Practical Aspects of Compress and Forward with BICM in the 3-Node Relay Channel

Daniel Kern, Volker Kühn
Institute of Communications Engineering, University of Rostock, Germany
E-Mail: {daniel.kern, volker.kuehn}@uni-rostock.de

***Abstract*—The classical relay channel is well investigated in literature. The two most common relaying techniques are Decode-and-Forward (DF) and Compress-and-Forward (CF), whereby the achievable rates of these techniques outperform each other depending on the quality of links between nodes. Based on the results from information theory assuming Gaussian codebooks, this paper focuses on practical aspects of the CF relay protocol which outperforms DF if the source-relay link becomes the bottleneck of the system. In practice, appropriate quantizers have to be found whose output can be exploited by real decoders. As the relay's receive signal contains also noise, maximum entropy quantizers are unrewarding. Therefore, the Information Bottleneck (IB) method is used to find the optimal quantizer for a specific scenario. Furthermore, it is a priori not clear whether signal processing before quantizing the received signal is useful considering coded modulation with iterative decoders. In a nutshell, the received signals may be either quantized directly, or after demapping, or even after a few iterations of decoding. For either case, it is shown how the respective quantization indices are optimally exploited by a joint decoder/demapper at the destination. Results reveal that performing soft-output decoding and subsequent quantization provides the best performance.**

I. Introduction

The 3-node relay channel, introduced by [1], [2], consists besides source and destination node of only one relay node which can pursue different strategies [3], [4]. The most common are Decode-and-Forward (DF), Compress-and-Forward (CF), and Amplify and Forward (AF). ...

The rest of the paper is organized as follows. Sec. II describes the system setup including channel model, CF relaying scheme, and Modulation and Coding Schemes (MCSs) used for practical coding. Then, Sec. III introduces the Information Bottleneck (IB) method to get the optimal quantizer for the given setup. Sec. IV describes how to exploit the output of quantization in an iterative decoder for different approaches. Finally, Sec. VI shows simulation results and Sec. VII concludes the paper.

II. System Setup

A. The classical (3-Node) Relay Channel

The 3-node relay channel, as depicted in Fig. 1, consists of one source node S, one relay node R, and one destination node D, where links between nodes are modeled as Additive White Gaussian Noise (AWGN) channels with $n_f \sim \mathcal{CN}(0,1)$ being the noise at receiving node $f \in \{R, D\}$. Furthermore, a path-loss is considered by channel coefficients $a_{ef} = d_{ef}^{(-\alpha/2)} \forall e \in \{S, R\}, \forall f \in \{R, D\}$, where α and d_{ef} are path-loss exponent and distance between node e and f, respectively.

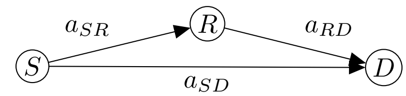

Fig. 1. The Classical Relay Channel

The transmission is organized in two time slots of length $\tau \in [0, 1]$ and $(1-\tau)$ denoted as broadcast and Multiple Access (MAC) phase, respectively. First, S transmits $\mathbf{x_{S1}}$ to R and D

$$\mathbf{y_R} = a_{SR}\sqrt{P_{S1}}\mathbf{x_{S1}} + \mathbf{n_R} \tag{1}$$

$$\mathbf{y_{D1}} = a_{SD}\sqrt{P_{S1}}\mathbf{x_{S1}} + \mathbf{n_{D1}} \tag{2}$$

where P_{S1} denotes the transmit power of related transmit vector $\mathbf{x_{S1}}$ whose elements are realizations of random variable X_{S1} with $E\{|X_{S1}|^2\} = 1$.

In the MAC phase, R transmits a compressed version of $\mathbf{y_R}$ and S a new message which is separately encoded and modulated. Hence, D receives a superposition of both.

$$\mathbf{y_{D2}} = a_{SD}\sqrt{P_{S2}}\mathbf{x_{S2}} + a_{RD}\sqrt{P_R}\mathbf{x_R} + \mathbf{n_{D2}}. \tag{3}$$

For comparison, the source may also be quiet in the 2nd time slot to have orthogonal channel access, i.e., $P_{S2} = 0$.

B. Compress and Forward

Ensuing from information theory, Wyner-Ziv coding [5] is applied to compress the received sequence $\mathbf{y_R}$ (in two steps) at the relay exploiting the side information $\mathbf{y_{D1}}$ at the destination. First, $\mathbf{y_R}$ will be compressed following the distribution

$$\Pr\{z\} = \sum_{y_R} \Pr\{z|y_R\} \Pr\{y_R\}, \tag{4}$$

where $\mathbf{z}$ denotes the compression indices of the compressed received signal. The distribution $\Pr\{z|y_R\}$ is obtained by the IB method and represents a random vector quantization. In a second step, the indices $\mathbf{z}$ will be source encoded with side information (binning) delivering indices $\mathbf{s}$ which are actually transmitted via $\mathbf{x_R}$.

By decoding of $\mathbf{y_{D2}}$ (treating $\mathbf{x_{S2}}$ as noise) the destination detects $\mathbf{s}$ and recovers $\mathbf{z}$ with side information $\mathbf{y_{D1}}$. Then $\mathbf{z}$ and $\mathbf{y_{D1}}$ are used jointly to decode the message transmitted by S in the broadcast phase. Please note that S transmits a second message directly in the MAC phase. Thus it can be detected from $\mathbf{y_{D2}}$ after subtracting the influence of $\mathbf{x_R}$.

As the focus of this investigation lies on exploiting $\mathbf{z}$ in an iterative decoder, the source coding step with side information to get $\mathbf{s}$ from $\mathbf{z}$ is omitted, i.e., $\mathbf{z}$ is assumed to be directly available at D for the iterative decoding described in Sec. IV.

C. Modulation and Coding Schemes

For practical coding, a set of 40 MCSs is available. More precisely, the well known Universal Mobile Telecommunications System (UMTS)/Long Term Evolution (LTE) turbo code [6] and M-Quadrature Amplitude Modulation (QAM) with orders $m = \log_2 M, m \in \{2, 4, 6, 8, 10\}$ are used. The inherent code rate $R_c = 1/3$ of the turbo code is extended to a set of 8 code rates via puncturing as shown in Table I [7]. For decoding, a turbo decoding process with 8 iterations

TABLE I. PUNCTURING PATTERNS (OCTAL)

4/5	2/3	4/7	1/2	4/9	2/5	4/11	1/3
100	101	101	121	125	125	335	377
001	021	261	263	363	377	377	377

is implemented exchanging soft information between two log-map decoders (Bahl Cocke Jelinek Raviv (BCJR) [8]). The demapper is separated from the code by a random interleaver to split error bursts. Furthermore, it is not included in the turbo process known as Bit Interleaved Coded Modulation (BICM) with parallel decoding [9].

III. INFORMATION BOTTLENECK METHOD

This section introduces the IB method [10]–[13] which finds the conditional distribution $\Pr\{z|y\}$ to quantize an observation y of x to z forming a markov chain $X \to Y \to Z$. The algorithm thereby finds a trade-off between the mutual information $I(X;Z)$ and source coding rate $I(Y;Z)$ defining the information-rate function

$$I(r) \triangleq \max_{\Pr\{z|y\}} I(X;Z) \qquad \text{s.t.} \qquad I(Y;Z) \leq r \tag{5}$$

for $0 < r \leq H(Y)$. The same trade-off may be described by the rate-information function

$$r(I) \triangleq \min_{\Pr\{z|y\}} I(Y;Z) \qquad \text{s.t.} \qquad I(X;Z) \geq I \tag{6}$$

Applying the method of Lagrangian multipliers, (6) can be solved by an iterative optimization algorithm similar to the Blahut-Arimoto algorithm [14]. Therefore, (6) will be rewritten choosing a Lagrangian multiplier $\beta > 0$.

$$\min_{\Pr\{z|y\}} I(Y;Z) - \beta I(X;Z) \tag{7}$$

Considering the 3-node relay channel, (5) can be extended to the trade-off between $I(X_{S1};Z|Y_{D1})$ and $I(Y_R;Z|Y_{D1})$ exploiting the side information which is available at destination D due to the broadcast phase. Following the derivation in [13], the extended information rate function given the joint distribution $\Pr\{X_{S1}Y_RY_{D1}\}$ is defined as

$$I(r) \triangleq \max_{\Pr\{z|y_R\}} I(X_{S1};Z|Y_{D1}) \quad \text{s.t.} \quad I(Y_R;Z|Y_{D1}) \leq r, \tag{8}$$

where $0 < r \leq H(Y_R|Y_{D1})$ denotes the rate after source coding with side information (Wyner Ziv). Hence, the IB method delivers $\Pr\{z|y_R\}$ given $\Pr\{x_{S1}y_Ry_{D1}\}$ with respect to a

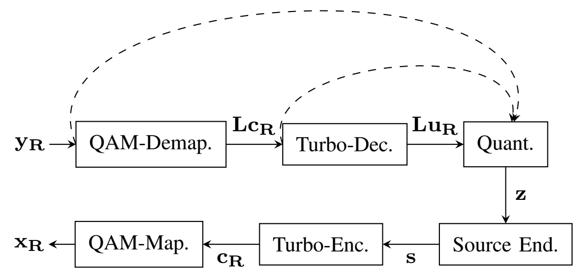

Fig. 2. Processing chain at the relay. Demapping and Decoding are optional.

specific trade-off $I(r(\beta))$ depending on Lagrangian multiplier $\beta > 0$, i.e., the algorithm takes β as input parameter and outputs additionally the pair $(I(r(\beta)), r(\beta))$. To calculate the whole information rate curve, a range of β is used, whereby the resulting quantizers are random except for $\beta \to \infty$. The maximum β delivers the maximum rate $r = H(Y_R|Y_{D1})$ leading to a deterministic quantizer, i.e., $\Pr\{z|y_R\}$ equals either zero or one. According to the CF relay protocol, r is restricted by the capacity of the relay destination link such that $\tau \cdot r \leq (1-\tau)I(X_R;Y_{D2})$ holds.

Please note that the input distribution $\Pr\{x_{S1}, y_R, y_{D1}\}$ to the IB algorithm is discrete whereas the relay channel delivers a continuous distribution $p_{X\tilde{Y}_R\tilde{Y}_{D1}}(x, \tilde{y_R}, \tilde{y}_{D1})$, that is, a pre-quantization of the channel outputs is necessary. In practice, this is mostly done in any case due to usual digital signal processing.

The derivation of the complete algorithm will be stated in the full paper. As the algorithm is iterative, an usually random initialization for $\Pr\{z|y_R\}$ is needed. Furthermore, the algorithm guaranties only local convergence [10] due to the non-convex nature of the problem. Thus, a random initialization needs several runs until a close to optimum value for $(I(r(\beta)), r(\beta))$ is obtained. To avoid repeatedly executions, Maximum Output Entropy (MOE) initialization [15] is used in this work.

IV. JOINT DECODING

From an information theoretic perspective it is optimal to compress the received signal $\mathbf{y_R}$ and apply Wyner Ziv coding exploiting $\mathbf{y_{D1}}$. In practice, however, the question arises how to exploit the compression indices, e.g., in an iterative turbo decoder exchanging log-likelihood ratios (LLRs).[1] More precisely, three relay processing strategies as shown in Fig. 2 are distinguished:

1) Direct quantization of $\mathbf{y_R}$ to compression indices $\mathbf{z_y}$,
2) demapping of $\mathbf{y_R}$ to LLRs $\mathbf{Lc_R} = L(\mathbf{c}|\mathbf{y_R})$ and subsequent quantization to indices $\mathbf{z_c}$,
3) additional soft-output decoding to get LLRs $\mathbf{Lu_R} = L(\mathbf{u}|\mathbf{y_R})$ and subsequent quantization to $\mathbf{z_u}$.

[1] As the quantization found by the IB method is random, there is no deterministic index for a received symbol.

For 4-QAM or Binary Phase Shift Keying (BPSK), the LLR $\mathbf{Lc_R}$ at the demapper output is a linear function of $\mathbf{y_R}$.

$$\mathbf{Lc_R} = 4a_{SR}\frac{P_{S1}}{\sigma_n^2}\mathbf{y_R} \tag{9}$$

Hence, there is no difference between quantizing before and after demapping. However, considering higher order modulation, the relation between $\mathbf{y_R}$ and $\mathbf{Lc_R}$ is non-linear. Thus, it may lead to different performance in practice. Usually, CF is applied when error free decoding is not possible. However, considering iterative decoding, the reliability of LLRs may be improved after a few iterations. Thus, all three approaches will be compared by the help of Monte Carlo simulations with turbo decoding exploiting either $\mathbf{z_y}$, $\mathbf{z_c}$ or $\mathbf{z_u}$.

A symbol-by-symbol Maximum-A-Posteriori (MAP) decoder delivers

$$L(\hat{u}_l) = \log\frac{\Pr\{u_l = 0, \mathbf{y_{D1}}, \mathbf{z}\}}{\Pr\{u_l = 1, \mathbf{y_{D1}}, \mathbf{z}\}} \tag{10}$$

for the final decision. As these joint distributions are not directly accessible, the set of all possible code words is divided into two subsets $\Gamma_l^{(1)}$ and $\Gamma_l^{(0)}$ containing code words $\mathbf{c}$ whose lth information bit is $u_l = 1$ and $u_l = 0$, respectively.

$$L(\hat{u}_l) = \log\frac{\sum_{\mathbf{c}\in\Gamma_l^{(0)}}\Pr\{\mathbf{c}, \mathbf{y_{D1}}, \mathbf{z}\}}{\sum_{\mathbf{c}\in\Gamma_l^{(1)}}\Pr\{\mathbf{c}, \mathbf{y_{D1}}, \mathbf{z}\}} \tag{11a}$$

$$= \log\frac{\sum_{\mathbf{c}\in\Gamma_l^{(0)}}\Pr\{\mathbf{y_{D1}}, \mathbf{z}|\mathbf{c}\}\Pr\{\mathbf{c}\}}{\sum_{\mathbf{c}\in\Gamma_l^{(1)}}\Pr\{\mathbf{y_{D1}}, \mathbf{z}|\mathbf{c}\}\Pr\{\mathbf{c}\}} \tag{11b}$$

$$= \log\frac{\sum_{\mathbf{c}\in\Gamma_l^{(0)}}\Pr\{\mathbf{y_{D1}}|\mathbf{c}\}\Pr\{\mathbf{z}|\mathbf{c}\}\Pr\{\mathbf{c}\}}{\sum_{\mathbf{c}\in\Gamma_l^{(1)}}\Pr\{\mathbf{y_{D1}}|\mathbf{c}\}\Pr\{\mathbf{z}|\mathbf{c}\}\Pr\{\mathbf{c}\}} \tag{11c}$$

$$= \log\frac{\sum\limits_{\mathbf{c}\in\Gamma_l^{(0)}}\prod\limits_{i=0}^{n-1}\Pr\{y_i|c_i\}\Pr\{z_i|c_i\}\prod\limits_{j=0}^{k-1}\Pr\{u_j\}}{\sum\limits_{\mathbf{c}\in\Gamma_l^{(1)}}\prod\limits_{i=0}^{n-1}\Pr\{y_i|c_i\}\Pr\{z_i|c_i\}\prod\limits_{j=0}^{k-1}\Pr\{u_j\}} \tag{11d}$$

$$= \log\frac{\sum\limits_{\mathbf{c}\in\Gamma_l^{(0)}}\prod\limits_{i=0}^{n-1}e^{-(L(y_i|c_i)+L(z_i|c_i))c_i}\prod\limits_{j=0}^{k-1}e^{-L(u_j)u_j}}{\sum\limits_{\mathbf{c}\in\Gamma_l^{(1)}}\prod\limits_{i=0}^{n-1}e^{-(L(y_i|c_i)+L(z_i|c_i))c_i}\prod\limits_{j=0}^{k-1}e^{-L(u_j)u_j}} \tag{11e}$$

The first exponential term in (11e) represents information about the code bits from the channels ($S \to D$, $S \to R$) and the second exponential term a priori knowledge about the information bits. Both will be given as input to an appropriate decoder like the BCJR [8]. It becomes clear that the decoder itself needs not to be modified. Solely, the LLRs $L(z_i|c_i)$ have to be found and added to the LLRs $L(y_{D_i}|c_i)$ which are delivered by the demapper.

A. Direct Quantization

For the direct quantization with no previous processing at the relay, z corresponds to z_y. Then, the LLR of interest for each i is

$$\begin{aligned} L(z_y|c) &= \log\frac{\Pr\{z_y|c=0\}}{\Pr\{z_y|c=1\}} = \log\frac{\sum\limits_{y_R\in\mathcal{Y}_R}\Pr\{z_y, y_R|c=0\}}{\sum\limits_{y_R\in\mathcal{Y}_R}\Pr\{z_y, y_R|c=1\}} \\ &= \log\frac{\sum\limits_{y_R\in\mathcal{Y}_R}\Pr\{z_y|y_R, c=0\}\Pr\{y_R|c=0\}}{\sum\limits_{y_R\in\mathcal{Y}_R}\Pr\{z_y|y_R, c=1\}\Pr\{y_R|c=1\}} \\ &= \log\frac{\sum\limits_{y_R\in\mathcal{Y}_R}\Pr\{z_y|y_R\}\Pr\{y_R|c=0\}}{\sum\limits_{y_R\in\mathcal{Y}_R}\Pr\{z_y|y_R\}\Pr\{y_R|c=1\}}, \end{aligned} \tag{12}$$

where the condition on c in the first term cancels due to Markov property $C \to X \to Y_R \to Z$. The first distribution $\Pr\{z_y|y_R\}$ is known from IB method. The second distribution $\Pr\{y_R|c\}$ can be considered as the demapper output $L(y_R|c)$ for all possible $y_R \in \mathcal{Y_R}$. In this context (12) may be seen as a virtual relay demapper delivering an average LLR.

B. Quantization of Soft-Demapper-Output

When the relay applies demapping prior to quantization, the IB method uses $\Pr\{c, Lc_R, Lc_{D1}\}$ to find the quantizer $\Pr\{z_c|Lc_R\}$. This case is only of interest for higher order modulation where the demapping is non-linear. Hence, the distribution $\Pr\{c, Lc_R, Lc_{D1}\}$ cannot be described analytically and has to be found numerically. Similarly as before, the LLR of interest for each i is

$$\begin{aligned} L(z_c|c) &= \log\frac{\Pr\{z_c|c=0\}}{\Pr\{z_c|c=1\}} = \log\frac{\sum\limits_{Lc_R\in\mathcal{L}_R^c}\Pr\{z_c, Lc_R|c=0\}}{\sum\limits_{Lc_R\in\mathcal{L}_R^c}\Pr\{z_c, Lc_R|c=1\}} \\ &= \log\frac{\sum\limits_{Lc_R\in\mathcal{L}_R^c}\Pr\{z_c|Lc_R\}\Pr\{Lc_R|c=0\}}{\sum\limits_{Lc_R\in\mathcal{L}_R^c}\Pr\{z_c|Lc_R\}\Pr\{Lc_R|c=1\}}, \end{aligned} \tag{13}$$

where $\Pr\{z_c|Lc_R\}$ is the distribution of the quantizer known from the IB method. Furthermore, the distribution $\Pr\{Lc_R|c=0\}$ is given by $\Pr\{c, Lc_R, Lc_{D1}\}$ which is an input of the IB method.

C. Quantization of Soft-Decoder-Output

When the relay applies additional decoding prior to quantization, the IB method delivers $\Pr\{z_u|Lu_R\}$ given the distribution $\Pr\{u, Lu_R, Lu_{D1}\}$ which is obtained numerically. As z_u represents knowledge about the information bit, let us rewrite (11c) exploiting $\Pr\{\mathbf{z}|\mathbf{c}\} = \Pr\{\mathbf{z}|\mathbf{u}\}$. Following the same steps as before this leads to

$$
\begin{aligned}
L(\hat{u}_l) &= \log \frac{\sum_{\mathbf{c}\in\Gamma_l^{(0)}} \Pr\{\mathbf{y_{D1}}|\mathbf{c}\}\Pr\{\mathbf{z}|\mathbf{u}\}\Pr\{\mathbf{u}\}}{\sum_{\mathbf{c}\in\Gamma_l^{(1)}} \Pr\{\mathbf{y_{D1}}|\mathbf{c}\}\Pr\{\mathbf{z}|\mathbf{u}\}\Pr\{\mathbf{u}\}} \\
&= \log \frac{\sum\limits_{\mathbf{c}\in\Gamma_l^{(0)}} \prod\limits_{i=0}^{n-1}\Pr\{y_i|c_i\}\prod\limits_{j=0}^{k-1}\Pr\{z_j|u_j\}\prod\limits_{j=0}^{k-1}\Pr\{u_j\}}{\sum\limits_{\mathbf{c}\in\Gamma_l^{(1)}} \prod\limits_{i=0}^{n-1}\Pr\{y_i|c_i\}\prod\limits_{j=0}^{k-1}\Pr\{z_j|u_j\}\prod\limits_{j=0}^{k-1}\Pr\{u_j\}} \\
&= \log \frac{\sum\limits_{\mathbf{c}\in\Gamma_l^{(0)}} \prod\limits_{i=0}^{n-1} e^{-L(y_i|c_i)c_i}\prod\limits_{j=0}^{k-1} e^{-(L(u_j)+L(z_j|u_j))u_j}}{\sum\limits_{\mathbf{c}\in\Gamma_l^{(1)}} \prod\limits_{i=0}^{n-1} e^{-L(y_i|c_i)c_i}\prod\limits_{j=0}^{k-1} e^{-(L(u_j)+L(z_j|u_j))u_j}},
\end{aligned}
\tag{14}
$$

where $L(z_j|u_j)$ is now added to the a priori information $L(u_j)$ that is fed into a practical decoder. Similar as in (13), this LLR is for each j

$$
L(z_u|u) = \log \frac{\sum\limits_{Lu_R\in\mathcal{L}_R^u} \Pr\{z_u|Lu_R\}\Pr\{Lu_R|u=0\}}{\sum\limits_{Lu_R\in\mathcal{L}_R^u} \Pr\{z_u|Lu_R\}\Pr\{Lu_R|u=1\}}. \tag{15}
$$

V. Rate Allocation for Practical Codes

This section describes the allocation of a discrete rate $R_b = m\cdot R_c$ (ensuing from the MCSs presented in Sec. II-C) to a specific link which is defined by its signal to noise ratio (SNR). Therefore, Monte Carlo Simulations are applied to a simple AWGN channel to find frame error rate (FER) vs. SNR for all MCS. From these curves, one can find a threshold SNR for each rate R_b such that a target FER of 10^{-2} is reached (cf. Fig. 3). Then, Fig. 3 is used to determine the

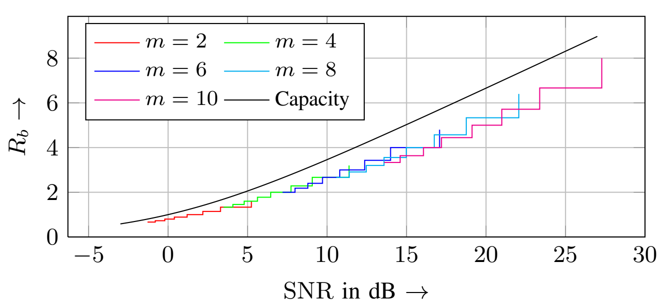

Fig. 3. Achievable rates R_b versus SNR for FER $=10^{-2}$ on direct link.

rates R_b^R and R_b^{S2} of $\mathbf{x_R}$ and $\mathbf{x_{S2}}$, respectively. To determine R_b^{S1} of $\mathbf{x_{S1}}$, a modified Monte Carlo simulation depicted in Fig. 4 is applied following the description in Sec. IV. Please remember that the Wyner Ziv coding and decoding as well as the transmission $R\rightarrow D$ are not included into the simulation rather the compression indices $\mathbf{z}\in\{\mathbf{z_y},\mathbf{z_c},\mathbf{z_u}\}$ are assumed to be available at the destination decoder.

Ensuing from the rates R_b^R, R_b^{S1} and R_b^{S2} related to the SNRs of the different links for a specific setup, the total

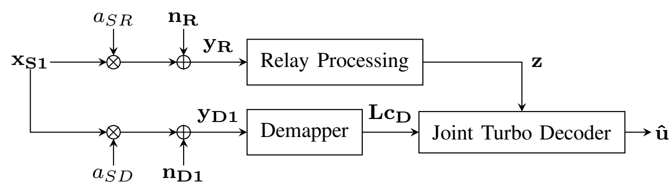

Fig. 4. Simulation Setup excluding Wyner Ziv coding.

throughput is

$$
\eta = \max_{\tau}\{\tau R_b^{S1} + (1-\tau)R_b^{S2}\} \text{ s.t. } \tau\cdot R_s \le (1-\tau)R_b^R, \tag{16}
$$

with $R_s = 2\cdot r_y$, $R_s = m_{S1}\cdot r_c$, or $R_s = R_b^{S1}\cdot r_u$ depending on the processing strategy of the relay introduced in Sec. IV.[2] Solving the condition in (16) with equality gives τ depending on a specific source coding rate $r\in\{r_y,r_c,r_u\}$ since R_b^R, m_{S1}, and R_b^{S1} are constant for one setup. Hence, to find a close to maximum value for η, the simulation is executed for a few different r, i.e. , different quantizations at the relay. These quantizers can be computed offline by the IB algorithm and, thus, need only evaluated once for each SNR.

For an orthogonal CF scheme, where S is quiet in the MAC phase, R_b^{S2} is set to zero.

Details will be given in the full paper.

VI. Results

For the above mentioned Simulation of CF the different strategies regarding the relay pre-processing will be compared in terms of the total throughput η. First results are depicted in Fig. 5 for R being at $d=0.5$ assuming that all nodes are placed on a line with S and D at $d=0$ and $d=1$, respectively. In the

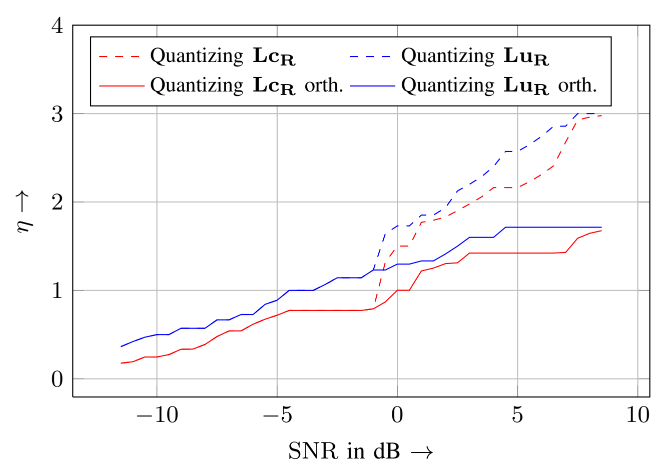

Fig. 5. Total throughput η versus SNR for strategies, where the relay performs soft-output demapping and soft-output decoding, respectively. Dashed lines denote the general case with non-orthogonal channel access in the MAC phase. Solid lines refer to orthogonal channel access, where $P_{S2}=0$

low SNR range, the solid and dashed curves match because

[2] Here, the factors in front of the specific source coding rates r_y, r_c and r_u (given by the IB method) denote the rate change due the specific pre-processing at the relay. The factor 2 related to r_y is necessary because inphase and quadrature component are quantized independently.

there is no low enough rate R_b^{S2} in the set of the available MCSs to enable a direct transmission between S and D.

In the full paper, we will give results for all three presented strategies and also for other relay positions especially for positions of R close to D. Furthermore, we will analyze the third strategy of applying soft-output decoding before quantization in more detail, that is, comparing the total throughput for a varying number of iterations at the relay decoder. For the respective results in Fig. 5, 8 iterations are used.

Another interesting question is whether the loss due to suboptimal deterministic quantization compared to optimal random quantization carries weight regarding the limited amount of discrete rates R_b. Thus, we compare the results obtained with the optimum random quantizer found by the IB method to similar results obtained with a deterministic quantizer either found by IB method with $\beta \to \infty$ or simply considering MOE without optimization.

VII. Conclusion

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