Optimal Partner Selection Strategies in Wireless Cooperative Networks with Fixed and Variable Transmit Power

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Introduction

- Cooperative diversity：
  - Share each other's antenna to form virtual antenna array.
  - Multiple independent transmission paths can be created to provide spatial diversity.
  - Greatly enhance the transmission reliability.

Introduction

- Before any cooperation starts, there should be some scheme to divide these nodes into cooperative groups.
- This paper concerns about the partner selection problem in centralized networks, where an AP performs this task and schedules all the transmissions in a Round-Robin(RR) fashion.

System Model

- The network considered here consists of *N* fixed nodes and one AP.
- AP acts as both the transmission scheduler and the common destination for all nodes.

System Model

- AP schedules all nodes' transmissions in a *Round-Robin*(RR) fashion
  - All transmission process is divided into *rounds.*
  - in each of the *round*, every node is given a time *frame* once to transmit its packets, according to some predetermined order.
- Suppose that the AP has the knowledge of the instantaneous channel state information(ICSI) on each link.

System Model

- For a node in its own time frame, in order to apply relay-based cooperation scheme
  - Amplify and Forward (AF)
  - Divide the node's frame into two sub-frames
  - Finally the AP combines the two sub-frame data using *Maximum Ratio Combining* (MRC).

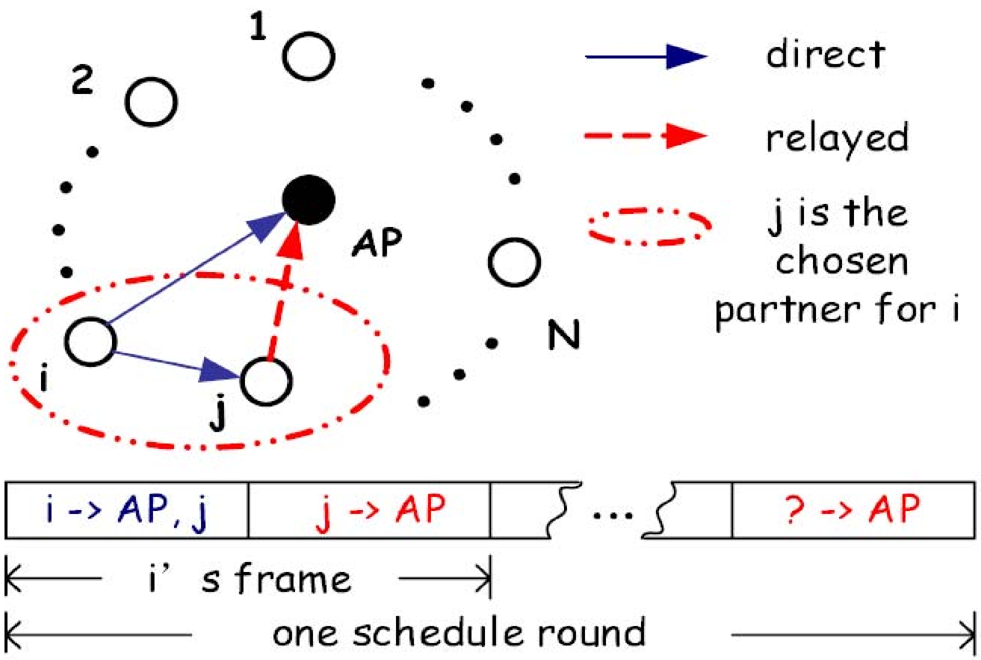


Fig. 1. The network scenario assumed in this paper. The single AP schedules and receives all nodes' transmission. The chosen partner acts as AF relay in the second sub-frame.

Utility Function

- Two key factors in the view of MAC layer performance
  - Throughput
  - Transmit power
- The utility function of node i, with node j as its partner, can be expressed as

$$U_{ij}(P_i, P_j) = \frac{T_i(P_i, P_j)}{P_i} \quad \text{bits/joule}$$

Partner Selection Problem

- Assume that all nodes are willing to cooperate, and to guarantee the fairness, each node has to be and can only be partner *once* in every round.
- Let a_{ij} be an indicator of AP's partner selection decision.
  - $a_{ij} = 1$ means j is chosen as i's partner
  - $a_{ij} = 0$ means j is not i's partner

Partner Selection Problem

- Define $S(\cdot)$ as AP's selection strategy, then the partner selection problem can be addressed as

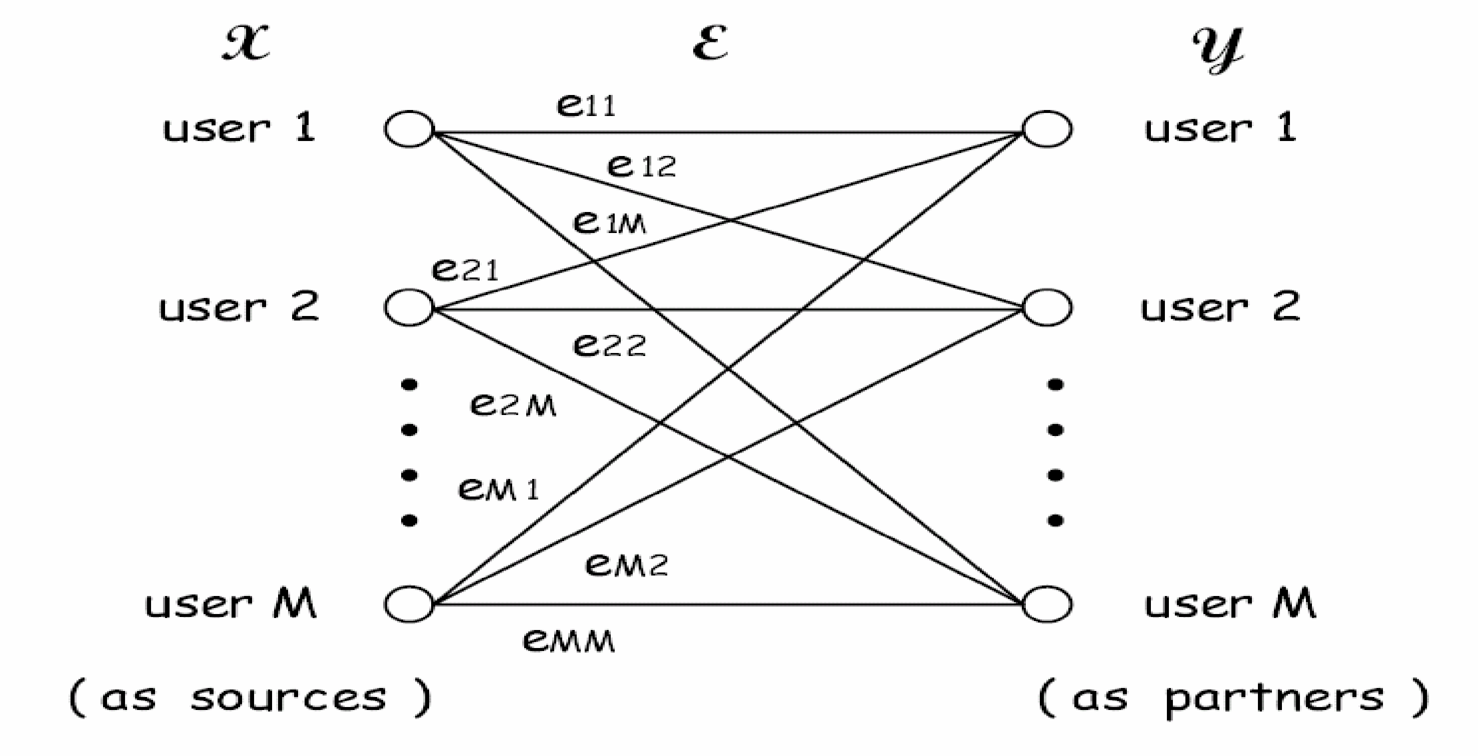
$$\mathcal{S}(\{U_{ij}(P_i, P_j)\}, \{a_{ij}\})$$

subject to
$$\begin{cases} \sum_{i=1}^{N} a_{ij} = 1, \ \forall j, \ j = 1, \cdots, N \\ \sum_{j=1}^{N} a_{ij} = 1, \ \forall i, \ i = 1, \cdots, N \end{cases}$$

where $\{U_{ij}(P_i,P_j)\}$ is a $N * N$ utility matrix for all possible cooperation pairs.

Partner Selection Problem

- The problem formulated above can be generalized to a set of *perfect matching* problems on bipartite graph *G* = (*X*, *Y*, *E*)[7]



Partner Selection Problem

- The weights on the edges denote the achievable utility, i.e. $w(e_{ij}) = U_{ij}$, $i,j = 1, \cdots, N$.
- Thus, one of AP's task is to find the specific *perfect matching* under strategy S.

Three Optimal Partner Selection Strategies

- *Maximum Total Utility* (MTU) strategy
  - Maximize the sum utility of all nodes.
- *Maximum Minimum Utility* (MMU) strategy
  - Guarantee the node-level fairness, that is, maximize the minimum node's utility.
- *Maximum Product Utility* (MPU) strategy
  - Provide a balance for the former two strategies.

MTU in Fixed Transmit Power Case

- MTU strategy

$$\mathcal{S}_{MTU}: \max_{\{a_{ij}\}} \sum_{i=1}^{N} \sum_{j=1}^{N} U_{ij}(P) \cdot a_{ij}$$

Substituting Uij(P) for Uij(Pi,Pj)

- The selection problem formulated above is another special case of the maximum weighted matching problems.

MMU in Fixed Transmit Power Case

- MMU strategy

$$\mathcal{S}_{MMU}: \max_{\{a_{ij}\}} \min_{i} \sum_{j=1}^{N} U_{ij}(P) \cdot a_{ij}$$

- The selection problem formulated above is another special case of the perfect matching problems.

MPU in Fixed Transmit Power Case

- MPU strategy

$$\hat{\mathcal{S}}_{MPU}: \max_{\{a_{ij}\}} \prod_{i=1}^{N} \sum_{j=1}^{N} (U_{ij}(P) - U_i^{bas}) \cdot a_{ij}$$

$$\bar{U}_{ij}(P) = \begin{cases} \log(U_{ij}(P) - U_i^{bas}), & U_{ij}(P) > U_i^{bas} \\ -\infty, & U_{ij}(P) \leqslant U_i^{bas} \end{cases}$$

$$\bar{\mathcal{S}}_{MPU}: \max_{\{a_{ij}\}} \sum_{i=1}^{N} \sum_{j=1}^{N} \bar{U}_{ij}(P) \cdot a_{ij}$$

Variable Transmit Power Case

- When the transmit power can be varied according to different channel conditions, the first question we should answer is how the user's utility U_{ij} varies with P_i and P_j.

We see that with fixed *P_j*, there exists only one optimal Pi that maximizes *$U_{ij}(P_i)$*, but with fixed *P_i*, increasing *P_j* monotonically increases node *i*'s utility.

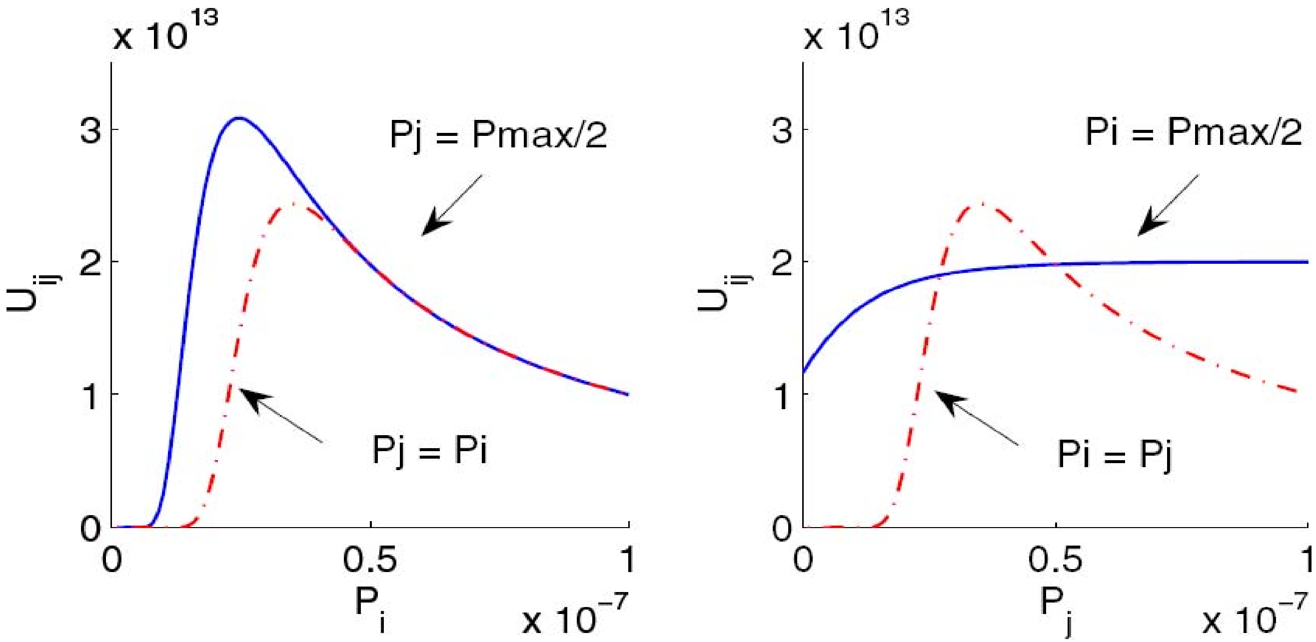


Fig. 3. Utility of node i when node j acts as i's partner under variable P_i and P_j respectively. Here we assume $W = 10^6\ Hz$, $M = 80\ bits/frame$, $N_0 = 5 * 10^{-15}\ Watt$ and set $H_{ia} = 1$, $H_{ja} = 1$ and $H_{ij} = 4$.

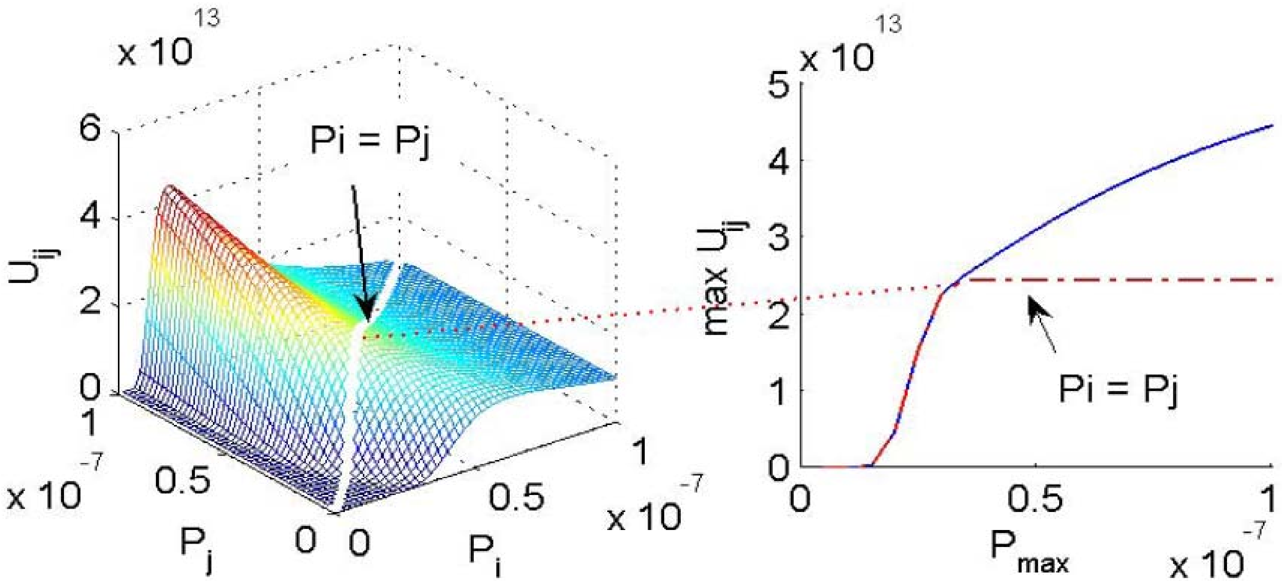


Fig. 4. The left one shows $3-D$ mesh of node i's utility with node j acts as its partner under variable P_i and P_j. The right one shows the maximum utility node i can achieve with and without $P_i = P_j$ constraint. Other settings are the same as Fig. 3.

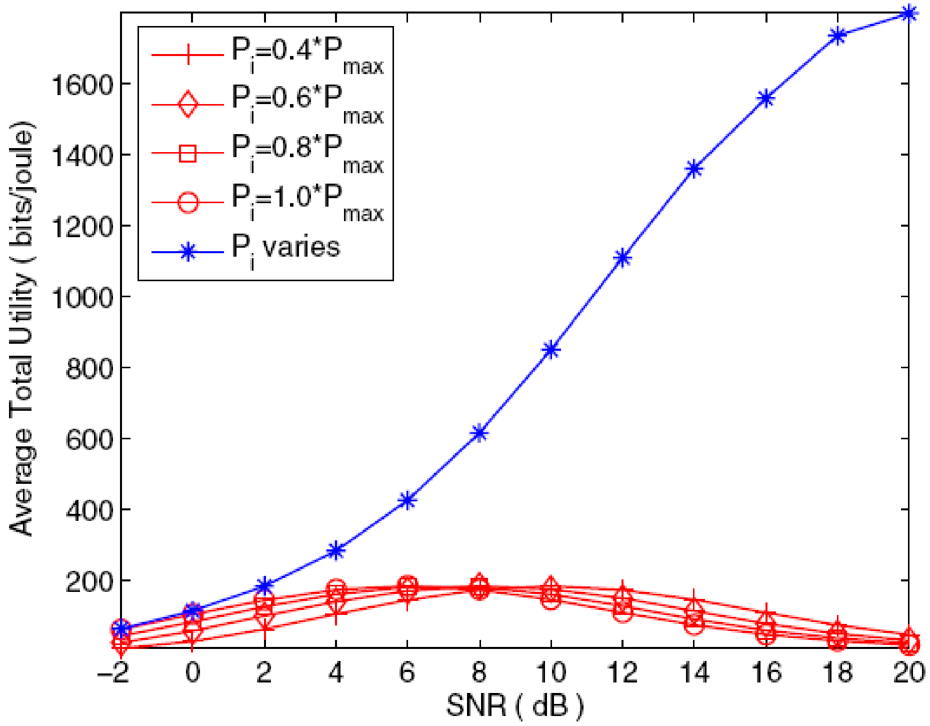
Variable Transmit Power Case

- Based on the calculated $\{U_{ij}^{max}\}$ matrix, the AP then can make its assignment decision according to any of the optimum partner selection strategies, i.e., MTU, MMU and MPU.

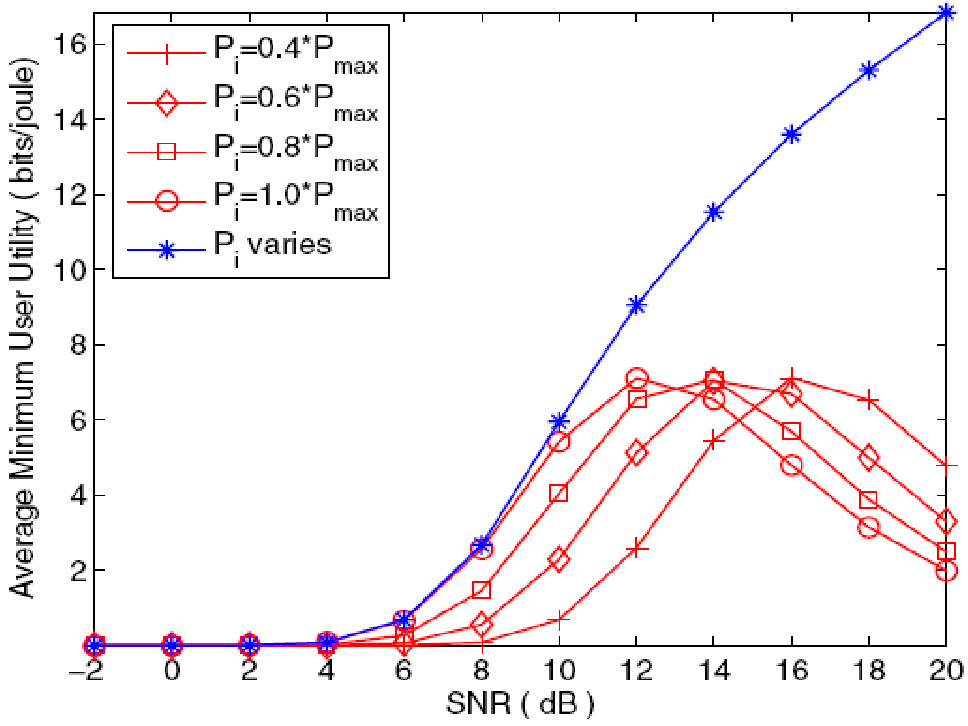
Simulation

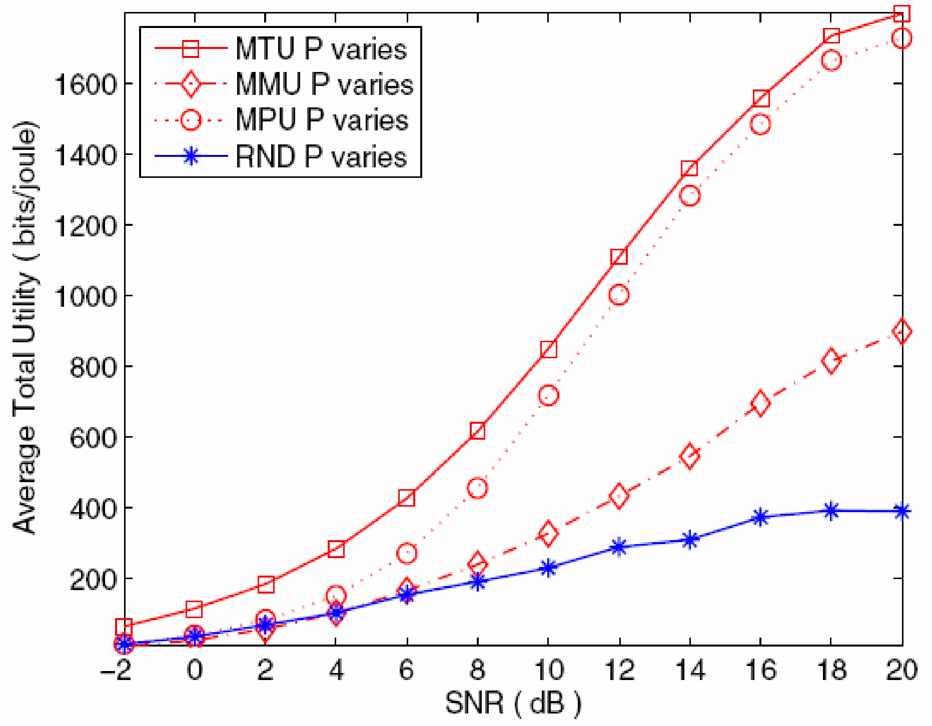
- 10 nodes are randomly distributed in a round area with radius $r = 2$.
- Path loss and quasi-static Rayleigh fading are considered.
- All the simulation results are averaged over 10 topologies, and for each fixed topology, 1000 times channel realizations are generated.

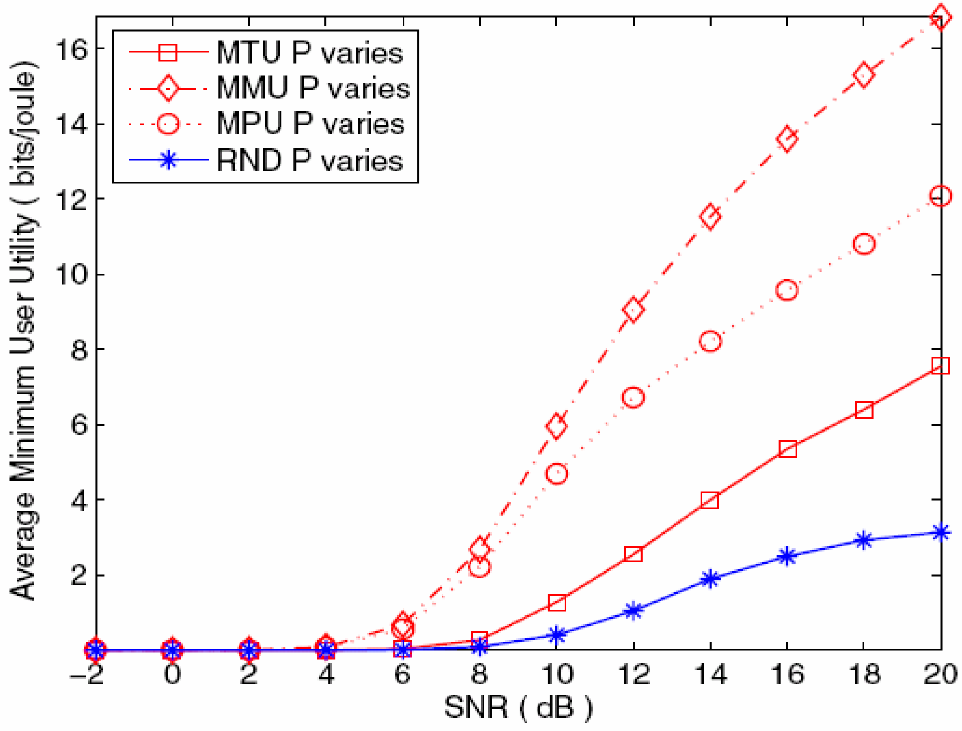
MTU


P_i=0.4*P_max
P_i=0.6*P_max
P_i=0.8*P_max
P_i=1.0*P_max
P_i varies
Average Total Utility (bits/joule)
SNR (dB)

MMU


P_i=0.4*P_max
P_i=0.6*P_max
P_i=0.8*P_max
P_i=1.0*P_max
P_i varies
Average Minimum User Utility (bits/joule)
SNR (dB)


MTU P varies
MMU P varies
MPU P varies
RND P varies
Average Total Utility (bits/joule)
SNR (dB)


MTU P varies
MMU P varies
MPU P varies
RND P varies
Average Minimum User Utility (bits/joule)
SNR (dB)

Conclusion

- This paper studies the partner selection problem in multiuser networks with a centralized scheduler AP.
- With all the CSI gathered at the AP, this problem can be converted into generic assignment problem with different requirements, and we focus on finding the globally optimum strategies.