12). In (13) $\widetilde{P}_i = \widetilde{P_D}(\gamma_D, L_i)$, from (7), when using DF cooperation, $\widetilde{P}_i = \widetilde{P_A}(\gamma_A, \gamma_{sd}, L_i)$ when using AF cooperation, and we have defined $R_0 = 0$, $\widetilde{P}_{Q+1} = 1$ and $\widetilde{P}_0 = 0$.

IV. NUMERICAL RESULTS

Our ultimate goal is to study what decision a protocol should make before transmission of each conversational multimedia frame. Figures 1 - 4 show the D-SNR results for the schemes studied in Sec. III, where we assumed $n_1 = n$ (even split in communication capacity between each phase) for AF and DF cooperation. By changing the source-relay and relay-destination SNRs we considered two scenarios: the relay is close to the source and far from the destination (Figs. 1 and 3) and vice versa (Figs. 2 and 4). Other setups showed results that can be inferred from the ones presented here. In all cases we set $b = 5$ bits, $N = 150$ samples and $F = 190$ channel code symbols per transmission period and call.

For layered coding, we considered $Q = 2$ and $Q = 3$ and we changed the number of layers sent using cooperation so as to study the effect on performance. We label these cases by first indicating the total number of layers and then how many are sent with cooperation. For illustrative purposes, we include also results for AF and DF cooperation combined with multiple description coding, which were reported in [13]. We see that layered coding performs best at low source-destination SNR when all layers are sent using cooperation. This setup provides the best performance of all schemes. This is because the UEP applied to each layer can fit the available bandwidth and outweigh the reduction in communication capacity when using cooperation. Furthermore, we note that increasing the number of layers from 2 to 3 provides useful performance gains in AF cooperation but not in DF cooperation.

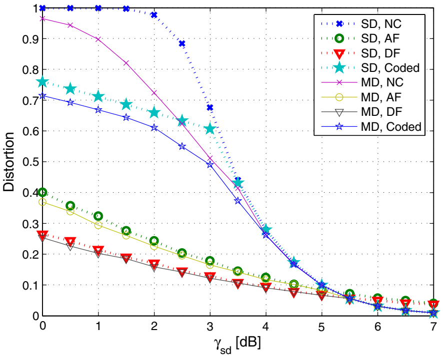

Fig. 1. Distortion for non-layered source coding, $\gamma_{sr} = 10$ and $\gamma_{rd} = 3$.

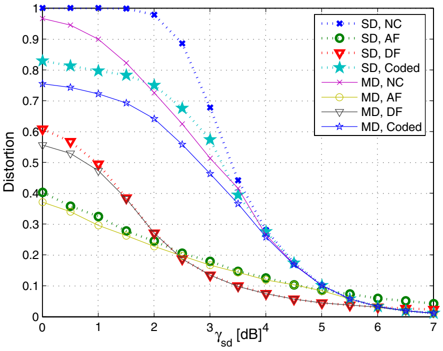

Fig. 2. Distortion for non-layered source coding, $\gamma_{sr} = 3$ and $\gamma_{rd} = 10$.

Figures 1 and 2 also show that both AF and DF have better performance than coded cooperation. In Figure 5 we study the channel coding rates used in DF and the punctured and mother code used in coded cooperation so as to gain insight into this behavior. Even when the relay is close to the source, significant communication capacity is used to ensure successful decoding at relay (if this fails the system would be force to not cooperate). Although coded cooperation is more bandwidth efficient because only incremental redundancy is sent during phase 2, this is done over a channel with SNR γ_{rd}, which is worst in most cases than the SNR at the output of the MRC in the other schemes (e.g. $\gamma_{rd} + \gamma_{sd}$ in DF). When the relay is far from the destination, the communication capacity available during phase 2 is not enough for the incremental redundancy to drastically improve performance. In AF and DF, the better channel allows for the use of a channel code that is weaker than the one used in coded cooperation, thus countering some of the bandwidth inefficiency. When the relay is far from the source, so much communication capacity is needed to ensure successful decoding at the relay that little is left for transmission of incremental redundancy. Note that there is no transmission of incremental redundancy for those values of γ_{sd} for which the source-destination channel is better than the one through the relay and that coded cooperation as studied here, without feedback from the destination, is unable

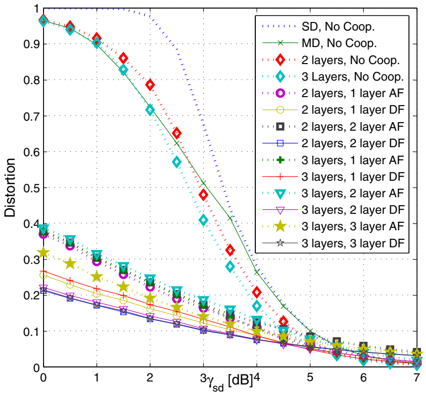

Fig. 3. Distortion for layered source coding, $\gamma_{sr} = 10$ and $\gamma_{rd} = 3$.

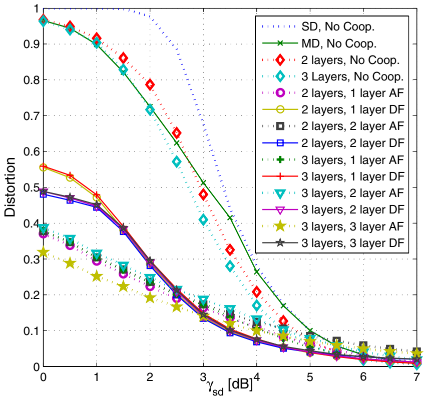

Fig. 4. Distortion for layered source coding, $\gamma_{sr} = 3$ and $\gamma_{rd} = 10$.

to send redundancy only when needed, which is the reason that makes incremental redundancy efficient .

The results also show that the choice for the technique that shields best performance depends on all involved channel SNRs. In general, non-cooperative schemes yield the best performance for good source-destination channel SNR. For a degraded source-destination channel, DF shield better performance in most of the cases, except when the source-destination and the source-relay channels have very low SNR.

Finally, we also studied how performance of single description with AF and DF cooperation is affected by a change in the proportion of communication capacity used during phase 2. We searched for the number of symbols sent during phase 2, $n_1 \leq n$, that yield the best performance. We noticed that in practically all cases the optimal adaptation coincides with $n_1 = n$ studied so far. This implies that the loss in communication capacity needed to implement cooperation does not reduce performance as much as it is improved by the added diversity. Also, we noticed that any departure from the optimal setting significantly reduces performance.

V. CONCLUSIONS

We studied how to best combine different source coding methods with cooperative diversity for conversational multimedia communications. We concluded that layered coding when all layers are sent with user cooperation provides the best performance. In terms of cooperation, the best overall performance is obtained when the mobile can switch between non-cooperative operation, when the source-destination channel is good, and cooperative operation (DF scheme in most cases) when the source-destination channel is bad. Both AF and DF cooperation perform better than coded cooperation because of the lack of feedback in the later and because the improvement in bandwidth utilization cannot outweigh the gains due to cooperative diversity in the other methods. We also noted that the gains from cooperative diversity outweigh the loss due to the sacrifice in overall bandwidth and that cooperation performance is sensitive to the proportion of communication capacity allocated to cooperation.

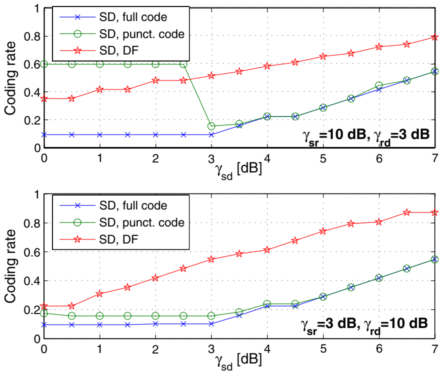

Fig. 5. Channel coding rates used in DF and coded cooperation with single description coding.

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