

Resource Allocation in Successive Relaying for Half-Duplex Relay-Based OFDMA Systems

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Abstract—In this paper, we consider a four-node relay-based OFDMA system. The expression of the upper bound for the achievable rate in Successive Relaying (SUR) protocol is derived by using the cut-set theorem for half-duplex systems. Based on this expression, the near-optimal solution of the achievable rate is obtained in the joint power and subcarrier allocation constraint, according to the dual problem decomposition approach and the subgradient method. Moreover, we make a comparison on the achievable rate between SUR and Simultaneous Relaying (SIR) in the pathloss model accepted by the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) Advanced system. The simulation results demonstrate the enhancement of the achievable rate in SUR protocol is expanded in high signal-to-noise ratio (SNR) compared with the achievable rate in SIR protocol under both the symmetric and asymmetric cases. And for SUR protocol, the achievable rate in symmetric case performs better in high SNR.

I. INTRODUCTION

Cooperative transmission has been extensively studied as a means to improve the spectral efficiency and coverage of the high data rates in wireless network. Although the full-duplex relay can receive and transmit simultaneously in the same frequency band, it requires complex and expensive equipment. Then, the half-duplex relay is proposed [1], [2] and considered for 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE)-Advanced system [3], which has drawn a great attention.

Most existing works concentrate on either Simultaneous Relaying (SIR) or Successive Relaying (SUR) in the half-duplex relay systems. In no direct link scenarios, [4] has concluded that the optimum relay ordering is SUR based on Dirty Paper Coding (DPC) in high signal-to-noise ratio (SNR), whereas deploying SIR protocol is more reasonable on improving achievable rate in low SNR, when each relay employs Dynamic Decode and Forward. And the capacity bound in SUR protocol is even obtained in [5]. For the scenario with direct link, the achievable rate in SUR is analyzed in [6] using repetition coding. Nevertheless, all these works concern about the single carrier system. Currently, orthogonal frequency-division multiple access (OFDMA) has been envisioned as a

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promising technology for next generation cellular system. In [7] and [8], the resource allocation to maximize the achievable rate with direct link has been investigated in SIR protocol based on OFDMA systems. However, the achievable rate for SUR with direct link in OFDMA systems is seldom examined so far. And the comparison between SIR and SUR on the achievable rate when direct link exists in OFDMA systems has not been provided yet.

In this paper, we focus on the resource allocation in SUR with direct link to maximize the achievable rate and evaluate the achievable rates of SUR and SIR in symmetric and asymmetric cases based on OFDMA systems. In Decode and Forward (DF) half-duplex relay systems, the expression of the achievable rate is derived by applying the cut-set theorem [9] under the power constraint and the orthogonal subcarrier allocation. Based on this expression, we set the objective function and use the dual problem decomposition and subgradient method [10] to have a joint power and subcarrier allocation in order to obtain the near-optimal solution of the maximal achievable rate. In the simulation, a comparison on the achievable rate between SIR and SUR with direct link in OFDMA systems is made in the path-loss model [11] accepted by 3GPP. The achievable rate in SUR protocol has a growing gain as the SNR increases than that in SIR protocol. And for SUR protocol, it can provide higher achievable rate in symmetric case with the increasing SNR. While, for the SIR protocol, the enhancement of the achievable rates are closed for both symmetric and asymmetric cases.

The remainder of this paper is organized as follows. In Section II, the system model is given. Section III provides an analysis of the achievable rate based on the cut-set theorem. In Section IV, the maximal achievable rate through the joint power and subcarrier allocation is achieved by applying the decomposition approach and the subgradient method. Simulation results are presented in Section V. Finally, Section VI concludes the paper.

II. SYSTEM MODEL

A four-node relay network consisting of one source (S), two relays (R_1 and R_2) and one destination (D) is depicted in Fig. 1 and numbered from node 0 to node 3, respectively. It is assumed that the link from node m to node n (i.e., $m \rightarrow n$

link) is frequency selective, and OFDMA is employed for data transmission to convert the channel into a set of N orthogonal subcarriers with the flat channel responses. H_{mn}^k stands for the channel coefficient on the k th subcarrier for the $m \rightarrow n$ link. All nodes are perfectly synchronized with one another in order to guarantee the orthogonality among the subcarriers.

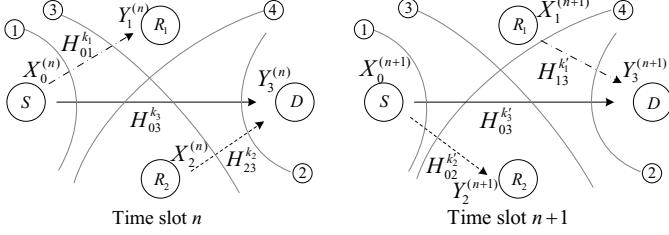


Fig. 1. System Model

Suppose that both R_1 and R_2 are DF relays in the half-duplex operation. The system works by Time Division Multiplexing (TDM). In the odd time slot, indexed as n , $n \in \{2l+1, l = 0, 1, 2, \dots\}$, the source sends the data $X_0^{(n)}$ with the power P_{01,k_1} and P_{03,k_3} to R_1 and D on the k_1 th and k_3 th subcarriers, respectively. Simultaneously, R_2 forwards the message $X_2^{(n)}$, which is received and re-encoded in the $(n-1)$ th time slot, with the power P_{23,k_2} to D on the k_2 th subcarrier.

In the even time slot $n+1$, S sends a new message on the k'_2 th and k'_3 th subcarriers referred as $X_0^{(n+1)}$ with the power P_{02,k'_2} and P_{03,k'_3} to R_2 and D , respectively, while R_1 transmits $X_1^{(n+1)}$ received and re-encoded in the n th time slot with the power P_{13,k_1} to D . Assume each subcarrier is occupied by only one transmitter-receiver pair. That means $k_1 \neq k_2 \neq k_3$ and $k'_1 \neq k'_2 \neq k'_3$, which can avoid the interference between R_1 and R_2 . For clarity, we introduce the following notation:

$$C(P_{mn,k}) = \log(1 + g_{mn}^k P_{mn,k}), \quad (1)$$

where C_{mn}^k is the capacity of $m \rightarrow n$ link on the k th subcarrier with the transmitted power $P_{mn,k}$ and $g_{mn}^k = |H_{mn}^k|^2 / \sigma^2$, where σ^2 is denoted by the variance of a zero mean complex additive white Gaussian noise $\mathcal{CN}(0, \sigma^2)$.

III. ACHIEVABLE RATE ANALYSIS IN SUR PROTOCOL

we refer to $w_{mn,k}$ ($v_{mn,k'}$) as an indicator to demonstrate whether the subcarrier is allocated to the $m \rightarrow n$ link on the k th (k' th) subcarrier in the odd (even) time slot. For an energy constrained network, define P_m as the total transmit power of the node m . Suppose that the time-sharing parameter for each stage is $1/2$, and the best time-sharing allocation is beyond the scope of this paper. Using the four cut-sets in Fig. 1, the upper capacity bound for SUR protocol in OFDMA systems can be derived by applying the cut-set bound theorem for half-duplex systems in [9].

Theorem 1: The maximum achievable rate for SUR protocol in OFDMA systems is

$$\begin{aligned} R = \max & \left\{ \frac{1}{2} \min \left\{ \sum_k w_{01,k} C(P_{01,k}), \sum_{k'} v_{13,k'} C(P_{13,k'}) \right\} \right. \\ & + \frac{1}{2} \min \left\{ \sum_{k'} v_{02,k'} C(P_{02,k'}), \sum_k w_{23,k} C(P_{23,k}) \right\} \\ & \left. + \frac{1}{2} \left\{ \sum_k w_{03,k} C(P_{03,k}) + \sum_{k'} v_{03,k'} C(P_{03,k'}) \right\} \right\}, \end{aligned} \quad (2)$$

$$\text{s.t. } w_{01,k} + w_{23,k} + w_{03,k} = 1, \quad (3a)$$

$$v_{13,k'} + v_{02,k'} + v_{03,k'} = 1, \quad (3b)$$

$$w_{mn,k} \in \{0, 1\}, (m, n) \in \{(0, 1), (0, 3), (2, 3)\}, \quad (3c)$$

$$v_{mn,k'} \in \{0, 1\}, (m, n) \in \{(1, 3), (0, 2), (0, 3)\}. \quad (3d)$$

Proof: The OFDMA constraint (3) implies that there is no subcarrier reused at the same time slot, which guarantees that each subcarrier is occupied by only one transmitter-receiver pair as mentioned in Section II. Consequently, the interference between R_1 and R_2 can be avoided.

Applying Corollary 2 in [9], for the first cut-set, it has

$$R_1 = \frac{1}{2} \left\{ I(X_0^{(n)}; Y_1^{(n)}, Y_3^{(n)} | X_2^{(n)}) + I(X_0^{(n+1)}; Y_2^{(n+1)}, Y_3^{(n+1)} | X_1^{(n+1)}) \right\}. \quad (4)$$

Assume the data transmitted at S is independent with the data transmitted in the previous time slot, so $X_0^{(n)}$ and $X_2^{(n)}$ are independent with each other. Likewise, $X_0^{(n+1)}$ is also independent with $X_1^{(n+1)}$. Moreover, the channel between a transmit-receive pair is turned to be the independent subchannels due to the OFDMA constraint. Thus, (4) can be rewritten by

$$\begin{aligned} R_1 = & \frac{1}{2} \left\{ I(X_0^{(n)}; Y_1^{(n)}, Y_3^{(n)}) + I(X_0^{(n+1)}; Y_2^{(n+1)}, Y_3^{(n+1)}) \right\} \\ = & \frac{1}{2} \left\{ \sum_k (w_{01,k} C(P_{01,k}) + w_{03,k} C(P_{03,k})) \right. \\ & \left. + \sum_{k'} (v_{02,k'} C(P_{02,k'}) + v_{03,k'} C(P_{03,k'})) \right\}. \end{aligned} \quad (5)$$

Similarly, for the third and fourth cut-sets, we obtain

$$\begin{aligned} R_3 = & \frac{1}{2} \left\{ I(X_0^{(n)}, X_2^{(n)}; Y_1^{(n)}, Y_3^{(n)}) + I(X_0^{(n+1)}, Y_3^{(n+1)} | X_1^{(n+1)}) \right\} \\ = & \frac{1}{2} \left\{ I(X_0^{(n)}, X_2^{(n)}; Y_1^{(n)}, Y_3^{(n)}) + I(X_0^{(n+1)}; Y_3^{(n+1)}) \right\} \\ = & \frac{1}{2} \left\{ \sum_k (w_{01,k} C(P_{01,k}) + w_{03,k} C(P_{03,k})) \right. \\ & \left. + w_{23,k} C(P_{23,k}) + \sum_{k'} v_{03,k'} C(P_{03,k'}) \right\}, \end{aligned} \quad (6)$$

$$\begin{aligned} R_4 = & \frac{1}{2} \left\{ I(X_0^{(n)}, Y_3^{(n)} | X_2^{(n)}) + I(X_0^{(n+1)}, X_1^{(n+1)}; Y_2^{(n+1)}, Y_3^{(n+1)}) \right\} \\ = & \frac{1}{2} \left\{ I(X_0^{(n)}, Y_3^{(n)}) + I(X_0^{(n+1)}, X_1^{(n+1)}; Y_2^{(n+1)}, Y_3^{(n+1)}) \right\} \\ = & \frac{1}{2} \left\{ \sum_k w_{03,k} C(P_{03,k}) + \sum_{k'} (v_{13,k'} C(P_{13,k'}) \right. \\ & \left. + v_{02,k'} C(P_{02,k'}) + v_{03,k'} C(P_{03,k'})) \right\}. \end{aligned} \quad (7)$$

Likewise, from the second cut-set, it yields

$$\begin{aligned} R_2 &= \frac{1}{2} \left\{ I(X_0^{(n)}, X_2^{(n)}; Y_3^{(n)}) + I(X_0^{(n+1)}, X_1^{(n+1)}; Y_3^{(n+1)}) \right\} \\ &= \frac{1}{2} \left\{ \sum_k (w_{03,k} C(P_{03,k}) + w_{23,k} C(P_{23,k})) \right. \\ &\quad \left. + \sum_{k'} (v_{13,k'} C(P_{13,k'}) + v_{03,k} C(P_{03,k'})) \right\}. \end{aligned} \quad (8)$$

According to (5), (6), (7) and (8), the maximal achievable rate can be upper bounded by

$$R \leq \sup \min \{R_1, R_2, R_3, R_4\}, \quad (9)$$

which is equivalent to the following,

$$R = \max \min \{R_1, R_2, R_3, R_4\}. \quad (10)$$

After some mathematical manipulation, (2) can be achieved. This concludes the proof. ■

IV. JOINT POWER AND SUBCARRIER ALLOCATION FOR ACHIEVABLE RATE OPTIMIZATION

Based on the derivation of *Theorem 1*, we set (2) as the objective function. Unfortunately, the above problem belongs to the integer programming problems, which needs an exhaustive search to find the exact solution. Hence, for an easier formulation, we relax the integer constraints (3c) and (3d) as $w_{mn,k} \geq 0$ and $v_{mn,k'} \geq 0$. This continuous relaxation permits time sharing of each subcarrier, thus taking the similar approach in [12] and using the Lemma 1 in [7], (2) and (3) can be reformulate as

$$\begin{aligned} R &= \max \frac{1}{4} \left(\sum_k (A_{01,k} + A_{23,k}) + \sum_{k'} (B_{13,k'} + B_{02,k'}) \right) \\ &\quad + \frac{1}{2} \left(\sum_k A_{03,k} + \sum_{k'} B_{03,k'} \right), \end{aligned} \quad (11)$$

$$\text{s.t. } \sum_k A_{01,k} = \sum_{k'} B_{13,k'}, \quad (12a)$$

$$\sum_k A_{23,k} = \sum_{k'} B_{02,k'}, \quad (12b)$$

$$\sum_k \sum_{n=1,3} P_{0n,k} \leq P_0, \quad \sum_k P_{23,k} \leq P_2 \quad (12c)$$

$$\sum_{k'} \sum_{n=2,3} P_{0n,k'} \leq P_0, \quad \sum_{k'} P_{13,k'} \leq P_1, \quad (12d)$$

$$w_{01,k} + w_{03,k} + w_{23,k} = 1, \quad (12e)$$

$$v_{02,k'} + v_{03,k'} + v_{23,k'} = 1, \quad (12f)$$

$$w_{mn,k} \geq 0, \quad (m, n) \in \{(0, 1), (0, 3), (2, 3)\}, \quad (12g)$$

$$v_{mn,k'} \geq 0, \quad (m, n) \in \{(1, 3), (0, 2), (0, 3)\}. \quad (12h)$$

where

$$A_{mn,k} = w_{mn,k} C\left(\frac{P_{mn,k}}{w_{mn,k}}\right) \quad (13a)$$

$$B_{mn,k'} = v_{mn,k'} C\left(\frac{P_{mn,k'}}{v_{mn,k'}}\right). \quad (13b)$$

Since this is a convex optimization problem, the duality gap is zero, which means the solution of the dual problem is equal to that of the primal problem. So the Lagrangian is formulated as follows,

$$\begin{aligned} \mathcal{L}(\mathbf{P}, \mathbf{w}, \mathbf{v}, \lambda, \mu, \xi) &= \sum_k \left(\frac{1}{4} (A_{01,k} + A_{23,k}) + \frac{1}{2} A_{03,k} \right) + \sum_{k'} \left(\frac{1}{4} (B_{13,k'} + B_{02,k'}) + \frac{1}{2} B_{03,k'} \right) \\ &\quad - \lambda_1 \left(\sum_k A_{01,k} - \sum_{k'} B_{13,k'} \right) - \lambda_2 \left(\sum_k A_{23,k} - \sum_{k'} B_{02,k'} \right) \\ &\quad + \mu_0 (P_0 - \sum_k \sum_{n=1,3} P_{0n,k}) + \mu_2 (P_2 - \sum_k P_{23,k}) \\ &\quad + \xi_0 (P_0 - \sum_{k'} \sum_{n=2,3} P_{0n,k'}) + \xi_1 (P_1 - \sum_{k'} P_{13,k'}), \end{aligned} \quad (14)$$

where λ_1 and λ_2 denote the vector of dual variables for the equality constraints given in (12a) and (12b), respectively and we refer $\mu \triangleq [\mu_0, \mu_2]^T$ and $\xi \triangleq [\xi_0, \xi_1]^T$ as the vectors of dual variables for the power constraints given in (12c) and (12d). Then, the dual objective function problem is defined as

$$g(\lambda, \mu, \xi) = \begin{cases} \max_{(\mathbf{P}, \mathbf{w}, \mathbf{v})} \mathcal{L}(\mathbf{P}, \mathbf{w}, \mathbf{v}, \lambda, \mu, \xi) \\ \text{s.t. (12e) - (12h)} \end{cases} \quad (15)$$

and the dual problem is given as

$$\begin{aligned} \min_{\lambda, \mu, \xi} g(\lambda, \mu, \xi) \\ \text{s.t. } \mu \geq 0, \xi \geq 0. \end{aligned} \quad (16)$$

From (14) and (15), we observe that the dual objective function can be decoupled into two independent subproblems as $g(\lambda, \mu) = g_1(\lambda, \mu) + g_2(\lambda, \xi)$, where

$$g_1(\lambda, \mu) = \begin{cases} \left(\frac{1}{4} - \lambda_1 \right) \sum_k A_{01,k} + \left(\frac{1}{4} - \lambda_2 \right) \sum_k A_{23,k} + \frac{1}{2} \sum_k A_{03,k} \\ + \mu_0 (P_0 - \sum_k \sum_{n=1,3} P_{0n,k}) + \mu_2 (P_2 - \sum_k P_{23,k}) \\ \text{s.t. (12e) and (12g)} \end{cases} \quad (17)$$

and

$$g_2(\lambda, \xi) = \begin{cases} \left(\frac{1}{4} + \lambda_1 \right) \sum_{k'} B_{13,k'} + \left(\frac{1}{4} + \lambda_2 \right) \sum_{k'} B_{02,k'} + \frac{1}{2} \sum_{k'} B_{03,k'} \\ + \xi_0 (P_0 - \sum_{k'} \sum_{n=2,3} P_{0n,k'}) + \xi_1 (P_1 - \sum_{k'} P_{13,k'}) \\ \text{s.t. (12f) and (12h)}. \end{cases} \quad (18)$$

Given $\lambda^{(i)}$, $\mu^{(i)}$ and $\xi^{(i)}$, the solution of (17) can be derived for each k as

$$w_{mn,k}^{(i)} = \begin{cases} 1, & (m, n) = (\tilde{m}, \tilde{n}), X_{\tilde{m}\tilde{n},k}^{(i)} > 0 \\ 0, & \text{otherwise} \end{cases} \quad (19)$$

$$P_{mn,k}^{(i)} = w_{mn,k}^{(i)} \left(\frac{d_{mn}^{(i)}}{\mu_m^{(i)}} - \frac{1}{g_{mn}^k} \right)^+ \quad (20)$$

where

$$X_{\tilde{m}\tilde{n},k'}^{(i)} \triangleq \arg \max_{(m,n) \in \{(0,1),(0,3),(2,3)\}} X_{mn,k'}^{(i)}, \quad (21)$$

$$\begin{aligned} X_{mn,k'}^{(i)} &\triangleq d_{mn}^{(i)} \ln \left(1 + g_{mn}^k \left(\frac{d_{mn}^{(i)}}{\mu_m^{(i)}} - \frac{1}{g_{mn}^k} \right)^+ \right) \\ &\quad - \mu_m^{(i)} \left(\frac{d_{mn}^{(i)}}{\mu_m^{(i)}} - \frac{1}{g_{mn}^k} \right)^+ \end{aligned} \quad (22)$$

and

$$d_{mn}^{(i)} = \begin{cases} \frac{1}{4} - \lambda_1^{(i)}, m = 0, n = 1 \\ \frac{1}{4} - \lambda_2^{(i)}, m = 2, n = 3 \\ \frac{1}{2}, m = 0, n = 3. \end{cases} \quad (23)$$

Similarly, the solution of (18) is given as

$$v_{mn,k'}^{(i)} = \begin{cases} 1, (m,n) = (\hat{m},\hat{n}), Y_{\hat{m}\hat{n},k'}^{(i)} > 0 \\ 0, \text{otherwise} \end{cases} \quad (24)$$

$$P_{mn,k'}^{(i)} = v_{mn,k'}^{(i)} \left(\frac{e_{mn}^{(i)}}{\mu_m^{(i)}} - \frac{1}{g_{mn}^{k'}} \right)^+ \quad (25)$$

where

$$(\hat{m},\hat{n}) \triangleq \arg \max_{(m,n) \in \{(1,3),(0,2),(0,3)\}} Y_{mn,k'}^{(i)} \quad (26)$$

$$\begin{aligned} Y_{mn,k'}^{(i)} &\triangleq e_{mn}^{(i)} \ln \left(1 + g_{mn}^{k'} \left(\frac{e_{mn}^{(i)}}{\mu_m^{(i)}} - \frac{1}{g_{mn}^{k'}} \right)^+ \right) \\ &\quad - \mu_m^{(i)} \left(\frac{e_{mn}^{(i)}}{\mu_m^{(i)}} - \frac{1}{g_{mn}^{k'}} \right)^+ \end{aligned} \quad (27)$$

and

$$e_{mn}^{(i)} = \begin{cases} \frac{1}{4} + \lambda_1^{(i)}, m = 1, n = 3 \\ \frac{1}{4} + \lambda_2^{(i)}, m = 0, n = 2 \\ \frac{1}{2}, m = 0, n = 3. \end{cases} \quad (28)$$

For i th iteration, the dual variables are updated as

$$\lambda_1^{(i+1)} = \lambda_1^{(i)} + s_1^{(i)} \left(\sum_k A_{01,k} - \sum_{k'} B_{13,k'} \right) \quad (29a)$$

$$\lambda_2^{(i+1)} = \lambda_2^{(i)} + s_2^{(i)} \left(\sum_k A_{23,k} - \sum_{k'} B_{02,k'} \right) \quad (29b)$$

$$\mu_0^{(i+1)} = \mu_0^{(i)} - u_0^{(i)} \left(P_0 - \sum_k \sum_{n=1,3} P_{0n,k} \right) \quad (29c)$$

$$\mu_2^{(i+1)} = \mu_2^{(i)} - u_2^{(i)} \left(P_2 - \sum_k P_{23,k} \right) \quad (29d)$$

$$\xi_0^{(i+1)} = \xi_0^{(i)} - t_0^{(i)} \left(P_0 - \sum_{k'} \sum_{n=2,3} P_{0n,k'} \right) \quad (29e)$$

$$\xi_1^{(i+1)} = \xi_1^{(i)} - t_1^{(i)} \left(P_1 - \sum_{k'} P_{13,k'} \right). \quad (29f)$$

, where $\mathbf{s}^{(i)} > 0$, $\mathbf{u}^{(i)} > 0$ and $\mathbf{t}^{(i)} > 0$ is a sequence of step size for the subgradient method, respectively. The near-optimal solution for (11) can be obtained with a sufficiently large number of iterations [10].

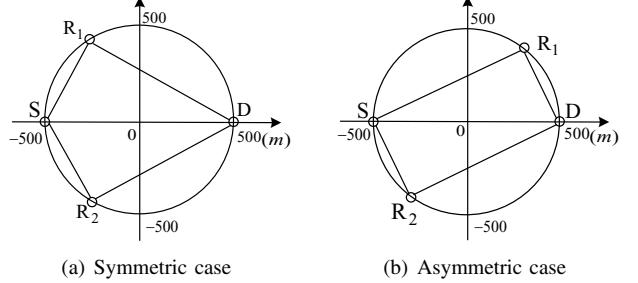


Fig. 2. Simulation Model

V. SIMULATION RESULTS

In this section, we present the results of the achievable rate in SIR and SUR protocols based on OFDMA systems via Monte-Carlo simulation. For simplicity, we firstly consider a symmetric case as shown in Fig. 2(a) that R_1 and R_2 are located symmetrically on the circle with radius r centered at the origin and have the coordinates $(X_R, \pm Y(X_R))$, while the asymmetric case is also investigated in Fig. 2(b) that R_1 and R_2 are located at points $(X_R, Y(X_R))$ and $(-X_R, -Y(X_R))$, respectively, where $X_R \in \{-500, 500\}$ and $Y(X_R) = \sqrt{r^2 - X_R^2}$. Moreover S and D are separately lying at points $(-500, 0)$ and $(500, 0)$ in Fig. 2. Using 3GPP Spatial Channel Model [13], the system parameters are summarized by Table I, where the distance of the $m \rightarrow n$ link is denoted by d_{mn} . Define $PL_{mn}(d)$ as the pathloss model of the $m \rightarrow n$ link at the distance d . We refer to

$$SNR_{ref} = \frac{P_0}{N\sigma^2 PL_{03}(\frac{d_{03}}{2})} \quad (30)$$

as the reference SNR which is used to determine σ^2 , then g_{mn}^k can also be determined. It is noted that the value of the system capacity is normalized to the number of OFDM subcarriers N .

TABLE I
SYSTEM PARAMETERS

Parameter	Value
System Bandwidth	5 MHz
Carrier Frequency	2 GHz
Sample Rate	7.68 MHz
FFT size	512
# of used subcarriers N	300
cyclic prefix	36
Cell radius d_{03}	1000 m
TX Power (P_0, P_1, P_2)	30 dBm
MS Velocity	3 km/h
Height (S,R,D)	32 m, 5 m, 1.5 m
Pathloss Model [11] (in dB)	S-R: $100.7 + 23.5 \log_{10}(R)$ (LOS) S-D: $131.1 + 42.8 \log_{10}(R)$ (NLOS) R-D: $145.4 + 37.5 \log_{10}(R)$ (NLOS) (R in kilometers)

Fig. 3 pictorially depicts the normalized achievable rate in SUR protocol with proposed resource allocation and in SIR protocol with resource allocation as in [7], when $X_{R_1} = X_{R_2} = -250$ m in symmetric case and $X_{R_1} = -X_{R_2} = -250$ m in asymmetric case , with respect to the SNR_{ref} .

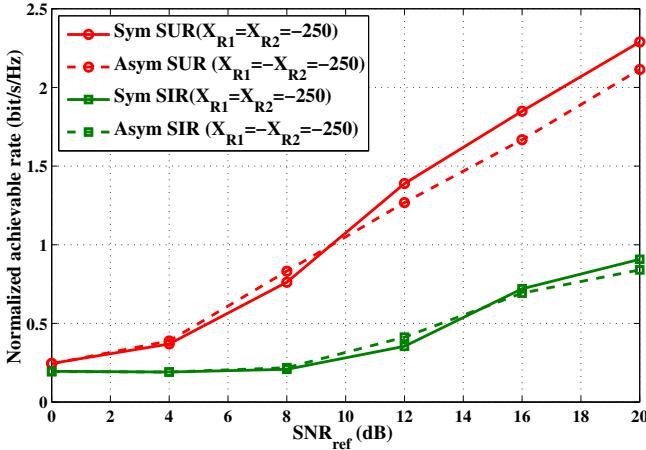


Fig. 3. Normalized achievable rate with optimal resource allocation in SUR and SIR protocols under the symmetric case when $X_{R_1} = X_{R_2} = -250$ m and the asymmetric case when $X_{R_1} = -X_{R_2} = 250$ m

The normalized achievable rates in both SUR and SIR have growing gains as SNR_{ref} increases. When $SNR_{ref} = 0$ dB, the achievable rates for both SUR and SIR protocols are close to each other. And the gap of the achievable rates between SUR protocol and SIR protocol is expanded in high SNR for both symmetric and asymmetric cases. For the SUR protocol, the achievable rate in symmetric case outperforms that in asymmetric case when $SNR_{ref} > 10$ dB. However, the achievable rates for SIR protocol are not sensitive to either symmetric or asymmetric case.

VI. CONCLUSION

In this paper, the resource allocation in SUR for OFDMA systems is considered. Based on the analysis of the capacity bound in SUR OFDMA systems, the near-optimal achievable rate is obtained by using the Lagrangian dual decomposition approach and subgradient method. In the simulation, we employ the path-loss model in 3GPP LTE Advanced programs to evaluate the achievable rate for both SUR and SIR protocols. The simulation results have shown that SUR has the advantage of improving the achievable rate as SNR increases. In low SNR, this two protocols have a close achievable rate, however the gap is expanded in high SNR. And the SUR protocol in symmetric case has the best performance on improving the achievable rate of the system within the four simulation cases depicted in Fig. 3.

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