Distributed Multiuser Two-Way AF Relaying Systems under Jamming Environment

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Abstract - A distributed multiuser two-way amplify-and-forward (AF) wireless relay strategy consisting of 2M sources (or 2M destinations) and N relays all equipped with single antenna per communication node is studied in this paper. All sources act as both sources and destinations with a self-interference cancelation process at the 2M destinations. The main objective is to design the closed-form of minimum mean square error (MMSE)-based relay amplifying matrices under a jamming environment with the transmit power constraint at the relays. Additionally, the system performance is evaluated in relation to the average bit error rate (BER) by computer simulation. With the derived optimal diagonal relay amplifying matrix, the jamming influence on system performance with various jamming fractions is examined numerically by using Monte-Carlo simulations. Furthermore, the BER performance under the broadband noise jamming environment is better than the one under the partial-band noise jamming (PBNJ) environment. Finally, the BER performance degrades as the PBNJ jamming fraction γ decreases.

Keywords - Amplify-and-forward (AF), Two-way relaying, relay amplifying matrix, minimum mean square error (MMSE), partial-band noise jamming (PBNJ).

1. INTRODUCTION

Diverse relay schemes have been studied over the past years in the wireless relay systems in order to achieve the gain of diversity order during data transmission between the source and destination. Therefore, an amplifying-and-forward (AF) relaying system has received more attention due to the lower complexity and shorter delay at the relays among various relay schemes [1]–[17]. In contrast to this, the relay amplifying matrices can be diagonal with the assumption that relays cooperate during data transmission in [5]–[8].

Recently, in [9]–[17], the two-way AF relaying strategy is applied in the wireless relaying systems for the purpose of reducing the spectral efficiency loss during data transmission between the source and the destination. As a result, the authors in [10]–[17] studied two-way AF wireless relay systems consisting of one relay with multiple antennas between two sources with multiple antennas per source. They designed the relay amplifying matrices under the transmit power constraint based on various criterions, such as minimum mean square error (MMSE), zero-forcing, and so on [10]–[17].

In particular, in [9], the multiuser two-way relaying scheme for interference limited systems where multiple pairs of users exchange information with their partners via an intermediate relay node in a two-phase communication scenario was studied. In [9], the case of only a single relay node with one antenna was investigated in the distributed multiuser two-way AF wireless relaying system during data transmission. Namely, to the best of authors’ knowledge, the distributed multiuser two-way AF wireless relay system consisting of 2M sources with only a single antenna per source, exchanging their information with each other, and N relays with only a single antenna per relay was not investigated in the literature, up to now.
In reality, wireless communication nodes are exposed to the risk of either friendly user interference or jamming signals during data transmission. Jamming signals can be intentionally broadcasted by enemies to disrupt the friendly user systems [18]. Additionally, the partial-band noise jamming (PBNJ) has been reported as a strong jamming strategy when a desired user employs a broadband system [19], [20]. To the best of authors’ knowledge, the distributed multiuser two-way AF relaying systems under PBNJ has not been analyzed in the literature.

Therefore, we force on a distributed multiuser two-way AF wireless relaying system consisting of 2M sources with only a single antenna per source and multiple relays with only a single antenna per relay in this paper. Additionally, PBNJ is considered for a jamming environment in this paper. That is, this paper will be the first one dealing with the PBNJ in the distributed multiuser two-way AF wireless relaying system consisting of 2M sources with only a single antenna per source and multiple relays with only a single antenna per relay. Moreover, a self-interference cancelation process at the 2M destinations is applied during data transmission. In addition, all sources act as both sources and destinations. The closed form of the optimal diagonal relay amplifying matrix is determined with both the relay transmit power constraint and the jamming environment based on the MMSE criterion. Additionally, the system performance is evaluated in relation to the average bit error rate (BER) by computer simulation. It was also observed that the gain of diversity order can occur as N increases in wireless relay systems, while the diversity order can suffer loss as the jamming signal power increases. Finally, it was seen that the BER performance degrades as the PBNJ fraction γ decreases for given M, N, and signal-to-noise ratio (SNR).

The remainder of this paper is organized into four sections. Section II describes the proposed system model and data transmission strategies. Section III provides the MMSE relay strategy for the distributed multiuser two-way AF wireless relaying system with the transmit power constraint at the relays under the jamming environment. Section IV shows the average BER simulation result. Finally, Section V concludes the paper.

Notation: Matrices, vectors, and scalars are denoted, respectively, by uppercase boldface, lowercase boldface, and italic characters (e.g., A, a, and a). The inverse, transpose, trace, and Hermitian of A are denoted, respectively, by $A^{-1}$, $A^T$, $tr(A)$, and $A^H$. The $N \times N$ identity and diagonal matrices are denoted, respectively, by $I_N$ and $\text{diag}(a_1, \ldots, a_N)$. Notations $||a||$ and $||A||_F$ denote the 2-norm of a and Frobenius-norm of A, respectively. The expectation, real, and Hadamard product operators are denoted by $E[\cdot]$, $\text{Re}(A) = (A + A^*)/2$, and $\otimes$, respectively.

II. SYSTEM MODEL AND DATA TRANSMISSION

Figure 1 shows the distributed multiuser two-way AF relay system consisting of 2M sources with only a single antenna per source under the jamming environment, exchanging their information with each other, and N relays with only a single antenna per relay to help their reliable communications, where M and N are greater than or equal to 2 for beamforming purposes with $N \geq 2M$. Here, all sources act as both sources and destinations, as shown in Fig. 1.

The bandpass noise at a receiver is modeled as a Gaussian noise with the power spectral density in a rectangular shape, e.g., the power spectral density of a bandpass additive white Gaussian noise (AWGN) with height $\frac{N_0}{2}$ over the band $|f - f_c| < \frac{BW}{2}$, else zero. Similarly, the PBNJ can be modeled as a bandpass Gaussian with PSD $\frac{N_0}{2}\gamma$ over $|f - f_c| < \frac{2BW}{2}$, else zero. Here, $f_c$ and $f$ denote the carrier frequency of the signal and the center frequency of the PBNJ, respectively, $\gamma$ is the PBNJ jamming fraction, $0 < \gamma < 1$, and $BW$ is the system bandwidth. Hence, the PBNJ is modeled as a complex Gaussian noise with zero mean and power $\frac{N_0 BW}{\gamma}$. In this paper, the $BW$ is normalized to 1. And $N_s = \frac{J}{BW}$ denotes the one-sided power spectral density of a jammer with total jamming power $J$, and the PBNJ fraction $\gamma$ is also equal to the probability of a jamming signal presence during the desired signal transmission in a frequency-hopped system. For example, in an orthogonal frequency division multiple access, a user subcarrier can be jammed with probability $\gamma$ because the subcarrier can be located in $\gamma BW$ band out of total BW. Here, the PBNJ column vectors $j_1 \in \mathbb{C}^{N_1}$, $j_2 \in \mathbb{C}^{N_2}$, and $j_3 \in \mathbb{C}^{M_1}$ are zero-mean complex AWGN with covariance matrices $\frac{N_0}{\gamma}I_{N_1}$, $\frac{N_0}{\gamma}I_{N_2}$, and $\frac{N_0}{\gamma}I_{M_1}$, respectively.

The complex channel matrices between the sources (group 1) located in the left side of the relay and the relay, the sources (group 2) located in the right side of the relay...
and the relay, the relay and the sources located in the left side of the relay, and the relay and the sources located in the right side of the relay are represented by $H_i \in \mathbb{C}^{N \times M} = [h_{i,1}, h_{i,2}, \cdots, h_{i,M}]$, $H_j \in \mathbb{C}^{N \times M} = [h_{j,1}, h_{j,2}, \cdots, h_{j,M}]$, $H^H_j \in \mathbb{C}^{M \times N} = [h_{j,1}, h_{j,2}, \cdots, h_{j,N}]$, and $H^H_i \in \mathbb{C}^{M \times N} = [h_{i,1}, h_{i,2}, \cdots, h_{i,N}]$ with $h_{i,m} = [h_{i,m,1}, h_{i,m,2}, \cdots, h_{i,m,N}]^T$, $h_{j,n} = [h_{j,n,1}, h_{j,n,2}, \cdots, h_{j,n,N}]^T$, $h^H_{i,m} = [h^*_{i,m,1}, h^*_{i,m,2}, \cdots, h^*_{i,m,N}]$, and $h^H_{j,n} = [h^*_{j,n,1}, h^*_{j,n,2}, \cdots, h^*_{j,n,N}]$. The entries of all backward and forward channels are independent and identically distributed (i.i.d.) zero-mean and unit-variance circular complex Gaussian. The time division duplex is identically distributed (i.i.d.) zero-mean and unit-variance of all backward and forward channels are independent and identically distributed (i.i.d.) zero-mean and unit-variance circular complex Gaussian. The time division duplex is employed for data transmission. Namely, there are two time slots for one exchange of information between the left sources (group 1) and the right sources (group 2) through the relay. In the first time slot, all sources broadcast their signal vectors $s_1 \in \mathbb{C}^{M \times 1} = [s_{1,1}, s_{1,2}, \cdots, s_{1,M}]$ and $s_2 \in \mathbb{C}^{M \times 1} = [s_{2,1}, s_{2,2}, \cdots, s_{2,M}]$ to the relay, simultaneously, with $E[\|\mathbf{s}\|] = E[\|\mathbf{s}_1\|] = M$. Therefore, the received signal vector $r \in \mathbb{C}^{N \times 1}$ at the relay inputs under the jamming environment can be written as

$$r_i = H^H_i s_1 + H^H_i s_2 + v_i + j_i$$

where $v_i \in \mathbb{C}^{N \times 1} = [v_{i,1}, v_{i,2}, \cdots, v_{i,N}]^T$ is an AWGN vector with zero-mean and covariance matrix $\sigma^2 v_i I_N$, i.e., $\sigma^2 v_{i,m} = \cdots = \sigma^2 v_{i,n} = \sigma^2 v_i$. In the second time slot, all the relays retransmit their received signals to the left and right sources (called left and right destinations) multiplied by a diagonal $N \times N$ relay amplifying matrix $F \in \mathbb{C}^{N \times N}$, i.e., $F = \text{diag} (f_1, \cdots, f_N)$, for the linear processing operation. Here, the reason why $F$ is diagonal is that multiple relays with only a single antenna per relay are distributed. In addition, the role of $F$ is to minimize the MSE between the equalized signals at two destinations and the originally transmitted signals from two sources. The transmitted signal vector $x \in \mathbb{C}^{N \times 1}$ at the relay outputs can be represented as

$$x = Fr$$

with the average total transmitted power given by $E[\|x\|^2] = P_x$. The received signal vectors $y_i \in \mathbb{C}^{M \times 1} = [y_{i,1}, \cdots, y_{i,M}]$ and $y_j \in \mathbb{C}^{M \times 1} = [y_{j,1}, \cdots, y_{j,M}]$ at the left and right destinations under the jamming environment are written, respectively, as

$$y_i = H^H_i x + v_i + j_i$$

and

$$y_j = H^H_j x + v_j + j_j$$

where $v_i = [v_{i,1}, \cdots, v_{i,M}]^T$ and $v_j = [v_{j,1}, \cdots, v_{j,M}]^T$ are AWGN vectors with zero-mean and covariance matrices $\sigma^2 v_i I_N$, i.e., $\sigma^2 v_{i,m} = \cdots = \sigma^2 v_{i,n} = \sigma^2 v_i$ and $\sigma^2 v_j I_N$, i.e., $\sigma^2 v_{j,m} = \cdots = \sigma^2 v_{j,n} = \sigma^2 v_j$, respectively. Substituting (1) and (2) into (3), respectively, the received signal vectors $y_i$ and $y_j$ after perfect cancelation of self-interference at the two groups of the destinations can be rewritten, respectively, as

$$y_i = H^H_i F H_1 s_1 + H^H_i F h_2 v_i + v_i + j_i$$

and

$$y_j = H^H_j F H_2 s_1 + H^H_j F h_1 v_j + v_j + j_j$$

The channel state information of $H_1, H_2, H^H_1$, and $H^H_2$ at the relay and the destinations can be obtained through standard training methods and fed back to the sources [21]. In addition, every channel coefficient is assumed to be invariant during data transmission.

Note that PBNJ $J_1$, $J_2$, and $J_3$ are independent in practice. And $P$ (signal jammed by $J_1$) = $\gamma_1$, $P_s$ (signal jammed by $J_2$) = $\gamma_2$, and $Pr$(signal jammed by $J_3$) = $\gamma_3$. For simplicity, it is assumed that $\gamma_1 = \gamma_2 = \gamma_3 = \gamma$.

Note also that, as stated earlier, the $N \times N$ relay amplifying matrix $F$ is diagonal, i.e., $F = \text{diag} (f_1)$. Additionally, an $N \times 1$ vector $a = \text{diag} (A)$ is denoted by the diagonal elements of $A$. Hence, using this notation, $F$ can be expressed by an $N \times 1$ relay amplifying vector $f = \text{diag} (F)$. This notation will be used to design the optimal diagonal $N \times N$ relay amplifying matrix $F^* \in \mathbb{C}^{N \times N}$ in the next section, where the superscript $\dagger$ stands for the optimum.

In the next section, the optimal relay amplifying matrix $F^*$ will be determined by using the MMSE criterion with the relay transmit power constraint under jamming environment.

III. DISTRIBUTED AF MMSE RELAY STRATEGY

To determine an optimal diagonal $F^*$ to minimize the MSE between the originally transmitted signal vectors from the sources and the expected signal vectors at the destinations. Hence, the desired optimization problem with the average total relay power constraint under the jamming environment can be written as
\[
F^* = \text{arg} \min J(F)
\]
\[s.t. \ E[\|h\|^2] = p_r \]
(6)
(7)

where the sum of the cost function \(J(F)\) in [22] is defined as

\[
J(F) = E[\|s_t - s_h\|^2] + E[\|s_y - s_s\|^2]
\]
(8)

where the expected signal vectors \(s_t\) and \(s_h\) are defined as \(s_t = \alpha_{1}^j y_2\) and \(s_h = \alpha_{1}^j y_1\), respectively. Here, scaling parameters \(\alpha_{1}^j\) at the group 1 of the destinations and \(\alpha_{2}^j\) at the group 2 of the destinations are introduced for the simplification of the derivation for the optimal \(F^*\). In addition, \(\alpha_{1}^j\) and \(\alpha_{2}^j\) are, in fact, equalization factors in the power constraint at the relay under the jamming environment. Hence, the optimal \(F^*\), \(\alpha^j\), and \(\lambda^j\) with the transmit power constraint at the relay under the jamming environment can be obtained, respectively, as

\[
F^* = diag(H_z H_z^H) \lambda^j
\]
\[\alpha^j = \sqrt{\frac{\lambda^j}{\lambda^j + h^H H_z^H H_h H_h^H}}
\]
\[\lambda^j = \frac{1}{\lambda^j + h^H H_z^H H_h H_h^H}
\]
(16)
(17)
(18)

where

\[
H_y = H_2 H_2^H + \frac{N_y}{\gamma} I_y + \frac{N_h}{\gamma} I_y
\]
\[H_z = H_2 H_2^H + H_2 H_2^H + \frac{N_y}{\gamma} I_y + \frac{N_h}{\gamma} I_y
\]
\[\varepsilon = M \left( \sigma_\gamma^2 + \sigma_\gamma^2 + \frac{N_y}{\gamma} + \frac{N_h}{\gamma} \right)
\]
(11)
(12)
(13)

using the linearity and cyclic properties of the trace function, under the assumption that data symbols, channel coefficients, and noises are independent of each other. Since the average total power at the relays is constrained to \(p_r\), the constrained Lagrangian optimization \(L(F, \alpha, \lambda)\) under the jamming environment [23], [24] can be applied as

\[
L(F, \alpha, \lambda) = J(F) + \lambda \left( tr(F H F^H) - p_r \right)
\]
(15)
and \( N = 10 \sim 30 \). It is assumed that all nodes have the same thermal noise power, i.e., \( \sigma^2 = \sigma^2_s = \sigma^2_n \). Additionally, various PBNJ conditions, i.e., 0.1%, 1%, and 10% of the desired signal bit energy with \( \gamma = 0.2 \sim 0.6 \), are modeled as AWGN, respectively. Namely, the variances of the jamming signals are chosen, respectively, to satisfy \( 10 \log_{10} \left( \frac{\sigma^2}{\sigma^2_s} \right) = 30, 20, \) and 10 dB, where \( \sigma^2 = E_s, \sigma^2_s = \frac{N}{\gamma} = E_j, t = 1, 2, 3. \)

Figure 2 shows the average BER versus input SNR in the distributed multiuser (\( M = 2 \)) two-way AF relaying system under the no-jamming environment using (16). It is found that the better BER performance is observed as the number of relays (\( N \)) increases for a given \( M \).

Figure 3 shows the BER performance versus input SNR in the distributed multiuser two-way AF relaying system under a jamming environment and relay transmit power constraints with three different jamming conditions, i.e., 10 dB, 20 dB, 30 dB, using \( M = 2, N = 6 \), and \( \gamma = 0.5 \), respectively. It can be seen that the BER performance worsens as the variances of jamming signals increase.

Figure 4 provides the average BER performance versus input SNR in the distributed multiuser two-way AF relaying system with the relay transmit power constraints under the jamming environment using three different PBNJ jamming fraction \( \gamma \), i.e., \( \gamma = 0.2, 0.4, 0.6 \), and the optimal diagonal relay amplifying matrix \( F \) in (16). The case of the broadband noise jamming is also presented. In other words, the PBNJ jamming fraction \( \gamma \) is equivalent to be 1, i.e., \( \gamma = 1 \). The no-jamming case is also provided to compare the difference between the no-jamming and jamming environments. For given \( M, N, \) and SNR, the BER performance degrades as the PBNJ jamming fraction \( \gamma \) decreases. It can be seen that the BER performance under the broadband noise jamming environment is better than the one under the PBNJ environment.

Figure 5 shows the BER performance versus input SNR in the distributed multiuser two-way AF relaying system under relay transmit power constraints with four different
jamming environments using $M = 2$, $N = 15$, and $\gamma = 0.5$, respectively. In practice, jamming signals can be added by enemies to disrupt friendly user systems throughout an entire wireless relay system. For instance, only source-relay (S-R) links, i.e., $j_0 \neq 0$, $j_0 = 0$ in (3), can be attacked by enemies during data transmission. Hence, Fig. 5 also provides the BER performance when jamming signals are added in both S-R and relay-destination (R-D) links, i.e., $j_0 \neq j_0 \neq 0$ in (3), and only S-R links, i.e., either $j_0 = j_0 = 0$ or $j_0 = j_0 = 0$, are added in all links, the BER performance is worse than the one when they are continuously added either S-R or R-D links under the same jamming condition. Finally, it is seen that the BER performance when $j_0 = j_0 = 0$, and $j_0 \neq 0$ are attacked is almost the same as the one when $j_0 = j_0 = 0$, $j_0 = 0$, and $j_0 \neq 0$ are applied.

V. CONCLUSION

The distributed multiuser two-way AF wireless relaying system under the jamming environment with the relay transmit power constraints was investigated in this paper. In addition, the closed form of the optimal diagonal relay amplifying matrix was determined by using the MMSE criterion. Furthermore, during data transmission, a self-interference cancelation process was carried out at the two groups of the destinations.

It was observed that the gain of diversity order can occur as $N$ increases in wireless relay systems, while the diversity order can suffer loss as the jamming signal power increases. Additionally, it was seen that the BER performance degrades as the PBNJ jamming fraction $\gamma$ decreases for given $M$, $N$, and SNR. Finally, it was found that the BER performance under the broadband noise jamming environment is better than the one under the PBNJ environment.

REFERENCES


Fig. 5. Average BER performance versus input SNR in distributed multiuser two-way AF relaying system under relay transmit power constraints with four different jamming environments using $M = 2$, $N = 15$, $\gamma = 0.5$, respectively.