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# Sum-Rate Maximization of Multi-User OFDMA Two-way Relay Networks under Sub-Carrier Pairing and Fairness Constraints

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## Abstract

*In this paper, we invoke sub-carrier pairing based sum-rate maximization problem in wireless cooperative networks. Two-way relaying (TWR) with amplify-and-forward (AF) protocol is considered in multi-user, multi-carrier environment over two-hop with single fixed relay station (FRS), in which direct link between source and destination is not available. We formulate to maximize the overall sum-rate and individual sum-rate achieved by users subject to sub-carrier pairing and data rate fairness. The joint optimization of resources turn the problem to be combinatorial having NP-hard solution due to its utmost computational complexity. Firstly, we propose an optimal solution and then a low-complexity resource allocation scheme based on "Hungarian Algorithm" is presented. Finally, the simulation results of performance evaluation describe the effectiveness of sub-carrier pairing for sum-rate maximization.*

**Key Words:** Two way relaying, amplify-and-forward, sum-rate, sub-carrier pairing, OFDMA.

## 1. Introduction

The demand of high speed data rates, enhanced coverage and reliability of data transfer is remarkably growing fast. Cooperative Communication has been proposed to meet with this growing trend in future wireless networks. Cooperative Communication [1] – [3] is a new paradigm, key technology aspect in Next-Generation (NG) wireless networks and has recently attracted great attention in research community, although the pioneering work on relaying concepts was carried out by Van Der Meulen [4] in 1971 and Cover El Gamal [5] in 1979.

In cooperative communication technique, are liable wireless communication link can be established between the sender and receiver by creating independent propagation paths with the help of intermediate nodes known as wireless relay stations. An overview is shown in Fig 1.

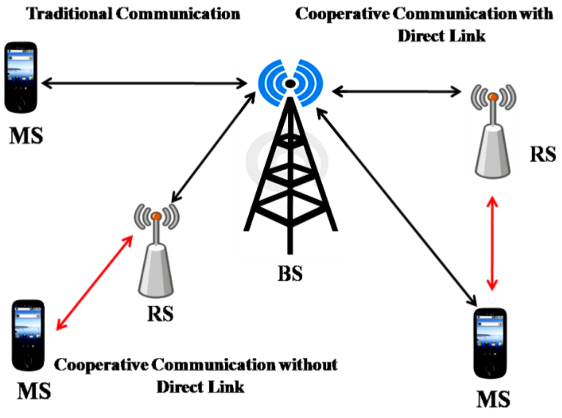

**Fig. 1** Overview of Wireless Relaying Network

Wireless Cooperative Communication combats the fading effects and achieves the same spatial diversity that is offered by Multiple-Inputs-Multiple-Outputs (MIMO) systems. A MIMO wireless network achieves spatial diversity through multi-antennas but deploying multiple antennas at Mobile

Station (MS) might be impracticable due to power, size and cost constraints. In cooperative communication, different relays and nodes share their resources to form virtual paths to achieve spatial diversity without actual deploying multiple antennas at each relay and node. Thus, wireless cooperative communication exploits benefits of spatial diversity of MIMO communication systems and provide high throughput at cell edges.

The synergy of Wireless Cooperative System with Orthogonal Frequency Division Multiple Access (OFDMA) is a promising technique in order to meet with the future demands for next-generation wireless broadband communication systems such as throughput enhancement, coverage extension, power saving, bandwidth efficiency and reduced latency. Wireless industry has already been considered OFDMA in the standardization process of next-generation mobile communication systems such as IEEE 802.11a, IEEE 802.11g Wireless Local Area Networks (WLANs) and IEEE 802.16 Wireless Metropolitan Area Networks (WMANs). OFDM is also considered to be employed in NG-Wireless networks as IEEE 802.16m, IEEE 802.16j and LTE-Advanced [6]. [7].

In recent years, substantial research work performed and published in wireless cooperative communications and TWR has been actively studied and gained much attraction due to its efficient spectral performance. The work in [8], studied tone permutation and power allocation for AF two-way relaying over OFDMA and a greedy based approach for tone permutation and dual de-composition technique for power allocation is proposed. In [9], the authors considered OFDMA based two hop One-Way Relaying (OWR). Both AF and DF relay links were analyzed for ordered sub-carrier pairing under optimal power allocation. The outage performance for multi-user, two-way cooperative cellular networks under Rayleigh and Rician fading is analyzed in [10].Recently, joint radio resource allocation problem in multi-user, multi-carrier one-way relaying network with resource block pairing, where multiple user pairs communicate through a single relay terminal was examined in [11].

However, to the best of authors' knowledge, a unified scheduling considering sub-carrier allocation, sub-carrier pairing, individual sum-rate guarantee and maximization of overall sum-rate in multi-user OFDMA based TWR system, all together has not been probed, so far.

In this paper, we propose an optimal radio resource allocation with sub-carrier pairing and fairness constraints intended for multi-user, multi-carrier (OFDMA) considering single cell, single relay and two way relaying system under rayleigh fading channel environment with focus on half-duplex relaying. The rest of this paper is structured as follow. Section II describes system model, protocol description and sub-carrier pairing schemes. Mathematical analysis is presented in Section III. Problem formulation and constraint details are available in Section IV. We developed resource allocation algorithms in Section V. Performance analysis and simulations results are explained in Section VI and finally the results are concluded in Section VII.

## 2. System Model and Description

### *a) System Model*

Consider a multi-user, two-way relay network which consists of M Mobile Stations (MSs) and one Fixed Relay Station (FRS), all having single antenna which cannot transmit and receive simultaneously (i.e. half duplex mode) as shown in Fig 2. All MSs are assumed to be cell edge terminals, so that each MS needs to transmit and receive through RS and no direct link is considered.

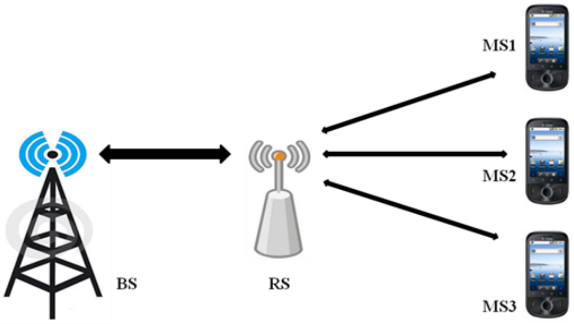

**Fig. 2** Multi-user TWR Communication section

In this paper, Time Division Duplex (TDD) mode is selected to separate uplink and downlink transmission, as RS is working in half-duplex mode.

Suppose that there are *"K"* resource blocks (RBs) containing OFDM symbols. Each RB consists of twelve sub-carriers in frequency domain and seven time slots in time domain as explained in 3GPP Long Term Evolution (LTE). In this paper the term sub-carrier and RB are used alternatively.

### *b) Propagation Model*

The Rayleigh fading is assumed for frequency selective channel for which each sub-carrier in one RB encounters the same channel conditions but various RBs under-go different channel conditions. Additive White Gaussian Noise (AWGN) with variance $\sigma^2$ is assumed which is identical across all RBs for all nodes. There is perfect synchronization among the nodes and no inter-carrier interference is considered.

### *c) Protocol Description*

Two types of TWR are proposed in literature [12]. The first type assumes that there is only relay link and no direct link available between source and destination; therefore for complete exchange of information two time-slots will be required. While the second type considers direct link (between source and destination) in to account, therefore three time slots are needed for complete information exchange. These types of TWR (based on AF) are named as Analog Network Coding (ANC) and Time Division Broad Cast (TDBC) protocols [13]. We have considered AF-based ANC protocol as it improves the average sum rate significantly by using the smallest number of transmission phases.

In ANC protocol, exchange of information is completed in two phases. The first phase is called Multiple-Access (MA) phase and the second is called Broad Cast (BC) phase. In MA-phase, both BS and MS transmit information to RS simultaneously. In BC-phase, RS broadcast the received signal (in MA-phase) after amplification as shown in Fig 3. In BC-phase, the received signal at BS and MS consist of their own signals transmitted in MA-phase, called as self-interference signals. With the complete knowledge of CSI and their own signals, the self-interference signals will be subtracted accordingly.

### *d) Sub-Carrier Pairing Schemes*

In cooperative communication, it is assumed that signal transmitted from the sender on a certain RB is processed at RS and then re-transmitted towards the destination on the same resource block regardless the channel conditions. Due to independent channel characteristics on the RB over the two hops, the system performance deteriorates and does not guarantee throughput and quality of service (QoS) because channel variability is not exploited. The system efficiency can be improved through RB-pairing over the two hops according to the instantaneous channel condition. In this paper, we probed Selective-Order-Pairing (SOP) and compared with Fixed-order-Pairing (FOP).

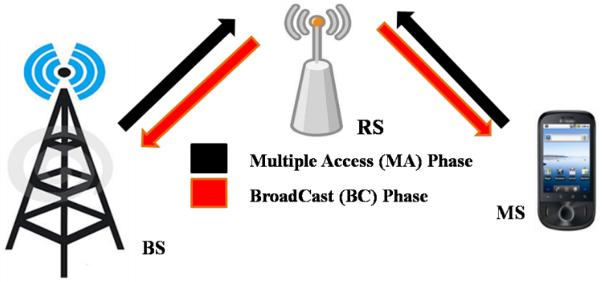

**Fig. 3** MABC Phases for Two Way Relaying

### 1) Fixed order Pairing (FOP)

It is the simplest and commonly used RB-pairing scheme. A certain RB in the MA-phase is paired with the same RB in the BC-phase as shown in Fig 4(a). This shows that exchange of information over the two hops is completed with same RB irrespective of the channel conditions. Therefore, a lower system throughput is expected.

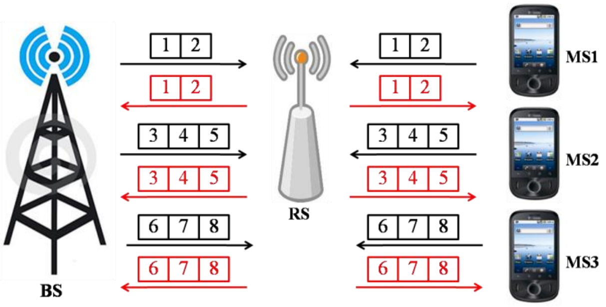

**Fig. 4(a)** FOP Pairing Scheme

### 2) Selective order Pairing (SOP)

In this RB-pairing scheme, the RB in the first phase (i.e. MA-phase) is paired with RB in the second phase (i.e. BC-phase) according to the channel conditions as shown in Fig 4(b). Each RB (available) with highest instantaneous channel gain in MA-phase is paired with that RB (available) with highest instantaneous channel gain in BC-phase for the selected source-destination pair.

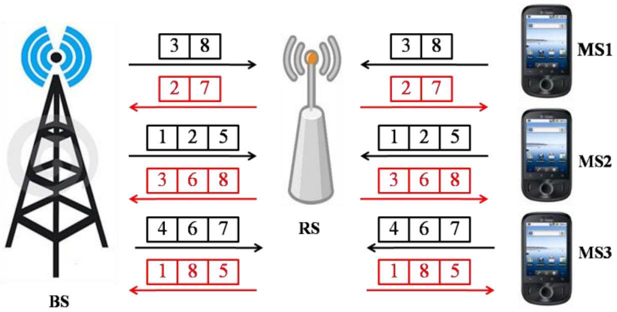

**Fig.4(b)** SOP Pairing Scheme

Mathematical representation of SOP-pairing criteria is as follow:

$$(K,J) = \arg\max\,(C_{MA}, C_{BC})\ k \in C_{MA}, f \in C_{BC}$$

where and are sets of RBs in MA and BC phases, respectively.

After pairing, "$k^{th}$" and"$j^{th}$" RBs are removed from the sets $C_{MA}$ and $C_{BC}$, respectively. This process is continued till the available RBs are paired for the two phases. After that, these paired RBs are allocated to user pairs. This process of pairing and allocation can be implemented easily in single-user or multi-user environment if fairness in terms of individual data rate is not considered. However, when data rate fairness is considered then pairing and allocation process is jointly carried out to ensure fairness among users. This problem of joint RB allocation and RB pairing will be optimized in this paper.

Both forward-link and reverse-link communication is considered. The signal received at RS (in MA-phase) on RB with index *"k"* is broadcasted (in BC-phase) over the RB with index *"j"*. The RB index *"k"* may or may not be same as *"j"* and this form a RB-pair *(k, j)*.

## 3. Mathematical Analysis

Consider $m^{th}$ MS and the BS transmit information simultaneously on the same RB say $k^{th}$in MA-phase(MS1 and MS2 will not transmit on same RBs) and in BC-phasethe received signal is sent back over different RB say "$j^{th}$" RB. Let the channel coefficients from BS to RS as $h^k_{BR,m}$ and the one from MS to RS as $h^k_{MR,m}$. Then the received signal at RS over the "$k^{th}$" RB is[14]:

$$y^k_{RS} = \sqrt{p^k_{B,m}}\, h^k_{BR,m} x^k_{B,m} + \sqrt{p^k_{M,m}}\, h^k_{MR,m} x^k_{M,m} + w^k_{RS} \tag{1}$$

where $x^k_{B,m}$ and $x^k_{M,m}$ are the input symbols; $p^k_{B,m}$ and $p^k_{M,m}$ are the corresponding powers over carrier and $w^k_{RS}$ is additive white Gaussian noise (AWGN) having variance $\sigma^2$.

For power $p^j_R$ allocated at RS over the "$j^{th}$" RB, then the signals received at BS and MS for "$m^{th}$" MS can be written as:

$$y^j_{BS,m} = \sqrt{p^j_R}\, h^j_{RB,m} g_m \sqrt{p^k_{B,m}} h^k_{BR,m} x^k_{B.m} + \sqrt{p^j_R}\, g_m h^j_{RB,m} w^k_{RS} + \sqrt{p^j_R}\, h^j_{RB,m} g_m \sqrt{p^k_{M,m}}\, h^k_{MR,m} x^k_{M,m} + w^j_{BS,m} \tag{2}$$

$$y^j_{MS,m} = \sqrt{p^j_R}\, h^j_{RM,m} g_m \sqrt{p^k_{M,m}} h^k_{RM,m} x^k_{M.m} + \sqrt{p^j_R}\, g_m h^j_{RM,m} w^k_{RS} + \sqrt{p^j_R}\, h^j_{RM,m} g_m \sqrt{p^k_{B,m}}\, h^k_{BR,m} x^k_{B,m} + w^j_{MS,m} \tag{3}$$

where $g_m$ is the scaling factor at RS and $w^j_{BS,m}$ and $w^j_{MS,m}$ are received Additive White Gaussian Noise (AWGN) at BS and MS for $m^{th}$ user, respectively and both having variance as $\sigma^2$. The respective SNRs are given as:

$$\gamma^{k,j}_{BS,m} = \frac{p^j_R \left|h^j_{RB,m}\right|^2 g_m^{k,j^2}\, p^{k,j^2}_{M,m} \left|h^k_{MR,m}\right|^2}{\left(g_m^{k,j^2}\, p^j_R \left|h^j_{RB,m}\right|^2 + 1\right)\sigma^2} \tag{4}$$

$$\gamma^{k,j}_{MS,m} = \frac{p^j_R \left|h^j_{RM,m}\right|^2 g_m^{k,j^2}\, p^k_{B,m} \left|h^k_{BR,m}\right|^2}{\left(g_m^{k,j^2}\, p^j_R \left|h^j_{MR,m}\right|^2 + 1\right)\sigma^2} \tag{5}$$

The scaling factor $g_m$ [14] is given in (6):

$$g_m = \sqrt{\frac{1}{p_{B,m}^{k}\left|h_{BR,m}^{k}\right|^2 + p_{M,m}^{k}\left|h_{MR,m}^{k}\right|^2 + \sigma^2}} \qquad (6)$$

Now, the instantaneous throughput of"*m^th*" MS over the RB-pair *(k, j)*with TWR AF protocol is given as:

$$\gamma_m^{k,j} = \frac{1}{2}\log_2\left(1+\gamma_{BS,m}^{k,j}\right) + \frac{1}{2}\log_2\left(1+\gamma_{MS,m}^{k,j}\right) \qquad (7)$$

$$\gamma_m^{k,j} = \frac{1}{2}\log_2\left(1+\gamma_m^{k,j}\right) \qquad (8)$$

The factor half arises in above equation due to half duplex relay operation, therefore two timeslots are required for complete communication.

## Problem Formulation

Due to exclusive RB-allocation and RB-pairing, two binary variables are defined as $\delta^{k,j}$ and $\alpha_m^{k,j}$ and are called as RB-pairing index and RB-allocation index, respectively. The indexes are given as:

$$\delta^{k,j} = \begin{cases} 1, & \text{if } k^{th} \text{ RB is paired with } j^{th} \text{ RB} \\ 0, & \text{Otherwise} \end{cases}$$

$$\delta_m^{k,j} = \begin{cases} 1, & \text{if RB pair}(k,j) \text{ is allocated to } m^{th} \text{ MS} \\ 0, & \text{Otherwise} \end{cases}$$

The total achievable network throughput (Rs) for all the RBs and all the MSs can be expressed as:

$$R_s = \sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{j=1}^{K}\delta^{k,j}\alpha_m^{k,j}\left[\frac{1}{2}\log_2\left(1+\gamma_{BS,m}^{k,j}\right) + \frac{1}{2}\log_2\left(1+\gamma_{MS,m}^{k,j}\right)\right] \qquad (9)$$

We solicit to jointly optimize the RB-allocation, RB-pairing, individual data rate fairness and power allocation. Our objective is to maximize the overall system sum rate under sub-carrier pairing and data fairness constraints. The problem can be formulated as:

$$\max_{\delta,\ \alpha,\ p_B, p_R, p_M} = \sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{j=1}^{K}\delta^{k,j}\alpha_m^{k,j} \left[\frac{1}{2}\log_2\left(1+\gamma_{BS,m}^{k,j}\right) + \frac{1}{2}\log_2\left(1+\gamma_{MS,m}^{k,j}\right)\right] \qquad (10)$$

S.t. the following constraints:

*C# 01: RB-Pairing*: It describes that each RB in the MA-phase can be paired with only one RB in the BC-phase.

$$\sum_{K=1}^{k}\delta^{k,j} = 1, \text{ and } \sum_{j=1}^{K}\delta^{k,j} = 1, \quad \forall k, \forall \qquad (10.a)$$

*C# 02: RB-Allocation*: It states that each RB-pair *(k,j)* can be allocated to only one MS to avoid intra-cell multi-user interference.

$$\sum_{m=1}^{M}\alpha_m^{k,j} = 1, \ \ \alpha_m^{k,j} \in \{0,1\} \forall (k,j) \qquad (10.b)$$

***C# 03 Individual Data Rate*:** This constraint ensures that each MS meets its Minimum Sum Rate (MSR) requirement. Many next generations applications (especially video flows) likely to have associated minimum data rate requirement for satisfactory QoS by the end users. MSR is denoted by $r_{m,min}$ for $m^{th}$ MS, then:

$$\sum_{k=1}^{K}\sum_{j=1}^{K}\delta^{k,j}\alpha_m^{k,j}\gamma_m^{k,j} \geq \gamma_{m,min} \forall m \qquad (10.c)$$

*C# 04: Total Power*: Sum of powers transmitted at all nodes is limited and described as:

$$\sum_{k=1}^{K}\sum_{j=1}^{K}(P_B^{k,j} + P_R^{j} + P_M^{k}) \leq P_T^{k,j} \forall k, j \qquad (10.d)$$

*C# 05: Individual Power at each Node*: Total transmitted power at each node is limited and described as:

$$\sum_{k=1}^{K} P_{B,m}^{k} \leq P_{B,m}, \ \sum_{k=1}^{K} P_{M,m}^{k} \leq P_{M,m} \quad \forall m \qquad (10.e)$$

$$\sum_{j=1}^{K} P_R^{j} \leq P_R \quad \forall j$$

$$P_{B,m}^{k} \geq 0,\ P_{M,m}^{k} \geq 0, P_R^{j} \geq 0 \quad \forall m, k, j \qquad (10.f)$$

## 4. Proposed Resource Allocation Schemes

The jointly optimized problem formulated in (10) is a combinatorial problem because it contains both discrete as well as continuous quantities. Ideally, resource scheduling should be made jointly to achieve the optimal solution. That's why the solution of such problem is NP-Hard (Non deterministic Polynomial Hard) due to its utmost computation complexity.

However, to overcome this computation complexity, two resource allocation algorithms have been proposed and discussed in below sub-sections.

### *A: RB-Pairing and Allocation Algorithm (RBPA)*

In this sub-section, we solve the joint optimization problem by following step-wise approach in which each resource is allocated and optimized by fixing the other. Therefore, RB allocation and pairing is proposed with equal fixed power at RS and MSs.

Assume

$$P_{B,m}^{k} = \frac{P_{B,m}}{K}, P_{M,m}^{k} = \frac{P_{M,m}}{K}, P_{R}^{j} = \frac{P_{R}}{K}$$

The RB allocation and pairing completes in following three steps:

i. Firstly, user pair selection is prioritized depending on their received SNRs. This step ensures that user pair with highest received SNR will use the best RB. This process is repeated until all RBs are allocated to user-pairs i.e. *k*<sup>*th*</sup> RB having highest received SNR is allocated to *m*<sup>*th*</sup> MS pair, such that:

$$m^{k} = \arg\max\left(\gamma_{BS,m}^{k} + \gamma_{MS,m}^{k}\right),$$

$$k^{*} = \arg\max\left(p_{B,m}^{k}\left|h_{BR,m}^{k}\right|^{2} + p_{M,m}^{k}\left|h_{MR,m}^{k}\right|^{2}\right), \forall m, k$$

RB-pairing is carried out in such a way that selected RB in MA-phase (in step-i) is paired with $j^{th}$ RB with highest received SNRs in BC-phase. Each RB-pair is allocated to only user-pair to avoid from intra cell interference; however multiple RBs can be allocated to same user-pair depending on the data requirement of the same user-pair. RB in BC-phase is assigned such that:

$$j^{*} = \arg\max\left(k^{*}, j\right), \forall j$$

ii. After allocation of selective RB-pairing to user-pairs, individual data rate is guaranteed to user pairs. This step ensures that user pairs with high data rate requirement or with best channel characteristics may not use all the RBs at the cost of others. The user-pair which meets its minimum required data rate is temporarily removed from resource scheduling process. This process is continued till the user-pairs attain their minimum data requirement ($R_{min}$) or all the RBs got allocated.

iii. When all the user-pairs have achieved their minimum rate requirement and still there are un-allocated RB-pairs, then these RB-pairs are allocated to the best user-pairs (having the highest achieved SNRs) to maximize the overall system sum-rate. This step continues till all the RB-pairs have been allocated.

Resource allocation process is illustrated in Algorithm-01.

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**Algorithm-01** Proposed Resource Allocation Algorithm

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Step-1 (Initialization):
    $M = \{1,2,3,...M\}, C_{MA} = \{1,2,3,...K\},$
    $C_{BC} = \{1,2,3...K\},$
Step-2 (RB Allocation):
    $m^{k} = \arg\max\left(\gamma_{BS,m}^{k} + \gamma_{MS,m}^{k}\right), \quad \forall m, k$
Step-3 (RB Pairing):
    $k^{*} = \arg\max\left(p_{B,m}^{k}\left|h_{BR,m}^{k}\right|^{2} + p_{M,m}^{k}\left|h_{MR,m}^{k}\right|^{2}\right), \forall m, k$
    $j^{*} = \arg\max\left(k^{*}, j\right), \forall j$
    $\left(k^{*}, j^{*}\right) = \arg\max\left(C_{MA}, C_{j}\right)$
Step-4 (Individual Rate):
        If $r_{m}^{k,j} < r_{m,min}$
    $\delta^{kj} = 1, \alpha_{m}^{kj} = 1, \qquad \forall k, j$
        $C_{MA} = C_{MA} - \{k\}, C_{BC} = C_{BC} -$
        else if $r_{m}^{kj} \geq r_{m,min}$
    $M = M - \{m\}$
Step-5 (System Capacity Maximization):
        if $C_{m}$
    $(m^{k}, (k^{*}, j^{*}) = \arg\max(R_{system}), \quad \forall m, k, j$
        U
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The computational complexity of the RB-pairing in above proposed algorithm is *O* ($M$ x $K^K$). With increasing number of RBs and MSs, the complexity becomes too high which needs to be avoided in practical applications to obtain the required optimized results. Therefore in the next subsection, a new Low Complexity Sub-carrier Allocation (LCSA) algorithm is proposed.

### *B: Low Complexity Sub-carrier Allocation (LCSA)*

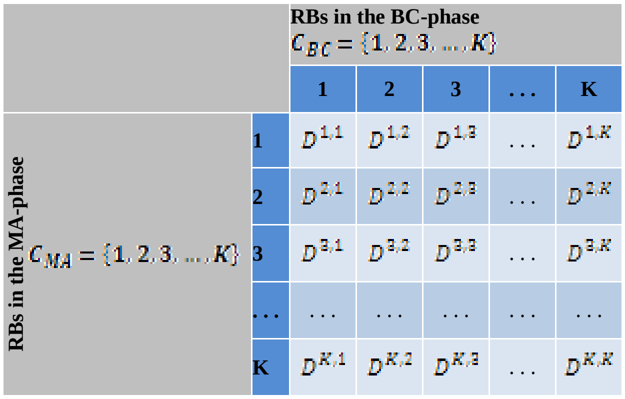
We proposed RB pairing with the standard optimization technique known as "The Hungarian Method" [15]. It is one-to-one optimization algorithm which finds an optimal assignment for a given profit matrix. Hungarian profit matrix of TWR for MABC is depicted in Fig 5. The linear assignment problem such as RB pairing can be solved efficiently with this method.

The steps involved in this proposed algorithm are enlisted below:

1. The profit matrix *(K x K)* is formed such that rows indicating RBs for MA-phase and columns indicating RBs for BC-phase.
2. The profit metric $D^{k,j}$ is calculated such that each entry in the matrix is maximized by choosing the data rate of $m^{th}$ MS over M-links.

$$D^{k,j} = \max\left\{r_m^{k,j}\right\}, \quad m \in \{1,2,3,\ldots,M\}$$

3. Applying HA method on profit matrix *(K x K)*, the RB pair with best channel characteristics is selected.
4. The selected RBs are assigned to the user pairs iteratively by implementing constraint (10.c).
5. Assigned RB pairs are eliminated from the profit matrix.
6. The users meeting the criteria mentioned in (10.c) are temporarily removed.
7. Step # 1 to #5 is repeated until all users have attained their minimum data rate requirement or spare RBs are not available.
8. To maximize the overall system throughput, the RB pairs (if available) are assigned to the best users (having highest received SNRs).



| | | RBs in the BC-phase $C_{BC} = \{1,2,3,\ldots,K\}$ | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | . . . | K |
| RBs in the MA-phase $C_{MA} = \{1,2,3,\ldots,K\}$ | 1 | $D^{1,1}$ | $D^{1,2}$ | $D^{1,3}$ | . . . | $D^{1,K}$ |
| | 2 | $D^{2,1}$ | $D^{2,2}$ | $D^{2,3}$ | . . . | $D^{2,K}$ |
| | 3 | $D^{3,1}$ | $D^{3,2}$ | $D^{3,3}$ | . . . | $D^{3,K}$ |
| | . . . | . . . | . . . | . . . | . . . | . . . |
| | K | $D^{K,1}$ | $D^{K,2}$ | $D^{K,3}$ | . . . | $D^{K,K}$ |

**Fig.5** Hungarian Profit Matrix for TWR [15]

The computation complexity of step-1 is *O* ($M$ x $K^2$) and the computational complexity of standard Hungarian algorithm with fairness is *O* ($K^4$), while the complexity of step-8 is *O* ($K^3$). Therefore, the overall complexity of proposed LCSA algorithm can be approximated as upper bound of *O* ($M$ x $K^6$+ $K^3$). Comparing with RBPA algorithm, the computational complexity has been reduced significantly giving the same performance.

## 5. Performance Evaluation

In this section, performance evaluation is presented for the proposed algorithms through simulation results. We consider Gaussian random variables for the links with total number of MSs as 5 and sub-carriers are set as 14. The performance of sum-rate versus SNR is shown in Fig6. Both algorithms i.e. RBPA and LCSA are simulated. The selective RB-pairing not only shows significant gain in system sum-rate over fixed RB-pairing but also the difference between FOP and SOP increases with the SNR.

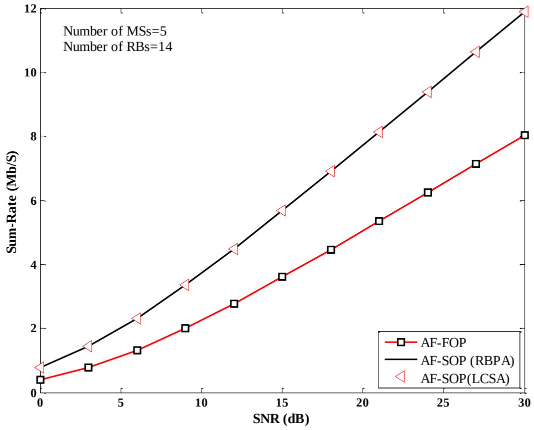


**Fig. 6** System throughput versus SNR

Further, it is revealed that both proposed algorithms produce the same results but with different computational complexity as described earlier.

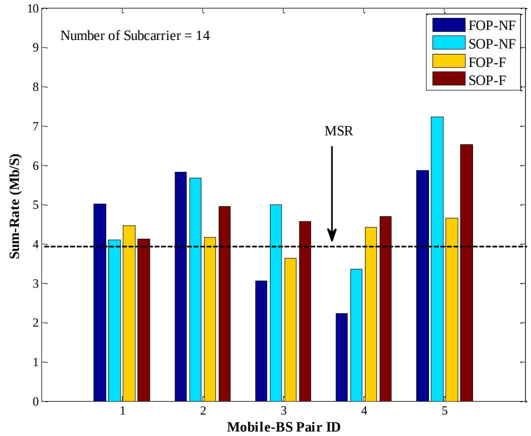


**Fig. 7** Individual throughput for each Pair

Fig 7 shows the individual sum-rate for TWR AF protocol with both FOP and SOP under data rate constraint (C#03) to ensure Minimum-Sum-Rate (MSR) requirement and better performance is observed for SOP-F. The fairness among user pairs is also achieved in SOP-F, while fairness is not observed for SOP-NF, FOP-F and FOP-NF as some of user pairs do not meet their MSR. But in SOP-F, all user pairs achieve equal or higher throughput than MSR.

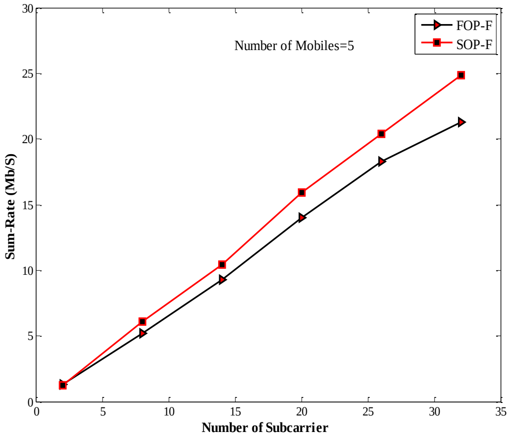


**Fig. 8** Sum-Rate versus sub-carrier chunks

In Fig 8, overall sum-rate is plotted against sub-carriers. There is significant increase in overall system sum-rate for SOP-F as compared with FOP-F for increasing number of sub-carriers.

By comparing results, it is obvious that SOP-F outperforms among all schemes in terms of overall system throughput, individual achieved sum-rate and fairness.

## 6. Conclusion

In this paper, we investigated joint resource allocation problem in multi-user, OFDMA two-way relaying systems. The main objective of our research is to maximize the overall sum-rate and minimum sum-rate guarantee to all user-pairs under sub-carrier pairing and data rate fairness. We solved the combinatorial problem with step-wise technique and proposed an optimal resource allocation algorithm (RBPA), which has significant computation complexity. Simulation results verified that proposed algorithm provided an efficient solution for radio resource management. To reduce the computational complexity, "Hungarian Method" based resource allocation algorithm (LCSA) is also proposed. Simulation results demonstrated the performance comparison and effectiveness of proposed algorithms for selective RB-pairing over fixed RB-pairing schemes. On the whole, this research work contributes towards radio resource management in wireless cooperative communication to enhance throughput and QoS of users at low cost, low complexity and make wireless cooperative networks a market realization. The add-on of this work with multi-relay, multi-cell and multi-antenna is interesting and need to be explored in future.

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