Cluster-based Fair Allocation Algorithm for Multi-relay Single Carrier Distributed Networks

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***Abstract*—In this paper, we investigate a novel Random-based Fair-Allocation Fuzzy Comprehensive Evaluation-based Strategy with Relay Clustering (RFRC) for dual-hop Single-Carrier Frequency-Domain Equalization (SC-FDE) in cooperative systems with multiple relays and amplify-and-forward (AF) relaying. We address the problem of fair resource allocation for SC-FDE minimum mean square error (MMSE) receivers. In particular, relays are classified into multiple disjoint clusters through the K-means algorithm, where each cluster is identified by a centroid. The centroids of the clusters are directly related to the average amount of resources available to the relays belonging to that cluster, as well as the quality of the relaying links. The final centroids of the clusters after the convergence of the K-means algorithm, are used to generate contribution factors for each group. Different sub-channels are further associated with uniform random distribution where the thresholds of the uniform random variables are associated with the clusters contribution factors. RFRC for SC-FDE proves superior SER performance as well as improved diversity gain which is achieved by randomizing the allocation. The employed algorithm further improves the performance by optimizing the number of clusters. Numerical results are provided to corroborate the mathematical modeling.**

I. INTRODUCTION

Recently, as an alternative to MIMO technology, cooperative communication has attracted much attention, providing further system performance improvement compared to direct link communication. The improvement in the system performance can be maximized by relay selection optimization and resource allocation [1], [2].

In [3], Dang et al, address the problem of optimal resource (power, sub-channel, relay nodes) allocation for an OFDM system, aiming to maximize the transmission rate. The problem of sub-channel matching and joint relay selection has been addressed in [4] as an integer programming problem. This approach is complex and practically not feasible.

Although there have been considerable research efforts on the area of cooperative diversity built upon the assumption of frequency flat fading channels (e.g., [5] and references therein), many results have been reported on relaying schemes for cooperative networks with underlying frequency selective channels using OFDM technology (e.g., [6], [7]).

In this paper we address the fair allocation of sub-channels over clusters of relays to improve the system's SER performance. Fairness is guaranteed by considering cluster's contribution factors evaluated through the K-means algorithm and fuzzy evaluation-based method. Several selection ratio factors are presented, i.e. norm-based selection ratio (NBSR), instantaneous capacity-based selection ratio (CBSR), singular value based selection ratio (SVSR), and equalizer output signal quality-based selection ratio (EQSR) strategies, which are motivated by minimizing the instantaneous error rate and can be related to the relays' links' quality. These factors are further utilized by the fuzzy comprehensive evaluation algorithm to assign a weight to each relay. These weights and the amount of resources available to the relays are further used by the K-means algorithm to group the relays into disjoint clusters. The final cluster centroids are used to generate each cluster's contribution factor. The idea is to introduce an additional diversity through random allocation of the resources to different clusters according to their contribution factors. The proposed novel random resource allocation strategy is assessed in a dual-hop multi-relay SC-FDE system with underlying frequency selective Rayleigh fading channels.

Notation: $\overline{(.)}, (.)^{\mathrm{T}}, (.)^{\dagger}\mathrm{and}(.)^{\mathrm{H}}$ denote conjugate, transpose, pseudo inverse and Hermitian transpose operations, respectively. $*$ denotes linear convolution, $\|.\|_{\mathbf{F}}$ denotes the Frobenius norm of a vector, $|.|$ denotes the Cardinality of a vector, $[.]_{k,l}$ denotes the $(k,l)^{th}$ entry of a matrix, $[.]_k$ denotes the k_{th} entry of a vector, $\mathbf{I}_M$ denotes the identity matrix of size M, and $\mathbf{0}_{M\times M}$ denotes all-zero matrix of size $M \times M$. $\mathbf{Q} = \mathbf{Q}_M^{-1} = \mathbf{Q}_M^H$ represents the $M \times M$ IFFT matrix whose *(l,k)* element is given by $\mathbf{Q}(l,k) = 1/\sqrt{M}\exp(j2\pi lk/M)$ where $0 \leq l,k \leq M-1$. Bold upper-case letters denote matrices and bold lower-case letters denote vectors.

II. SYSTEM MODEL

We consider a multiple-relay assisted cooperative wireless communication system with a single source (S), N_R half-duplex relay terminals (R_i), $i = 1,2,...,N_R$, and a single destination (D). The source, destination, and all relays are equipped with single transmit and receive antennas. We assume the AF relaying and adopt the user cooperation protocol proposed by Nabar *et al.* [8]. Specifically, in the broadcasting phase, the source node transmits to the relay nodes and the destination node. In the relaying phase, the relay nodes forward a scaled noisy version of the received signal to the destination node.

The channel impulse responses (CIRs) for $S \rightarrow R_i$, $S \rightarrow D$, and $R_i \rightarrow D$ links for the i^{th} relay ter-

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minal and j^{th} transmission block are given by $\mathbf{h}^j_{SR_i} = \left[h^j_{SR_i}[0], ..., h^j_{SR}[L_{SR_i}]\right]^{\mathrm{T}}$, $\mathbf{h}^j_{SD} = \left[h^j_{SD}[0], ..., h^j_{SD}[L_{SD}]\right]^{\mathrm{T}}$ and $\mathbf{h}^j_{R_iD} = \left[h^j_{R_iD}[0], ..., h^j_{R_iD}[L_{R_iD}]\right]^{\mathrm{T}}$, respectively, where L_{SR_i}, L_{SD}, and L_{R_iD} denote the corresponding channel memory lengths. All $S \to R_i$, $S \to D$, and $R_i \to D$ links are assumed to experience frequency selective Rayleigh fading. The random vectors $\mathbf{h}_{SR_i}$, $\mathbf{h}_{SD}$, and $\mathbf{h}_{R_iD}$ are assumed to be independent zero-mean complex Gaussian with uniform power delay profile vectors.

During broadcasting phase, the information symbols are parsed to streams of $M \times 1$ blocks. To further remove inter-block interference and make the channel matrix circulant, a cyclic prefix (CP) with length $L_{CP} = L_{SR_i} + L_{R_iD} + 1$, i.e. the length of $\mathbf{h}_{SR_iD} = \mathbf{h}_{SR_i} * \mathbf{h}_{R_iD}$, is added between adjacent information blocks resulting $\mathbf{x}$. The received block symbol at the i^{th} relay terminal during the broadcasting phase will be given by

$$\mathbf{r}_{R_i} = \sqrt{E_{SR_i}}\mathbf{H}_{SR_i}\mathbf{x} + \mathbf{n}_{R_i}, \tag{1}$$

where $\mathbf{n}_{R_i}$ is the additive white Gaussian noise vector with each entry having zero-mean and variance of $N_0/2$ per dimension, E_{SR_i} is the average energy available at the relay terminal R_i which takes into account possibly different path loss and shadowing effects between the $S \to R_i$ link, and $\mathbf{H}_{SR_i}$ is $N \times N$ circulant matrix with entries $[\mathbf{H}_{SR_i}]_{k,l} = \mathbf{h}_{SR_i}((k-l) \bmod N)$, where N is the frame length. The relay terminals normalize each entry of the received signal $[\mathbf{r}_{R_i}]_n$, $n = 1, 2, ..., N$ by a factor of $\mathrm{E}\left(|[\mathbf{r}_{R_i}]_n|^2\right) = E_{SR_i} + N_0$ to ensure unit average energy and re-transmit the signal during the relaying phase one at a time. After some mathematical manipulations, the i^{th} relay's received signal at the destination terminal during the second signaling phase is given by

$$\mathbf{r}_i = \sqrt{\frac{E_{R_iD}E_{SR_i}}{E_{SR_i} + N_0}}\mathbf{H}_{R_iD}\mathbf{H}_{SR_i}\mathbf{x} + \tilde{\mathbf{n}}, \tag{2}$$

where E_{R_iD} is the average energy available at the destination terminal which takes into account possibly different path loss and shadowing effects between the $R_i \to D$ link, $\mathbf{H}_{R_iD}$ is $N \times N$ circulant matrix with entries $[\mathbf{H}_{R_iD}]_{k,l} = \mathbf{h}_{R_iD}((k-l) \bmod N)$, and each entry of the *effective* noise term $\tilde{\mathbf{n}}$ (conditioned on $\mathbf{h}_{R_iD}$) has zero mean and a variance of ρN_0 where ρ is defined by

$$\rho = 1 + \frac{E_{R_iD}}{E_{SR_i} + N_0}\sum_{m=0}^{L_{R_iD}} |\mathbf{h}_{R_iD}(m)|^2. \tag{3}$$

The destination terminal normalizes the received signal $\mathbf{r}_{R_i}$ by a factor of $\sqrt{\rho}$. This does not affect the signal-to-noise ratio (SNR), but simplifies the ensuing presentation [8]. After normalization, we obtain

$$\mathbf{r}_{D_i} = \sqrt{\gamma_i}\mathbf{H}_{R_iD}\mathbf{H}_{SR_i}\mathbf{x}_M + \mathbf{n}, \tag{4}$$

$$\gamma_i = \frac{(E_{SR_i}/N_0)E_{R_iD}}{1 + E_{SR_i}/N_0 \sum\limits_{l_{SR_i}=0}^{L_{SR_i}} \left|\mathbf{h}_{SR_i}(l_{SR_i})\right|^2 + E_{R_iD}/N_0 \sum\limits_{l_{R_iD}=0}^{L_{R_iD}} \left|\mathbf{h}_{R_iD}(l_{R_iD})\right|^2}, \tag{5}$$

where $\mathbf{n}$ is complex Gaussian with zero mean and variance of $N_0/2$ per dimension and γ is the scaling coefficient.

Next, we transform the received signal $\mathbf{r}_{D_i}$ to the frequency domain by applying the DFT (Discrete Fourier Transform) , i.e. multiplying by the $\mathbf{Q}$ matrix as following

$$\mathbf{Q}\mathbf{r}_{D_i} = \sqrt{\gamma_i}\mathbf{Q}\mathbf{H}_{R_iD}\mathbf{H}_{SR_i}\mathbf{x} + \mathbf{Q}\mathbf{n}. \tag{6}$$

Exploiting the circulant structure of the channel matrices, we have

$$\mathbf{H}_i = \mathbf{Q}^{\mathrm{H}}\mathbf{\Lambda_i}\mathbf{Q}, \tag{7}$$

where $\mathbf{\Lambda}_i$, i denotes SR_i, R_iD, is a diagonal matrix whose (n, n) element is equal to the n^{th} DFT coefficient of $\mathbf{h}_i$. Thus, (6) can be rewritten as following

$$\mathbf{Q}\mathbf{r}_{D_i} = \sqrt{\gamma_i}\mathbf{\Lambda_{R_iD}}\mathbf{\Lambda_{SR_i}}\mathbf{Q}\mathbf{x} + \mathbf{Q}\mathbf{n}. \tag{8}$$

Assigning N_C clusters, we use a fairness allocation technique by introducing the assignment matrix $\mathbf{A}_i$, $i = 1, \ldots, N_C$. $\mathbf{A}^k_i = 1$ if a relay in the i^{th} cluster contribute in relaying the k^{th} sub-channel and $\mathbf{A}^k_i = 0$, if it does not for $k = 1, \ldots, N$. Our goal is to find the values for $\mathbf{A}^k_i$, $i = 1, \ldots, N_C$, $k = 1, \ldots, N$, such that the fairness in sub-channels allocation is guaranteed, while providing better SER performance. Note that we assume $\sum\limits_{i=1}^{N} \mathbf{A}^k_i = 1$, for all values of k, i.e. each subchannel will be relayed through a relay of one cluster only.

III. Selection Criteria for SC-MMSE receivers

In order to implement joint fair resource allocation and relay clustering, we associate each relay R_i to a point in $\mathcal{R}^2$, i.e. R_i:$(s_i, \mathbf{e}(i))$, where s_i represents the amount of resources available to R_i, and $\mathbf{e}(i)$ stands for the relay's link qualities. In order to find $\mathbf{e}(i)$, we can consider different measures, all of which provide some perspective from the relays' underlying channel qualities.

In this section, we use different relay selection ratios for SC-FDE MMSE receivers, which can represent the relays' channel conditions and further be used as fuzzy factors to build the fuzzy relation matrix. All strategies mentioned in this section perform calculations assuming full and perfect channel knowledge at the receiver. In the following, the distributed system's overall $NN_R \times NN_R$ channel matrix $\mathbf{\Lambda}$ is defined as following

$$\mathbf{\Lambda} = \begin{pmatrix} \sqrt{\gamma_1}\mathbf{\Lambda}_{R_1D}\mathbf{\Lambda}_{SR_1} & \cdots & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & \cdots & \sqrt{\gamma_{N_R}}\mathbf{\Lambda}_{R_{N_R}D}\mathbf{\Lambda}_{SR_{N_R}} \end{pmatrix}. \tag{9}$$

1) Norm based Selection Ratio (NBSR): NBSR calculates the Frobenius norm of all rows of the channel matrix $\mathbf{\Lambda}$ and generates the corresponding ratio for each relay as follows

$$r_{NBSR,k} = \frac{\left\|\sqrt{\gamma_k}\mathbf{\Lambda}_{r_kD}\mathbf{\Lambda}_{Sr_k}\right\|_F}{\max r_{NBSR}}. \tag{10}$$

2) Capacity Based Selection Ratio (CBSR): In this strategy, the instantaneous mutual information ratio for different relays is evaluated as follows,

$$r_{CBSR,k} = \frac{\log_2\left(\det\left(\mathbf{I}_N + \frac{\gamma_k}{KN_o}\left(\mathbf{\Lambda}_{r_kD}\mathbf{\Lambda}_{Sr_k}\right)\left(\mathbf{\Lambda}_{r_kD}\mathbf{\Lambda}_{Sr_k}\right)^H\right)\right)}{\max r_{CBSR}}. \tag{11}$$

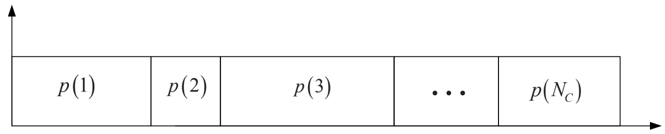

Fig. 1. Selection probability regions

3) Singular Value based Selection Ratio (SVSR): Following proposed method in [9], corresponding ratio related to the minimum eigenvalue ratio for each relay can be found as follows,

$$r_{SVSR,k} = \frac{\min\limits_{n=1,\dots,N} \min\limits_{k=1,\dots,N_R} \lambda^{(k,n)}}{\max r_{SVSR}}, \tag{12}$$

where $\lambda^{(k,n)}$ is the eigenvalue of the k^{th} relay's link for the n^{th} subcarrier.

4) Equalization Quality based Selection Ratio (EQSR): The equalizer signal quality is a metric that inherits effects such as synchronization or spatial correlation that can degrade the quality of the equalizer output signal. The typical signal quality metric is the Euclidean distance between the equalizer output symbols $\hat{\mathbf{x}}$ and the known transmit symbols $\mathbf{x}$. Defining the distortion power (DP) and signal to distortion ratio (SDR) to be

$$P_{distortion} = E\left\{|\mathbf{x} - \hat{\mathbf{x}}|^2\right\}, SDR = \frac{E\left\{|\hat{\mathbf{x}}|^2\right\}}{P_{distortion}}, \tag{13}$$

the equalization quality based ratio for each relay can be expressed as follows,

$$r_{EQSR,k} = \frac{SDR_k}{\max r_{EQSR}}. \tag{14}$$

Note that the four relay selection schemes, i.e. NBSR, CBSR, SVSR, and EQSR methods use a low rate feedback information from the transmitter to the receiver, and from receiver to the relay node correspondingly, that as we will see in the following section, significantly improves the performance of the open loop strategies.

IV. Random-based Fair-Allocation Fuzzy Comprehensive Evaluation-based Strategy with Relay Clustering (RFRC)

Fuzzy comprehensive evaluation is an efficient method to evaluate a subject that involves many elements. We use the fuzzy algorithm to evaluate $\mathbf{e}(i)$ for R_i, $i = 1, \dots, N_R$, i.e. channel quality index for each relay considering different selection ratio mentioned in Sec. III. Having this, each relay will be associated to a point in $\Re^2$, i.e. R_i:$(s_i, \mathbf{e}(i))$. We further apply the K-means algorithm to perform relay clustering. The finalized centroid of each cluster after the convergence of the K-means algorithm is further considered as cluster's contribution factor. The contribution factor gives an idea about the extent that the relays in each cluster should cooperate to guarantee fair allocation, as well as improved SER performance.

With N_C being the number of clusters, the RFRC algorithm is elaborated following the steps as detailed below:

STEP 1) Generate the factor set $U = \{r_{NBSR}, r_{CBSR}, r_{SVSR}, r_{EQSR}\}$.

STEP 2) Generate the evaluation set $V = \{r_1, \dots, r_{N_R}\}$, which contains the N_R relays.

STEP 3) Following the membership functions defined in Sec. III, we create the $(4 \times N_R)$ fuzzy relation matrix $\mathbf{R}$ that relates different factors in Step (1) to the corresponding relays in Step (2) as follows,

$$\mathbf{R} = \begin{bmatrix} r_{NBSR,1} & r_{NBSR,2} & \cdots & r_{NBSR,N_R} \\ r_{CBSR,1} & r_{CBSR,2} & \vdots & r_{CBSR,N_R} \\ r_{SVSR,1} & r_{SVSR,2} & \vdots & r_{SVSR,N_R} \\ r_{EQSR,1} & r_{EQSR,2} & \cdots & r_{EQSR,N_R} \end{bmatrix}. \tag{15}$$

STEP 4) We apply the fuzzy comprehensive evaluation $\mathbf{e} = \mathbf{w} \bullet \mathbf{R}$, where $\mathbf{w}$ is the judgement subset. $\mathbf{e}$ will be the evaluation result of the N_R participating relays and will be used to partition the relays into multiple sets.

STEP 5) We apply the K-means algorithm to perform relay clustering as given in the following **Algorithm 1**.

STEP 6) For each cluster, we generate the contribution factor $o_i = \|m_i\|$, i.e. the norm 2 of the centroid of C_i.

STEP 7) Following [10], we randomly allocate a number of sub-channels to each of the clusters proportional to the selection probability $p(i) = \frac{o_i}{\sum_{j=1}^{N_C} o_j}$. The probabilities $p(i)$ are then associated with selection regions as depicted in Fig. 1. The idea is to associate every subchannel k with a uniform random variable $U(0,1)$. Comparing these random variables with the clusters' contribution factors, it is possible to locate the selection regions.

STEP 8 Use the same probability $p(i)$ and allocate the resources randomly as given in the following **Algorithm2**.

STEP 9 Distribute the subchannels randomly among the relays residing in the same cluster.

We can further elaborate the problem more by optimizing the number of clusters N_C to maximize the overall system's fairness. Note that fairness is the feature of the algorithm that guarantees relays are used proportional to their corresponding resources. Conversely, in an unfair method, some sensors may die before others and this will disturb the sensing activity of the wireless sensor networks (WSNs).

We formulate the linear programming optimization model with the objective function as follows:

$$\begin{aligned} &\left(N_C^*, \{N_{R,C_k}\}_1^{N_C^*}\right) = \\ &\arg\min \sum_{k=1}^{N_C} \left[\sum_{R_i \in C_k} \left[\frac{o_i}{N_{R,C_k} \sum\limits_{j=1}^{N_C} o_j} - \frac{s_i}{\sum\limits_{j=1}^{N_R} s_j} \right]^2 \right], \\ &Subject\ to: \\ &\sum_{i=1}^{N_C} N_{R,C_i} = N_R, \\ &N_{R,C_i} \geq 1, i = 1, \dots, N_C \end{aligned} \tag{16}$$

The well known Mehrotra predictor-corrector algorithm is further implemented to treat (21).

Algorithm 1 Relay Clustering Algorithm

for i = 1 to N_R **do**
  Receive the fuzzy factors $\mathbf{e}\,(i)$ as evaluated by the Fuzzy algorithm in Step (4) for relay R_i.
  Receive the amount of resources available to each relay, s_i.
  Associate each relay to a point in $\mathcal{R}^2$, i.e. R_i:$(s_i, \mathbf{e}\,(i))$.
end for
[Generate initial value:] Generate N_C initial values for cluster centers $m_1, m_2, ..., m_{N_C}$, assuming N_C clusters.
repeat
  for i = 1 to N_R **do**
    [Allocate to the nearest center:] Allocate relay R_i to the cluster of the nearest center:
    $R_i \in C_j \Leftrightarrow j = \arg\min D\,(R_i, m_j),\ j = 1, \ldots, N_C$.
  end for
  for i = 1 to N_C **do**
    [Update centers:] Calculate new cluster centers as the centroids (center of gravity) of the corresponding clusters:
    $m_i = \frac{1}{N_{R,C_i}} \sum\limits_{R_k \in C_i} R_k$, where $N_{R,C_i} = |C_i|$.
  end for
until There are no changes in any cluster centroids

Algorithm 2 Random Selection

for i = 1 to N_C **do**
  Receive contribution factors o_i as evaluated in ***STEP 7***.
end for
for i = 1 to N_C **do**
  Compute the selection probability $p(i) = \frac{o_i}{\sum_{j=1}^{N_C} o_j}$.
end for
Generate selection regions as depicted in Fig. 1.
for k = 1 to N **do**
  • Generate uniform random variable for sub-channel k.
  • Locate the selection region j where the value of the uniform random variable is located.
  • Set the corresponding value in the assignment variable to one: $A_j^k = 1$.
  • Set $A_v^k = 0$ where $v \neq j$.
end for

V. Numerical Results

In this section, we present Monte-Carlo simulation results for the RFRC system considering a multi-relay scenario assuming a quasi-static Rayleigh fading channel for all the $S \rightarrow R_i$ and $R_i \rightarrow D$, $i = 1, \ldots, N_R$ links. We assume 4-PSK modulation.

First, we assume that there are ten relay nodes, where each node is equipped with one antenna, employing MMSE receiver. We set $SNR_{R_iD} = \alpha SNR_{SR_i}$, with $\alpha = 10$, $i = 1, \ldots, 10$. We further assume that $L_{SR_i} = L_{R_iD} = 1$, $i = 1, \ldots, 10$. The SER performance of the RFRC algorithm for SC-FDE MMSE receiver is studied, considering the scenarios given in Table I.

TABLE I
Simulation Scenarios for Fig. 2

Scen	s_i	i	N_C	w
1	1	$1, \ldots, 10$	1	[0.25,0.25,0.25,0.25]
2	1	$1, \ldots, 10$	2	[0.25,0.25,0.25,0.25]
3	1	$1, \ldots, 10$	3	[0.25,0.25,0.25,0.25]
4	$2i-1$	$1, \ldots, 10$	1	[0.25,0.25,0.25,0.25]
5	$2i-1$	$1, \ldots, 10$	2	[0.25,0.25,0.25,0.25]
6	$2i-1$	$1, \ldots, 10$	3	[0.25,0.25,0.25,0.25]

As can be verified from Fig. 2, SER performance can be improved by implementing relay clustering. For example, the SER performance of Scenarios 2 and 3, outperform that of Scenario 1 by $\sim$ 5 dB and $\sim$ 4 dB, at SER = 10^{-3}, correspondingly. Similarly, the SER performance of Scenarios 5 and 6, outperform that of Scenario 4 by $\sim$ 3 dB and $\sim$ 2 dB, at SER = 10^{-3}, correspondingly.

Fig. 3 illustrates the SER performance of RFRC algorithm for SC-FDE MMSE receiver, assuming three relays in the system. We set $SNR_{R_iD} = \alpha SNR_{SR_i}$, with $\alpha = 10$, $i = 1, \ldots, 3$. Also, we assume that $L_{SR_i} = L_{R_iD} = 1$, $i = 1, \ldots, 3$. The SER performance of the RFRC algorithm for SC-FDE MMSE receiver is studied, considering the scenarios given in Table II. As is illustrated in Fig. 3, similar to the scenario with ten participating relays, the RFRC method with relay clustering provides better SER performance as compared with the scenario with no clustering. For example, the SER performance of Scenario 2, outperforms that of Scenario 1 by $\sim$ 2 dB at SER = 10^{-3}, while the SER performance of Scenario 4 outperforms that of Scenario 3 by $\sim$ 4 dB at SER = 10^{-3}.

TABLE II
Simulation Scenarios for Fig. 3

Scen	s_i	i	N_C	w
1	1	$1, 2, 3$	1	[0.25,0.25,0.25,0.25]
2	1	$1, 2, 3$	2	[0.25,0.25,0.25,0.25]
3	$2i-1$	$1, 2, 3$	1	[0.25,0.25,0.25,0.25]
4	$2i-1$	$1, 2, 3$	2	[0.25,0.25,0.25,0.25]

In Fig. 4, we consider the optimization of N_C, assuming ten relays, $SNR_{R_iD} = \alpha SNR_{SR_i}$, with $\alpha = 10$, $i = 1, \ldots, 10$. We further assume that $L_{SR_i} = 1$, $L_{R_iD} = 2$, $i = 1, \ldots, 10$. The SER performance of the RFRC algorithm for SC-FDE MMSE receiver is studied, considering the scenarios given in Table III. As illustrated in Fig. 4, Scenario 2 with $N_C = 2$ has the best SER performance among the first three, i.e. outperforms Scenarios 1 and 3 by $\sim$ 3 dB, and $\sim$ 4 dB, at SER = 10^{-3}, correspondingly. Similarly, Scenario 5 with $N_C = 3$ has the best SER performance among the second three, i.e. outperforms Scenarios 6 and 4 by $\sim$ 2 dB, and $\sim$ 4 dB, at SER = 10^{-3}, correspondingly.

VI. Conclusion

We propose a novel Random-based Fair-Allocation Fuzzy Comprehensive Evaluation-based Strategy with Relay Clustering for SC-FDE multi-relay cooperative network over frequency selective fading channels. The proposed allocation strategy improved the diversity gain due to utilizing the

TABLE III
SIMULATION SCENARIOS FOR FIG. 4

Scen	s_i	i	N_C	**w**
1	$2i-1$	$1,\ldots,10$	1	[0.25,0.25,0.25,0.25]
2	$2i-1$	$1,\ldots,10$	2	[0.25,0.25,0.25,0.25]
3	$2i-1$	$1,\ldots,10$	3	[0.25,0.25,0.25,0.25]
4	$2i-1$	$1,\ldots,10$	2	[0.05,0.05,0.7,0.3]
5	$2i-1$	$1,\ldots,10$	3	[0.05,0.05,0.7,0.3]
6	$2i-1$	$1,\ldots,10$	4	[0.05,0.05,0.7,0.3]

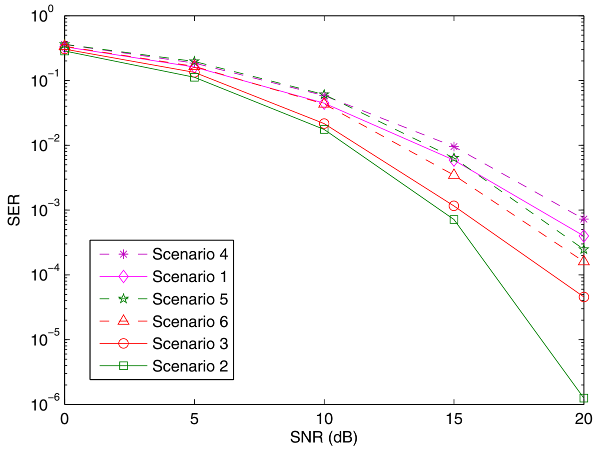

Fig. 2. SER performance comparison of RFRC SC-FDE with different amount of resources available to relays and different number of clusters, assuming ten participating relays.

random resource allocation algorithm. The proposed RFRC SC-FDE improved the SER performance due to the fuzzy evaluation algorithm which generates contribution factors that minimize the instantaneous SER.

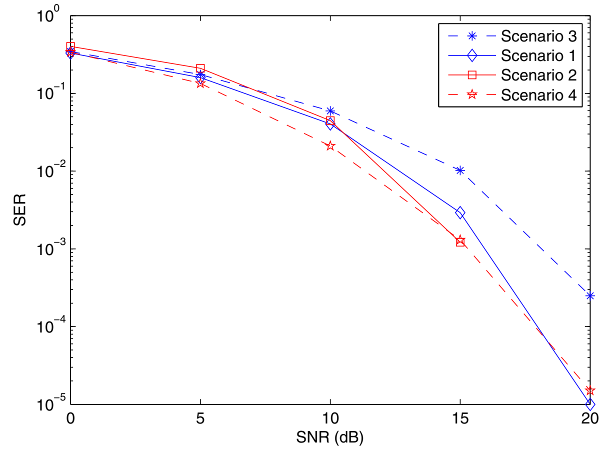

Fig. 3. SER performance comparison of RFRC SC-FDE with different amount of resources available to relays and different number of clusters, assuming three participating relays.

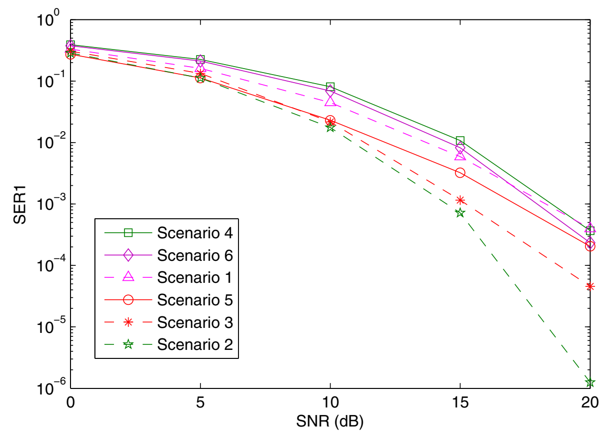

Fig. 4. SER performance comparison of RFRC SC-FDE with different cluster numbers, assuming ten participating relays.

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