Bargaining for Energy-efficient User Cooperation

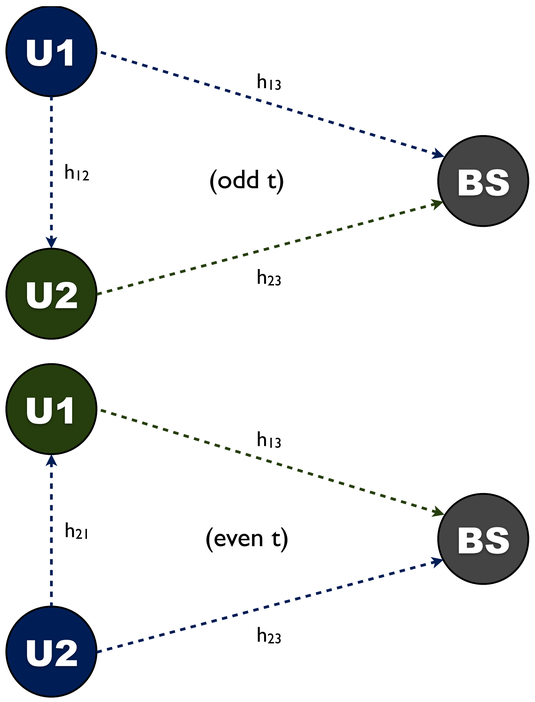
Matthew Nokleby and Behnaam Aazhang {nokleby,aaz}@rice.edu Rice University

Problem

- User cooperation increases data rates, but relaying requires extra energy!
- Incentive for users to refuse to cooperate
- Focus on bits-per-energy efficiency: is it possible for both users to improve energy efficiency through cooperation?
- Solve the problem by finding the Nash bargaining solution from game theory
- NBS provides a fair and efficient solution for user cooperation: both users increase efficiency.

Transmission Model

- Time-division two-user cellular system
- Idle user can act as relay:



- Block-fading Rayleigh channels
- Channel statistics $E[h_{12}^2], E[h_{13}^2], E[h_{21}^2]$, and $E[h_{23}^2]$ remain stationary
- Global channel state information

Utility functions

Each user's utility defined as amount of data transmitted per energy expended:

$$u_1(p_1, p_2) = \frac{\text{Amount of user 1's data transmitted}}{\text{Energy expended by user 1}}$$

$$u_2(p_1, p_2) = \frac{\text{Amount of user 2's data transmitted}}{\text{Energy expended by user 2}}$$

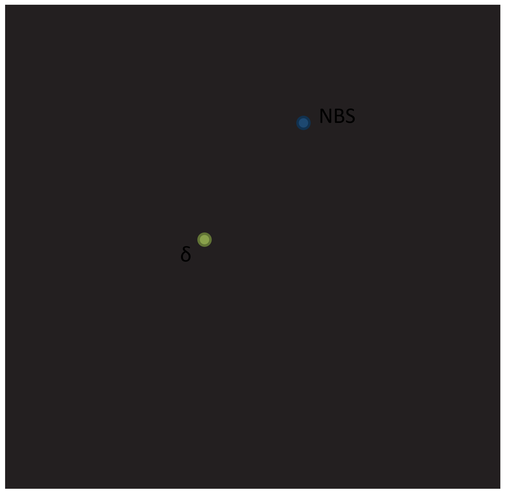
- Utilities determined by relay power allocations p_1 and p_2
- Taking the union over all power allocations gives achievable region

Nash Bargaining Solution

- Need to choose relay power allocations that maximize users' utilities
- Cannot simultaneously maximize u_1 and u_2
- Nash bargaining solution (NBS) defines a compromise between users:

$$\mathbf{u}^{\text{NBS}} = \arg\max_{u_1,u_2} [u_1 - u_1^{\text{NC}}]^+ [u_2 - u_2^{\text{NC}}]^+$$

- NBS is "fair" and on the boundary of the achievable region:



NBS power allocations

- Finding the NBS is a non-convex optimization problem
- But, all boundary points correspond to the convex optimizations:

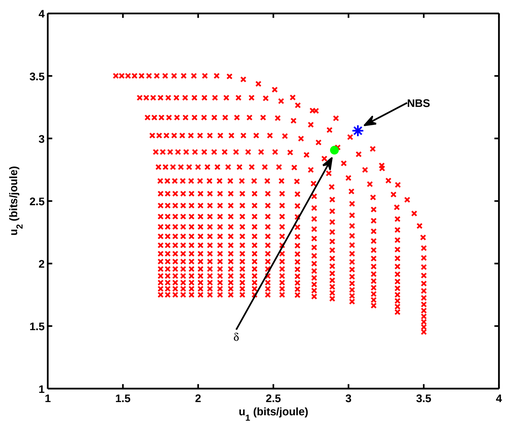
$$p_1^* = \arg\max_{p_1} \quad E\left[r_2(p_1)\right] \qquad \text{subject to} \quad E\left[p_1\right] = \alpha_1$$

$$p_2^* = \arg\max_{p_2} \quad E\left[r_1(p_2)\right] \qquad \text{subject to} \quad E\left[p_2\right] = \alpha_2$$

- Provides efficient characterization of boundary
- Find NBS by searching over (α_1, α_2) pairs

Achievable region

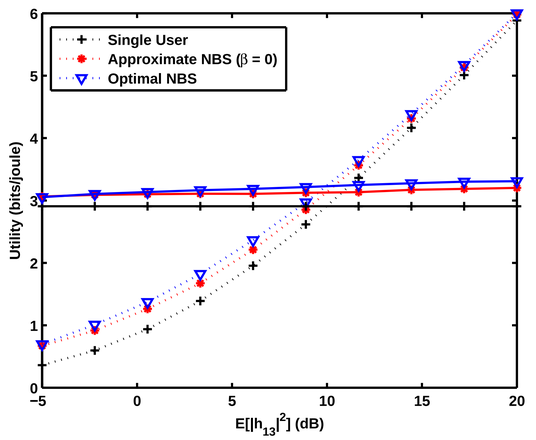
- $E[h_{12}^2] = E[h_{13}^2] = E[h_{21}^2] = E[h_{23}^2] = 10dB$



- Possible for both users to improve utility vs. non-cooperation!

NBS Utilities

- $E[h_{12}^2] = E[h_{13}^2] = E[h_{21}^2] = E[h_{23}^2]$



- NBS gives "fair" solution: stronger user benefits more from cooperation.

Conclusion/Future work

- User cooperation can not only improve data rates; it can do so with increased energy efficiency
- Efficient relay power allocations can be found via convex optimization
- Nash bargain provides fair + efficient compromise between users
- Future work:
  - More users?
  - Partial/incomplete CSI?