Interference Management for Multiuser Two-Way Relay Networks

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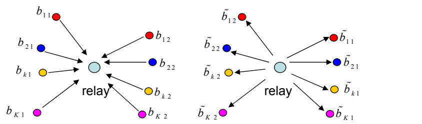
Multiuser Two-Way Relay Networks

- Two-way relaying outperforms traditional "one-way" relaying
- In wireless ad hoc networks:
  - it is likely that we have many more than two nodes
  - there are shared intermediate relay(s)

Proposal: Multiuser two-way relaying:
multiple pairs of partners communicate via a single relay



Phase 1: users transmit to relay Phase 2: relay broadcasts to users

Multiple Access Method

- Employ CDMA to support multiple users:
  - Conventional design: distinct signatures for all users in the system.

New insight:
utilize the bi-directional communication structure
- Each pair of partners share a common signature
- Only K signatures are needed for 2K users.

Objective

- Interference limited two-way relay system

Objective:
Interference management by jointly optimizing
- Transmit power levels
- Multiuser receivers at the relay and the users
- Relaying scheme

Results:
- Multiple Access Interference (MAI) is greatly reduced.
- More user pairs can be supported.

Communication in Phase I

- Communication in Phase I:
  - The i[th] pair of users share the common signature $\mathbf{s}_i$
  - Binary user symbols: $b_{i1}, b_{i2} \in \{-1,+1\}$
  - Received signal at the relay: $\mathbf{r}_0 = \sum_{i=1}^{K} (\sqrt{p_{i1} h_{i1}} b_{i1} + \sqrt{p_{i2} h_{i2}} b_{i2})\, \mathbf{s}_i + \mathbf{n}_0$

How does the relay forward the information?
Jointly demodulate-and-XOR-forward (JD-XOR-F) relaying

Upon receiving $\mathbf{r}_0$, the relay will
- employ a linear filter to obtain $y_i = \mathbf{c}_i^{\mathrm{T}} \mathbf{r}_0$
- generate $\hat{b}_i \in \{-1, 1\}$, the estimate of $b_i = b_{i1} \oplus b_{i2}$
- spread $\hat{b}_i$ with $\mathbf{s}_i$, and broadcast K symbols simultaneously

$$\mathbf{x}_0 = \sum_{i=1}^{K} \sqrt{p_{0i}}\, \hat{b}_i \mathbf{s}_i$$

Decision Rule in Phase I

- Relay decides in favor of two hypothesis: whether two partners have sent the same symbol or not

$$\hat{b}_i = -1 \ \text{when } b_{i1} = b_{i2}; \ \ \hat{b}_i = 1 \ \text{otherwise}$$

No closed-form solution unless equal received power per pair is employed.

- Near-optimum decision rule
  - Step 1: $(\hat{b}_{i1}, \hat{b}_{i2}) \in \{(-1,-1),(-1,1),(1,-1),(1,1)\}$
  - Step 2: $\hat{b}_i = \hat{b}_{i1} \oplus \hat{b}_{i2}$
  - Decision rule:

$$\hat{b}_i = \begin{cases} 1, & \text{when } y_i \in R = \{y_i \mid -y_{th} < y_i < y_{th}\} \\ -1, & \text{when } y_i \in R_C \end{cases}$$

where $y_{th} = \sqrt{q_{i1}}$ when $q_{i1} \ge q_{i2}$, and $y_{th} = \sqrt{q_{i2}}$ otherwise.

Communication in Phase II

- Received signal at terminal im (i=1,…K, m=1,2):

$$\mathbf{r}_{im} = \sqrt{h_{im}}\mathbf{x}_0 + \mathbf{n}_{im} = \sqrt{h_{im}} (\sum_{j=1}^{K} \sqrt{p_{0j}}\, \hat{b}_j \mathbf{s}_i) + \mathbf{n}_{im}$$

- Upon receiving $\mathbf{r}_{im}$, the terminal will
  - employ a linear filter to obtain $y_{im} = \mathbf{c}_{im}^{\mathrm{T}} \mathbf{r}_{im}$
  - generate $\hat{b}_{im}$, the estimate of $\hat{b}_i$
  - perform an XOR operation on $\hat{b}_{im}$ and b_{im} to recover the partner's symbol.

The unique feature of two-way communication:
Each user utilizes the side information (its own symbol) to subtract the self-interference from the signal broadcasted by the relay.

Interference Management Problem

- Optimum interference management for each phase:
  We seek to expend the minimum total transmit power while satisfying the QoS requirements

$$\min_{\{p_{i1}, p_{i2}, \mathbf{c}_i\}} \sum_{i=1}^{K} (p_{i1} + p_{i2})$$
$$s.t. \quad Pe1_i \le \rho 1_i$$
$$p_{i1} \ge 0, p_{i2} \ge 0, \mathbf{c}_i \in \Re^N, \forall i$$

Phase I QoS requirements

$$\min_{\{p_{0i}, \mathbf{c}_{i1}, \mathbf{c}_{i2}\}} \sum_{i=1}^{K} p_{0i}$$
$$s.t. \quad Pe2_{i1} \le \rho 2_{i1}, Pe2_{i2} \le \rho 2_{i2}$$
$$p_{0i} \ge 0, \mathbf{c}_{i1} \in \Re^N, \mathbf{c}_{i2} \in \Re^N, \forall i$$

Phase II QoS requirements

Phase I: Users→ Relay (Uplink)

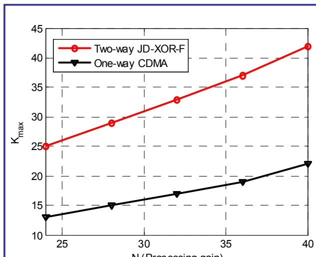
Phase II: Relay→ Users (Downlink)

Interference Management Solution

Key: the BER constraint can be converted to the received SIR constraint in each phase

- Phase I: (more involved)
  - Solve the power control subproblem for the i[th] user pair
  - Find a sufficient condition on the received SIRs for $Pe1_i \le \rho 1_i$ with the minimum total transmit power requirement on the i[th] user pair
- Phase II: (more straightforward)
  - One-to-one mapping between BER and SIR
- The iterative power control and receiver optimization algorithm can then be implemented in each phase, and converges to its corresponding minimum power solution.

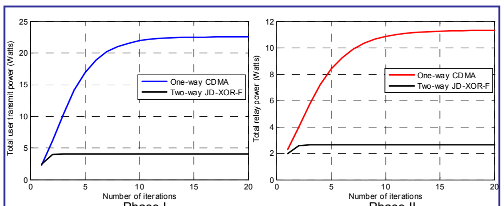
Maximum Number of User Pairs Can be Supported



- One-way CDMA: users have distinct spreading signatures.
- Equal received SNR = 10 dB, i.e., no power control.
- K_{max}—Maximum # of user pairs that can be supported with an end-to-end BER requirement ≤ 0.01.

- The multiuser two-way JD-XOR-F relaying almost ***doubles*** the numbers of user pairs that can be supported by the "one-way" CDMA relaying.

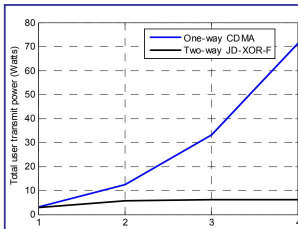
Total Power with Iterative Power Control



Phase I Phase II

- Iterative power control and receiver updates
  →Total transmit power is minimized.
- Two-way JD-XOR-F relaying achieves significant power savings.

Overloaded System in Phase I



- 13 partner pairs, i.e., 26 users
- Processing gain=20
- All BER requirements: 0.0189
- One-way CDMA: user capacity=24<26

- One-way CDMA → Infeasible power control problem
- Two-way relaying scheme still has a feasible solution
  → Benefit of considering the two-way communication structure

Conclusions

- Resource sharing in two-way communications differs from that of one-way communications.
- Interference can be managed using power control, multiuser detection and the appropriate relaying scheme.
- Optimum physical layer is designed by using iterative power control and multiuser detection updates with guaranteed convergence to the optimum.
- Taking into account the bi-directional nature of communication leads to significant power savings.

Sponsored by NSF and DARPA ITMANET Program