An Improved Detection Scheme for Distributed IDM-STCs in Relay-Systems

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***Abstract*—This paper is concerned with the application of distributed Interleave-Division-Multiplexing Space-Time Codes (dIDM-STCs) in relaying systems with error-prone relays applying Decode-and-Forward (DF). In case of erroneous decoding at the relays, error propagation occurs which is not considered by the original detection scheme for IDM-STCs. Hence, a new Reliability Aware Iterative Detection Scheme (RAID) is proposed which takes the decoding success of the relays as well as their decoding reliability into account. By optimally incorporating this knowledge in the detection process at the destination, substantial performance gains compared to the original detection scheme are achieved. The proposed RAID scheme even outperforms adaptive relaying as it explicitly exploits also erroneous relays, which is not the case for the adaptive scheme.**

I. Introduction

Space-Time Coding is one of the prominent techniques which evolved in the context of Multiple Input Multiple Output (MIMO) systems as it has shown to be a very efficient transmit diversity exploiting strategy if no Channel State Information (CSI) is available at the transmitter [1], [2]. Nowadays, Space-Time Codes (STCs) are also applied in distributed form in relaying systems, since multiple relays can be grouped into so-called virtual antenna arrays (VAAs) which allow the adoption of MIMO techniques [3], [4]. However, due to the distributed fashion of VAAs, some restrictions apply. Particularly, the exchange of information among the relays is limited and, thus, a perfect cooperation among the relays of one VAA is not possible. Moreover, imperfect synchronisations among the nodes of a VAA may lead to severe drawbacks for transmission schemes which require orthogonality among the relay signals. These restrictions have to be taken into account when applying MIMO techniques to relay systems as they can severely influence the overall system performance.

In [5] and [6] a STCs approach has been presented based on the non-orthogonal multiple access scheme Interleave-Division Multiple Access (IDMA) [7]. This Interleave-Division-Multiplexing Space-Time Code (IDM-STC) does not require any synchronisation among the transmitting nodes, making it a promising candidate also for relay systems. Hence, the IDM-STC has first been applied to uncoded Decode-and-Forward (DF) relay systems in a distributed fashion in [8] and has later on been extended for coded systems and additional relay protocols in [9]. It has been shown, that the distributed IDM-STC (dIDM-STC), due to its flexibility regarding code rate and number of transmitting nodes and due to its robustness against asynchronisms, is in fact a good choice for relay systems. But it also has been pointed out, that imperfect decoding at the relays has to be taken into account as it leads to error propagation which severely degrades the overall performance. Consequently, in [10] a modification of the common iterative detection strategie for IDM-STCs [5] has been presented which explicitly takes the decoding reliability of the relays into account. Specifically, the relay signals have been weighted according to the reliability of the corresponding relays, before they have been combined. The resulting DFq-INST scheme has shown a significant performance improvement compared to the common detection scheme from [9]. However, the achieved performance was still poor compared to adaptive relay schemes in which only correct relays forward to the destination, while all erroneous relays stay silent [4].

In this paper, a Reliability Aware Iterative Detection scheme (RAID) for dIDM-STCs in two-hop relay systems is proposed, which leads to an even better performance than adaptive relay schemes. This is achieved by optimally exploiting all available information at the destination from the correct as well as from the erroneous relays. The idea behind this scheme is, that depending on the number of erroneous bits, the relay information of the erroneous relays is still highly correlated to the source information and, hence, may still contribute to the overall detection. Specifically, a grouping of the relays is introduced and the relays are split into those, which could decode successfully and those which could not. While the successful relays are combined and jointly decoded as by the common detector, the erroneous relays are all processed separately. After the final iteration, the signals of the correct relays and of the erroneous relays are combined using a weighting similar to [10].

II. System Model

A. Overview

A two-hop relay-system as depicted in Fig. 1 is considered, where a single source S communicates with one destination D via N parallel relays $R_n,\ 1 \leq n \leq N$. No direct link from source to destination is assumed and the channel impulse responses from S to R_n and from R_n to D are given by $\mathbf{h}_n$ and $\mathbf{g}_n$, respectively. Frequency-selective block Rayleigh fading channels $\tilde{\mathbf{h}}_n$ and $\tilde{\mathbf{g}}_n$ with L_h and L_g i.i.d channel taps

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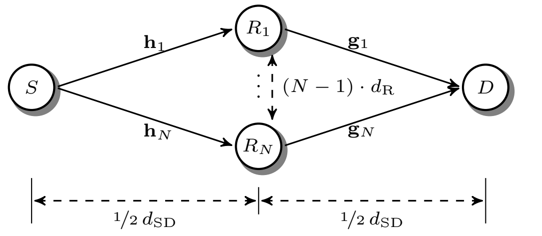

Fig. 1. Topology of the considered two-hop relay system.

are assumed and the channel impulse responses are normalized such, that the total received power does not depend on L_{h} and L_{g}, i.e., $\mathrm{E}\{||\tilde{\mathbf{h}}_n||^2\} = \mathrm{E}\{||\tilde{\mathbf{g}}_n||^2\} = 1$. The path loss on each hop is given by d^{ϵ} such that $\mathbf{h}_n = d^{-\epsilon/2}\tilde{\mathbf{h}}_n$ and $\mathbf{g}_n = d^{-\epsilon/2}\tilde{\mathbf{g}}_n$, where d denotes the distance between the corresponding nodes and ϵ is the path loss exponent. Moreover, each receiving node, i.e., R_n and D experiences additive white gaussian noise (AWGN) of power σ_{n}^2. Due to the half-duplex constraint, the transmission time can be divided into a *Broadcast Phase* in which the source broadcasts its information to the relays and a *Multiple Access Phase* in which the relays simultaneously forward the processed information to the destination.

B. Broadcast Phase

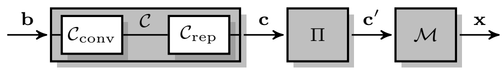

Fig. 2. Block diagram of Source S.

In the first phase, the source broadcasts its information to the relays applying IDMA [7]. Fig. 2 shows the transmitter structure of the source, where the binary information sequence $\mathbf{b} \in \mathbb{F}_2^{L_{\mathrm{b}}}$ of length L_{b} is encoded by a channel code $\mathcal{C}$ of rate R_{c} consisting of a serial concatenation of a convolutional code $\mathcal{C}_{\mathrm{conv}}$ of rate $R_{\mathrm{c,conv}}$ and a repetition code $\mathcal{C}_{\mathrm{rep}}$ of rate $R_{\mathrm{c,rep}}$. Furthermore, a Cyclic Redundancy Check (CRC) code is applied which allows the relays and the destination to determine their decoding success. The coded sequence $\mathbf{c} \in \mathbb{F}_2^{L_{\mathrm{c}}}$ of length L_{c} is then interleaved by an interleaver Π resulting in the interleaved code sequence $\mathbf{c}'$. Finally, the interleaved code bits are mapped onto symbols from the normalized QPSK alphabet $\mathcal{A}$ resulting in the transmit sequence $\mathbf{x} \in \mathcal{A}^{L_{\mathrm{x}}}$ of length L_{x} with $\sigma_{\mathrm{x}}^2 = 1$. The symbols $\mathbf{x}$ are then broadcasted to all relays.

The received signal $\mathbf{y}_n$ at relay R_n is given as the convolution of the source signal $\mathbf{x}$ with the corresponding channel impulse response $\mathbf{h}_n$ plus additive white gaussian noise $\mathbf{n}_n \in \mathbb{C}^{L_{\mathrm{x}}+L_{\mathrm{h}}-1}$ of power σ_{n}^2 as

$$\mathbf{y}_n = \mathbf{h}_n * \mathbf{x} + \mathbf{n}_n\,. \tag{1}$$

In Fig. 3 the structure of the relay R_n is shown. First, in order to resolve inter-symbol interference (ISI) introduced by the first hop, IDMA multi-user detection (MUD) is performed using the iterative soft-RAKE algorithm [7]. The MUD at relay R_n delivers Log-Likelihood-Ratios (LLRs) $\mathbf{\Lambda}_{\mathrm{b}}^{R_n}$ of the user information sequence $\mathbf{b}$. After hard decision, these estimates $\hat{\mathbf{b}}^{R_n} = \mathcal{Q}\left(\mathbf{\Lambda}_{\mathrm{b}}^{R_n}\right)$ form the relay information sequence $\mathbf{b}_n$

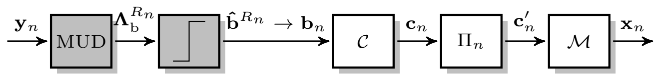

Fig. 3. Block diagramm of Relay R_n.

as $\hat{\mathbf{b}}^{R_n} \to \mathbf{b}_n$ where $\mathbf{b}_n$ denotes the information sequence at relay R_n containing the hard estimates of the user sequence $\mathbf{b}$. Note, that due to decoding errors at the relay, the information sequences $\mathbf{b}$ and $\mathbf{b}_n$ can be different from each other. Hence, a CRC check is applied in order to determine the decoding success. The outcome of this CRC check is signaled to the destination where it is later on used by the new proposed detection scheme. However, independent of this outcome, the relay information sequences are encoded using the same channel code $\mathcal{C}$ as the source, interleaved by a relay specific interleaver Π_n and mapped onto symbols from the same symbol alphabet $\mathcal{A}$.

C. Multiple Access Phase

In the second phase, the transmit signals $\mathbf{x}_n \in \mathcal{A}^{L_{\mathrm{x}}}$ of all relays are broadcasted simultaneously to the destination D. Under the assumption of perfect decoding at all relays, the user signal is transmitted from all N relays and, hence, a distributed IDM-STC is formed across the N relays, comparable to [6]. The receive signal $\mathbf{y}$ at the destination consists of the superposition of the relay signals $\mathbf{x}_n$ convolved with the corresponding channel impulse responses $\mathbf{g}_n$ plus additive white gaussian noise $\mathbf{n} \in \mathbb{C}^{L_{\mathrm{x}}+L_{\mathrm{g}}-1}$ as

$$\mathbf{y} = \sum_{n=1}^{N} \mathbf{g}_n * \mathbf{x}_n + \mathbf{n}\,. \tag{2}$$

III. Common Detection Scheme

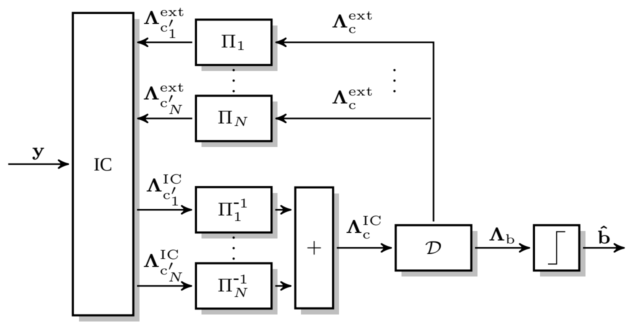

Fig. 4. Structure of the common detection scheme for dIDM-STCs.

In order to separate all N relay signals $\mathbf{x}_n$ at the destination, an iterative turbo detection as depicted in Fig. 4 is applied [5]. After soft-RAKE based Interference Cancelation (IC) with respect to all N layers, relay specific interleaving is reversed $\Pi_n^{-1}(\cdot)$, and the LLRs $\mathbf{\Lambda}_{\mathrm{c}_n}^{\mathrm{IC}}$ describing $\mathbf{c}$ are summed up.

$$\mathbf{\Lambda}_{\mathrm{c}}^{\mathrm{IC}} = \sum_{n=1}^{N} \Pi_n^{-1}\left(\mathbf{\Lambda}_{\mathrm{c}'_n}^{\mathrm{IC}}\right)\,. \tag{3}$$

Eq. (3) can be interpreted as decoding of the IDM-STC. Using $\mathbf{\Lambda}_{\mathrm{c}}^{\mathrm{IC}}$, soft-input soft-output channel decoding $\mathcal{D}$ is performed. After decoding of the repetition code $\mathcal{C}_{\mathrm{rep}}$ which is a summation of the corresponding LLRs, the convolutional code $\mathcal{C}_{\mathrm{conv}}$ is decoded using the well-known BCJR algorithm

[11]. The BCJR delivers LLRs $\mathbf{\Lambda}_{\mathrm{b}}$ for the information bits $\mathbf{b}$ as well as LLRs $\mathbf{\Lambda}_{\mathrm{c}}$ for the code bits $\mathbf{c}$.

In order to obtain the extrinsic information generated by the overall decoder, the input LLRs are substracted from the output LLRs, $\mathbf{\Lambda}_{\mathrm{c}}^{\mathrm{ext}} = \mathbf{\Lambda}_{\mathrm{c}} - \mathbf{\Lambda}_{\mathrm{c}}^{\mathrm{IC}}$. The extrinsic information is then re-interleaved by the relay specific interleavers Π_n and fed back to the IC where it is used as a-priori information for the next iteration. This iterative detection process is repeated until the maximum number of iterations N_{it} is reached. Finally, a hard quantization of the LLRs $\mathbf{\Lambda}_{\mathrm{b}}$ of the information bits leads to the hard estimates $\hat{\mathbf{b}}$. The described detection scheme is optimal if all relays transmitted the same codeword, i.e., $\mathbf{c}_n = \mathbf{c}$, $1 \leq n \leq N$.

In practical relaying systems, however, perfect decoding at the relays cannot be achieved. In this case, the common detection scheme is no longer optimal, as it does not take any reliability information regarding the first hop transmission and the decoding at the relays into account. One possibility to overcome these drawbacks is to apply an adpative relay scheme, i.e., allowing only correct relays to forward to the destination [4]. However, since erroneous relays may still contribute to the overall transmission it does not seem reasonable to disable them but to let them transmit anyway. It should then be the task of the destination to handle the correct als well as the erroneous relays properly, and to optimally exploit all available information.

IV. Improved Detection Scheme

In order for the detector at the destination to be able to cope with decoding errors at the relays, a suitable model describing the overall transmission including the decoding reliabilities of the relays is required. On the one hand, this model should be accurate enough to actually improve the detection at the destination, on the other hand it should be simple enough to avoid an excessive increase in the complexity of the detector or in the signaling overhead.

A. Equivalent transmission model

In [12], [13] the correlation between a source information word and its hard estimate at the relay was modeled based on a binary symmetric channel (BSC) with a certain crossover probability. Adopting this description, the relay information word $\mathbf{b}_n$ is modeled here as

$$\mathbf{b}_n = \mathrm{BSC}_n \left\{ \mathbf{b}, q_n \right\} . \tag{4}$$

where q_n is the bit error probability of the estimate $\hat{\mathbf{b}}^{R_n}$ regarding the source information word $\mathbf{b}$, i.e.,

$$q_n = \frac{d_{\mathrm{H}}(\mathbf{b}, \hat{\mathbf{b}}^{R_n})}{L_{\mathrm{b}}} , \tag{5}$$

with $d_{\mathrm{H}}(\cdot)$ denoting the Hamming distance and L_{b} the length of the information sequence $\mathbf{b}$. For perfect decoding at the relay this crossover probability is zero and it increases as the decoding reliability of the relay decreases. Based on this description, an equivalent joint transmission model consisting of source processing, transmission over the first hop to the relay and processing at the relay, as depicted in Fig. 5 can be formulated.

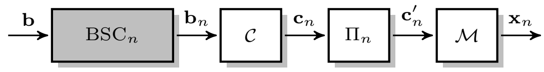

Fig. 5. Equivalent transmission model for transmission of $\mathbf{b}$ via R_n to D. The shaded BSC block represents the shaded blocks from Fig. 2 and Fig. 3.

Obviously, the calculation (5) requires perfect knowledge of $\mathbf{b}$ at R_n which is not available in practical systems. However, an estimation of q_n using the LLRs $\mathbf{\Lambda}_{\mathrm{b}}^{R_n}$ of the information bits generated by the MUD at the relay is possible [14]. Denoting this estimate $\hat{q}_n$, it holds

$$\hat{q}_n = \mathrm{E}\left\{ \frac{1}{1 + e^{|\mathbf{\Lambda}_{\mathrm{b}}^{R_n}|}} \right\} \approx \frac{1}{L_{\mathrm{b}}} \sum_{i=1}^{L_{\mathrm{b}}} \frac{1}{1 + e^{|\Lambda_{\mathrm{b},i}^{R_n}|}} . \tag{6}$$

In this paper, it is assumed that in case of successful decoding at the relay, ACK is signaled to the destination, while unsuccessful decoding leads to the signaling of a NAK in form of $\hat{q}_n$. For a detailed discussion of this signaling refer to [10].

B. Reliability Aware Iterative Detection (RAID)

Using the presented equivalent joint transmission model, the new Reliability Aware Iterative Detection scheme (RAID) for detection at the destination is proposed. In order to improve the detection quality significantly compared to the common detection scheme discussed in section III, this detection scheme takes the decoding success (ACK/NAK) of the relays as well as the error probabilitities $\hat{q}_n$ into account.

1) Relay grouping: One problem of the common detection scheme as well as the improved scheme from [10] is the summation (3) of the LLRs $\mathbf{\Lambda}_{\mathrm{c}'_n}^{\mathrm{IC}}$ of all relays, regardless of their decoding success. Since all layers are decoded jointly, only extrinsic information for the sum signal is available. By using this common extrinsic information as a-priori information for the next iteration for all relay signals, it is implicitly assumed that all relays transmitted the exact same signal. This is, however, clearly not the case if one or more relays were erroneous and, hence, transmitted a different code word than the correct relays.

Processing all signals separately and combining them after the final iteration, on the other hand, is also suboptimal, as all correct relays in fact have transmitted the same signal and should, hence, be combined in order exploit this knowledge during the iterative detection. Therefore, a grouping of the correct relays on the one hand and all erroneous relays on the other hand is introduced. Since all correct relays have transmitted the same code word $\mathbf{c}_n = \mathbf{c}$, their LLRs are combined after relay specific de-interleaving. All erroneous relays, however, may have transmitted pairwise different code words and, hence, are all processed separately.

For the sake of notational simplicity, the set of indices of the correct relays $\mathcal{R}$ and the set of indices of erroneous relays $\bar{\mathcal{R}}$ with

$$\mathcal{R} = \{ n \,|\, \hat{q}_n = 0,\, 1 \leq n \leq N \} \tag{7a}$$

$$\bar{\mathcal{R}} = \{ n \,|\, \hat{q}_n \neq 0,\, 1 \leq n \leq N \} , \tag{7b}$$

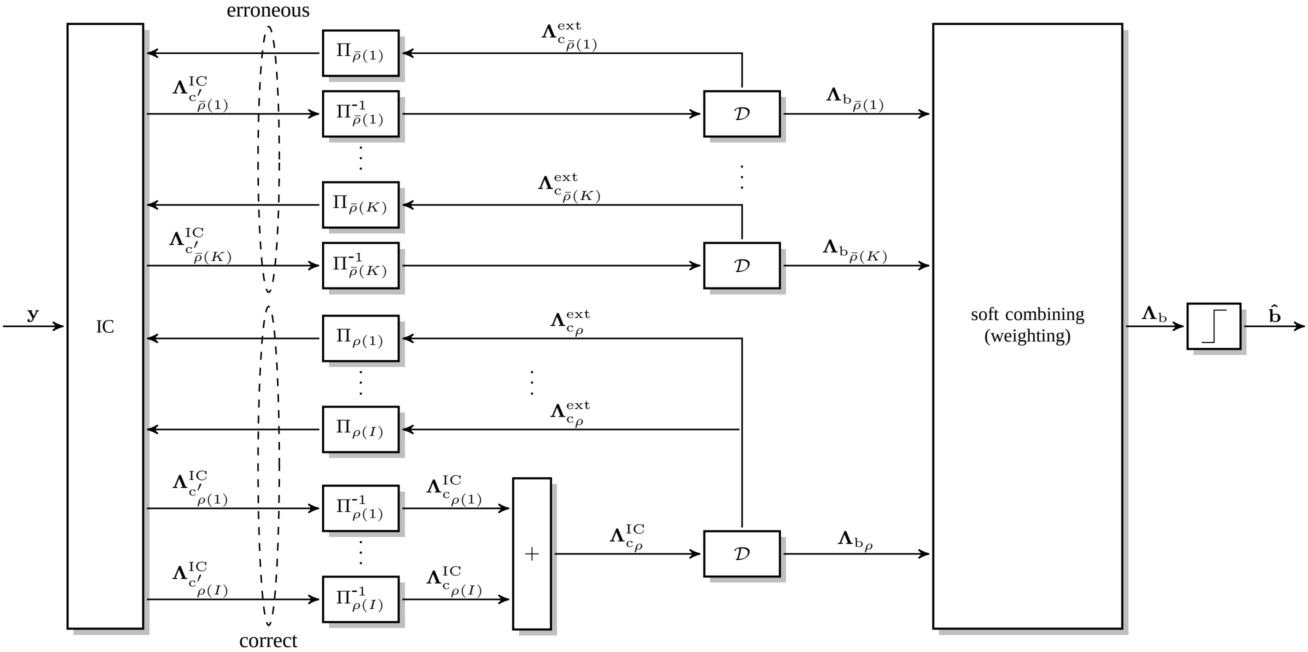

Fig. 6. Structure of the proposed RAID scheme for dIDM-STCs.

and the corresponding indexing functions $\rho(i)$, $1 \le i \le I = |\mathcal{R}|$ and $\bar{\rho}(k)$, $1 \le k \le K = |\bar{\mathcal{R}}|$ are introduced. Thus, the indices of the correct relays are given by $\rho(1)$ up to $\rho(I)$ and the indices of the erroneous relays by $\bar{\rho}(1)$ up to $\bar{\rho}(K)$, i.e.,

$$\mathbf{b}_{\rho(i)} = \mathbf{b}, \quad 1 \le i \le I \tag{8a}$$

$$\mathbf{b}_{\rho(k)} \neq \mathbf{b}, \quad 1 \le k \le K\,. \tag{8b}$$

Applying this grouping results in the detection structure given in Fig. 6. The LLRs delivered from the IC are grouped based on the decoding success (ACK/NAK) at the relays. Since the correct relays have transmitted the same code words, their LLRs are summed up after relay specific deinterleaving $\boldsymbol{\Lambda}^{\mathrm{IC}}_{\mathrm{c}_\rho} = \sum_{i=1}^{I} \Pi^{-1}_{\rho(i)}\left(\boldsymbol{\Lambda}^{\mathrm{IC}}_{\mathrm{c}'_{\rho(i)}}\right)$ and are then jointly decoded, similar to the common detection scheme (bottom part). The erroneous relays, however, have transmitted different code words and are, therefore, processed and decoded separately (top part). The explicit decoding, hard decision and subsequent re-encoding at the relays ensures, that all relays actually transmitted a valid code word which is fundamental for the validity of the presented equivalent transmission model. The goal of this first stage of the detection is the best possible estimation of the relay information words $\mathbf{b}_n$ and not of the source information word $\mathbf{b}$. After the last iteration, the estimates for the relay information words are given as LLRs at the output of the $K+1$ decoders $\mathcal{D}$.

2) Weighted Combining: Having estimated the relay information words $\mathbf{b}_n$, now an overall estimate for the source information word $\mathbf{b}$ should be determined. This estimate should not only include the information from the correct relays, but also the information from the erroneous relays as, depending on the error probabilities $\hat{q}_{\bar{\rho}(k)}$, the relay information of the erroneous relays is still correlated to the source information.

Taking the BSC model (4) into account, an estimate $\boldsymbol{\Lambda}_{\mathrm{b}}^{\bar{\rho}(k)}$ for $\mathbf{b}$ based on the decoder output $\boldsymbol{\Lambda}_{\mathrm{b}_{\bar{\rho}(k)}}$ can be formulated [13]

$$\boldsymbol{\Lambda}_{\mathrm{b}}^{\bar{\rho}(k)} = \log\left(\frac{e^{\boldsymbol{\Lambda}_{\mathrm{b}_{\bar{\rho}(k)}}/2}\left(1-\hat{q}_{\bar{\rho}(k)}\right) + e^{-\boldsymbol{\Lambda}_{\mathrm{b}_{\bar{\rho}(k)}}/2}\,\hat{q}_{\bar{\rho}(k)}}{e^{-\boldsymbol{\Lambda}_{\mathrm{b}_{\bar{\rho}(k)}}/2}\left(1-\hat{q}_{\bar{\rho}(k)}\right) + e^{\boldsymbol{\Lambda}_{\mathrm{b}_{\bar{\rho}(k)}}/2}\,\hat{q}_{\bar{\rho}(k)}}\right)\,. \tag{9}$$

The error probability $\hat{q}_{\bar{\rho}(k)}$ of the BSC hereby leads to a weighting of the estimate of the relay information word given by the LLRs $\boldsymbol{\Lambda}_{\mathrm{b}_{\bar{\rho}(k)}}$. For completely uncorrelated $\mathbf{b}_{\bar{\rho}(k)}$ and $\mathbf{b}$, i.e. $\hat{q}_{\bar{\rho}(k)} = 0.5$, the relay transmitted no information regarding $\mathbf{b}$ and, hence, $\boldsymbol{\Lambda}_{\mathrm{b}}^{\bar{\rho}(k)} = 0$. But as $\hat{q}_{\bar{\rho}(k)}$ decreases, $\boldsymbol{\Lambda}_{\mathrm{b}}^{\bar{\rho}(k)}$ tends to $\boldsymbol{\Lambda}_{\mathrm{b}_{\bar{\rho}(k)}}$ giving an estimate of $\mathbf{b}$ with respect to the information from relay $R_{\bar{\rho}(k)}$.

Since all channels are statistically independent, the observations from all relays can be summed up resulting in the estimate

$$\boldsymbol{\Lambda}_{\mathrm{b}} = \boldsymbol{\Lambda}_{\mathrm{b}_\rho} + \sum_{k=1}^{K} \boldsymbol{\Lambda}_{\mathrm{b}}^{\bar{\rho}(k)}\,. \tag{10}$$

Finally, hard quantization leads to the overall estimate $\hat{\mathbf{b}}$.

V. Numerical Results

A two-hop relay system with one source, $N = 4$ parallel relays R_n and one destination D as depicted in Fig. 1 is considered. The distance between the source and the destination is normalized to $d_{\mathrm{SD}} = 1$ and the inter-relay distance is set to $d_{\mathrm{R}} = 0.2$. Frequency-selective block Rayleigh fading with $L = L_{\mathrm{h}} = L_{\mathrm{g}}$ i.i.d. channel taps is assumed on both hops and the path loss exponent is set to $\epsilon = 3$. For channel coding, a combination of the non-recursive half-rate $(5,7)_8$ convolutional code and a repetition code of rate $R_{\mathrm{c,rep}} = 1/4$ is applied and the codeword length is set to $L_{\mathrm{c}} = 1024$ codebits. The QPSK alphabet $\mathcal{A}$ with $\sigma_{\mathrm{x}}^2 = 1$ is chosen. For detection at the relays and at the destination, respectively, $N_{\mathrm{it}} = 10$ iterations are performed.

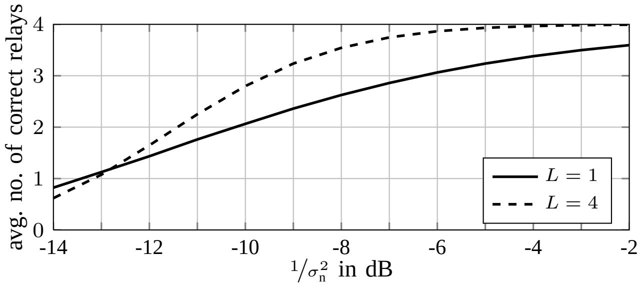

Fig. 7. Average number of correct relays for flat ($L = 1$, solid) and frequency selective channels ($L = 4$, dashed).

First, the average number of correct relays is given in Fig. 7. As can be seen, in the low SNR region, i.e., up to approx. $^1/\sigma_n^2 = -13\,\mathrm{dB}$, on average more relays are correct for the flat channel ($L = 1$) as for the frequency selective channel ($L = 4$). This is due to the soft-RAKE detetion at the relays, which resolves every multi-path propagation seperately. Since the channel impulse responses are normalized to unit power, the SNR per channel tap is lower for the frequency selective channel than for the flat channel and, hence, a worse performance is achieved. However, above $^1/\sigma_n^2 = -13\,\mathrm{dB}$ the influence of the offered frequency diversity for the frequency selective channel dominates the drawback of a lower SNR per channel tap, resulting in a better performance for the frequency selective channel.

In Fig. 8 the achieved Frame Error Rates (FERs) at the destination for the common detection scheme (cDF) as well as for the proposed RAID scheme are given. As benchmark, also the scheme from [10] (DFq-INST) and the adaptive scheme are shown. The proposed RAID clearly outperforms cDF as well as DFq-INST for flat (solid) as well as for frequency selective channels (dashed). It even achieves a better performance than the adaptive scheme due to the exploitation of erroneous relays. Interestingly, by comparing the slopes of the FER curves, the RAID scheme achieves the same diversity degree for flat channels as the common scheme for frequency selective channels. This is due to the choice of the simulation parameters, i.e., $N = 4$ relays and $L = 4$ channel taps for the frequency selective channels. The common scheme obviously only exploits frequency-diversity but almost no spatial diversity while the RAID scheme also fully exploits the available spatial diversity.

VI. Conclusion

In this paper, distributed Interleave-Division Multiplexing Space-Time Codes (dIDM-STC) have been applied for two-hop Decode-and-Forward relay systems. After introducing an equivalent transmission model for the source-relay transmission, the novel Reliability Aware Iterative Detection Scheme (RAID) was proposed which explicitly takes the decoding success as well as the decoding reliabilities of the relays into account for detection at the destination. Due to the optimal combining of the information from the correct as well as from the erroneous relays, the proposed RAID scheme outperforms even adaptive relaying schemes, as these do not exploit erroneous relays. Morever, the presented scheme is very flexible and can easily be extended to multi-user scenarios.

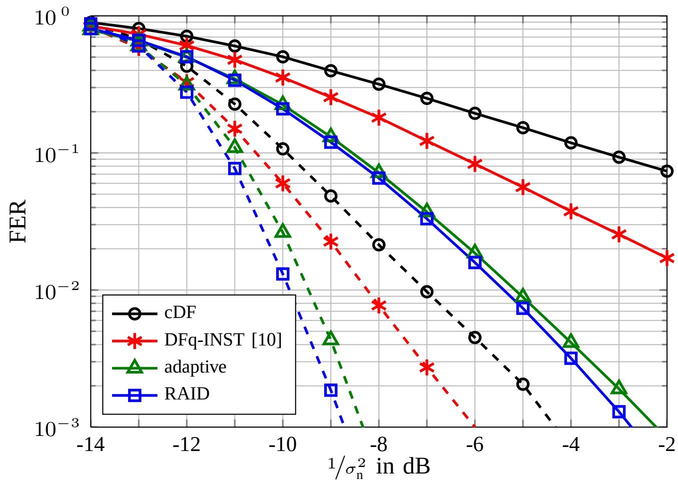

Fig. 8. FERs at the destination for common detection (cDF), modified detection with weighting from [10] (DFq-INST), the adaptive relay scheme and the proposed RAID scheme for $L = 1$ (solid) and $L = 4$ (dashed) channel taps.

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