Decode-Quantize-Forward for OFDM-based Relaying Systems

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***Abstract*—In this paper, we present a new relaying protocol for coded OFDM-based relaying systems. The classical Decode-Forward (DF) protocol exploits the coding gain within the relay, however the overall performance suffers from error propagation in case of decodings errors at the relay as no reliability information about the source-relay (SR) link can be exploited. This drawback is avoided by the proposed Decode-Quantize-Forward (DQF) scheme, where the code bits estimated by the decoder in the relay are directly forwarded to the destination. Based on the observation, that code bit errors at the relay occur likely on subcarriers with low signal to noise ratio (SNR) on the SR link, we propose a modified maximum ratio combining (mMRC) scheme for the destination. As this approach exploits the varying channel reliability per subcarrier it outperforms the well-known DF protocol significantly.**

I. Introduction

The usage of relays to support the communication from source to destination has attracted increasing attention in the last years. Several relaying protocols like Amplify-Forward (AF), Decode-Forward (DF), and Quantize-Forward (QF) have been presented for single-carrier systems [1], [2]. The regenerative protocol DF makes use of the discrete alphabet and of coding gain available in coded systems, but suffers from error propagation in case of decoding failures at the relay. To overcome this drawback, soft information relaying techniques like Decode-Amplify-Forward (DAF) [3], [4] and Decode-Estimate-Forward (DEF) have been developed [5], [6]. The main challenge is the consideration of the different link qualities at the receiver.

Most of the relaying protocols discussed in the literature have been restricted to single-carrier systems. However, in practical mobile communication systems OFDM (orthogonal frequency division multiplexing) is the main technique to exploit the benefits of frequency selectivity while keeping the complexity of equalization low. By the application of FFT (fast Fourier transformation), IFFT (inverse FFT) and the transmission of a cyclic prefix the frequency selective channel is divided into a large number of parallel subcarriers. This multiplexing in frequency domain requires modified relaying functions, as the different subcarriers of a link experience varying reliability. Approaches to consider this variation is either discussed for non-regenerative relaying [7], [8] or considered in adapted resource allocation schemes. For example, power allocation for regenerative relaying schemes assuming perfect decoding at the relay is investigated in [9] and generalized to an adaptive relaying scheme in [10].

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In this paper we present a new non-adaptive relaying protocol called Decode-Quantize-Forward (DQF) to reduce the average number of erroneously transmitted code bits at the relay. To this end, not the log-likelihood-ratios (LLRs) of the information bits but the LLRs of the code bits are quantized at the relay. This does not guarantee, that valid code words are transmitted by the relay. However, in combination with a modified MRC (maximum ratio combiner) the varying link quality per subcarrier can be considered at the destination yielding improved performance.

The remainder of this paper is organized as follows. The OFDM relaying system is introduced in Section II. In Section III the basic relaying protocols are presented with emphasize to OFDM specific implementation aspects. The distribution of decoding errors at the relay is investigated and the new approach DQF as well as the modified MRC are derived. The different concepts are compared in Section IV and the results are summarized in Section V.

II. System Description

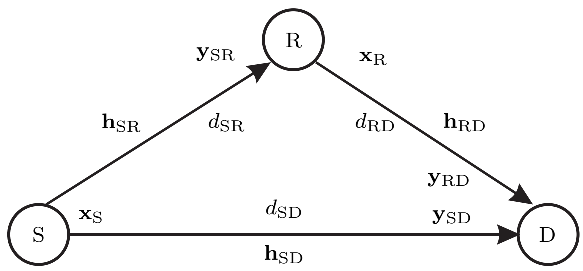

Fig. 1. Relaying system consisting of a source S, a relay R and a destination D.

We consider an OFDM-based relaying system consisting of a source S, a relay R and a destination D as depicted in Figure 1. All nodes are equipped with single antenna and operate in half-duplex mode. At S the information bit vector $\mathbf{b}$ is encoded by a linear channel code $\mathcal{C}$ and the code bit vector $\mathbf{c} \in \Gamma$ is interleaved by a random interleaver Π. The interleaved code bit vector $\mathbf{c}'$ is finally mapped to N_{C} symbols of the chosen M-QAM symbol alphabet, with N_{C} indicating the number of subcarriers. Denoting the transmit symbol on subcarrier k by $x_{\mathrm{S},k}$, the receive signals on subcarrier $1 \leq k \leq N_{\mathrm{C}}$ at R and D are given by

$$y_{\mathrm{SR},k} = h_{\mathrm{SR},k} x_{\mathrm{S},k} + n_{\mathrm{SR},k} \tag{1a}$$

$$y_{\mathrm{SD},k} = h_{\mathrm{SD},k} x_{\mathrm{S},k} + n_{\mathrm{SD},k} \ . \tag{1b}$$

Using the receive signal vector $\mathbf{y}_{\mathrm{SR}} = [y_{\mathrm{SR},1} \dots y_{\mathrm{SR},N_{\mathrm{C}}}]^T$ the relay generates the transmit vector $\mathbf{x}_{\mathrm{R}} = [x_{\mathrm{R},1} \dots y_{\mathrm{R},N_{\mathrm{C}}}]^T$ for the second transmission phase based on the selected relaying protocol described in the subsequent section. Thus, the receive signal on subcarrier $1 \leq k \leq N_{\mathrm{C}}$ at D is

$$y_{\mathrm{RD},k} = h_{\mathrm{RD},k} x_{\mathrm{R},k} + n_{\mathrm{RD},k} \ . \tag{2}$$

At the destination we restrict ourself to MRC, i.e., $\mathbf{y}_{\mathrm{SD}}$ and $\mathbf{y}_{\mathrm{RD}}$ are linearly combined to achieve the resulting signal $\tilde{x}_{\mathrm{MRC},k}$ with maximum SNR. By a demapper the LLRs for the permuted code bits are determined and fed after de-interleaving to the a-posteriori probability (APP) decoder, e.g. Sum-Product-Algorithm (SPA) for LDPC codes or BCJR algorithm for convolutional codes. By quantizing the calculated LLRs for the information bits the estimates for the information bits are achieved. As MRC is assumed at D, for decoding based relaying protocols the same channel code $\mathcal{C}$ and the same modulation scheme has to be applied at R and S. The average transmit power of the source on subcarrier k is denoted by $\mathcal{P}_{\mathrm{S},k} = \mathrm{E}\left\{|x_{\mathrm{S},k}|^2\right\}$. Throughout the paper perfect channel state information (CSI) is assumed at the receiving terminals, however no CSI information is available at the corresponding transmit terminal. Thus, equal power is allocated on all subcarriers and the total transmit power of the source is given by $\mathcal{P}_{\mathrm{S}} = N_{\mathrm{C}} \cdot \mathcal{P}_{\mathrm{S},k}$. Similarly, $\mathcal{P}_{\mathrm{R},k} = \mathrm{E}\left\{|x_{\mathrm{R},k}|^2\right\}$ and $\mathcal{P}_{\mathrm{R}}$ denote the average transmit power on subcarrier k and the total transmit power at the relay. However, the power is not necessarily equal on all subcarriers as discussed in Section III-B.

The distances of the source-destination (SD), the source-relay (SR), and the relay-destination (RD) links are given by d_{SD}, d_{SR}, and d_{RD}, respectively. The frequency selective transmission channels are modeled as block Rayleigh fading channels containing N_{H} taps in time domain. As equal power delay profiles are considered, the channel coefficients have a variance of $\sigma_{\mathrm{H}}^2 = 1/(N_{\mathrm{H}} d^{\alpha})$ with α denoting the path loss factor and distance $d \in \{d_{\mathrm{SD}}, d_{\mathrm{SR}}, d_{\mathrm{RD}}\}$. The coefficients $h_{\mathrm{SD},k}$, $h_{\mathrm{SR},k}$, and $h_{\mathrm{RD},k}$ in (1) and (2) correspond to the FFT of the time domain channel coefficients. Finally, all additive noise terms are assumed to be i.i.d zero-mean complex random variables with variance σ_n^2.

III. Relaying Protocols

In this section, the basic relaying protocols are presented for OFDM systems. After considering AF and DF the new approach DQF is described in detail.

A. Amplify-Forward with Constant Power (AF-CP)

For AF, the relay simply retransmits an amplified copy of the received signal [1]. For OFDM systems the question arises, if the amplification should take place in time domain or in frequency domain. For the later, on each subcarrier the same transmit power $\mathcal{P}_{\mathrm{R},k} = \mathcal{P}_{\mathrm{R}}/N_{\mathrm{C}}$ is achieved. In order to meet this power constraint per subcarrier, the amplification factor on subcarrier k calculates as

$$\beta_k = \sqrt{\frac{\mathcal{P}_{\mathrm{R},k}}{|h_{\mathrm{SR},k}|^2 \mathcal{P}_{\mathrm{S},k} + \sigma_n^2}} \ . \tag{3}$$

The transmit signal on subcarrier k is $x_{\mathrm{R},k} = \beta_k \cdot y_{\mathrm{SR},k}$. Correspondingly, the receive signal (2) at D equals

$$y_{\mathrm{RD},k} = h_{\mathrm{RD},k}\, \beta_k \cdot y_{\mathrm{SR},k} + n_{\mathrm{RD},k} \tag{4a}$$

$$= \beta_k h_{\mathrm{RD},k} h_{\mathrm{SR},k} \cdot x_{\mathrm{S},k} + \beta_k h_{\mathrm{RD},k} n_{\mathrm{SR},k} + n_{\mathrm{RD},k} \tag{4b}$$

$$= h_{\mathrm{SRD},k} \cdot x_{\mathrm{S},k} + n_{\mathrm{SRD},k} \tag{4c}$$

with equivalent channel coefficient $h_{\mathrm{SRD},k} = \beta_k h_{\mathrm{RD},k} h_{\mathrm{SR},k}$ and equivalent noise term $n_{\mathrm{SRD},k} = \beta_k h_{\mathrm{RD},k} n_{\mathrm{SR},k} + n_{\mathrm{RD},k}$ of variance $\sigma_{n,\mathrm{SRD},k}^2 = (\beta_k^2 |h_{\mathrm{RD},k}|^2 + 1)\sigma_n^2$. Both receive signals $\mathbf{y}_{\mathrm{SD}}$ and $\mathbf{y}_{\mathrm{RD}}$ are than combined using MRC per subcarrier. In ordert to achieve the maximum SNR on each subcarrier, the varying noise variances of both links have to be considered in the MRC as

$$\tilde{x}_{\mathrm{MRC},k} = \frac{h_{\mathrm{SD},k}^*}{\sigma_n^2} \cdot y_{\mathrm{SD},k} + \frac{h_{\mathrm{SRD},k}^*}{\sigma_{n,\mathrm{SRD},k}^2} \cdot y_{\mathrm{RD},k} \tag{5a}$$

$$= h_{\mathrm{MRC},k} \cdot x_{\mathrm{S},k} + n_{\mathrm{MRC},k} \tag{5b}$$

with equivalent parameters

$$h_{\mathrm{MRC},k} = \frac{|h_{\mathrm{SD},k}|^2}{\sigma_n^2} + \frac{|h_{\mathrm{SRD},k}|^2}{\sigma_{n,\mathrm{SRD},k}^2} \tag{6a}$$

$$\sigma_{n,\mathrm{MRC},k}^2 = h_{\mathrm{MRC},k} \ . \tag{6b}$$

B. Amplify-Forward with Constant Gain (AF-CG)

In contrast to AF-CP an amplification in time domain does not require any FFT or IFFT at R and corresponds to an equal gain on all subcarriers (compare instantaneous power scaling (IPS) in [7]). In order to meet the power constraint $\mathcal{P}_{\mathrm{R}}$, the amplification factor calculates as

$$\beta = \sqrt{\frac{\mathcal{P}_{\mathrm{R}}}{\|\mathbf{h}_{\mathrm{SR}}\|^2 \mathcal{P}_{\mathrm{S},k} + N_{\mathrm{C}}\, \sigma_n^2}} \tag{7}$$

and the transmit signal on subcarrier k is now given by $x_{\mathrm{R},k} = \beta \cdot y_{\mathrm{SR},k}$. Thus, more power is allocated by the relay to subcarriers with receive signals of larger amplitude $|y_{\mathrm{SR},k}|$, i.e., to subcarriers with high SNR on the SR link. The MRC equals (5) and (6) with constant β.

C. Decode-Forward (DF)

In order to exploit the channel code $\mathcal{C}$ at the relay, the receive sequence $\mathbf{y}_{\mathrm{SR}}$ is demodulated and an APP decoder is used to calculate the LLRs for the information and the code bits as shown in Figure 2. The calculated LLRs L_b for the information bits are quantized and the estimates $\hat{b}_{\mathrm{DF}}$ for the information bits are than re-encoded by the same channel code $\mathcal{C}$ yielding the estimate $\hat{\mathbf{c}}_{\mathrm{DF}} \in \Gamma$ for the codeword. The interleaved code bits are again mapped to N_{C} M-QAM

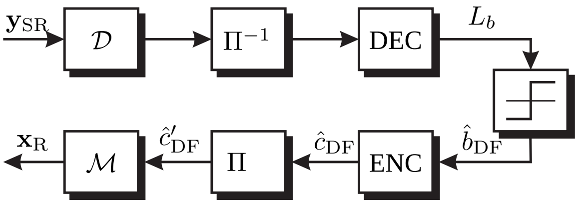

Fig. 2. Block diagram for a Decode-Forward (DF) relay, where the estimated information bits $\hat{b}_{\mathrm{DF}}$ given by the quantized LLRs L_b are used for re-encoding.

symbols and the corresponding OFDM word $\mathbf{x}_{\mathrm{R}}$ is transmitted to the destination.

Assuming perfect decoding at the relay (i.e., $\mathbf{x}_{\mathrm{R}} = \mathbf{x}_{\mathrm{S}}$), the optimum MRC at the destination is given by

$$\tilde{x}_{\mathrm{MRC},k} = \frac{1}{\sigma_n^2}\left(h^*_{\mathrm{SD},k} \cdot y_{\mathrm{SD},k} + h^*_{\mathrm{RD},k} \cdot y_{\mathrm{RD},k}\right) \tag{8a}$$

$$= h_{\mathrm{MRC},k} \cdot x_{\mathrm{S},k} + n_{\mathrm{MRC},k} \tag{8b}$$

with equivalent parameters

$$h_{\mathrm{MRC},k} = \frac{1}{\sigma_n^2}\left(|h_{\mathrm{SD},k}|^2 + |h_{\mathrm{RD},k}|^2\right) \tag{9a}$$

$$\sigma^2_{n,\mathrm{MRC},k} = h_{\mathrm{MRC},k}\ . \tag{9b}$$

However, in general the decoding at R is not perfect leading to decision errors at the relay. If the RD link is much stronger then the SD link, these decision errors will have an dominating impact to the performance at D as perfect decoding is the underlying assumption for the MRC (8). Consequently, it would be very beneficial to exploit knowledge about reliability of the relay at the destination, e.g., by using knowledge about the SNR on the SR link.

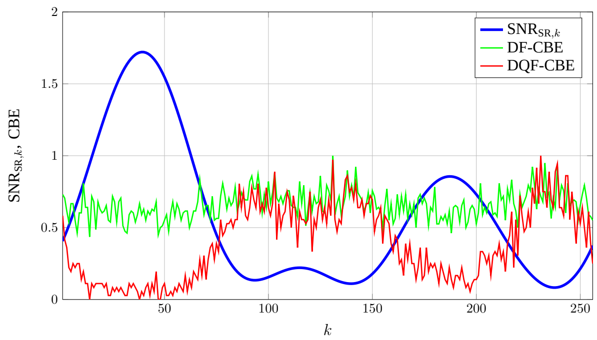

Fig. 3. $\mathrm{SNR}_{\mathrm{SR},k}$ and normalized code bit errors (CBEs) of DF and DQF for an arbitrary channel realization with $N_{\mathrm{H}} = 5$ taps in time domain and $N_{\mathrm{C}} = 256$ subcarriers.

Fig. 3 shows for a fixed arbitrary channel the SNR on the $N_{\mathrm{C}} = 256$ subcarriers of the source-relay link. Additionally, the normalized bit errors for the interleaved code bits $\hat{c}'_{\mathrm{DF}}$ achieved by the transmission of a large number of blocks over this channel are shown. For these simulations, BPSK modulation and an optimized LDPC code have been applied. Obviously, the code bit errors (CBEs) are uniformly distributed over the subcarriers and no direct relationship between the $\mathrm{SNR}_{\mathrm{SR},k}$ and the CBE is observable. In case of a decoding failure (i.e., $\hat{\mathbf{b}}_{\mathrm{DF}} \neq \mathbf{b}$), an erroneous information sequence is used for the re-encoding leading to a wrong code word $\hat{\mathbf{c}}_{\mathrm{DF}}$ and interleaved code word $\hat{\mathbf{c}}'_{\mathrm{DF}}$. Based on the encoder structure, information bit errors may distribute over the whole code word and, thereby, over the whole OFDM word $\mathbf{x}_{\mathrm{R}}$. Thus, it is difficult to achieve some kind of reliability information of the SR-link at the destination subcarrier-wise.

D. *Decode-Estimate-Forward (DEF)*

One approach to exploit the varying reliability of the bits at R is given by the application soft information relaying techniques. In case of Decode-Estimate-Forward (DEF) the expectation values for the code bits are transmitted by the relay [6]. However, as the transmit signal is now continuously distributed, the distribution of $x_{\mathrm{R},k}$ has to be determined in order to calculate the corresponding LLRs at the destination correctly. For single-carrier systems the distribution can be approximated by investigating the sequence of soft bits as described in [6]. In case of OFDM, the quality of the subcarriers varies and consequently it is not possible to determine the distribution of the soft bits in this way [11]. Thus, in order to utilize the channel quality of the SR-link at the destination, the new approach DQF is proposed subsequently.

E. *Decode-Quantize-Forward (DQF)*

For the new Decode-Quantize-Forward (DQF) approach not the LLRs L_b for the information bits but the LLRs L_c for the code bits determined by the APP are quantized leading to the estimate $\hat{\mathbf{c}}_{\mathrm{DQF}}$ for the code bits as shown in Figure 4. In contrast to DF, this estimate $\hat{\mathbf{c}}_{\mathrm{DQF}}$ is not necessarily a valid code word of Γ.

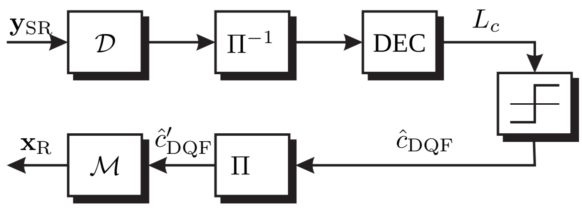

Fig. 4. Block diagram for a Decode-Quantize-Forward (DQF) relay, where the estimated code bits $\hat{c}_{\mathrm{DQF}}$ given by the quantized LLRs L_c are transmitted.

As can be observed in Fig. 3, for DQF less CBEs occur at high $\mathrm{SNR}_{\mathrm{SR},k}$, whereas erroneous estimates for the code bits are more likely for low $\mathrm{SNR}_{\mathrm{SR},k}$. In order to exploit this effect, a modified MRC (mMRC) for the destination is proposed which reduces the influence of decoding errors at R. To this end, we construct a model for the relay based on a linear zero forcing (ZF) equalizer and derive the corresponding MRC based on this DQF model. It is important to note, that this mMRC follows a heuristic and is not constructed to guarantee the maximum SNR at D.

Assuming a linear ZF equalizer at R, the output

$$\tilde{x}_{\mathrm{R,ZF},k} = \frac{y_{\mathrm{SR},k}}{h_{\mathrm{SR},k}} = x_{\mathrm{S},k} + \frac{n_{\mathrm{SR},k}}{h_{\mathrm{SR},k}} \tag{10a}$$

$$= x_{\mathrm{S},k} + n_{\mathrm{ZF},k} \tag{10b}$$

corresponds to the transmit signal $x_{\mathrm{S},k}$ disturbed by an equivalent noise term $n_{\mathrm{ZF},k}$ with variance $\sigma^2_{\mathrm{ZF},k} = \sigma_n^2/|h_{\mathrm{SR},k}|^2$. Thus, weak subcarriers lead to a strong amplification of the effective noise and would likely cause decision errors. However, as such a quantization would again neglect reliability, for the derivation of the DQF model it is assumed, that the equalizer output (10) is directly forwarded to D yielding the receive signal

$$\begin{aligned} y_{\mathrm{RD,ZF},k} &= h_{\mathrm{RD},k} \cdot \tilde{x}_{\mathrm{R,ZF},k} + n_{\mathrm{RD},k} && \text{(11a)} \\ &= h_{\mathrm{RD},k} \cdot x_{\mathrm{S},k} + \frac{h_{\mathrm{RD},k}}{h_{\mathrm{SR},k}} n_{\mathrm{SR},k} + n_{\mathrm{RD},k} && \text{(11b)} \\ &= h_{\mathrm{RD},k} \cdot x_{\mathrm{S},k} + n_{\mathrm{RD,ZF},k} && \text{(11c)} \end{aligned}$$

with equivalent noise term $n_{\mathrm{RD,ZF},k}$ of variance

$$\sigma^2_{n,\mathrm{RD,ZF},k} = \left(1 + \frac{|h_{\mathrm{RD},k}|^2}{|h_{\mathrm{SR},k}|^2}\right) \sigma_n^2 \, . \tag{12}$$

Following the idea, that the transmit signal $\mathbf{x}_{\mathrm{R}}$ of the DQF relay and the transmit signal of the ZF equalizer (10) share the same property that a weak SR link leads to strong disturbance, one may use the MRC being optimum for (11) and (12) as an approach for DQF.

Using this ZF based model for the DQF relay, the received signals $\mathbf{y}_{\mathrm{SD}}$ and $\mathbf{y}_{\mathrm{RD}}$ are once again combined by MRC

$$\begin{aligned} \tilde{x}_{\mathrm{mMRC},k} &= \frac{h^*_{\mathrm{SD},k}}{\sigma_n^2} \cdot y_{\mathrm{SD},k} + \frac{h^*_{\mathrm{RD},k}}{\sigma^2_{n,\mathrm{RD,ZF},k}} \cdot y_{\mathrm{RD},k} && \text{(13a)} \\ &= \frac{h^*_{\mathrm{SD},k}}{\sigma_n^2} \cdot y_{\mathrm{SD},k} + \frac{1}{\sigma_n^2} \frac{h^*_{\mathrm{RD},k}}{1 + \frac{|h_{\mathrm{RD},k}|^2}{|h_{\mathrm{SR},k}|^2}} \cdot y_{\mathrm{RD},k} && \text{(13b)} \\ &= h_{\mathrm{mMRC},k} \cdot x_{\mathrm{S},k} + n_{\mathrm{mMRC},k} && \text{(13c)} \end{aligned}$$

with equivalent parameters

$$\begin{aligned} h_{\mathrm{mMRC},k} &= \frac{1}{\sigma_n^2} \left(|h_{\mathrm{SD},k}|^2 + \frac{|h_{\mathrm{RD},k}|^2}{1 + |h_{\mathrm{RD},k}|^2/|h_{\mathrm{SR},k}|^2} \right) && \text{(14a)} \\ \sigma^2_{n,\mathrm{mMRC},k} &= h_{\mathrm{mMRC},k} \, . && \text{(14b)} \end{aligned}$$

This approach performs a weighting with respect to the $\mathrm{SNR}_{\mathrm{SR},k}$ or, correspondingly, with respect to the reliability of the estimates of the decoder output. For $|h_{\mathrm{SR},k}| \gg |h_{\mathrm{RD},k}|$ this mMRC equals the common MRC (cMRC) where perfect decoding at the relay is assumed inherently. In contrast, for very unreliable SR subcarriers (i.e., $|h_{\mathrm{SR},k}| \ll |h_{\mathrm{RD},k}|$) the signal $y_{\mathrm{RD},K}$ is discarded at the destination. Thus, a simple approach for exploitation of the varying decoding reliability at the relay is achieved, which does not suffer from any computational problems as DEF [11].

IV. System Evaluation

In this section we present simulation results for an OFDM-based relaying system with $N_{\mathrm{C}} = 256$ subcarriers, where block fading channels of length $N_{\mathrm{H}} = 5$ with a path loss factor of $\alpha = 4$ are assumed. The SD distance is fixed to one (i.e., $d_{\mathrm{SD}} = 1$) and the distances d_{SR} and d_{RD} are normalized with respect to d_{SD}. Investigated are the BER at the destination for direct transmission (DT), AF with equal transmit power per subcarrier (AF-CP), AF with equal gain per subcarrier (AF-CG), DF, and DQF with common MRC (cMRC) as well as with modified MRC (mMRC). In order to compare systems of same spectral efficiency, 4-QAM is considered for direct transmission and 16-QAM is used for relaying systems. For coding either optimized LDPC codes of rate $R_{\mathrm{C}} = 0.5$ in combination with SPA or non-recursive non-systematic convolutional encoder of same rate with constraint length 5 in combination with BJCR decoder are used.

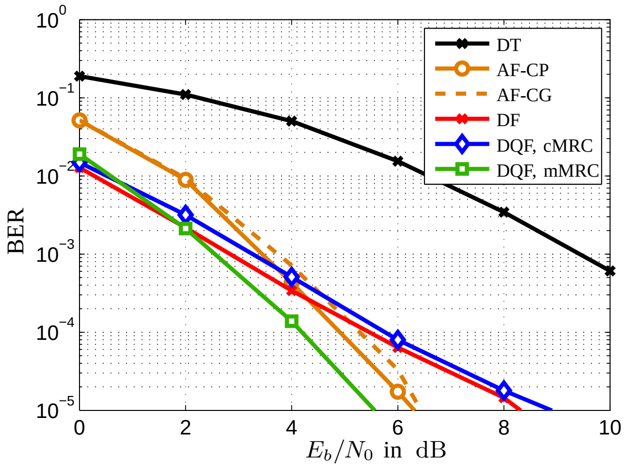

Fig. 5. BER for Decode-Forward (DF), Amplify-Forward with Constant Power (AF-CP), Amplify-Forward with Constant Gain (AF-CG), Decode-Quantize-Forward (DQF) with common and with modified MRC (cMRC, mMRC) and 16-QAM transmission, LPDC code with code rate $R_{\mathrm{C}} = 0.5$, $N_{\mathrm{H}} = 5$ channel taps, path loss factor $\alpha = 4$, $N_{\mathrm{C}} = 256$ subcarrier. Direct transmision (DT) with 4-QAM. Relay located in the middle between S and R.

Figure 5 shows the BER assuming LDPC codes and the relay positioned in the middle between S and R, i.e., $d_{\mathrm{SR}} = d_{\mathrm{RD}} = 0.5$. Obviously, the relaying approaches outperform the direct transmission in this system configuration significantly. The new approach DQF in combination with the modified MRC achieves the best performance results, as the effect of error propagation based on decoding errors at the relay is limited by the mMRC. For example, it outperforms DF by approximately $2.5\,\mathrm{dB}$ at BER 10^{-5}. Additionally, it can be observed that DQF with a common MRC (based on the assumption of error-free decoding at the relay (8)) leads to worse performance. Finally, the new scheme is able to achieve the same diversity as both AF schemes.

Figure 6 shows for the same relay position the BER in case of convolutional codes. Basically, the same performance behavior is observable, i.e. DQF with mMRC outperforms DF significantly and achieves diversity comparable to the AF approaches. The AF approaches behave quite similar, with slight gains for AF-CP. Taking the reduced complexity of AF-CG due to the direct amplification in time domain into account, the later one achieves a good tradeoff between performance and complexity.

Figure 7 shows for the LDPC coded system and fixed $E_b/N_0 = 4\,\mathrm{dB}$ the BERs for varying positions of the relay on

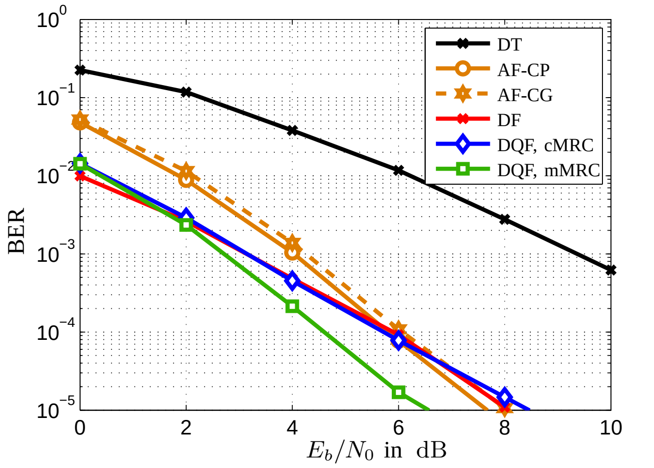

Fig. 6. BER for Decode-Forward (DF), Amplify-Forward with Constant Power (AF-CP), Amplify-Forward with Constant Gain (AF-CG), Decode-Quantize-Forward (DQF) with common and with modified MRC (cMRC, mMRC) and 16-QAM transmission, convolutional code with code rate $R_C = 0.5$ and constraint length 5, $N_H = 5$ channel taps, path loss factor $\alpha = 4$, $N_C = 256$ subcarrier. Direct transmision (DT) with 4-QAM. Relay located in the middle between S and R.

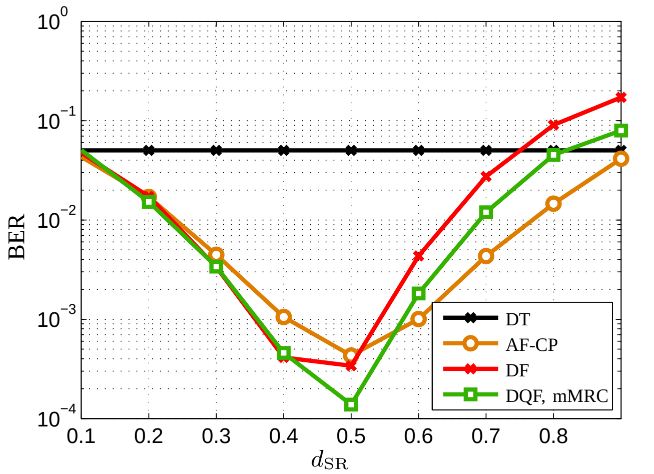

Fig. 7. BER for Decode-Forward (DF), Decode-Quantize-Forward (DQF) with modified MRC (mMRC) and 16-QAM transmission, LPDC code with code rate $R_C = 0.5$, $N_H = 5$ channel taps, path loss factor $\alpha = 4$, $N_C = 256$ subcarrier, and varying relay position. Direct transmision (DT) with 4-QAM and fixed $E_b/N_0 = 4$ dB.

the line between S and D, i.e., $d_{SD} = d_{SR} + d_{RD}$. Obviously, the new DQF approach with cMRC outperforms DF for all positions of this investigated scenario. However, if the relay is positioned closer to the destination the well-known superior behavior of AF-CP is recognized.

V. Summary

In this paper OFDM-based relaying systems are considered. The exploitation of the quality of the source-relay link plays an important role in the implementation of regenerative relaying protocols. As soft information relaying can not be applied easily in OFDM systems due to the varying channel quality per subcarrier, we present here a new approach called Decode-Quantize-Forward (DQF). In combination with a modified maximum ratio combiner (mMRC) this approach outperforms the well-known Decode-Forward (DF) method significantly. In the future, improved combining schemes should be investigated.

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