

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

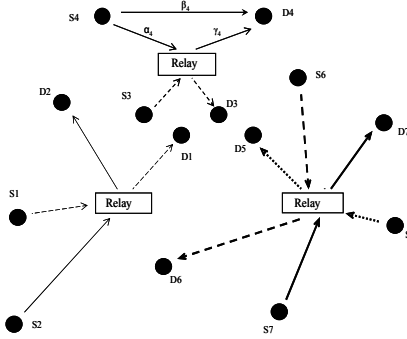
- **Relay assisted ad hoc networks**
 - Multiple source-destination pairs
 - **Relay nodes to serve for multiple users**
 - **Limited relay power**
- **How should each relay node allocate its available power between transmissions of multiple users it is "helping" ?**
- **Optimize the power allocation 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_{s_i} : Transmit power of user i
 - P_{r_i} : Transmit power of the relay node dedicated to user i
 - $P_{R_j, total}$: Total transmit power of the relay node j
 - **Transmit power constraint for relay node j**

$$\sum_{i \in A_j} P_{r_i} \leq P_{R_j, total}$$

- 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.



- The relay transmission strategies
 - **Regenerative Decode-and-Forward (RDF)**: Decode → Re-encode (Same Codebook) → Transmit
 - **Non-regenerative Decode-and-Forward (NDF)**: Decode → Re-encode (Different Codebook) → Transmit
 - **Amplify-and-Forward (AF)**: Amplify → Transmit
 - **Compress-and-Forward (CF)**: Compress → Transmit
- **The sum capacity optimization problem is**

$$\max_{\{P_{r_i}\}} \sum_{i \in A_j} C_{i,*}(P_{r_i})$$

$$\text{s.t. } \sum_{i \in A_j} P_{r_i} \leq P_{R_j, total}$$

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

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
 - $P_{r_i} = 0$ if $\alpha_i^2 \leq \beta_i^2$ (Direct link is better than user-to-relay link)
 - Upper bounds for the individual capacities: $C_{i,RDF} \leq C_{i,NDF} \leq C_{i,upperDF} = \frac{1}{2K} \log(1 + \alpha_i^2 P_{s_i})$

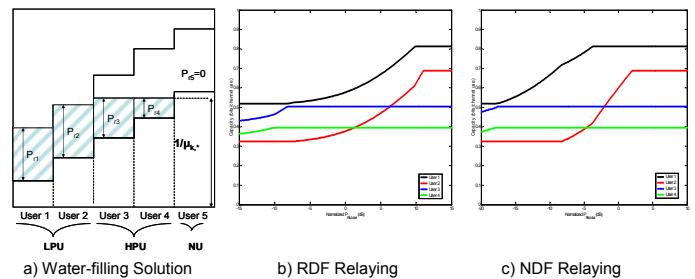
$$C_{i,RDF} = \max(\min(\underbrace{\frac{1}{2K} \log(1 + P_{s_i} \beta_i^2 + P_{r_i} \gamma_i^2)}_{\text{User-to-Relay Link}}, \underbrace{\frac{1}{2K} \log(1 + P_{s_i} \alpha_i^2)}_{\text{Direct Link}}, \underbrace{\frac{1}{2K} \log(1 + P_{s_i} \beta_i^2)}_{\text{Direct Link}}))$$

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

- **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.



AF and CF Relaying

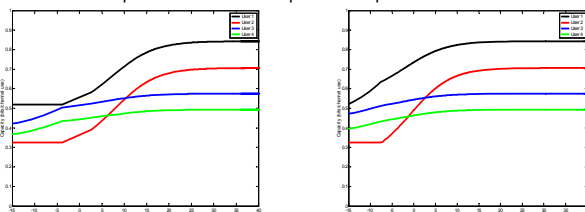
- When AF relay transmission is used, the individual capacity of user i is

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

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

$$C_{i,CF} = \frac{1}{2K} \log(1 + P_{s_i} \beta_i^2 + \frac{P_{s_i} \alpha_i^2}{\sigma_w^2 + 1}) \quad \text{with } \sigma_w^2 = \frac{P_{s_i} (\alpha_i^2 + \beta_i^2) + 1}{P_{r_i} \gamma_i^2 (P_{s_i} \beta_i^2 + 1)}$$

- Power allocation problem is a convex optimization problem



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.**
- **Hybrid relaying strategies can further improve performance.**