International Journal on Emerging Technologies **11**(5): 164-169(2020)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

Effective Cooperative Hybrid Precoder for Multiuser Mmwave MIMO Communication

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(Received 17 June 2020, Revised 20 July 2020, Accepted 10 August 2020)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: This paper aims to apply the Lagrangian algorithm and adaptive power allocation for finding optimum hybrid precoders for all Base Stations in the cooperative communication system. Firstly, the cooperative model can be implemented where some Base Stations and some Mobile Stations with the Signal to Interference and Noise Ratio (SINR) are considered for each user, wherein useful signal is from a set of cooperative Base Stations hybrid precoders to the desired user. In contrast, interference is transmitted signals from remaining hybrid precoders that do not belong to this set. The SINR is related deeply to channel rate for each user, which is a component of sum-rate for all users. Secondly, the current algorithm can be reviewed when using the optimum RF (Radio Frequency) precoder found, then optimum BB (BaseBand) precoder determined. However, the studies are not yet interested in the adaptive power distribution, taken account of the Langrangian algorithm for the cooperative hybrid precoder. Therefore, a proposed method using the Lagrangian algorithm and adaptive power allocation for optimizing the hybrid precoder. Besides, a simulation is given that shows the sum-rate for all users using the proposed method is higher than the case, not using the Lagrangian algorithm or no power allocation.

Keywords: MIMO, mm Wave, SINR, hybrid precoder, Lagrangian algorithm.

Abbreviations: MIMO, Multiple Input – Multiple Output; SINR**,** Interference and Noise Ratio**;** RF, Radio Frequency; BB, Base Band; BS: Base Station; MS: Mobie Station.

I. INTRODUCTION

Massive MIMO is considered for the mm-Wave because it can give the gain enough for this transmission to compensate for the loss caused by the signal frequency (30 – 300 GHz). However, many antennas are used in BS, not in MS, because it is not useful to install many antennas on this end equipment [1]. One question is stated why using the hybrid precoding for massive MIMO? The significant cause for this use is that many RF chains are implemented for massive MIMO, which causes high hardware cost and energy consumption. The RF chain can be defined consisting of the cascade of a digital-to-analog converter, a mixer, and a power amplifier for each transmit antenna [1].

Hybrid precoding for multiuser massive MIMO systems has been considered in [2-3]. Some papers consider a low complexity practical algorithm for RF and baseband precoders as well as RF chain allocation for different user clusters or users [3-7]. The hybrid precoder's advantage is that a high-dimensional RF processing unit is assembled to a low-dimensional BB processing unit through a limited number of RF chains, which significantly reduces the number of RF chains [1].

However, to guarantee the system throughput, cooperative communication is given. The concept of cooperative MIMO is seen as multiple radio links are combined to accomplish the receive data for any user. The joint transmission is the most useful solution among multiple BSs transmitting data to the same user share the same the data and channel state information fed back from the MSs.

Several approaches have been investigated for precoder design in cooperative MIMO systems, including block diagonalization based approach [8] virtual signal-to-noise-plus-interference (SINR) based approach [9], and Lagrangian based approach [10, 11]. Block diagonalization [8] can be seen as a generalization of channel inversion for situations with multiple antennas per user, with the purpose to find the transmit vectors. This algorithm's condition is the product of the network channel, and modulation matrices are diagonal, leading to nearly zero multiuser interference. It is hard to happen in reality. In [9], there are some clusters, which have some Base Stations (BSs). This paper gives the concept of the overlapping BSs that cause overlapping interference while the non-overlapping BSs cause the non- overlapping interference. The purpose of this paper is to maximize the virtual SINR, where the interference is a sum of the non- overlapping and the overlapping interferences. [8, 9] are not interested in using a adaptive power distribution for the hybrid precoder.

The papers [10-11] apply the Lagrangian to find the transmit and the receiver beam vectors with the constraint on power per node. However, they do not mention how to optimize hybrid precoder.

The paper [12] is recently interested in applying the Lagrangian algorithm together with the adaptive power distribution for the cooperative hybrid precoder. However, power optimization does not take into account the signal-to-noise ratio and given SINR noise at each user. Some articles interested in building the optimum hybrid precoder using the SVD (Singular Value Decomposition) [13], or using the secrecy rate is usually used as the performance metric [14] for mmWave MIMO systems, but not to the cooperative model. The article [15] covers the cooperative method, even extending the participation of relays, but only interested in the effect of the number of relays on the system's sum-rate.

That is an exciting topic that is concerned with this paper that considers some BSs serving a limited number of mobiles MSs, using the Lagrangian distribution, with the purpose to maximize the sum-rate for all these BSs and MSs and also apply the adaptive power allocation following the water filling principle to the hybrid precoders of all BSs. The proposed method can help the sum rate better than the cases of whether using Lagrangian distribution or not without power allocation.

II. COOPERATIVE CHANNEL MODEL

The channel model can be referenced by [1], where there are some BSs and some MSs.Each the kth BS has one baseband matrix of $\mathbf{F}_k^{BB}$ and one analog matrix $\mathbf{F}_k^{RF}$. The model can be described in Fig. 1.

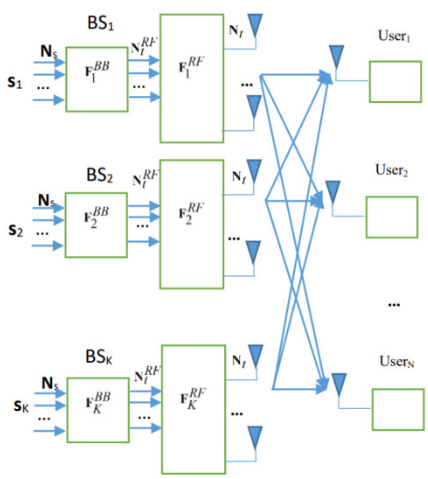


Fig. 1. Cooperative channel model.

Here, we can show the received signal:

$$y_n = \sum_{k\in B(n)} \mathbf{h}_{k,n}^H \mathbf{F}_k^{RF} \mathbf{F}_k^{BB} \mathbf{s}_k + \sum_{l\notin B(n)} \mathbf{h}_{l,n}^H \mathbf{F}_l^{RF} \mathbf{F}_l^{BB} \mathbf{s}_l + n_n \tag{1}$$

Where $\mathbf{s}_k$ is the symbol input with the size of $N_s \times 1$, $\mathbf{F}_k^{BB}$ is the baseband matrix with the size of $N_t^{RF} \times N_s$; The RF weight matrix for forming the beams $\mathbf{F}_k^{RF}$ has the size of $N_t \times N_t^{RF}$. B_n are set of the indices of the BSs which transmit the data to the n th user. $\mathbf{h}_{k,n}$ is the channel vector with the size of $N_t \times 1$ the kth BS to the n th user.

For clearer exlaination, we have:

$$\mathbf{F}_k^{BB} = \left[\mathbf{f}_{k,n_1}^{BB} \quad \mathbf{f}_{k,n_2}^{BB} \quad \cdots \quad \mathbf{f}_{k,n_{N_s}}^{BB} \right] \tag{2}$$

where $\mathbf{f}_{k,n_s}^{BB}$ is the column channel vector with the size of $N_t^{RF} \times 1$.

In the cooperative communication, the symbol sequence comes from all the RF matrix of $\mathbf{F}_k^{RF}$ in which the symbols $x_{k,n} = s_{k,n} = \{0,1\}$ with $k = 1:K$ for the n th user go through the baseband vectors of $\mathbf{f}_{k,n}^{BB}$ of the baseband matrix $\mathbf{F}_k^{BB}$, correspondingly.

The power of the desired signal to user n from all hybrid precoders $k = 1:K$ is:

$$S_n = \left| \sum_{k=1}^{K} \mathbf{h}_{k,n}^H x_{k,n} \mathbf{F}_k^{RF} \mathbf{f}_{k,n}^{BB} \right|^2 \tag{3}$$

Meanwhile, the other symbols $x_{k,m} = s_{k,m} = \{0,1\}$ to all remaining users $m = 1:N, m \neq n; k = 1:K$ cause the interference on the n th user after going through the baseband vector of $\mathbf{f}_{k,m}^{BB}$ and the $\mathbf{F}_k^{RF}$, respectively:

$$I_n = \sum_{\substack{m \neq n \\ m=1}}^{N} \left| \sum_{k=1}^{K} \mathbf{h}_{k,n}^H x_{k,m} \mathbf{F}_k^{RF} \mathbf{f}_{k,m}^{BB} \right|^2 \tag{4}$$

Therefore, the signal to interference and noise ratio can be denoted, taking account of noise power of signal n_n with value of σ^2:

$$\gamma_n = \frac{S_n}{\sigma^2 + I_n} = \frac{\left| \sum_{k=1}^{K} \mathbf{h}_{k,n}^H x_{k,n} \mathbf{F}_k^{RF} \mathbf{f}_{k,n}^{BB} \right|^2}{\sigma^2 + \sum_{\substack{m \neq n \\ m=1}}^{N} \left| \sum_{k=1}^{K} \mathbf{h}_{k,n}^H x_{k,m} \mathbf{F}_k^{RF} \mathbf{f}_{k,m}^{BB} \right|^2} \tag{5}$$

Some constraints, that are related to the transmit power and transmission mechanism for the system, are given:

$$\sum_{n=1}^{N} x_{k,n} \leq N_t^{RF}, \forall k, \; x_{k,n} \in \{0,1\}, \forall k, n \tag{6}$$

$$\sum_{n=1}^{N} \left\| \mathbf{F}_k^{RF} \mathbf{f}_{k,n}^{BB} \right\|_2^2 \leq P \text{ and } \left| \left(\mathbf{F}_k^{RF} \right)_{i,j} \right| = \frac{1}{\sqrt{N_t}}, \forall i, j, k \tag{7}$$

One criterion for transmission from the k th hybrid precoder to of the N users-developed from equation (5). It is defined as the sum of rates (sum_rate) that is the channel capacity between the kth hybrid precoder to each of the N users. This criterion considers the optimization of the baseband and RF precoder combination (hybrid precoder $\bar{\mathbf{f}}_n$):

$$sum\_rate = \max_{\left\{\bar{\mathbf{f}}_n\right\}_{n=1}^{N}} W \sum_{n=1}^{N} \left\{ \log_2 w_n \left(\frac{\sigma^2 + \sum_{m=1}^{N} \left| \tilde{\mathbf{h}}_{m,n}^H \bar{\mathbf{f}}_m \right|^2}{\sigma^2 + \sum_{\substack{m=1 \\ m \neq n}}^{N} \left| \tilde{\mathbf{h}}_{m,n}^H \bar{\mathbf{f}}_m \right|^2} \right) \right\} \quad (8)$$

Where

$$\bar{\mathbf{f}}_n = \left[\left(\mathbf{F}_k^{RF} \mathbf{f}_{k,n}^{BB} \right)^T, \forall k \;\; such\ as\ x_{k,n} = 1 \right]^T, \forall n \quad (9)$$

$$\tilde{\mathbf{h}}_{m,n} = \left[\left(\mathbf{h}_{k,n} \right)^T, \forall k \;\; such\ as\ x_{k,m} = 1 \right]^T, \forall m,n \quad (10)$$

$k_n = \sum_{q=1}^{k} x_{q,n}, \forall k,n$ is the index of one element of $\bar{\mathbf{f}}_n$

The constraints become:

$$\sum_{n=1}^{N} x_{k,n} \left\| \left(\mathbf{e}_{k_n}^T \otimes \mathbf{I}_{N_t} \right) \bar{\mathbf{f}}_n \right\|_F^2 \leq P, \forall k \text{ and } \left| \left(\mathbf{F}_k^{RF} \right)_{i,j} \right| = \frac{1}{\sqrt{N_t}}, \forall i,j,k \quad (11)$$

In which $\mathbf{e}_i$ is zero column vector with the value of 1 at the i th position.

After finding the optimum hybrid precoder $\bar{\mathbf{f}}_n$, we can find the optimum RF precoder through the below equations:

$$\mathbf{F}_k^{RF} = \begin{bmatrix} e^{j\angle\left(\bar{\mathbf{f}}_k\right)_{1,1}} & \cdots & e^{j\angle\left(\bar{\mathbf{f}}_k\right)_{1,N_t^{RF}}} \\ \cdots & \ddots & \cdots \\ e^{j\angle\left(\bar{\mathbf{f}}_k\right)_{N_t,1}} & \cdots & e^{j\angle\left(\bar{\mathbf{f}}_k\right)_{N_t,N_t^{RF}}} \end{bmatrix}^T, \forall k \quad (12)$$

where

$$\bar{\mathbf{f}}_k = \left[\bar{\mathbf{f}}_{k,n}, \forall n\ such\ as\ x_{k,n} = 1 \right], \forall k \quad (13)$$

$$\bar{\mathbf{f}}_n = \left[\bar{\mathbf{f}}_{k,n}, \forall k\ such\ as\ x_{k,n} = 1 \right], \forall n \quad (14)$$

After that, we still find the baseband matrix $\mathbf{F}_k^{BB}$ that is formed by the baseband vectors $\tilde{\mathbf{f}}_n^{BB}$ (2), respectively. The Eqn. (12) is deduced from (8):

$$sum\_rate = \max_{\left\{\tilde{\mathbf{f}}_n^{BB}\right\}_{n=1}^{N}} W \sum_{n=1}^{N} \left\{ \log_2 w_n \left(\frac{\sigma^2 + \sum_{m=1}^{N} \left| \mathbf{g}_{m,n}^H \tilde{\mathbf{f}}_m^{BB} \right|^2}{\sigma^2 + \sum_{\substack{m=1 \\ m \neq n}}^{N} \left| \mathbf{g}_{m,n}^H \tilde{\mathbf{f}}_m^{BB} \right|^2} \right) \right\} \quad (15)$$

where

$$\tilde{\mathbf{f}}_n^{BB} = \left[\left(\mathbf{f}_{k,n}^{BB} \right)^T, \forall k\ such\ as\ x_{k,n} = 1 \right]^T, \forall n \quad (16)$$

$$\mathbf{g}_{m,n} = \left[\mathbf{h}_{k,n}^H \mathbf{F}_k^{RF}, \forall k\ such\ as\ x_{k,m} = 1 \right]^T, \forall m,n \quad (17)$$

III. EXISTING ALGORITHM

The current algorithm is described below:

Input: $\{\mathbf{h}_{k,n}\}, \{x_{k,n}\}, \{w_n\}$

Output: $\left\{\mathbf{F}_k^{RF}\right\}, \left\{\mathbf{F}_k^{BB}\right\}$

The steps:

Step 1. Solve (8) to get $\left\{\bar{\mathbf{f}}_n\right\}$ as the strongest beam, not mentioning the interference of other users

Step 2. Obtain $\left\{\bar{\mathbf{f}}_k\right\}$ from $\left\{\bar{\mathbf{f}}_n\right\}$, using (13) and (14)

Step 3. Get $\left\{\mathbf{F}_k^{RF}\right\}$ from $\left\{\bar{\mathbf{f}}_k\right\}$, using (12)

Step 4. Solve (15) to get $\left\{\tilde{\mathbf{f}}_n^{BB}\right\}$ where $\mathbf{g}_{m,n}$ known in (15)

Step 5. Get $\left\{\mathbf{F}_k^{BB}\right\}$ from $\left\{\tilde{\mathbf{f}}_n^{BB}\right\}$, basing on (2) and (16)

Step 6. Return $\left\{\mathbf{F}_k^{RF}\right\}$ and $\left\{\mathbf{F}_k^{BB}\right\}$

IV. THE PROPOSED ALGORITHM

Step 1 (proposed): Apply the Lagrangian algorithm to (8), we have:

$$L = W \sum_{n=1}^{N} \log_2 w_n \left(\frac{\sigma^2 + \sum_{m=1}^{N} \left| \tilde{\mathbf{h}}_{m,n}^H \bar{\mathbf{f}}_m \right|^2}{\sigma^2 + \sum_{\substack{m=1 \\ m \neq n}}^{N} \left| \tilde{\mathbf{h}}_{m,n}^H \bar{\mathbf{f}}_m \right|^2} \right) + \sum_{n=1}^{N} \lambda_n \left(P - \sum_{n=1}^{N} \left| \bar{\mathbf{f}}_n \right|^2 \right) \quad (18)$$

$$\frac{\delta L}{\delta \bar{\mathbf{f}}_n} = 2 \left(\frac{W w_n}{\ln 2} \frac{\tilde{\mathbf{h}}_{n,n}^H \tilde{\mathbf{h}}_{n,n} \bar{\mathbf{f}}_n}{\left(\sigma^2 + \sum_{m=1}^{N} \left| \tilde{\mathbf{h}}_{m,n}^H \bar{\mathbf{f}}_m \right|^2 \right)} - \sum_{\substack{m=1 \\ m \neq n}}^{N} \frac{W w_m}{\ln 2} \frac{\gamma_n \left(\bar{\mathbf{f}} \right) \tilde{\mathbf{h}}_{m,n}^H \tilde{\mathbf{h}}_{m,n} \bar{\mathbf{f}}_n}{\left(\sigma^2 + \sum_{m=1}^{N} \left| \tilde{\mathbf{h}}_{m,n}^H \bar{\mathbf{f}}_m \right|^2 \right)} - \lambda_n \bar{\mathbf{f}}_n \right) \quad (19)$$

where

$$\gamma_n\left(\bar{\mathbf{f}}\right)=\frac{\left|\tilde{\mathbf{h}}_{n,n}^{H}\bar{\mathbf{f}}_n\right|^2}{\left(\sigma^2+\sum_{\substack{m=1\\m\neq n}}^{N}\left|\tilde{\mathbf{h}}_{m,n}^{H}\bar{\mathbf{f}}_m\right|^2\right)} \quad (20)$$

To satisfy the (19), we have some conditions below:

1. $\bar{\mathbf{f}}_n^{H}\bar{\mathbf{f}}_n=1,\forall n$

2. $W\left(\mathbf{A}_n\left(\bar{\mathbf{f}}\right)-\mathbf{B}_n\left(\bar{\mathbf{f}}\right)\right)\bar{\mathbf{f}}_n=\lambda_n\bar{\mathbf{f}}_n,\forall n$

(21)

Where

$$\mathbf{A}_n\left(\bar{\mathbf{f}}\right)=w_{n,A}\left(\tilde{\mathbf{h}}_{n,n}^{H}\tilde{\mathbf{h}}_{n,n}\right);w_{n,A}=\frac{w_n/\ln 2}{\left(\sigma^2+\sum_{m=1}^{N}\left|\tilde{\mathbf{h}}_{m,n}^{H}\bar{\mathbf{f}}_m\right|^2\right)}$$

$$\mathbf{B}_n\left(\bar{\mathbf{f}}\right)=\sum_{\substack{m\neq n\\m=1}}^{N}w_{m,B}\left(\tilde{\mathbf{h}}_{m,n}^{H}\tilde{\mathbf{h}}_{m,n}\right);w_{m,B}=\frac{\gamma_n\left(\bar{\mathbf{f}}\right)w_m/\ln 2}{\left(\sigma^2+\sum_{m=1}^{N}\left|\tilde{\mathbf{h}}_{m,n}^{H}\bar{\mathbf{f}}_m\right|^2\right)}$$

Step 4 (proposed): Solution for (15) is equivalent to (8) when we can replace $\tilde{\mathbf{h}}_{m,n}$, $\bar{\mathbf{f}}_n$, by $\mathbf{g}_{m,n}$, $\tilde{\mathbf{f}}_n^{BB}$, where $\mathbf{g}_{m,n}=\mathbf{h}_{k,n}^{H}\mathbf{F}_k^{RF}$ with $\mathbf{F}_k^{RF}$ is taken from (12), (13) an (14).

Step 7 (new): Power allocation:

7.1: $\lambda_n, n=1\rightarrow N$ are arranged in increasing order: $\lambda_1\leq\lambda_2\leq...\leq\lambda_N$.

7.2: In a situation where n is tested from 1 to N, B_n is defined as:

$$B_n=(1+\sigma^2/P_T(\lambda_{n+1})^2+\sigma^2/P_T(\lambda_{n+2})^2 +...+\sigma^2/P_T(\lambda_N)^2)/(L-n) \quad (22)$$

For $B_n<\sigma^2/P_T(\lambda_n)^2$, n will be increased by 1. However, for $B_n\geq\sigma^2/P_T(\lambda_n)^2$, n shall not be increased, and it is denoted that $B=B_n$.

7.3: The optimum power allocation for the l the transmit beam vector $\bar{\mathbf{f}}_n$ is expressed as:

$$p_n=\left[B-\sigma^2/P_T(\lambda_n)^2\right]^+ \quad (23)$$

where [ ]+ refers to definite positive value of the argument.

V. SIMULATION

It is assumed to have three base stations and three mobiles. The locations for these BSs and MSs (static MSs) can be seen in figure 2. Some assumptions are given where angles of departure for user 1, 2, 3 (three paths) are:

$\varphi_{11}=\pi/4;\varphi_{21}=5\pi/4;\varphi_{31}=7\pi/4$;

$\varphi_{11}=\pi/3;\varphi_{21}=5\pi/3;\varphi_{31}=7\pi/3$;

$\varphi_{13}=\pi/5;\varphi_{23}=5\pi/5;\varphi_{33}=7\pi/5$ (24)

The number of transmit antennas and antenna spacing are $N_t=4$, $s_t=0.01$, correspondingly. The wavelength of the signal is $\lambda=0.01$. If using current algorithm without the Lagrangian distribution [13-15], we can see the throughout can be lower than the case using this Lagrangian distribution. Moreover, if $\lambda_n, n=1:N$ are used for giving the power allocation for all $\bar{\mathbf{f}}_n, n=1:N$ (use of power water filling principle), the sum rate is often better than the case of using the Langrangian distribution.

Very few cases of the lower sum-rate using power allocation are because the most robust $\bar{\mathbf{f}}_n$ is good for user n but interfering much to other users $\bar{\mathbf{f}}_m, m=1:N, m\neq n$. Fig. 3 can show this situation.

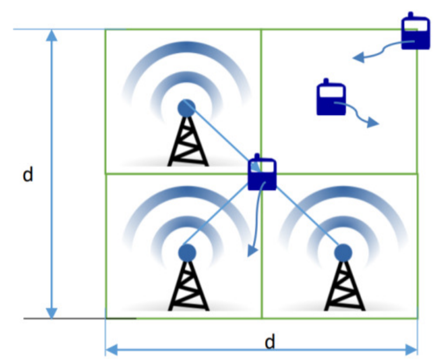


Fig. 2. The geometry of the BSs and MSs in simulation.

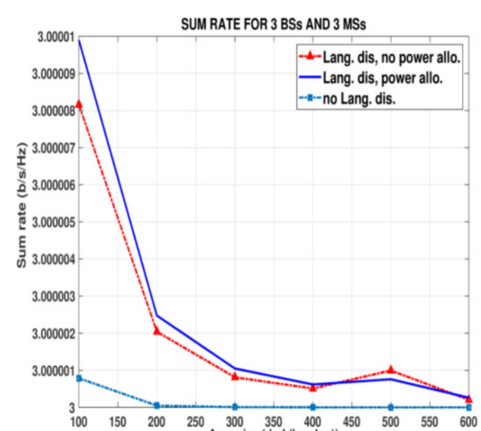
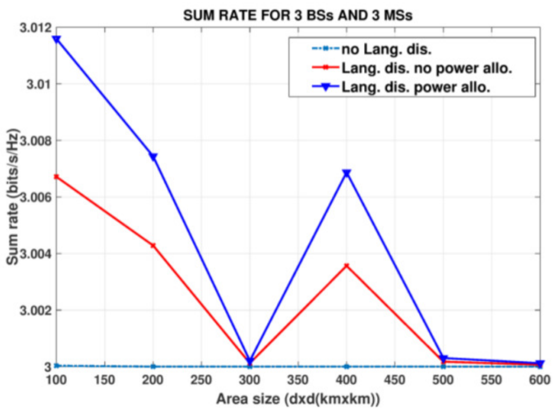
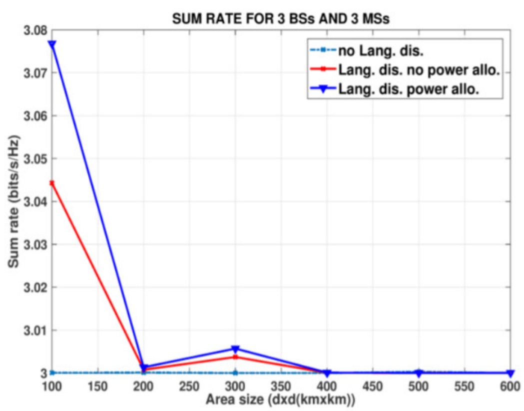


Fig. 3. Sum rates for two cases of Lagrangian algorithm and no Lagrangian algorithm (static MSs).

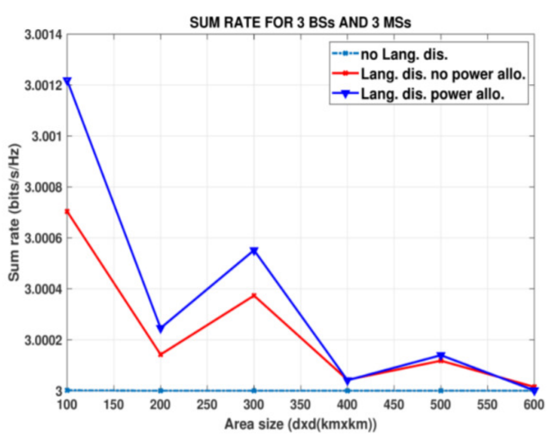
When the MSs move with the distance to the BSs are random (called randomly moving MSs), when applying the adaptive power distribution based on the Lagrangian algorithm, the simulation still results in higher total speed compared to the two cases. The traditional methods are to use the strongest vector or adopt a Lagrangian algorithm but with no compatible power distribution. Fig. 4 clearly describes these cases in which the MSs are no longer stationary; they have moved in different random directions in the area for consideration. The number of observations for these cases is 4.



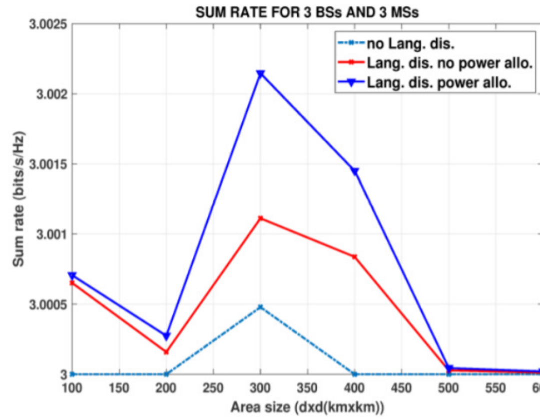
(a)



(b)



(c)



(d)

Fig. 4. Sum rates comparison with four cases of moving MSs.

VI. CONCLUSION

In this paper, the cooperative communication is considered where some Base Stations send the data to the same user. The criterion is the sum rate, which is related closely to the signal to interference and noise ratio SINR at each user. The interference herein is the signals of other users. To maximize the sum-rate for all users in the cooperative system, the author takes account of the Lagrangian algorithm and adaptive power allocation to maximize the total sum rate of this system. The proposed method can improve the system rate, compared to the traditional method using no Lagrangian algorithm. In the future, the author will consider applying the cooperative mmWave MIMO communication for the 5G.

Conflicts of Interest. I have identified and declared no conflict of interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results.

ACKNOWLEDGMENTS

I would like to thank the Univeristy of Transport and Communications, Vietnam to support this paper.

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How to cite this article: Tran, H. T. (2020). Effective Cooperative Hybrid Precoder for Multiuser Mmwave MIMO Communication. *International Journal on Emerging Technologies, 11*(5): 164–169.