Power Allocation for Interference Alignment Based Cognitive Radio Networks

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Abstract—**Interference alignment (IA) is a promising technique for interference management in cognitive radio (CR) networks. However, the sum rate may fall short of the theoretical maximum especially at low signal-to-noise ratio (SNR). Moreover, in most of the previous works, energy efficiency (EE) aspect is largely ignored. In this paper, energy-efficient power allocation (PA) and transmission-mode adaptation algorithms are proposed for IA based CR networks. We study a PA scheme aiming at optimizing the EE of networks and sum rate of secondary users (SUs), respectively, guaranteeing the rate of primary user (PU). When SNR is low, PU's rate constraint may be not ensured. Thus SUs may be switched into sleep mode and PU's transmission mode is adapted to achieve its rate constraint when SNR is low. Simulation results are presented to show the effectiveness and efficiency of the proposed algorithms for IA based CR networks.**

I. Introduction

Interference alignment (IA) is a promising technique for interference management in cognitive radio (CR) networks [1], [2]. The transmitted signals are designed to concentrate interferences in certain subspaces at the unintended receivers, and thus interference-free subspaces are left for the desired signal at each receiver. The sum rate by IA can approach the interference channel' capacity at very high signal-to-noise ratio (SNR). However, it may decrease at moderate and low SNRs [3], since IA mainly focuses on eliminating interference, without involving the quality of desired signal.

Some research works have focused on improving the performance of IA networks when SNR is low [3], [4]. Max-SINR algorithm was designed for IA in [4] to optimize the signal-to-interference-plus-noise ratio (SINR) of the desired signal, and it can improve the sum rate of interference networks obviously when SNR is low. However, its advantage tends to be lost when SNR becomes larger. An antenna-switching IA scheme was proposed to improve its sum rate in [3], and the performance degradation of IA when SNR is low is also analyzed. In [3], [4], only equal power allocation scheme was adopted. In these two yeas, power allocation (PA) and control are adopted to IA to further improve its performance [5], [6]. A distributed power control algorithm for IA networks was proposed, to ensure the data transmission at a fixed rate for each user in [5]. PA is introduced to IA in [6], to optimize the sum rate of the IA network.

Although some excellent works have been done on IA wireless networks, the *energy efficiency* (EE) issue is largely ignored in existing works, and only the energy-efficient PA for IA has been initially researched in our previous work [7]. Due to the rapidly rising energy costs and contributions to global CO_2 emissions, EE is becoming an important aspect in CR wireless communications [8], and we should concentrate more energy on the EE in IA based CR networks.

In this paper, we propose an PA and transmission-mode-adaption IA algorithm for CR network, and its contributions are as follows.

1) Different from the existing works that focused solely on sum rate, the energy efficiency aspect of IA based CR networks is also involved in this paper.
2) Two PA algorithms are proposed for IA based CR networks with rate constraint of primary user (PU). The first one is to maximize the energy efficiency of IA based CR network, and the second is to optimize the sum rate of secondary users (SUs), which can thus maximize the income of PU.
3) To guarantee the rate constraint of PU when SNR becomes lower, transmission-mode adaption scheme is proposed to further improve the rate of PU at low SNRs.

Notation: $\mathbf{I}_d$ represents the $d \times d$ identity matrix. $\mathbf{A}^\dagger$ and $|\mathbf{A}|$ are the Hermitian transpose and determinant of matrix $\mathbf{A}$, respectively. $\|\mathbf{a}\|$ is the ℓ^2-norm of vector $\mathbf{a}$. $|a|$ is the absolute value of complex number a. $\mathbb{C}^{M\times N}$ is the space of complex $M \times N$ matrices. $\mathcal{CN}(\mathbf{a}, \mathbf{A})$ is the complex Gaussian distribution with mean $\mathbf{a}$ and covariance matrix $\mathbf{A}$. $\mathbb{E}(\cdot)$ stands for expectation.

II. System Description

A. IA based CR Networks

Consider a K-user interference channel in a cognitive radio network, including one PU and $K-1$ SUs sharing the spectrum. The PU can be seen as the user 1, and the $K-1$ SUs are user $2, \dots, K$. $M^{[k]}$ and $N^{[k]}$ antennas at the kth transmitter and receiver, respectively.

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To avoid interference among PU and SUs, IA is performed in the CR network, through using precoding and interference suppression matrices. The received signal with $d^{[k]}$ data streams at the kth receiver can be expressed as

$$\mathbf{y}^{[k]}(n)=\mathbf{U}^{[k]\dagger}(n)\mathbf{H}^{[kk]}(n)\mathbf{V}^{[k]}(n)\mathbf{x}^{[k]}(n) + \sum_{j=1,j\neq k}^{K}\mathbf{U}^{[k]\dagger}(n)\mathbf{H}^{[kj]}(n)\mathbf{V}^{[j]}(n)\mathbf{x}^{[j]}(n)+\mathbf{U}^{[k]\dagger}(n)\mathbf{z}^{[k]}(n), \quad (1)$$

where $\mathbf{H}^{[kj]}(n) \in \mathbb{C}^{N^{[k]}\times M^{[j]}}$ is the channel coefficient matrix from the jth transmitter to the $k$the receiver in time slot n, with each of its entities independent and identically distributed (i.i.d.) and following $\mathcal{CN}(0,1)$. Block fading channel is adopted in this paper, and the channel remains constant over each time slot. Thus for clarity, the time slot number n is henceforth omitted. $\mathbf{V}^{[k]}$ and $\mathbf{U}^{[k]}$ are the unitary $M^{[k]} \times d^{[k]}$ precoding matrix and $N^{[k]} \times d^{[k]}$ interference suppression matrix of the kth user, respectively, following $\mathbf{V}^{[k]\dagger}\mathbf{V}^{[k]} = \mathbf{U}^{[k]\dagger}\mathbf{U}^{[k]} = \mathbf{I}_{d^{[k]}}$. $\mathbf{x}^{[k]}$ consists of $d^{[k]}$ data streams of user k with power constraint $P_t^{[k]}$, i.e., $\mathbb{E}\left[\left\|\mathbf{x}^{[k]}\right\|^2\right] = P_t^{[k]}$. $\mathbf{z}^{[k]} \in \mathbb{C}^{N^{[k]}\times 1}$ is the additive white Gaussian noise (AWGN) vector with distribution $\mathcal{CN}(\mathbf{0}, \sigma^2\mathbf{I}_{N^{[k]}})$ at receiver k, where σ^2 is the power noise at each antenna of the receivers.

When IA is feasible, the interferences in the CR network can be assumed to be completely eliminated if the following conditions are met [4].

$$\mathbf{U}^{[k]\dagger}\mathbf{H}^{[kj]}\mathbf{V}^{[j]} = 0, \ \forall j \neq k, \quad (2)$$

$$\mathrm{rank}\left(\mathbf{U}^{[k]\dagger}\mathbf{H}^{[kk]}\mathbf{V}^{[k]}\right) = d^{[k]}. \quad (3)$$

When conditions in (2) and (3) are satisfied, the interferences in the CR network can be perfectly eliminated. The desired signals of user k can be assumed to be received through a $d^{[k]} \times d^{[k]}$ full rank channel matrix $\overline{\mathbf{H}}^{[kk]} \triangleq \mathbf{U}^{[k]\dagger}\mathbf{H}^{[kk]}\mathbf{V}^{[k]}$, and thus (1) can be rewritten as

$$\mathbf{y}^{[k]} = \overline{\mathbf{H}}^{[kk]}\mathbf{x}^{[k]} + \overline{\mathbf{z}}^{[k]}, \quad (4)$$

where $\overline{\mathbf{z}}^{[k]} = \mathbf{U}^{[k]\dagger}\mathbf{z}^{[k]}$, also follows $\mathcal{CN}(\mathbf{0}, \sigma^2\mathbf{I}_{d^{[k]}})$.

Since this paper mainly focuses on the energy-efficient power allocation of CR networks among different users instead of DoFs, it is assumed that there is only one data stream for each user in the rest of this paper. The conclusion for the situation with more streams can be easily extended.

In most previous works of IA, the transmitted power of each user is set to be equal, i.e., $P_t^{[k]} = P_t, \forall k = 1, 2, \ldots, K$. Thus power allocation can be leveraged to further improve the performance of IA based CR network with adaptive transmitted power of each user.

B. Interference Temperature Limit and Rate Threshold

In the conventional underlay spectrum sharing of CR [9], interference temperature limit is usually set to constrain the total power of the interference and noise at the PU as [10]

$$P_{inf} + P_{no} \leq P_{th} = k_B T_{th} B, \quad (5)$$

where P_{inf} and P_{no} are the received power of the interferences imposed by SUs and the power of noise at the primary receiver, respectively. T_{th} is the interference temperature limit, and P_{th} is the interference-and-noise power limit corresponding to T_{th}. k_B is Boltzmann's Constant, B is the receiver bandwidth. Assume the received power of PU, P_{PU}, is unchanged, thus the threshold of the transmission rate of PU can be expressed as

$$R_{th} = \log_2\left(1+\frac{P_{PU}}{P_{th}}\right) \leq R_{PU} = \log_2\left(1+\frac{P_{PU}}{P_{inf}+P_{no}}\right). \quad (6)$$

Thus there is a one-to-one correspondence between the interference temperature limit T_{th} and the threshold of the transmission rate of PU R_{th}.

Remark 1: In the IA based CR network, although interferences among users can be effectively eliminated, the transmission rate may decrease due to exploiting IA [3]. Thus the threshold of the transmission rate of PU, R_{th}, which corresponds to the interference temperature limit, can be adopted to guarantee PU's QoS.

III. Energy-Efficient Power Allocation in IA-Based CR Networks

In Section II, equal transmitted power P_t is allocated to each user as usually assumed. However, this may hinder the improvement of IA's performance. In this section, we assume that the sum transmitted power of all the users is constrained to be lower than a constant, i.e., $\sum_{k=1}^{K} P_t^{[k]} \leq P_t^{max}$.

Energy efficiency issue is and important aspect in current wireless communications, and in this section, the energy-efficient power allocation problem in IA based CR networks is analyzed, and the PA algorithms aiming at maximizing the energy efficiency of the CR network are designed.

A. Power Allocation Maximizing EE of the Network

In IA based CR network, when power allocation among users is considered, the threshold of PU's rate should be satisfied, and Theorem 1 is presented.

Theorem 1: To satisfy the threshold of PU's rate when IA is performed in the CR network, R_{th}, the transmitted power of PU should abide by

$$\begin{aligned} P_t^{[1]} &\geq \frac{\left(2^{R_{th}}-1\right)\left(\sum_{k=2}^{K}\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[1k]}\mathbf{v}^{[k]}\right|^2 P_t^{[k]}+\sigma^2\right)}{\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[11]}\mathbf{v}^{[1]}\right|^2} \\ &> \frac{\left(2^{R_{th}}-1\right)\sigma^2}{\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[11]}\mathbf{v}^{[1]}\right|^2} \\ &= P_{t\_lower}^{[1]}. \end{aligned} \quad (7)$$

Proof: When power allocation is considered in the IA based CR network, the transmission rate of PU can be calculated as

$$R_p^{[1]} = \log_2\left(1+\frac{\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[11]}\mathbf{v}^{[1]}\right|^2 P_t^{[1]}}{\sum\limits_{k=2}^{K}\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[1k]}\mathbf{v}^{[k]}\right|^2 P_t^{[k]}+\sigma^2}\right), \tag{8}$$

where $\mathbf{v}^{[k]}$ and $\mathbf{u}^{[k]}$ are the precoding and interference suppression vectors of the kth user, respectively.

According to (5), (6) and *Remark 1*, we can know that the threshold of the PU's rate, R_{th}, corresponds to the interference temperature limit in the underlay spectrum sharing. Thus the transmission rate of PU should comply with

$$R_p^{[1]} \geq R_{th}. \tag{9}$$

From (8) and (9), we can obtain

$$P_t^{[1]} \geq \frac{\left(2^{R_{th}}-1\right)\left(\sum\limits_{k=2}^{K}\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[1k]}\mathbf{v}^{[k]}\right|^2 P_t^{[k]}+\sigma^2\right)}{\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[11]}\mathbf{v}^{[1]}\right|^2}. \tag{10}$$

In the feasible IA based wireless networks, the interferences are constrained in certain subspaces at the unintended receivers, and the interference leakage at the receivers is trivial. Besides, $P_t^{[k]}$ is larger than 0. Thus we have

$$\begin{aligned} &\frac{\left(2^{R_{th}}-1\right)\left(\sum\limits_{k=2}^{K}\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[1k]}\mathbf{v}^{[k]}\right|^2 P_t^{[k]}+\sigma^2\right)}{\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[11]}\mathbf{v}^{[1]}\right|^2} \\ > &\frac{\left(2^{R_{th}}-1\right)\sigma^2}{\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[11]}\mathbf{v}^{[1]}\right|^2} = P_{t\_lower}^{[1]}, \end{aligned} \tag{11}$$

where $P_{t\_lower}^{[1]}$ is the lower bound of the transmitted power of PU $P_t^{[1]}$ to met the threshold of PU's rate. ■

Remark 2: When IA is adopted in the CR network, the remaining interference at the primary receiver is trivial, and can be assumed to be perfect eliminated. Thus we can deem $P_{t\_lower}^{[1]}$ as the minimal transmitted power of PU to satisfy R_{th} requirement.

Energy efficiency becomes an important design criterion recently in wireless communications due to rapidly rising energy consumption in information communication technology. The EE of IA Based CR networks can be defined as the transmitted information in unit frequency per Joule energy consumption (bits/Hz/Joule), and the PA problem aiming at maximizing the EE of the whole CR network with R_{th} constraint of PU, when interferences are assumed to be perfectly eliminated, can be expressed as

$$\begin{aligned} \max_{P_t^{[1]},P_t^{[2]},\ldots,P_t^{[K]}} \quad & \frac{\sum\limits_{k=1}^{K} R^{[k]}}{\sum\limits_{k=1}^{K} P^{[k]}} = \frac{\sum\limits_{k=1}^{K}\log_2\left(1+\left|\mathbf{u}^{[k]\dagger}\mathbf{H}^{[kk]}\mathbf{v}^{[k]}\right|^2\frac{P_t^{[k]}}{\sigma^2}\right)}{\sum\limits_{k=1}^{K}\left(P_{ct}^{[k]}+P_{cr}^{[k]}+P_t^{[k]}\right)} \\ s.t. \quad & P_t^{[k]} \geq 0,\ \forall k=2,\ldots,K \\ & P_t^{[1]} \geq \frac{\left(2^{R_{th}}-1\right)\sigma^2}{\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[11]}\mathbf{v}^{[1]}\right|^2} \\ & \sum_{k=1}^{K} P_t^{[k]} \leq P_t^{max}. \end{aligned} \tag{12}$$

In (7), $P^{[k]}$ is the total power consumption of user k, and it comprises the transmitter-circuit power consumption $P_{cr}^{[k]}$, the receiver-circuit power consumption $P_{ct}^{[k]}$, and the transmitted power $P_t^{[k]}$ [11]. $\mathbf{v}^{[k]}$ and $\mathbf{u}^{[k]}$ are the precoding and interference suppression vectors of the kth user, respectively.

Remark 3: When SNR becomes lower, the problem described in (12) may have not any solutions. This happens when

$$\frac{\left(2^{R_{th}}-1\right)\sigma^2}{\left|\mathbf{u}^{[1]\dagger}\mathbf{H}^{[11]}\mathbf{v}^{[1]}\right|^2} > P_t^{max}. \tag{13}$$

That is to say, when the lower bound of PU's transmitted power $P_{t\_lower}^{[1]}$ is larger than the maximal sum transmitted power of the whole CR network P_t^{max}, the problem in (12) do not have any solutions.

To avoid case of no solutions of energy-efficient PA in the IA based CR network, we propose a Power Allocation algorithm Maximizing Energy Efficiency of the Network (PAMEEN) based on the power-allocation objective (12). The PAMEEN algorithm can be represented by the following steps in each time slot.

1) When a time slot starts, the precoding and interference suppression vectors $\mathbf{u}^{[k]}$ and $\mathbf{v}^{[k]}$ of the kth user are calculated [4], $k=1,2,\ldots,K$.
2) The lower bound of the transmitted power of PU to guarantee its rate threshold R_{th}, $P_{t\_lower}^{[1]}$, is calculated according to (11).
3) If $P_{t\_lower}^{[1]}$ is smaller than P_t^{max}, go to Step 4); else go to Step 5).
4) Perform energy-efficient power allocation of the IA based CR network as (12), and the optimal power allocation maximizing EE of the CR network with R_{th} constraint can be obtained.
5) Allocate P_t^{max} to PU. SUs are switched into sleep mode, and $P_{ct}^{[k]}=P_{cr}^{[k]}=P_t^{[k]}=0$, $k=2,3,\ldots,K$.
6) After transmission for duration T with the power allocated, one time slot ends, and go to Step 1).

In the PAMEEN algorithm, when $P_{t\_lower}^{[1]}$ is larger than P_t^{max}, although R_{th} can not be met, the power allocation is not performed any more, and it can maximize the PU's rate in the IA based CR network. Thus the proposed PAMEEN algorithm can improve the energy efficiency of the IA based

CR network, while avoid no-solution case and reduce the computational complexity effectively.

B. Power Allocation Maximizing SUs' Rate

In the spectrum trading based CR network [12], the income of PU is proportional to the transmission rate of SUs it provided. In the proposed PAMEEN algorithm, SUs' rate is not fully optimized when the transmission rate of PU may be larger than R_{th}, and this means more power than needed is allocated to the PU. Furthermore, if the transmission rate of SUs is not satisfied, the SUs may seek other PUs to share the spectrum. Thus the rate of SUs should be maximized with PU's R_{th} constraint, and a Power Allocation algorithm Maximizing Rate of SUs (PAMRSU) is proposed in this subsection. The PAMRSU algorithm can be expressed by the following steps in each time slot.

1) When a time slot starts, the precoding and interference suppression vectors $\mathbf{u}^{[k]}$ and $\mathbf{v}^{[k]}$ of the kth user are calculated [4], $k = 1, 2, \ldots, K$.
2) The lower bound of the transmitted power of PU to guarantee its rate threshold R_{th}, $P_{t\_lower}^{[1]}$, is calculated according to (11).
3) If $P_{t\_lower}^{[1]}$ is smaller than P_t^{max}, go to Step 4); else go to Step 5).
4) Allocate minimal power to the PU satisfying R_{th} constraint, i.e., $P_t^{[1]} = P_{t\_lower}^{[1]}$. The optimization problem of the power allocation of the $K-1$ SUs can be represented as

$$\begin{aligned} \max_{P_t^{[2]}, P_t^{[3]}, \ldots, P_t^{[K]}} \; & \sum_{k=2}^{K} \log_2 \left(1 + \left| \mathbf{u}^{[k]\dagger} \mathbf{H}^{[kk]} \mathbf{v}^{[k]} \right|^2 \frac{P_t^{[k]}}{\sigma^2} \right) \\ s.t. \quad & P_t^{[k]} \geq 0, \; \forall k = 2, \ldots, K \\ & \sum_{k=2}^{K} P_t^{[k]} \leq P_t^{max} - P_{t\_lower}^{[1]}. \end{aligned} \tag{14}$$

5) Allocate P_t^{max} to PU. SUs are switched into sleep mode, and $P_{ct}^{[k]} = P_{cr}^{[k]} = P_t^{[k]} = 0$, $k = 2, 3, \ldots, K$.
6) After transmission for duration T with the power allocated, one time slot ends, and go to Step 1).

Remark 4: Form the description of PAMEEN and PAMRSU, we can find that the two algorithms are the same when $P_{t\_lower}^{[1]} \geq P_t^{max}$. When $P_{t\_lower}^{[1]} < P_t^{max}$, the SUs' rate in PAMRSU algorithm is larger than that of PAMEEN algorithm.

IV. Transmission-Mode Adaptation Based on PA of IA Based CR Network

When IA is performed, we can know that it is equal to a single-input and single-output (SISO) channel for each user, and thus the rate of each user in IA (equal to SISO) is lower than that of the MIMO single-user channel [3]. On the other hand, in the proposed PAMEEN and PAMRSU algorithms when $P_{t\_lower}^{[1]} \geq P_t^{max}$, the transmitted power is all allocated to the PU, and SUs are switched into sleep mode. Thus we can propose a transmission-mode adaptation (TMA) scheme to change the transmission mode from IA to a single-user (PU) MIMO system with SUs sleep to further improve the rate of PU to satisfy the constraint R_{th}.

In the proposed TMA scheme, when $P_{t\_lower}^{[1]} \geq P_t^{max}$, SUs are switched into sleep mode, and PU adopt MIMO to communicate in the time slot solely. The transmission rate of PU using MIMO can be expressed as

$$R_p^{[1]} = \log_2 \left| \mathbf{I}_{N^{[1]}} + \frac{P_t^{max}}{\sigma^2} \mathbf{H}^{[11]} \mathbf{Q}^{[1]} \mathbf{H}^{[11]\dagger} \right|. \tag{15}$$

The CSI at transmitters (CSIT) of the network is available at all the transceivers, thus in (15) the transmitted power at each antenna can be optimized through using waterfilling strategy. The optimal signal covariance $\mathbf{Q}^{[1]} = \widetilde{\mathbf{V}}^{[1]} \mathbf{S}^{[1]} \widetilde{\mathbf{V}}^{[1]\dagger}$, and $\widetilde{\mathbf{V}}^{[1]}$ can be obtained by singular value decomposition of the channel matrix as $\widetilde{\mathbf{U}}^{[1]} \mathbf{D}^{[1]} \widetilde{\mathbf{V}}^{[1]\dagger} = \mathbf{H}^{[11]}$. The optimal diagonal PA matrix $\mathbf{S}^{[1]} = \text{diag}\left(s_1, \ldots, s_{\min\left(M^{[1]}, N^{[1]}\right)}, 0, \ldots, 0\right)$. The optimal PA among antennas of user k can be achieved through using waterfilling strategy as

$$s_i = \left(\mu - \frac{\sigma^2}{P_t^{max} \delta_i^{[1]2}} \right)^+, i = 1, \ldots, \min\left(M^{[1]}, N^{[1]}\right), \tag{16}$$

where $x^+ \triangleq \max(x, 0)$. $\delta_1^{[1]}, \ldots, \delta_{\min\left(M^{[1]}, N^{[1]}\right)}^{[1]}$ are the diagonal elements of $\mathbf{D}^{[i]}$, and μ should satisfy

$$\sum_{i=1}^{\min\left(M^{[1]}, N^{[1]}\right)} s_i = 1. \tag{17}$$

Thus the proposed PAMEEN and PAMRSU algorithms can be further combined with TMA scheme to improve the PU's rate when R_{th} constraint can not be guaranteed in the IA based CR network, and we call them PAMEEN-TMA and PAMRSU-TMA algorithms. Only Step 5) of PAMEEN and PAMRSU algorithms should be changed accordingly when TMA is involved.

V. Simulation Results and Discussions

In the simulation, an IA based CR network with $M^{[k]} = N^{[k]} = 2$ antennas equipped at each transceiver is considered, and data streams of each user is equal to 1. Rayleigh block fading is adopted, and perfect CSI is assumed to be available at each node. According to [11], the transmitter-circuit power consumption $P_{cr}^{[k]}$, the receiver-circuit power consumption $P_{ct}^{[k]}$ of all the users are set to 112mW, 98mW, respectively. P_t^{max}/K is set to 20dbmW, and thus the constrained total transmitted power of the network (also the maximum transmitted power of each user) is equal to 300mW. MinIL IA algorithm is adopted to obtained the solutions of IA in the simulation [1], [4]. R_{th} for PU is set to 5 bits/s/Hz.

The energy efficiency of the IA based CR network with different algorithms is compared in Fig. 1. From the results, it is shown that the proposed PAMRSU-TMA and PAMEEN-TMA algorithms can improve the energy efficiency of the CR network effectively at low SNRs. When SNR is high, energy efficiency of the network with PAMEEN-TMA and PAMEEN

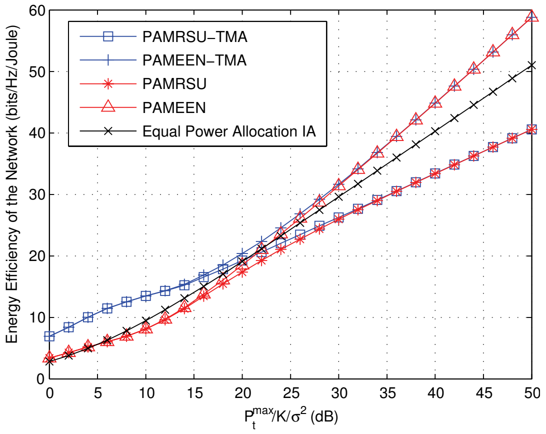

Fig. 1. Energy efficiency comparison of different algorithms in a 3-user IA based CR network with 2 antennas at each transceiver.

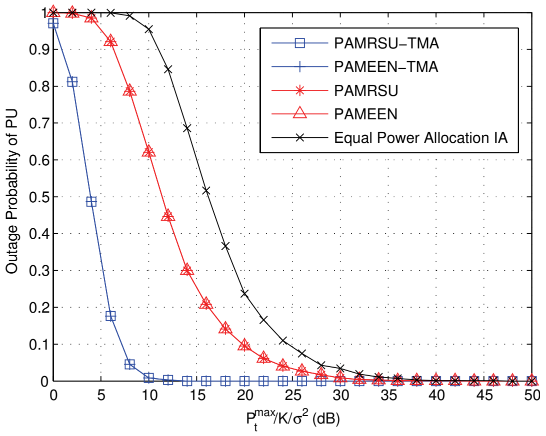

Fig. 2. PU's outage probability comparison of different algorithms in a 3-user IA network with 2 antennas at each transceiver.

algorithms is effectively improve, while energy efficiency with PAMRSU-TMA and PAMRSU algorithms is lower than that with equal power allocation IA, because sum rate of SUs is maximized in these two algorithms.

Outage probability of PU is compared in Fig. 2. From the results, it is shown that the PAMRSU-TMA and PAMEEN-TMA algorithms can effectively improve the outage probability of PU due to TMA scheme. The SNR requirement is reduced by nearly 25dB due to TMA when outage probability is 0.1.

The sum rate of SUs is compared in Fig. 3. It is shown that the PAMRSU-TMA and PAMRSU algorithms can improve the sum rate of SUs effectively at high SNRs while guaranteeing the R_{th} constraints of PU, which can enhance the income of PU in spectrum trading. The sum rate of SUs with PAMEEN-TMA and PAMEEN algorithms is decreased, because the energy efficiency of the network is increased with lower transmitted power at high SNRs.

VI. Conclusions

In this paper, we have proposed energy-efficient PA and TMA algorithms for IA based CR network. In the algorithms,

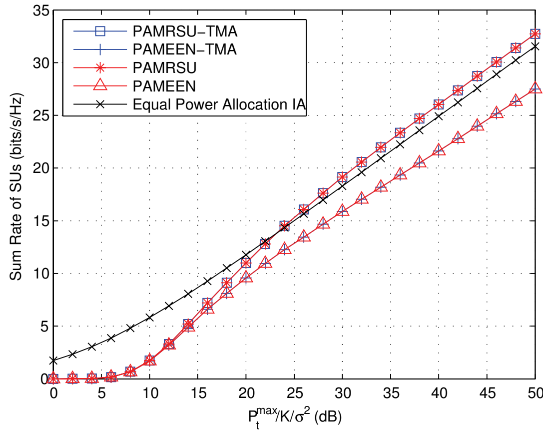

Fig. 3. SUs' sum rate comparison of different algorithms in a 3-user IA network with 2 antennas at each transceiver.

PA was designed to improve the EE of the network and sum rate of SUs, respectively. To further guarantee the rate constraint of PU, TMA algorithm to adaptive the transmission mode to improve the performance of PU was proposed, and it can be combined with the two proposed PA algorithms easily. Simulation results were presented to show effectiveness and efficiency of the proposed algorithms for IA based CR networks.

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