Partner Selection Based on Optimal Power Allocation in Cooperative-Diversity Systems

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Introduction

- Cooperation among a group of users to transmit and relay the same signal can emulate a multiple transmit antenna environment to achieve spatial diversity gains.
- Battery life becomes the bottleneck for wireless devices.

Introduction

- Cooperation between two users, i.e. two users relaying for each other, on the following bases：
  - The inter-user channels incur transmission errors in practice.
  - The implementation complexity increases with the number of users participating in the cooperation.
  - The spectral efficiency of the wireless channel decreases with the number of participating users.

Introduction

- Optimizing the system performance involves：
  - Physical-layer cooperative-diversity (CD) schemes
    - Amplify and forward CD scheme
    - Regenerate and forward CD scheme
  - Transmission power level of each user to satisfy their QoS requirements
  - Partner selection or matching strategy for the whole network

System Model

- The base station (BS) of a radio cell supports N mobile.
- A user is capable of cooperating with another user, i.e., cooperation between two active users.
- The uplink signals transmitted by the sender and relayed by the partner are combined at the BS using maximal ratio combining.
- The CD scheme thus emulates a “two-input one-output” situation.

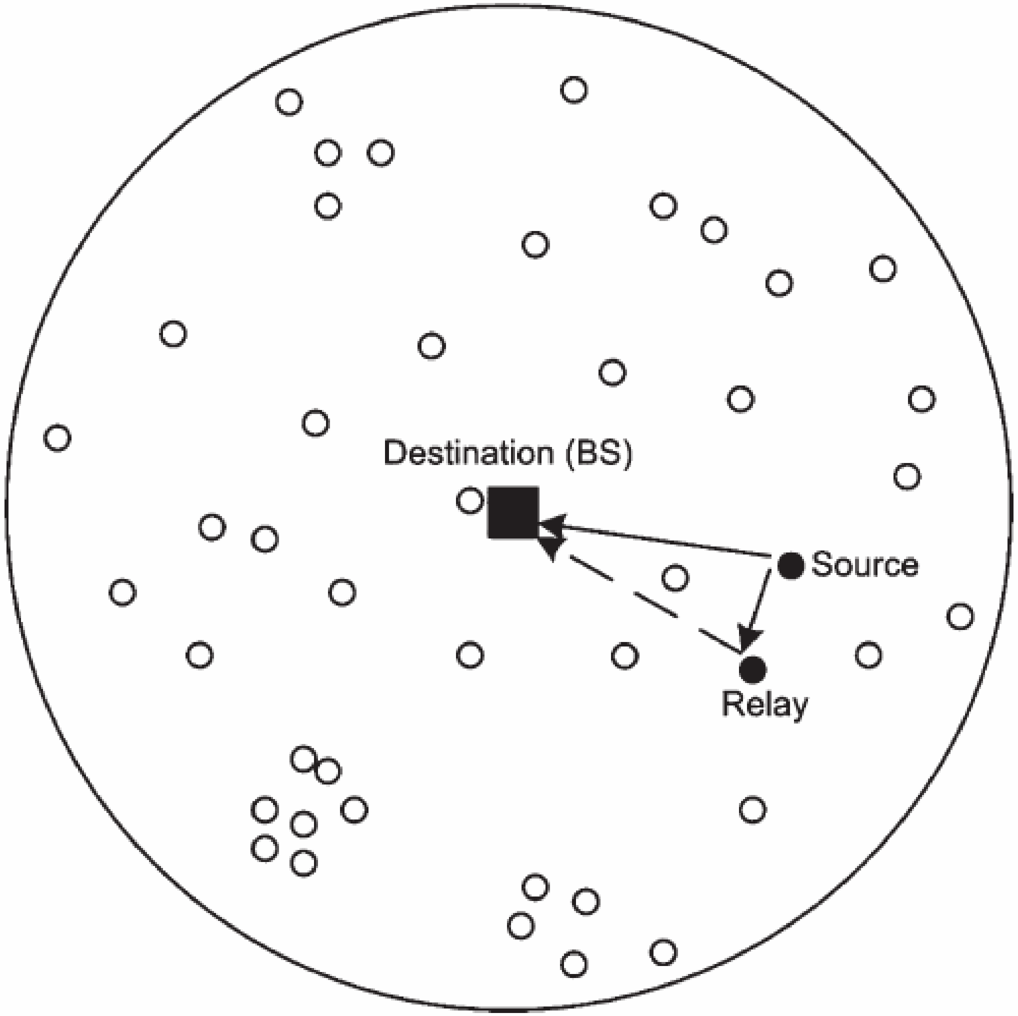


Fig. 1. Cellular network with user cooperation.

System Model

- Optimal power allocation (OPA)
- Equal power allocation (EPA)

Amplify and Forward CD Scheme

- Each of the cooperating users is allocated with different frequency bands (centered at f_1 and f_2), and in each band, a user transmits signals in two time frames: One frame is dedicated for its own bits, and the other is for relaying the partner's bits.

Amplify and Forward CD Scheme

- Approximate bit error probability (BEP)

$$P_{\mathrm{b1}} = \frac{3}{16\bar{\gamma}_1\bar{\gamma}_2} + \frac{3}{16\bar{\gamma}_1\bar{\gamma}_{1,2}}$$

Power Allocation for Amplify and Forward CD Schemes

- The OPA problem is

$$\min\left(E_{\mathrm{b1}}^{\mathrm{S}} + E_{\mathrm{b1}}^{\mathrm{R}} + E_{\mathrm{b2}}^{\mathrm{S}} + E_{\mathrm{b2}}^{\mathrm{R}}\right)$$

$$\text{s.t. } P_{\mathrm{b1}} \le e_1 \quad \textbf{and} \quad P_{\mathrm{b2}} \le e_2$$

Here, *e*1 and *e*2 are the maximum tolerable BEPs for users 1 and 2, respectively.

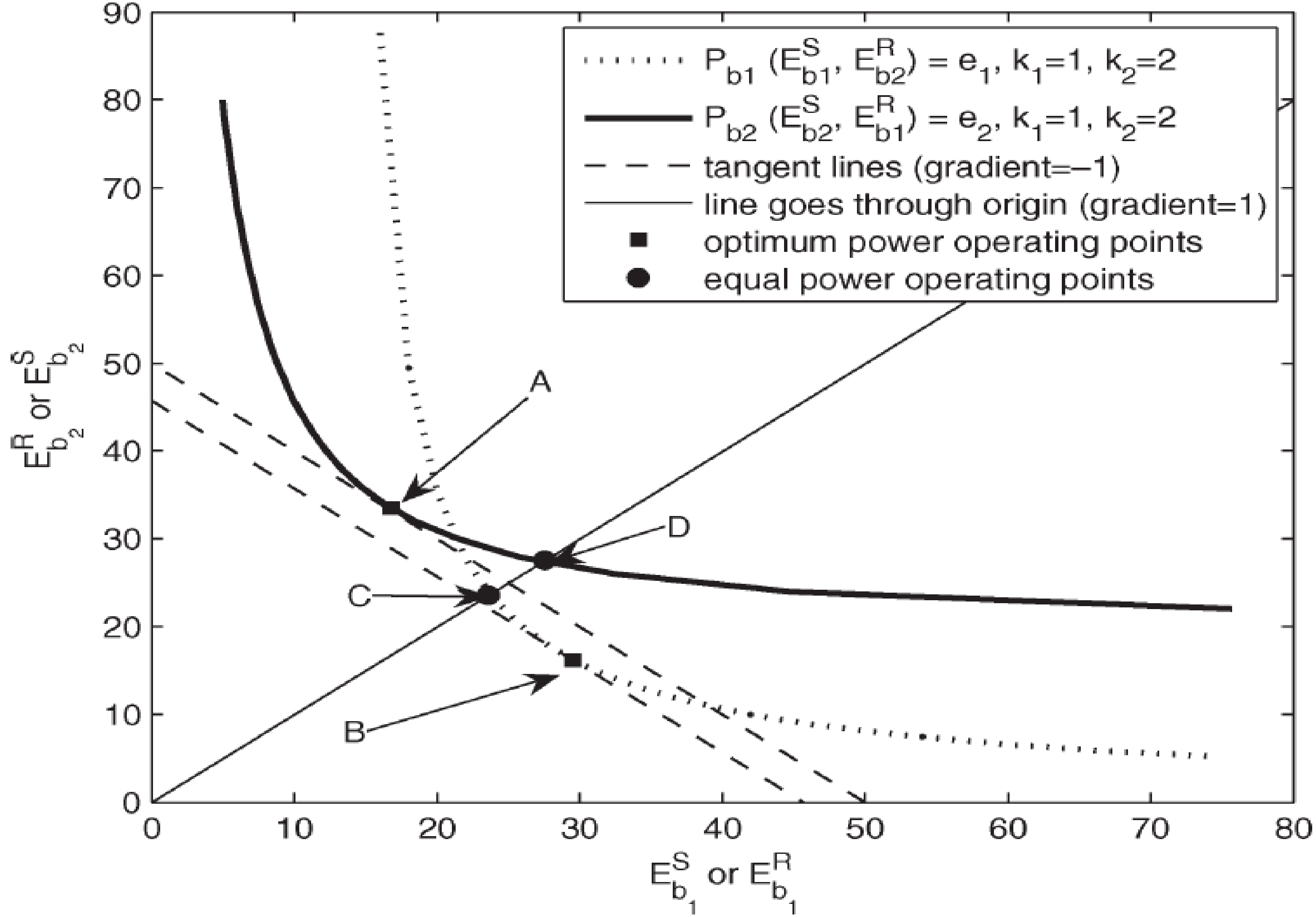
Power Allocation for Amplify and Forward CD Schemes

- $E_{\mathrm{b}}^{\mathrm{S}}$ and $E_{\mathrm{b}}^{\mathrm{R}}$ are independent of each other.

$$\min\left(E_{\mathrm{b}1}^{\mathrm{S}} + E_{\mathrm{b}2}^{\mathrm{R}}\right)$$
$$\text{s.t. } P_{\mathrm{b}1}\left(E_{\mathrm{b}1}^{\mathrm{S}}, E_{\mathrm{b}2}^{\mathrm{R}}\right) \le e_1$$

and

$$\min\left(E_{\mathrm{b}2}^{\mathrm{S}} + E_{\mathrm{b}1}^{\mathrm{R}}\right)$$
$$\text{s.t. } P_{\mathrm{b}2}\left(E_{\mathrm{b}2}^{\mathrm{S}}, E_{\mathrm{b}1}^{\mathrm{R}}\right) \le e_2$$



$P_{b1}(E^S_{b1}, E^R_{b2}) = e_1, k_1=1, k_2=2$
$P_{b2}(E^S_{b2}, E^R_{b1}) = e_2, k_1=1, k_2=2$
tangent lines (gradient=−1)
line goes through origin (gradient=1)
optimum power operating points
equal power operating points
A
B
C
D
$E^R_{b_2}$ or $E^S_{b_2}$
$E^S_{b_1}$ or $E^R_{b_1}$
0
10
20
30
40
50
60
70
80
90

Optimal Power Location

- It is trivial to prove that the optimal partners' locations, which maximize the cooperative energy gain of the pair and minimize the power consumption rate of the user, are both on the line connecting the source and the destination (BS).
- Assume that the average CSI is proportional to the respective distance raised to the power α, i.e.,

$$\sigma_1^2 \propto d_1^{-\alpha}$$

Optimal Power Location

- Define maximum unit energy =

$$\max\{E_{\mathrm{b1}}^{\mathrm{S}}, E_{\mathrm{b2}}^{\mathrm{S}}, E_{\mathrm{b1}}^{\mathrm{R}}, E_{\mathrm{b2}}^{\mathrm{R}}\}$$

- Saved unit energy =

$$E_{\mathrm{b1}}^{\mathrm{no}} + E_{\mathrm{b2}}^{\mathrm{no}} - E_{\mathrm{b1}}^{\mathrm{S}} - E_{\mathrm{b2}}^{\mathrm{S}} E_{\mathrm{b1}}^{\mathrm{R}} - E_{\mathrm{b2}}^{\mathrm{R}}$$

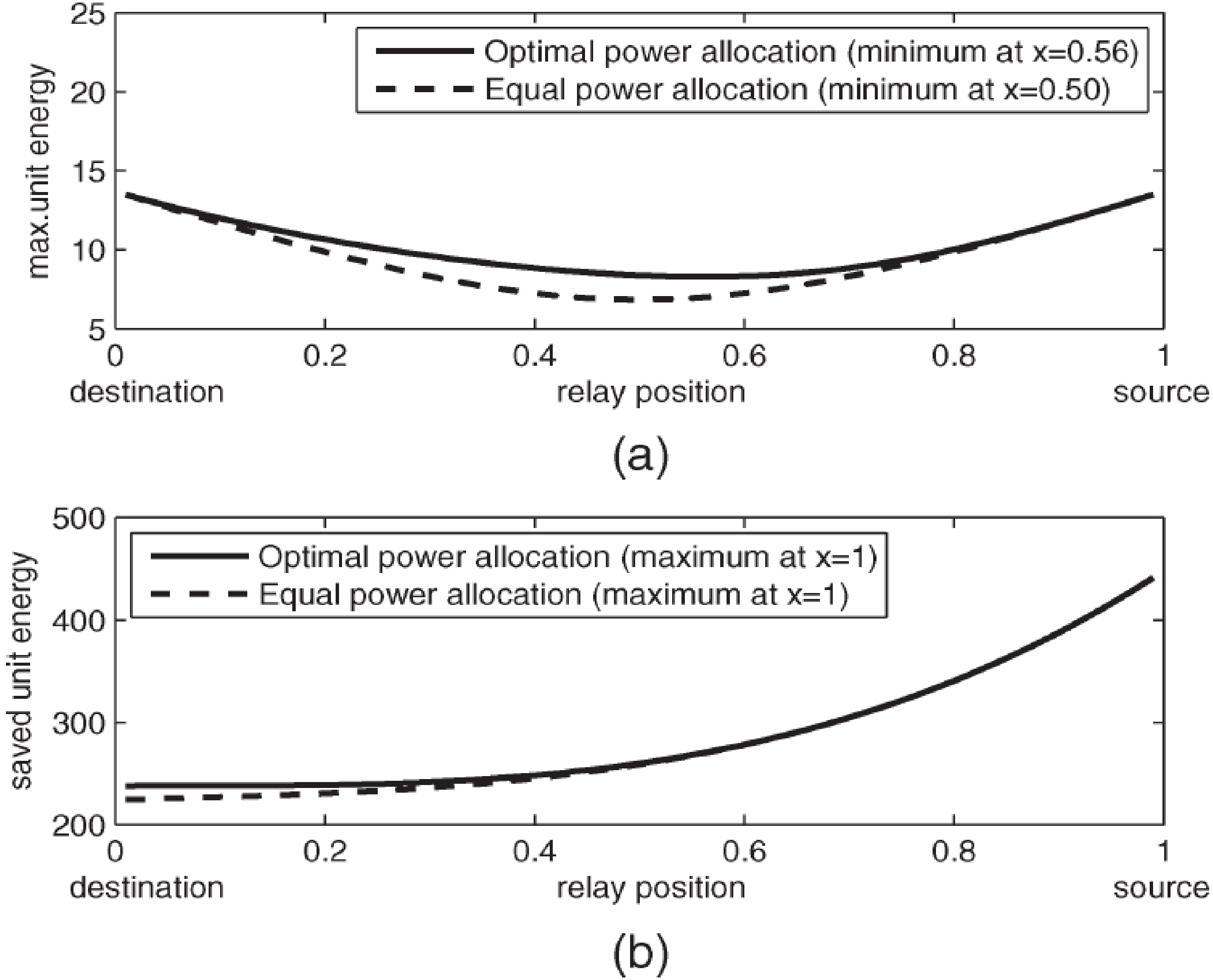


Fig. 4. One-dimensional analysis of the amplify and forward CD scheme.

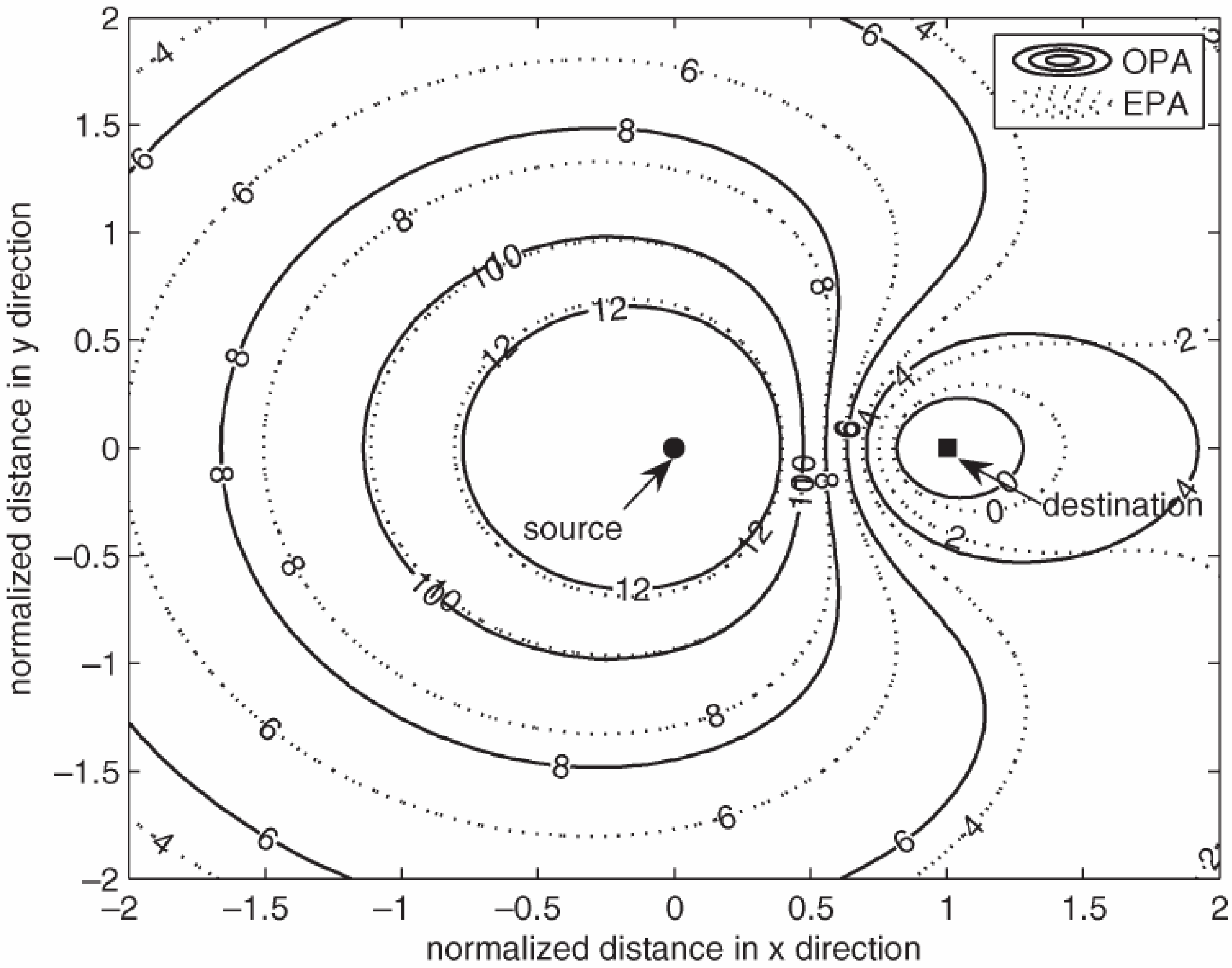


Fig. 6. Cooperative region of the amplify and forward scheme for both power allocation.

Matching Algorithms

- The objective of matching is to maximize the total energy gained by cooperation in the network.
- The energy gain of the network is defined as the ratio of the sum of energy spent by the users when there is no cooperation to the sum of energy spent by the users with cooperation.
- Given the CD energy gain of any pair of users, a non-bipartite maximum weighted matching problem can be solve in polynomial time $O(n^3)$.

Worst-Link-First by Maximizing Gain (WLF-Maxgain)

- The WLF-MaxGain matching algorithm proposed in [8] is given for easy reference.
  1) The BS selects an unmatched user *i* with the worst channel quality among all unmatched users.
  2) The BS selects an unmatched user *j* such that the energy gain $w(e_{i,j})$ provided by the cooperation of users *i* and *j* over no cooperation is the maximum one among all $w(e_{i,k})$'s, where *k* is an unmatched user other than *i*.
  3) Repeat steps 1) and 2) until the number of unmatched users is less than two.

Worst-Link-First by Minimizing Maximum Energy

- The weights used for the pair of users being matched in step 2) are different:

The BS selects an unmatched user *j* such that $\max(E_i^{\mathrm{S}}+E_i^{\mathrm{R}}, E_j^{\mathrm{S}}+E_j^{\mathrm{R}})$ is minimized among all $\max(E_i^{\mathrm{S}}+E_i^{\mathrm{R}}, E_k^{\mathrm{S}}+E_k^{\mathrm{R}})$'s ,

where *k* is an unmatched user other than *i*.

Matching Algorithms

- It is easy to prove that the distributed WLF matching result is stable.
  1) The algorithm terminates with at most $N/2$ iterations since each iteration will result in at least one pair.
  2) For any unpaired user, it cannot break the existing pairs since at least one user of any existing pair has a higher priority than the unpaired user.
  3) For any two pairs of users (u_{11}, u_{12}) and (u_{21}, u_{22}), they cannot exchange partners.

Numerical Results

- The numerical results of the three matching algorithms with the OPA and the EPA.
- The coordinates of the BS are (0, 0).
- The *N* users are randomly placed on a unit disk centered at the BS.
- Assume that the BS can track the user locations and, thus, estimate their pair-wise distances and average CSIs.
- $P_{b1} = P_{b2} = 10^{-3}$, $B = 128$, $N_O = 1$ unit power/Hz, and $\alpha = 3$.

Numerical Results

- Cell CD gain, which is the energy gain of a cell with user cooperation over a cell without user cooperation, is defined as

$$G_{\mathrm{CD}} = 10\log_{10}\left(\frac{\sum_{i=1}^{N} E_{\mathrm{b}i}^{\mathrm{no}}}{\sum_{i=1}^{K}\left(E_{\mathrm{b}i}^{\mathrm{S}} + E_{\mathrm{b}i}^{\mathrm{R}}\right) + \sum_{i=K+1}^{N} E_{\mathrm{b}i}^{\mathrm{no}}}\right)$$

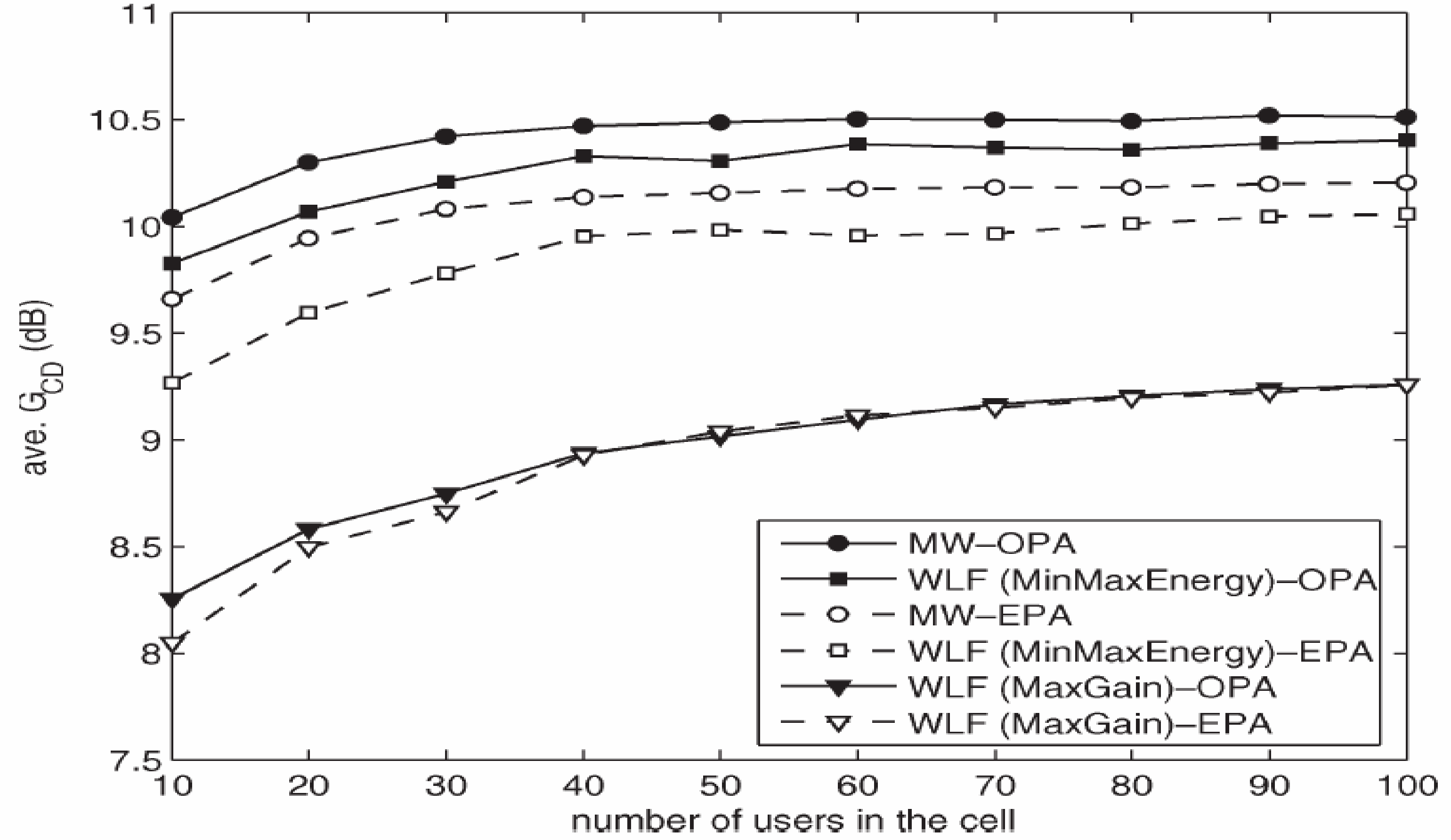


Fig. 8. Average G_{CD} of the amplify and forward scheme for both the OPA and the EPA.

The numerical results demonstrate the importance of the combination of the power allocation and the partner selection.

Conclusions

- The proposed optimal power allocation strategy is different from the previous work, by minimizing the power consumption of the pair of users to ensure their BEP requirements.
- In addition, the proposed partner selection algorithm enhances not only the individual user performance but the network performance as well.