Optimal Power Allocation for Relay Nodes in Time/Frequency Division Multi-user Relay Networks

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Introduction

- **Increasing demand for high data rate and reliable wireless communications**
- Spatial Diversity
  - Antenna arrays [Telatar, Foschini & Gans]
  - Relay assisted communications [Van der Meulen, Cover & El Gamal]
- Relaying has the potential to improve the performance
  - Capacity of the relay channel [Van der Meulen, Cover & El Gamal]
  - Simple relay transmission schemes [Laneman et. al.]
  - Cooperative transmission [Sendonaris et. al.]
- **Relay assisted transmission** is expected to **improve** the performance of multi-user systems

➔ **Multi-user Relay Networks**

Motivation

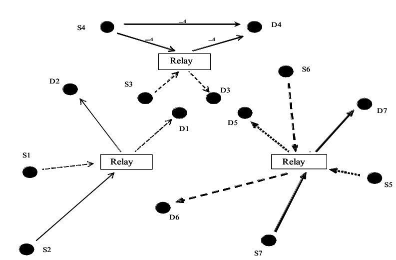
- **Relay assisted ad hoc networks**
  - Multiple source-destination pairs
  - Relay nodes to serve for multiple users
  - Limited relay power
- **How should each relay node allocate its available power between transmissions of multiple users it is "helping" ?**
- **Optimize the power allocation at the relay nodes to improve the system performance:**
  - Find the **optimum power allocation for the relay nodes** that will **maximize the sum capacity** of a relay assisted F/TDMA ad hoc network with multiple relay nodes.

Relay Assisted Ad Hoc Network

- Multiple source-destination pairs
  - Pre-assigned relay nodes
  - Each relay node 'assigned' to help multiple users
  - A_j : The set of users that are assigned to the relay node *j*
- P_{si} : Transmit power of user *i*
- P_{ri} : Transmit power of the relay node dedicated to user *i*
- $P_{Rj,total}$: Total transmit power of the relay node *j*
- Transmit power constraint for relay node *j*

$$\sum_{i\in A_j} P_{ri} \le P_{Rj,total}$$

- Channels are static and known at the relay node



- Each user is assigned two channels (time slots).
- **First channel**: the user broadcasts its signal.
- **Second channel**: the relay node transmits the user's information.
  - Regenerative Decode-and-Forward (RDF) [Laneman et.al.]: Decode ➔ Re-encode (Same Codebook) ➔ Transmit
  - Non-regenerative Decode-and-Forward (NDF) [Yates et.al.]: Decode ➔ Re-encode (Different Codebook) ➔ Transmit
  - Amplify-and-Forward (AF) [Laneman et.al.]: Amplify ➔ Transmit
  - Compress-and-Forward (CF) [Kramer et.al.]: Compress ➔ Transmit
- The sum capacity optimization problem is

$$\max_{\{P_{ri}\}} \sum_{i\in A_j} C_{i,*}(P_{ri})$$
$$\text{s.t.} \quad \sum_{i\in A_j} P_{ri} \le P_{Rj,total}$$

where $*\in\{\text{RDF},\text{NDF},\text{AF},\text{CF}\}$

Decode-and-Forward Relaying

- The relay node should be able to decode the signal **perfectly.**
- Decodability constraint of decode-and-forward (DF) relay transmission schemes
  - $P_{ri} = 0 \;\; if \;\; \alpha_i^2 \le \beta_i^2$ (Direct link is better than user-to-relay link)
  - Upper bounds for the individual capacities: $C_{i,RDF} \le C_{i,NDF} \le C_{i,upperDF} = \frac{1}{2K}\log(1+\alpha_i^2 P_{si})$

$$C_{i,RDF} = \max(\min(\frac{1}{2K}\log(1+P_{si}\beta_i^2+P_{ri}\gamma_i^2), \underbrace{\frac{1}{2K}\log(1+P_{si}\alpha_i^2)}_{\text{User-to-Relay Link}}), \underbrace{\frac{1}{2K}\log(1+P_{si}\beta_i^2)}_{\text{Direct Link}}))$$

$$C_{i,NDF} = \max(\min(\frac{1}{2K}\log(1+P_{si}\beta_i^2)+\frac{1}{2K}\log(1+P_{ri}\gamma_i^2), \underbrace{\frac{1}{2K}\log(1+P_{si}\alpha_i^2)}_{\text{User-to-Relay Link}}), \underbrace{\frac{1}{2K}\log(1+P_{si}\beta_i^2)}_{\text{Direct Link}}))$$

- **High potential users (HPU)**: The set of users that are allocated nonzero power at their pre-assigned relay node and yet do not achieve the individual capacity upper bound

The individual capacities would be further increased, if more relay power were available.

- **Low potential users (LPU)**: The set of users that achieve $C_{i,upperDF}$

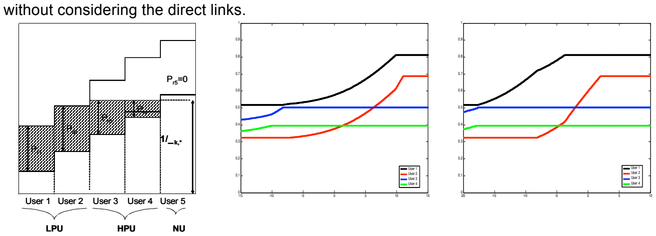
Even if more total relay power were available, the individual capacities would not increase.

- **Non-relayed users (NU)**: The set of users that are not assisted by the relay node.

High quality direct links, or low quality relay to destination links.

Optimal Power Allocation for RDF and NDF

- Modified water-filling solution
- For RDF, the optimal PA tries to help the **weak users** that it can efficiently assist.
- For NDF, the optimum PA tries to use the relay to destination channels as efficiently as it can without considering the direct links.



a) Water-filling Solution b) RDF Relaying c) NDF Relaying

AF and CF Relaying

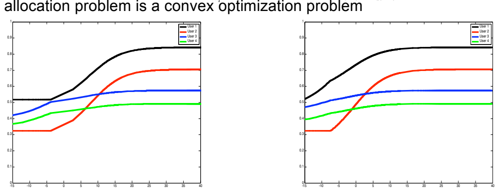
- When AF relay transmission is used, the individual capacity of user *i* is

$$C_{i,AF} = \frac{1}{2K}\log(1+P_{si}\beta_i^2+\frac{P_{si}\alpha_i^2 P_{ri}\gamma_i^2}{P_{si}\alpha_i^2+P_{ri}\gamma_i^2+1})$$

- When CF relaying is used, the individual capacity of user *i* is

$$C_{i,CF} = \frac{1}{2K}\log(1+P_{si}\beta_i^2+\frac{P_{si}\alpha_i^2}{\sigma_{W_i}^2+1}) \quad \text{with } \sigma_{W_i}^2 = \frac{P_{si}(\alpha_i^2+\beta_i^2)+1}{P_{ri}\gamma_i^2(P_{si}\beta_i^2+1)}$$

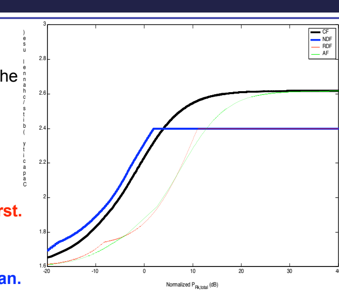
- Power allocation problem is a convex optimization problem



a) AF Relaying b) CF Relaying

Conclusions

- Relay nodes can efficiently distribute their powers between multiple users to enhance the system performance in F/TDMA Ad Hoc Networks.
- **RDF relay node tries to improve the individual capacities of the weak users first.**
- **NDF relay node tries to use the relay to destination channels as efficiently as it can.**



- **AF and CF relay nodes may provide higher sum capacities than the DF relay nodes for high relay powers and poor user-to-relay links.**

Sponsored by NSF grants CCF-0237727 and CNS-0508114.