Comparison of General Multi-Carrier Schemes in Two Way Relaying Channels

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***Abstract*—In this extended abstract multi-carrier transmission schemes applying general waveforms are discussed within two-phase two way relay channels (TWRCs), where two users communicate simultaneously on the same resources to an assisting relay between the users. The relay has to deal with the superposition of both users, interference of the channel and additional practical impairments like frequency and timing offsets. To be more robust with these impairments, filter bank multi-carrier (FBMC) with general waveforms offering better time-frequency properties than orthogonal frequency division multiplexing (OFDM) applying rectangular waveform by the cost of additional interference introduced by the waveforms. The main contribution of this work is the performance analysis w.r.t. the sensitivity against phase differences of the user channels in QAM/FBMC and OQAM/FBMC. The interference level of QAM/FBMC is immune against phase rations between the users. OQAM/FBMC suffers from phase differences, if the relay is equipped with one antenna. BER performance analysis show that under realistic channel conditions QAM/FBMC outperforms OFDM as well as OQAM/FBMC. By adding a second antenna at the relay the performance will change in favor to OQAM/FBMC.**

I. Introduction and System Model

In TWRCs two users A and B exchange data over a relay R with each other. The users are equipped with one antenna, whereas the relay is equipped with either one or two antennas. All nodes are restricted to the half duplex constraint. Here, we assume a two phase transmission, where in the multiple access (MA) phase both users transmit their data simultaneously to the relay forming a physical-layer network coding (PLNC) message based on the superposition of channel disturbed signals of both users. Based on the receive signal at the relay, the relay sends a relay message to the users in the broadcast (BC) phase. The users try to decode their messages, due to the knowledge of their own data. The multi-carrier scheme cyclic prefix OFDM (CP-OFDM) in combination with TWRC is analyzed in [1], [2]. However, CP-OFDM suffers from time variant channels or from practical constraints like carrier frequency offset (CFO), which cannot be completely removed within TWRCs. In [3]–[5], QAM/FBMC (QAM/FBMC) within TWRC has been analyzed to combat the weakness of CP-OFDM. FBMCs in general is more robust considering practical influences as conventional CP-OFDM [7], [8]. In this extended abstract non-orthogonal QAM/FBMC and the orthogonal schemes offset-QAM/FBMC (OQAM/FBMC) and OFDM will be compared within TWRC w.r.t. phase differences between users. By numerical evaluations, the BER performances of the different schemes are analyzed applying different detection schemes at the relay.

As illustrated in Fig. 1 two users A and B encode their information vectors $\mathbf{u}_i$ of $i \in \{\mathrm{A}, \mathrm{B}\}$ by a LDPC code to the code words $\mathbf{c}_i$. The modulator maps the code words to a symbol matrix $\mathbf{D}_i$ with size $N_k \times N_\ell$, where N_k is the number of sub-carriers and N_ℓ is the number of occupied time instances. Each complex symbol $d_i^{(k,\ell)}$ within the matrix $\mathbf{D}_i$ is a M-PSK modulated symbol shifted to the time-frequency point (k, ℓ) by a general transmit waveform given by

$$g_{\mathrm{Tx}}^{(k,\ell)}(t) = g_{\mathrm{Tx}}(t - \ell T_0)\, \mathrm{e}^{j2\pi k F_0 t}, \qquad (1)$$

where ℓT_0 is the time symbol spacing and kF_0 is the sub-carrier spacing. A general non-orthogonal waveform $g_{\mathrm{Tx}}^{(k,\ell)}(t)$ introduces interference into the multi-carrier system, but offers good localization properties in time and frequency direction even under practical constraints, e.g. timing offsets (TOs), CFOs, Doppler spread or time spreads.

QAM/FBMC: The transmit signal of user i is given by the summation of the complex data symbols shifted to the corresponding time- frequency point by

$$x_i(t) = \sum_{k=0}^{N_k-1} \sum_{\ell=0}^{N_\ell-1} d_i^{(k,\ell)} g_{\mathrm{Tx}}^{(k,\ell)}(t) \qquad (2)$$

With a rectangular waveform and applying additionally a cyclic prefix (CP) this corresponds to the well-known orthogonal CP-OFDM transmission. If the delay spread does not exceed the CP no inter-symbol interference (ISI) or inter-carrier interference (ICI) is introduced. Thus, simple one-tap equalization is sufficient. However, waveforms not fulfilling the first Nyquist criterion will introduce interference on neighboring time-frequency points.

OQAM/FBMC: When using offset-QAM (OQAM) modulation, a half symbol delay between real and imaginary components is introduced leading to

$$x_i(t) = \sum_{k=0}^{N_k-1} \sum_{\ell=0}^{N_\ell-1} \exp\left(j(\ell + k)\frac{\pi}{2}\right) \times \left[d_{\mathrm{Re},i}^{(k,\ell)} g_{\mathrm{Tx}}^{(k,\ell)}(t) + d_{\mathrm{Im},i}^{(k,\ell)} g_{\mathrm{Tx}}^{(k,\ell)}\left(t - \frac{T_0}{2}\right)\right]. \qquad (3)$$

Where, $d_{\mathrm{Re},i}^{(k,\ell)}$ determines the real part and $d_{\mathrm{Im},i}^{(k,\ell)}$ the imaginary part of the user symbol.

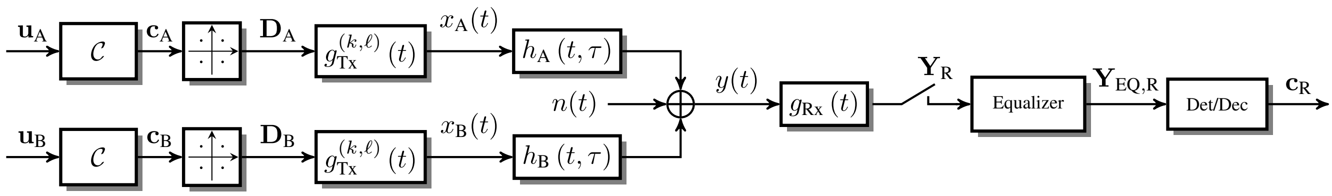

Fig. 1. Block diagram of the multiple access channel (MAC) phase used a relay with one antenna at the relay

The factor $\exp\left(j(\ell+k)\frac{\pi}{2}\right)$ leads to alternating purely real or purely imaginary symbols in the time-frequency grid. This overall design shifts the interference of the direct neighbors in the time-frequency grid introduced by the general waveform to the imaginary part [6]. At the receiver, the conjugated factor $\exp\left(-j(\ell+k)\frac{\pi}{2}\right)$ is applied and by taking the real part operator the interference in case of a Point-to-Point (P2P) transmission is suppressed totally [7]. Thus, if the waveforms only introduce interference to the direct neighbors in the time-frequency grid the system can suppress the internal interference totally and an orthogonal system is achieved.

Two Phase TWRC Communication: Especially, in TWRCs a robust design of the transmission scheme against practical influences is important. Subsequently, we focus on these multi-carrier schemes within TWRCs. Hence, both user signals $x_i(t)$ with $i \in \{A, B\}$ will be affected by doubly dispersive channels $h_i(t,\tau)$ and superimposed at the relay. After matched filtering and sampling, the signal is equalized to suppress the interference added by the channels and the waveforms. The matrix $\mathbf{Y}_{EQ,R}$ is achieved at the output of the equalizer with dimension $N_k \times N_\ell$.

Subsequently, we illustrate the impact of the chosen multi-carrier schemes on the received signal at the relay in case of varying phase condition between $h_A(t,\tau)$ and $h_B(t,\tau)$ for CP-OFDM, 2) QAM/FBMC with an isotropic Gaussian waveform and 3) OQAM/FBMC with squared root raised cosine (SRRC) waveform with roll-off factor of 1. The channel of user A is fixed to $h_A(t,\tau) = \delta(t)\,\delta(\tau)$ and the channel of user B is given by $h_A(t,\tau) = \delta(t)\,\delta(\tau)\,e^{j\phi}$ and evaluated at three different phases. Assuming BPSK modulation for simplicity Fig. 2 indicates the impact of the phase rotation on the transmit signals of user B, where the provided labels indicate the bit to symbol mapping.

Fot the different multi-carrier schemes the impact of the phase rotations on the superimposed signal is visualized by IQ diagrams in the right lower part. In case of CP-OFDM discrete points are achieved and labeled by the corresponding pair of code bits (c_A, c_B). In contrast, QAM/FBMC introduces interference leading to smearing signal points. The actual phase rotation does not affect the amount of interference.

Finally, in case of OQAM/FBMC without phase difference ($\phi = 0$) three straight lines are achieved in the signal space. By considering only the real part of the signals we would achieve the same discrete points as in CP-OFDM. However, with phase differences a huge amount of interference is caused by this superposition. Thus, considering only the real part is no longer adequate as this suppresses too much useful information.

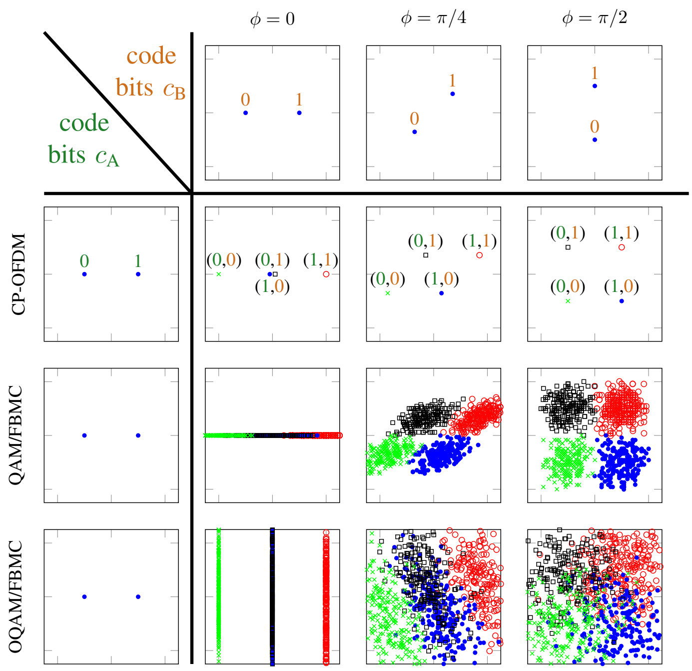

Fig. 2. IQ diagrams of the superposition at the relay w.r.t. different phase distortions.

In addition to this illustrative discussion, an analysis of the interference power at the relay will be given in the full paper.

Detection schemes: The relay estimates a joint message $\mathbf{c}_R$ based on the equalized signal $\mathbf{Y}_R$, which should be transmitted in the BC phase [9], [13]. In separate channel decoding (SCD), the relay detects the code bits c_A and c_B of each user individually and generates a network coded bit $c_R = c_A \oplus c_B$ by applying the XOR operator. The detection schemes joint channel decoding and physical-layer network coding (JCNC) and generalized JCNC (G-JCNC) directly estimate the network coded message c_R. JCNC works in the same Galois field as the LDPC encoder, whereas G-JCNC exploits higher Galois fields. The performance of all schemes are sensitive against phase rotations [13].

In Fig.3(a) the bit error rate (BER) performance of CP-OFDM w.r.t. to phase difference is shown. SCD suffers from the impossible separation of the code bits c_A and c_B in case of $\phi = 0$, where JCNC and G-JCNC achieves almost the same performance. The performance of SCD and G-JCNC improves with higher ϕ. Where $\phi = 0.5$ achieves the best performance, here the maximum euclidean distance of the possible discrete code bit pairs (c_A, c_B) of the discrete points

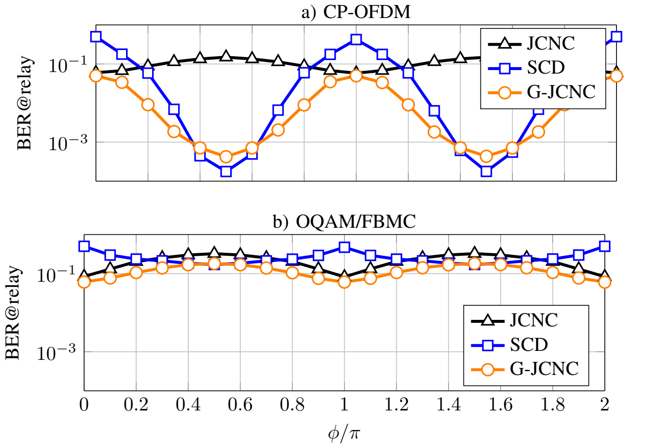

Fig. 3. BER performance of the detection schemes at the relay with different phases ϕ with a) OFDM [13] b) OQAM/FBMC with an SNR of 7dB

is achieved in the IQ diagram (in Fig. 2). Whereas, the BER performance of JCNC is degrading. In contrast, Fig. 3(b) shows the performance of OQAM/FBMC with SRRC. For no phase rotation, all detection schemes in OQAM/FBMC achieves comparable BER performances for all detection schemes. As expected the performance of all schemes suffer from the internal interference with phase rotation. In the full paper the corresponding equalizer will be introduced in detail.

II. Performance Evaluation

For the performance evaluation the multi-carrier schemes with QPSK modulation are considered, where Rayleigh fading channels with N_h complex channel coefficient h_ι are assumed. The time delay τ_ι and the Doppler shift of channel tap h_ι are equally distributed within a range of $[0\tau_{\max}]$ and $[-\nu_{\max}-\nu_{\max}]$, respectively. For simulations, the maximum time delay and maximum Doppler shift are restricted to $\tau_{\max} = 0.2T_0$ and $\nu_{\max} = 0.2F_0$, respectively, where F_0 is the sub-carrier spacing and T is the time symbol spacing. In total, 16 sub-carriers and 10 time symbols are used to generate a frame containing 160 data symbols.

Fig. 4(a) shows the BER performance at the relay for OFDM, QAM/FBMC and OQAM/FBMC with one antenna at the relay using G-JCNC as detection scheme. QAM/FBMC with an isotropic Gaussian waveform outperforms all other schemes. OFDM performs slightly worse, due to the broad characteristic of the rectangular waveform in the frequency domain. As mentioned above, OQAM/FBMC suffers from the phase difference of the channels and therefore has the worst performance in this scenario. The phase difference between two users is resolvable with two antennas as demonstrated in in Fig. 4(b). Here, OQAM/FBMC outperforms all other schemes offering the most robust design against huge distortions by doubly dispersive channels.

III. Summary And Outlook

In this extended abstract we analyze three different multi-carrier schemes and three different detection schemes regarding phase differences and BER performance at the re-

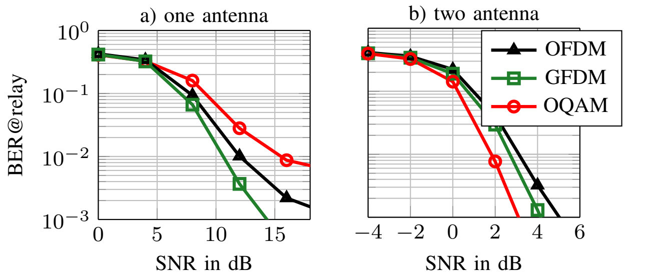

Fig. 4. BER performance at the relay of (a) one and (b) two antennas at the relay, with G-JCNC.

lay. QAM/FBMC outperforms OFDM and OQAM/FBMC if one antenna at the relay is used. If the relay is equipped with two antennas, the performance is shifted in favor of OQAM/FBMC. In the full paper we will provide a detailed derivation of the system model. Further performance investigations considering equalizers, detection schemes will be given, and the performance of different waveforms beside the Gaussian one will be compared by link level simulations. Furthermore, an extended bibliography will be provided.

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