Practical Compress-Forward in User Cooperation: Wyner-Ziv Cooperation

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***Abstract*— A novel user cooperation scheme, termed *Wyner-Ziv cooperation*, is proposed as generalization of *Slepian-Wolf cooperation* and a solid example for compress-forward. After motivating the idea, we present the framework of *Wyner-Ziv cooperation* and discuss the technical details including input/output relationships for a soft (BCJR) decoder, the cooperative strategy, quantizer optimization technologies, and an modified BCJR decoding algorithm. The gains observed in the computer simulations, up to 11.5 dB for the source-relay outage case and 3.5 dB on average, a strong testimony that it is not only feasible but also beneficial to exploit Wyner-Ziv coding in user cooperation.**

I. Introduction

User cooperation allows the nodes in a common network to leverage the resource, such as power, memory, and antennas, of their neighboring nodes to improve communication efficiency. The framework is particularly helpful for time-limited channels (i.e. slow fading) where time diversity is hard to achieve. Consider a basic relay system that consists of three parts: a source, a relay and a destination. The relay forwards part or all of what it receives from the source to the destination to provide to the source packet the much-needed (spatial) diversity. Based on what the relay does, cooperative schemes can be grouped in three major categories: *amplify-forward* (AF), where the relay rescales and retransmits the received signal waveform, *decode-forward* (DF), where the relay demodulates and decodes the packet and forwards the data possibly using a different code, and *code-forward* (CF), where the relay forwards the quantized/compressed/estimated version of its observations.

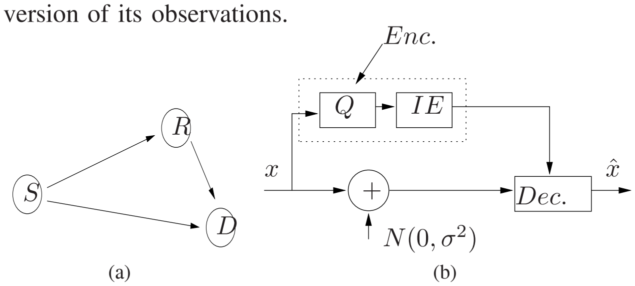

Fig. 1. (a)Relay System. (b)Wyner-Ziv System.

A variety of practical decode-forward schemes have been proposed, exploiting powerful channel codes, space-time codes and network codes (e.g. [1]-[4]). In demonstrating their substantial cooperative benefits, the prevailing assumption therein is that the source-relay channel is outage-free such that the relay always retrieves the source packet correctly. However, practical wireless channels experience fades from time to time, and DF schemes are therefore non-operational from time to time, causing a drastic performance degradation. Amplify-forward can resolve this problem to some extent, but sampling, amplifying, and retransmitting analog values are technologically nontrivial. Further, an AF-relayed packet may have been badly corrupted in the source-relay transmission and further distorted in the relay-destination transmission, and therefore becomes too noisy to be of any use. Compress-forward, which is close in spirit to multi-antenna reception, is shown in theory to be the best candidate to address this challenge [5], but practical CF schemes are far lagging behind theory.

Very recently, a novel CF cooperative scheme in the name of *Slepian-Wolf (SW) cooperation* is proposed [6]. Possibly the first practical CF scheme, Slepian-Wolf cooperation exploits practical Slepian-Wolf codes in wireless user cooperation to help combat inter-user outage. To illustrate how *Slepian-Wolf cooperation* works, consider a Slepian-Wolf system comprising two correlated (discrete) sources X and Y sending information to a common destination without inter-source communication. The Slepian-Wolf theorem states that if source Y ($H(Y)$) is known to the destination, then source X needs only transmit an amount of no more than $H(X|Y)$ in order for the destination to completely recover X (with the help of the side information Y). To put it in perspective with user cooperation, consider a source-relay outage case where the relay fails to correctly decode the packet. There is a good chance that the relay has failed on the detection of only a few bits, leaving the majority correctly decoded. Thus, instead of retrieving the original source X, the relay now obtains a copy Y which is highly correlated with X. Following the theory and practice SW coding, we let the relay forward Y, rather than discard it, and let the source transmit an additional small amount $H(X|Y)$. Now the destination has three packets, X from the source (initial transmission), Y from the relay, and $H(X|Y)$ from the source. The latter two form a Slepian-Wolf code which enables the extraction of a second copy of X, thus providing a diversity order of 2.

This *Slepian-Wolf cooperation* has considerably mitigated the negative impact of source-relay outage [6], but constraining the relay to perform compression in a discrete domain, as Slepian-Wolf codes do, prevents the relay from extracting maximal benefit from distributed source coding (DSC). For

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this reason, here we propose to exploit Wyner-Ziv (WZ) codes, generalization of SW codes with rate-distortion, in user cooperation. A Wyner-Ziv system can either be interpreted as a Slepian-Wolf System with continuous sources and rate-distortion metric, or more precisely, quantization with decoder side information, as shown in Fig. 1(b). The encoder of a conventional WZ system usually consists of two parts: Quantizer (Q) and Index Encoder (IE). To relate WZ codes to user cooperation as shown in Fig. 1(a), assume that the relay (R), after performing channel decoding, stores the soft reliability information, denoted as L, instead of the hard decisions Y. The direct source copy from the source (S) to the destination (D) being viewed as the decoder side information, the relay can borrow ideas from Wyner-Ziv coding to process and transmit L. Recall that in *Slepian-Wolf cooperation*, the relay has made hard decoding decisions on L before proceeding to SW coding. In view that hard decision is essentially a 2-level quantization[1], *Slepian-Wolf cooperation* can therefore be viewed as a special case of *Wyner-Ziv cooperation*, whose quantization now not only allows for higher order but can *explicitly account for the decoder side information*!

We discuss the technical details of the proposed *Wyner-Ziv cooperation* assuming that the source packet is encoded by a convolutional code. We first introduce some background, such as system model, *Channel LLR-Decoder LLR* relationships, and error estimation skills; we then discuss in detail the cooperative strategy, including quantizer optimization, and decoder design at the destination (modified BCJR algorithm). Encourage simulation results show that, although differences exist between the relay system and the Wyner-Ziv system, the relay system can nevertheless exploit such Wyner-Ziv techniques as high order quantization, quantizer optimization and rate reduction.

II. Preliminaries

A. Cooperative System

We consider two-user cooperation (Fig. 4) on block Rayleigh fading channels. Binary i.i.d sources x_s are encoded and binary shift keying (BPSK) modulated before transmission. The receiver observes $r = hb+n$, where $b = \pm 1$ denotes the transmitted signal, $n \sim N(0, \sigma^2)$ denotes the additive white Gaussian noise (AWGN), and $h \sim \mathcal{N}(0, 1)$ denotes the complex-valued channel gain or channel state information, which is assumed known to the receivers.

B. Relation between Channel LLR and Decoder LLR

As discussed in [8], for a soft-in soft-out decoder implementing the BCJR-algorithm, the probability density functions (PDFs) of the soft reliability input and output of the decoder approach Gaussian distributions, and the variances are two times the means of these distributions. The log likelihood (LLR) values for r at the input to the decoder, thereafter referred to as *Channel LLR*, can be calculated as

$$L_r = \ln\frac{p(r|b=+1)}{p(r|b=-1)} = \underbrace{\frac{2h^2}{\sigma^2}}_{\mu_l} b + \underbrace{\frac{2h}{\sigma^2}n}_{n_l} = \mu_l b + n_l \qquad (1)$$

As n is Gaussian distributed, so is $n_l \sim N(0, \sigma_l^2)$, and $\sigma_l^2 = \frac{4h^2}{\sigma^2}$ is two times $\mu_l = \frac{2h^2}{\sigma^2}$. The soft output from the BCJR decoder, thereafter referred to as *Decoder LLR*, can be formulated similarly as

$$\hat{r} = \mu_{\hat{r}} b + n_{\hat{r}} \qquad (2)$$

where $n_{\hat{r}} \sim N(0, \sigma_{\hat{r}}^2)$ is Gaussian distributed and $\mu_{\hat{r}} = \frac{\sigma_{\hat{r}}^2}{2}$. Because it is assumed $p(b=+1) = p(b=-1) = 0.5$, the PDF for the *Decoder LLR* is

$$p(\hat{r}) \;=\; \frac{1}{2}(p_{+1}(\hat{r}) + p_{-1}(\hat{r})), \qquad (3)$$

where
$$p_{\pm 1}(\hat{r}) \;=\; \frac{1}{\sqrt{2\pi}\sigma_{\hat{r}}} \exp\left\{\frac{-(\hat{r} \mp \mu_{\hat{r}})^2}{2\sigma_{\hat{r}}^2}\right\}. \qquad (4)$$

The probability distributions for $p(\hat{r})$, $p_0(\hat{r})$ and $p_1(\hat{r})$ are shown in Fig. 2. For illustration, the PDF for $p(\hat{r})$ is scaled up by a factor of two in the figure.

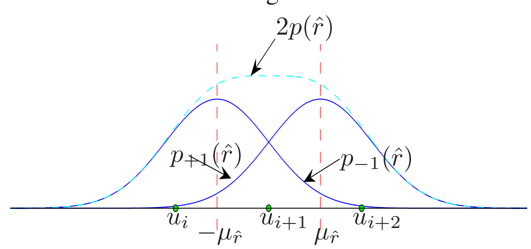

Fig. 2. Probability Distribution For *Decoder LLR*

Channel LLR and *Decoder LLR* are functions of μ_r and $\mu_{\hat{r}}$ respectively. Since $\mu_r = 2h^2/\sigma^2$ relates directly to the signal-to-noise ratio (SNR) at the input to the decoder, the input/output relationship therefore translates to a relation between the decoder input SNR and the output mean $\mu_{\hat{r}}$. The relationship for a (2000, 1000) recursive systematic convolutional (RSC) code with generator polynomial $(1, 35/21)_{oct}$ is shown in Fig. 3 by the Monte Carlo method, and can be approximated by a fourth order polynomial $g(s)$,

$$g(s) = \begin{cases} g_{40}s^4 + g_{30}s^3 + g_{20}s^2 + g_{10}s + g_{00} & s \le -5, \\ g_{41}s^4 + g_{31}s^3 + g_{21}s^2 + g_{11}s + g_{01} & s > -5, \end{cases} \qquad (5)$$

where $g_{40} = 4.230e-5,\ g_{30} = 3.046e-3,\ g_{20} = 8.192e-2,\ g_{10} = 9.940e-1,\ g_{00} = 4.751,\ g_{41} = 1.268e-2,\ g_{31} = -5.396e-2,\ g_{21} = 6.508e-1,\ g_{11} = 6.661$, $g_{10} = 14.267$ and s denotes input SNR (dB).

C. Reliability Measurement

Similar to *Slepian-Wolf cooperation*, *Wyner-Ziv cooperation* is most useful when the noisy copy retrieved at the relay has a high correlation with the original source. Otherwise, the complexity and bandwidth consumption incurred by *Wyner-Ziv cooperation* may outweigh the benefit it brings [6]. For this reason, we allow for the relay to switch to a no-cooperation

[1] SW coding is one way of implementing the index encoder that typically succeeds the quantizer in a Wyner-Ziv system.

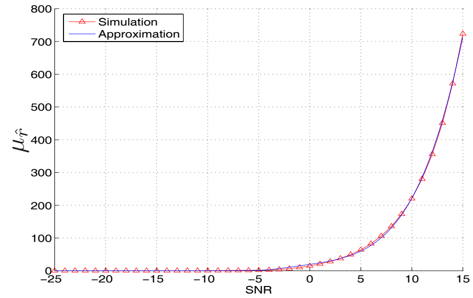

Fig. 3. Input-Output Relationship for a (2000, 1000) convolutional code with generator polynomial $(1, 35/21)_{oct}$.

mode should it determine that the packet is not worth processing (i.e. many errors) due to occasional deep fades in the source-relay transmission. This should be differentiated from decode-forward schemes that switch to no-cooperation as soon as a single error happens. For example, a packet, coded by a (2000, 1000) convolutional code with generator polynomial $(1, 35/21)_{oct}$, and transmitted over a block fading channel with a low SNR of 5 dB, has more than half of the erroneous packets (i.e. at least one error) contain less than 5% errors. It is the useful information contained in these slightly distorted packets, picked up by Slepian-Wolf or Wyner-Ziv processing, that make *SW cooperation* and *WZ cooperation* superior to mere decoder-forward.

The relay uses the number of errors in a decoded packet as a quantitative method to measure the distortion level of a decoded packet. The fewer the errors, the more reliable the information. For ease of exposition, let p_e denote the percentage of errors in the decoded data block. When $p_e \leq p_e^{th}$, we consider the information reliable enough to be exploited for further process; otherwise the information is regarded as useless and will be discarded.

Now how does the relay estimate the percentage of errors in a decoded packet? A simple mechanism proposed in [6] is to use the average of the absolute log-likelihood ratios (LLR) at the output of the decoder, denoted as $\mu_{|LLR|}$, as the metric. For details about evaluating p_e using $\mu_{|LLR|}$, please refer to Sec. III in [6]. In the proposed system, $\mu_{|LLR|}$ is combined with the cyclic redundant check (CRC) code, widely available in practical systems, to determine which of the three actions to take: decode-forward such as *cooperation*, *Wyner-Ziv cooperation*, and no-cooperation. The reason to include decode-forward as a possible state is because decode-forward, closer in spirit to multi-antenna transmission , generally outperforms compress-forward when the source-relay channel is in good condition [10].

III. Wyner-Ziv Cooperation

A. Cooperation Strategy

In the proposed *Wyner-Ziv cooperation*, the source and the relay will transmit in two consecutive time slots. As shown in the system model in Fig. 4, in the first time slot, the source encodes data x_s using a systematic channel code, which we assume to be a rate 1/2 convolutional code in this paper, and sends x_s and its parity x_p to the destination and the relay simultaneously. We use $(y_s,\ y_p)$ to denote the received signal of $(x_s,\ x_p)$ at the relay. After BCJR decoding, the relay obtains $\hat{y}$, the *Decoder LLR* of x_s.

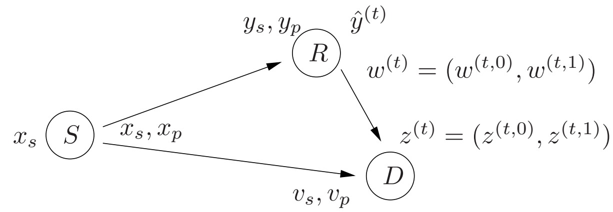

Fig. 4. System Model for Wyner-Ziv Cooperation

In *WZ cooperation* , $\hat{y}$ being viewed as the correlated source with the side information (v_s, v_p) at the receiver, the relay will then quantize $\hat{y}$ and transmit (compressed) bin index $w \in \{+1, -1\}$ to the destination, as will be in the conventional Wyner-Ziv system. The destination now collects two sets of data about x_s: (v_s, v_p) and z, where the former corresponds to (x_s, x_p) transmitted directly from the source, and latter corresponds to w forwarded from the relay. It tries to recover the data by performing modified BCJR decoding which will be discussed later.

To summarize, the overall proposed cooperative framework operates as follows:

1) In the first time slot, the source broadcasts (x_s, x_p) to the relay and the destination simultaneously.
2) The relay performs channel decoding on (y_s, y_p) to estimate x_s. Depending on the estimation result, it chooses one of following three options in the second time slot:
   - If x_s is decoded successfully, the relay resorts to a DF scheme which we use *coded cooperation* in this paper.
   - If the decoded data possess but a small percentage of errors (e.g. below a predefined threshold p_e^{th}), the relay invokes *WZ cooperation* by forwarding quantized version of $\hat{y}$ to the destination.
   - If the decoded data possess lots of errors, the relay reverts to the *no-cooperation* mode and stays idle.

   In the former two cases, an indicating bit will be piggybacked on the relay packet, so that the destination knows which case happens.
3) The destination will perform modified BCJR decoding using all the information it has received to make a best estimation on x_s.

B. Quantizer Optimization

A key issue to be addressed is how to quantize $\hat{y}^{(t)}$ at the relay, where superscript t is the index of a bit in a packet. In this paper we focus on scalar quantizers. Although more sophisticated quantizers are desirable, a tractable characterization is still unclear.

A quantizer is typically specified by the *boundaries* of the bins and their *reconstruction points*. For Wyner-Ziv quantizers, since the decoder has access to side information, the reconstruction point for each bin is not fixed but depends on the side information [9]. Hence, quantizer design here needs only determine the bin boundaries. In a Wyner-Ziv system, an index encoder (IE) typically succeeds the quantizer to compress the indexes of quantization-bins for further rate reduction. Hence, design of a Wyner-Ziv quantizer needs to take the type of the index encoder into consideration. While Slepian-Wolf coding and single-source entropy coding are good choices for the index encoder [9], here for simplicity, we consider fixed-rate index encoding. We discuss the design procedure by considering a four-level scalar quantizer. The method generalizes to higher-level quantizers, which may or may be desired for *Wyner-Ziv cooperation* due to the large bandwidth required.

Let $\{u_i, i = 0, ..., 4\}$ be the bin-boundaries, where u_0 and u_4 are set to be $-\infty$ and ∞ respectively. Since $\hat{y}$, the value to be quantized, has a symmetric PDF with respect to the origin (see Sec. II-B), it is reasonable to let $u_1 = -u_d$, $u_2 = 0$, and $u_3 = u_d$, where $u_d(> 0)$ is to be determined. Through quantizing $\hat{y}^{(t)}$, each data bit $x_s^{(t)}$ is mapped to a two-bit bin-index $w^{(t)} \triangleq (w^{(t,0)},\ w^{(t,1)})$. Let $u_l^{(t)} \in \{u_0, \cdots, u_4\}$ and $u_h^{(t)} \in \{u_0, \cdots, u_4\}$ denote the low-end bin-boundary and the high-end bin-boundary for $\hat{y}^t$. For a specific bin-index $\bar{w}^{(t)}$, we have

$$p(\bar{w}^{(t)}|x_s^{(t)}) = \int_{u_l^{(t)}}^{u_h^{(t)}} p_{x_s^{(t)}}(\hat{y})\mathrm{d}\hat{y} \quad (6)$$

and

$$p(\bar{w}^{(t)}) = \int_{u_l^{(t)}}^{u_h^{(t)}} p(\hat{y})\mathrm{d}\hat{y} \quad (7)$$

where $p(\hat{y})$ is what's shown as $p(\hat{r})$ in (3) and $p_{x_s^{(t)}}(\hat{y})$ is $p_{\pm 1}(\hat{r})$ in (4).

The general design goal for *Wyner-Ziv cooperation*, as well as other cooperative schemes, is for the relay to maximize the amount of "new" information about x_s, where by new we mean information that complements, rather than overlap with, the information conveyed directly to the destination by the source. However such a design goal appears hard to formulate for the Wyner-Ziv quantizer we consider here. We therefore approximates this goal with a tractable criterion: make the quantized data carry as much information about x_s as possible, regardless of it is new or old. The rational here is that, statistically, the more information w carries, the more new information there contains. Mathematically, this criterion is expressed as ,

$$\arg\min_{u_d}\ H(x_s^{(t)}|\bar{w}^{(t)}), \quad (8)$$

where $H(x_s^{(t)}|\bar{w}^{(t)})$ is the conditional entropy defined as

$$H(x_s^{(t)}|w^{(t)}) = -\sum_{x_s^{(t)},\bar{w}^{(t)}} p(x_s^{(t)}, \bar{w}^{(t)}) \log p(x_s^{(t)}|\bar{w}^{(t)}), \quad (9)$$

where

$$p(x_s^{(t)}, \bar{w}^{(t)}) = p(\bar{w}^{(t)}|x_s^{(t)})p(x_s^{(t)}), \quad (10)$$
$$p(x_s^{(t)}|\bar{w}^{(t)}) = p(x_s^{(t)}, \bar{w}^{(t)})/p(\bar{w}^{(t)}). \quad (11)$$

From (6), (7), and (9)-(11), we observe that $H(x_s^{(t)}|\bar{w}^{(t)})$ is a function of only $\mu_{\hat{y}}$ and u_d. Since $\mu_{\hat{y}}$ can be computed using knowledge of the channel SNR and the input-output relation such as the one derived in (5) and plotted in Fig. 3, we can rewrite $H(x_s^{(t)}|\bar{w}^{(t)})$ as $\phi(u_d|\mu_{\hat{y}})$, where ϕ denotes some function (which can be explicitly formulated but is omitted due to space limitation). Now (8) becomes

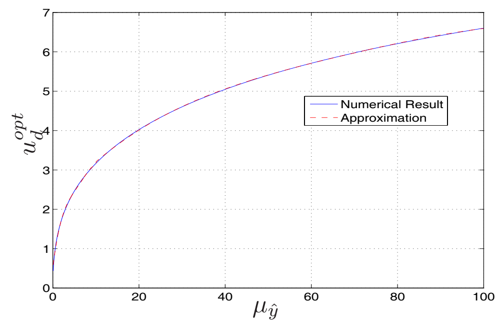

Fig. 5. Optimal u_d

$$\arg\min_{u_d}\ \phi(u_d|\mu_{\hat{y}}), \quad (12)$$

which targets finding a value for u_d that minimizes $\phi(u_d|\mu_{\hat{y}})$ with known $\mu_{\hat{y}}$. The necessary and sufficient condition for a u_d to be the solution of (12) is

$$\begin{cases} \frac{\partial \phi(u_d|\mu_{\hat{y}})}{\partial u_d} = 0, \\ \frac{\partial^2 \phi(u_d|\mu_{\hat{y}})}{\partial u_d^2} > 0. \end{cases} \quad (13)$$

To derive a closed-form solution is difficult, but for any given $\mu_{\hat{y}}$, (13) can be solved numerically. An example is shown in Fig. 5, where the solid line represents the solutions obtained through numerical methods. These solutions, u_s^{opt}s, can be approximated by a fourth order polynomial $u(\mu)$:

$$u(\mu) = \begin{cases} u_{40}\mu^4 + u_{30}\mu^3 + u_{20}\mu^2 + u_{10}\mu + u_{00}, & \mu \leq 10 \\ u_{41}\mu^4 + u_{31}\mu^3 + u_{21}\mu^2 + u_{11}\mu + u_{01}, & \mu > 10 \end{cases} \quad (14)$$

where $u_{40} = -7.431e(-4)$, $u_{30} = 1.871e(-2)$, $u_{20} = -1.761e(-1)$, $u_{10} = 8.955e(-1)$, $u_{00} = 5.007e(-1)$, $u_{41} = -5.792e(-8)$, $u_{31} = 1.668e(-5)$, $u_{21} = -1.912e(-3)$, $u_{11} = 1.272e(-1)$, $u_{01} = 2.109$, and μ is the simplified notation for $\mu_{\hat{y}}$.

C. Modified BCJR Decoder

In addition to quantization, another key issue in *Wyner-Ziv Cooperation* is how to exploit the information from the relay at the destination. Here we introduce a modified BCJR algorithm which can exploit z. Define $z^{(t)} = (z^{(t,0)},\ z^{(t,1)})$, $\mathbf{d}_1^k = \{d^{(1)}, \cdots, d^{(k)}\}$, and $d^{(t)} = \{v_s^{(t)}, v_p^{(t)}, z^{(t,0)}, z^{(t,1)}\}$. We have

$$L(x_s^{(t)}) = \ln \frac{p(x_s^{(t)} = 0|\mathbf{d}_1^k)}{p(x_s^{(t)} = 1|\mathbf{d}_1^k)} \quad (15)$$

where k is the length of the raw data sequence. The difference between the conventional BCJR algorithm and this modified algorithm is in the calculation of the branch metric $\gamma(\cdot)$, which now needs to account for $z^{(t,0)}$ and $z^{(t,1)}$,

$$\gamma(\mathbb{s}, \mathbb{s}') = p(S^{(t)} = \mathbb{s}, d^{(t)}|S^{(t-1)} = \mathbb{s}') = p(x_s^{(t)})p(v_s^{(t)}, v_p^{(t)}|x_s^{(t)}, x_p^{(t)})p(z^{(t)}|x_s^{(t)}) \quad (16)$$

where $S^{(t)}$ is the state of the encoder at time t, $x_p^{(t)}$ is the parity output of the encoder corresponding to the state transition from $S^{(t-1)} = \mathbb{s}'$ to $S^{(t-1)} = \mathbb{s}$ triggered by data input $x_s^{(t)}$. The first two terms in the right hand side of (16) stay the same as they are in the conventional algorithm, and the third term, by noting $x_s^{(t)} \rightarrow \hat{y}^{(t)} \rightarrow w^{(t)} \rightarrow z^{(t)}$ is a Markov chain, becomes

$$p(z^{(t)}|x_s^{(t)}) \quad = \quad \sum_{\bar{w}^{(t)}} p(z^{(t)}|\bar{w}^{(t)})p(\bar{w}^{(t)}|x_s^{(t)}), \qquad (17)$$

where

$$p(z^{(t)}|\bar{w}^{(t)}) = p(z^{(t,0)}|w^{(t,0)})p(z^{(t,1)}|w^{(t,1)}). \qquad (18)$$

Gathering (5) (6), (14), (17) and (18), we will get $p(z^{(t)}|x_s^{(t)})$, which leads to the solution to (16) and finally to (15), the optimal estimation of the original data.

IV. Simulations

This section evaluates the performance of the proposed scheme using computer simulations. We consider a (2000, 1000) convolutional code with generator polynomial $(1, 35/21)_{oct}$ in the system.

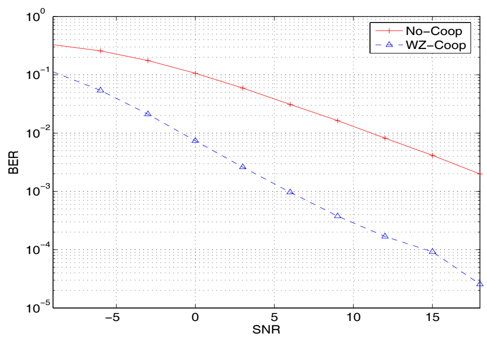

Fig. 6. Performance of *Wyner-Ziv Cooperation* in its favorable situation

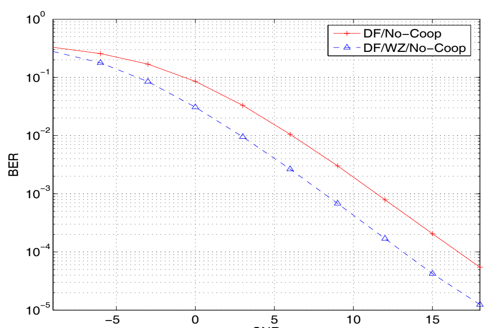

Fig. 7. Comparison of *Wyner-Ziv Cooperation* and *Coded Cooperation*

Fig. 6 shows the performance of the *Wyner-Ziv cooperation* in its favorable situation: when the inter-user is at outage (DF will fail) and when the decoded data contain less than $p_{th} = 5\%$ errors (Wyner-Ziv codes can help positively). In the plot, the X-axis denotes the SNR of the source-relay and source-destination channels, and the relay-destination channel is always 10dB better[2]. The dashed line represents *WZ cooperation*, and the solid line represents *coded cooperation*, a DF strategy which, due to inter-user outage, essentially reduces to no-cooperation. The strong capability of *Wyner-Ziv cooperation* to combat source-relay outage is evident from a gain of as much as 15 dB at a bit error rate (BER) of 10^{-3}, and 12dB even with normalized power!

To see the overall gain offered by *WZ cooperation*, we blend in the two other cases (i.e. successful decoding and severe errors at the relay) and plot in Fig. 7 the average performances. We observe an encouraging gain of 3.5 dB enabled by *WZ Cooperation* (for the same channel setup).

[2] This happens, for example, when the relay is close to the destination. Research shows CF is privileged in this scenario.

V. Conclusion and Future Work

Wyner-Ziv cooperation, as generalization of *Slepian-Wolf cooperation* and a solid example for compress-forward, is proposed in this paper. By exploiting practical Wyner-Ziv codes, the scheme effectively improves the inter-user outage performance in wireless user cooperation. We discuss relay estimation, quantizer optimization and decoder optimization using examples of scaler Wyner-Ziv quantizers and convolutional codes. The gains observed in the computer simulations are a strong testimony that it is not only feasible but also beneficial to exploit Wyner-Ziv coding in user cooperation.

The proposed scheme may be extended and enriched in two ways: the first is to exploit a non-trivial index encoder, such as Slepian-Wolf encoding and single-source entropy encoding, at the relay, to further exploit the correlation between y and v; and the second is to provide error protection, as needed, to the Wyner-Ziv compressed sequence during it transmission from the relay to the destination. In the current demonstration, a trivial index-encoder (fixed-rate encoder) is used and the quantized sequence is transmitted without any protection.

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