When Does Cooperation Have Better Performance in Sensor Networks?

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Outline

- Introduction
- System Model
- Performance Analysis
- Experimental and Simulation Results
- Discussions
- Conclusions

Introduction

- “Diversity”= “state of being varied, variety”
- The basic concept of diversity: transmit the signal via several independent diversity branches to get independent signal replicas via
  - time diversity
  - frequency diversity
  - space diversity
  - polarization diversity

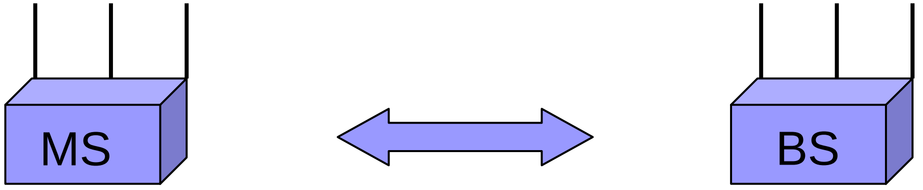
Introduction

- Frequency diversity
  - Multi-carrier communications
  - Multi-path diversity in spread spectrum communications.
- Space diversity
  - Antenna diversity

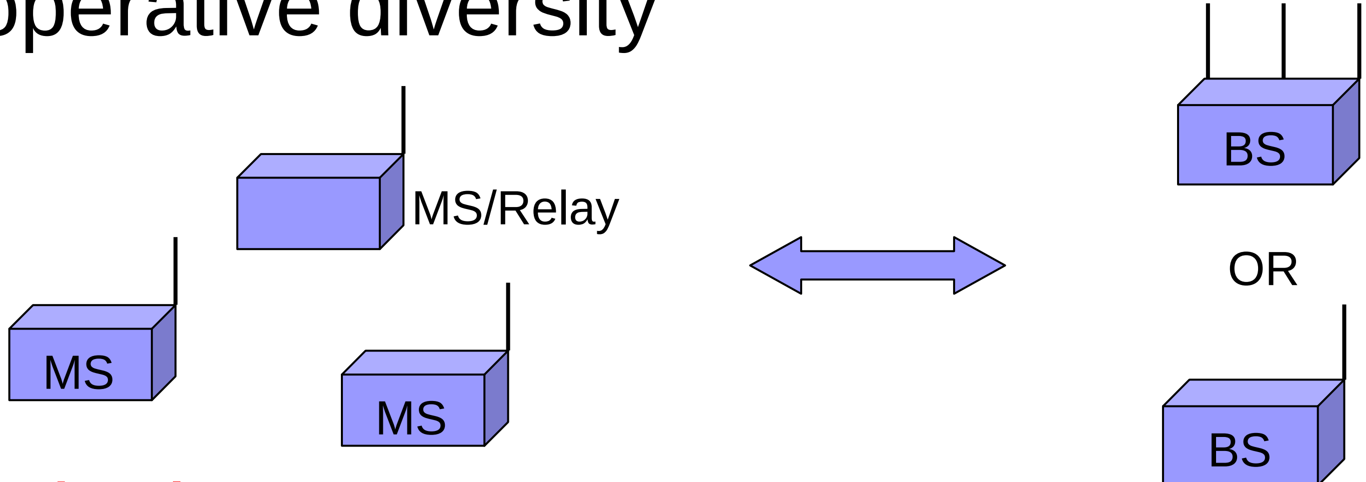
  E.g. Multiple-Input Multiple-Output (MIMO)

Introduction

- Original MIMO



- Cooperative diversity



Virtual antenna array

Introduction

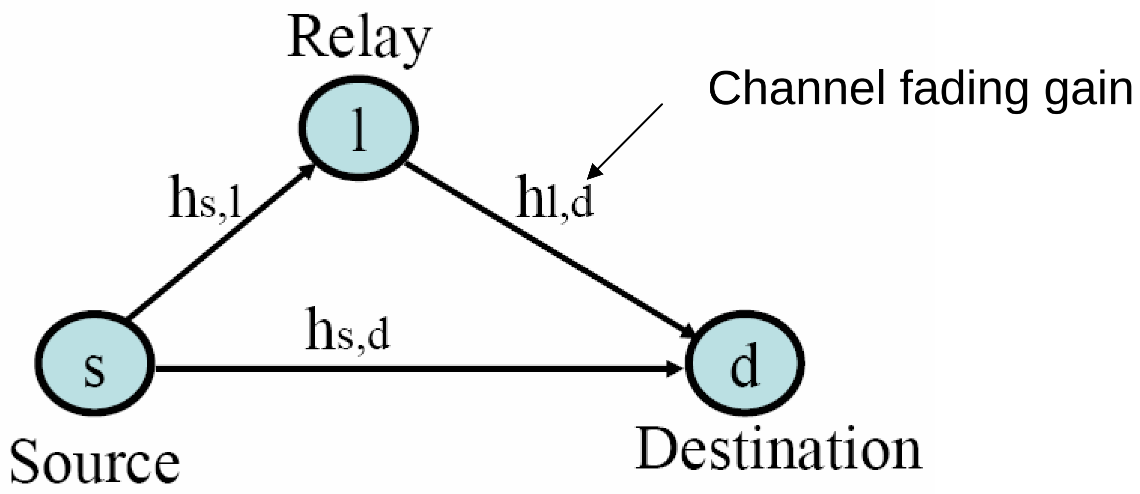
- Cooperation takes the advantage of the broadcast nature of the wireless channel
  - Overhearing
- The previous works studies the gain of cooperation diversity under ideal model of negligible listening and computing power.
  - In WSNs, these two power are the same order as the transmit power.

Introduction

- This paper takes into account the extra:
  - processing
  - receiving

  power consumption at relay and destination.
- There will be a tradeoff between the gains in the transmit power and the loses when applying cooperation.

System Model



- Considering a single hop in the network between two nodes.
- Three node model

System Model

- Direct transmission
  - Source → Destination
- Cooperative transmission
  - Phase **1**: Source → Relay

    Success → ACK

    Failure → NACK → phase 2
  - Phase **2**: Relay → Destination

System Model

- Outage Probability

$$\mathcal{P}_O = \mathcal{P}(\mathrm{SNR} \leq \beta).$$

  - β is a threshold which depends on the QoS requirement.

System Model

- Wireless channel
  - Narrow band Rayleigh fading
  - Propagation loss
  - AWGN
  - Channel fades are independent for different links
- Antenna
  - One antenna
  - Half-duplex mode

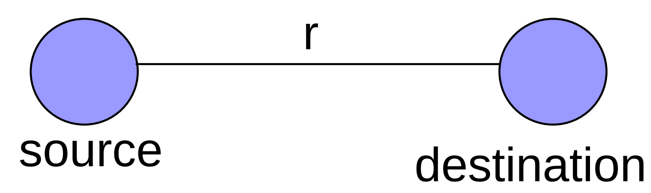
System Model

- Power consumption
  - Transmitting power: P
    - P(1-α) is actually used for RF transmission
    - α : power amplifier loss
  - Processing power: P_c
  - Receiving power: P_r

System Model

- The received signal strength

1. Direct mode



$$y_{sd} = \sqrt{P_s^D (1-\alpha) r_{sd}^{-\gamma}}\, h_{sd} x + n_{sd},$$

2. Cooperative mode

$$y_{sd} = \sqrt{P_s^c (1-\alpha) r_{sd}^{-\gamma}}\, h_{sd} x + n_{sd},$$
$$y_{sl} = \sqrt{P_s^c (1-\alpha) r_{sl}^{-\gamma}}\, h_{sl} x + n_{sl},$$

$$y_{ld} = \sqrt{P_l (1-\alpha) r_{ld}^{-\gamma}}\, h_{ld} x + n_{ld}.$$

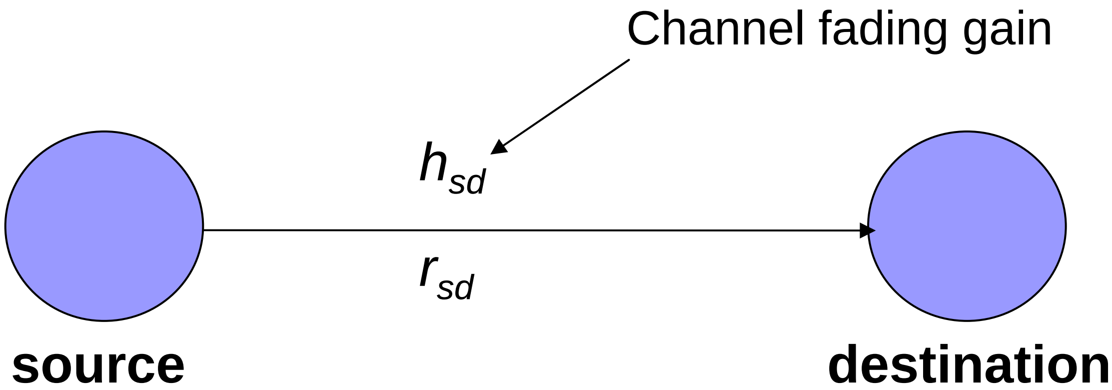
Summary

- Cooperation provides a new means to achieve signal reliability via spatial diversity.
- The **drawback** of the cooperation mode is the extra processing and receiving power required at the **relay** and **destination**.

Performance Analysis

- This paper formulates a constrained optimization problem to minimize the total consumed power subject to a given outage performance.

Direct Transmission



$$SNR(r_{sd}) = \frac{y_{sd}^2}{N_0} = \frac{|h_{sd}|^2 r_{sd}^{-\gamma} P_s^D (1-\alpha)}{N_0} \qquad (5)$$

Direct Transmission

- Outage probability

$$\mathrm{P}_{OD} = \mathrm{P}\left(SNR\left(r_{sd}\right) \le \beta\right) = 1 - \exp\left(-\frac{N_0 \gamma r_{sd}^{\gamma}}{\left(1-\alpha\right)P_s^D}\right) \quad (6)$$

- Total transmission power

$$P_{tot}^{D} = P_s^{D} + P_c + P_r$$

Fixed (P_c, P_r)

Direct Transmission

- Optimization problem

$$\min_{P_s^D} P_{tot}^D, \quad s.t. \quad \mathrm{P}_{OD} \leq \mathrm{P}_{out}^*$$

- Let $\mathrm{P}_{\mathrm{OD}} = \mathrm{P}_{\mathrm{out}}{}^*$

$$P_s^{D*} = -\frac{\beta N_0 r_{sd}^{\gamma}}{(1-\alpha)\ln\left(1-\mathrm{P}_{out}^*\right)}$$

Direct Transmission

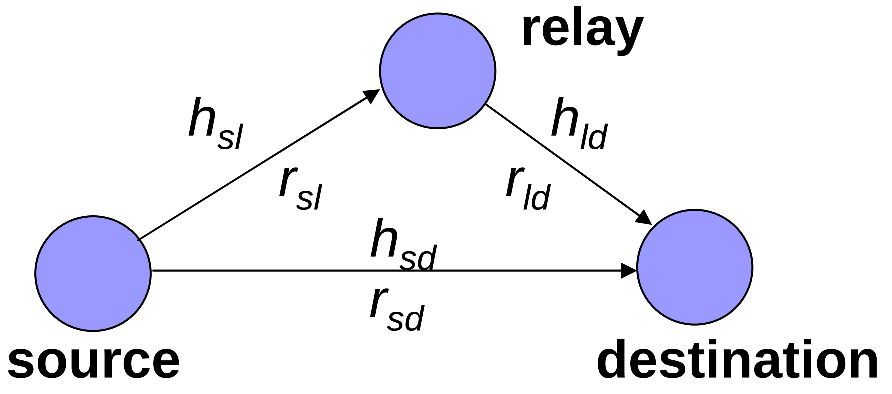
- The minimum total power required for direct transmission:

$$P_{tot}^{*} = P_c + P_r - \frac{\beta N_0 r_{sd}^{\gamma}}{(1-\alpha)\ln\left(1-\mathrm{P}_{out}^{*}\right)}$$

Cooperative Transmission

- Two possible power allocation scenarios
  1. Source and Relay have different transmission powers
     - Complex and infeasible
  2. Source and Relay have equal transmission powers

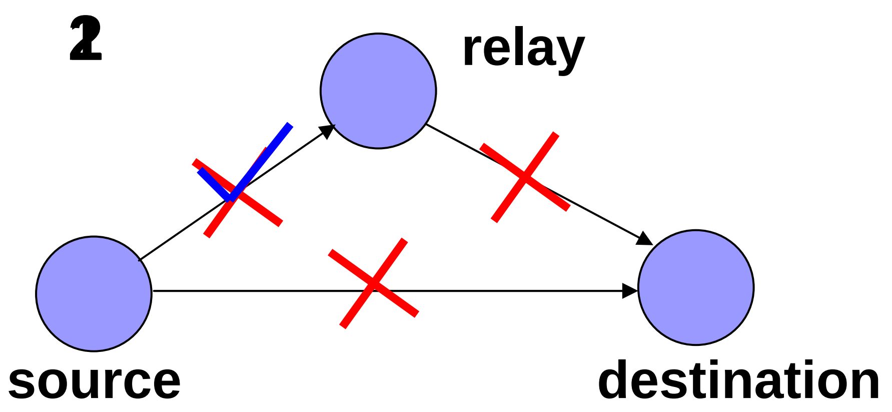
Cooperative Transmission



- Calculate each SNR value in each phase
  - Phase 1: SNR_{sd} , SNR_{sl} (11)
  - Phase 2: SNR_{ld} (12)

Cooperative Transmission

- Outage conditions



Cooperative Transmission

1

$$\mathcal{P}_{OC} = \mathcal{P}\left((\text{SNR}_{sd} \leq \beta) \cap (\text{SNR}_{sl} \leq \beta)\right) +$$

$$\mathcal{P}\left((\text{SNR}_{sd} \leq \beta) \cap (\text{SNR}_{ld} \leq \beta) \cap (\text{SNR}_{sl} > \beta)\right)$$

2

$$= \left(1 - f(r_{sd}, P_s^C)\right)\left(1 - f(r_{sl}, P_s^C)\right) + \left(1 - f(r_{sd}, P_s^C)\right)\left(1 - f(r_{ld}, P_l)\right) f(r_{sl}, P_s^C)$$

$$f(x, y) = \exp\left(-\frac{N_o \beta x^\gamma}{y(1-\alpha)}\right)$$

Cooperative Transmission

- Simplification

$$\mathcal{P}_{OC} = \left(1 - f(r_{sd}, P_s^C)\right)\left(1 - f(r_{sd}, P_l) f(r_{sl}, P_l)\right)$$

- The total consumption power

$$P_{tot}^C = (P_s^C + P_c + 2P_r)\underline{\mathcal{P}(SNR_{sd} \geq \beta)}$$
$$+ \underline{(P_s^C + P_c + 2P_r)\mathcal{P}(SNR_{sd} < \beta)\mathcal{P}(SNR_{sl} < \beta)}$$
$$+ (P_s^C + P_l + 2P_c + 2P_r)$$
$$\times \underline{\mathcal{P}(SNR_{sd} < \beta)\mathcal{P}(SNR_{sl} > \beta)}, \quad (15)$$

Cooperative Transmission

- Simplification

$$P_{tot}^{C} = (P_s^C + P_c + 2P_r) f(r_{sd}, P_s^C) + (P_s^C + P_c + 2P_r) \left(1 - f(r_{sd}, P_s^C)\right) \left(1 - f(r_{sl}, P_s^C)\right) + (P_s^C + P_l + 2P_c + 2P_r) \left(1 - f(r_{sd}, P_s^C)\right) \times f(r_{sl}, P_s^C). \quad (16)$$

Cooperative Transmission

- Optimization problem

$$\min_{P_s^C, P_l} P_{tot}^C(P_s^C, P_l), \qquad \text{s.t. } \mathcal{P}_{OC}(P_s^C, P_l) \le P_{out}^*.$$

$$\downarrow \quad Let \quad P_s^C = P_l = P_{CE}$$

$$\min_{P_{CE}} P_{tot}^C(P_{CE}), \qquad \text{s.t. } \mathcal{P}_{OC}(P_{CE}) \le P_{out}^*.$$

Cooperative Transmission

- The minimum total power required for direct transmission

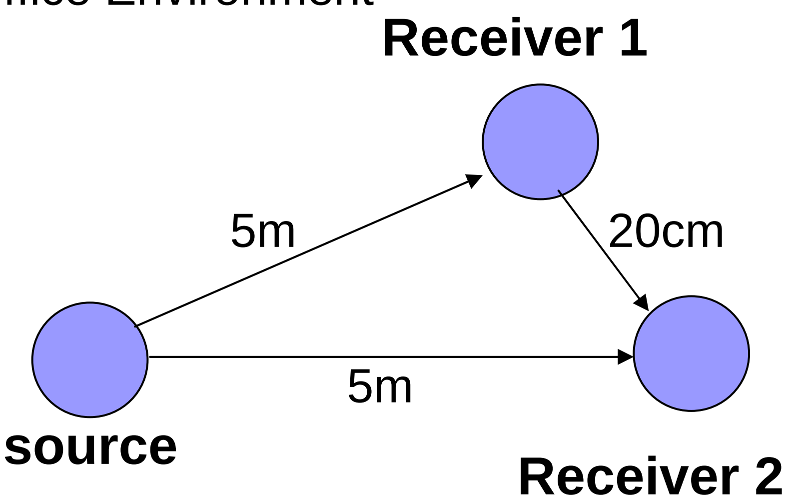
$$(k_1 k_2 + k_1 k_3)\, x^2 - k_1 k_2 k_3 x^3 = P^*_{out}.$$

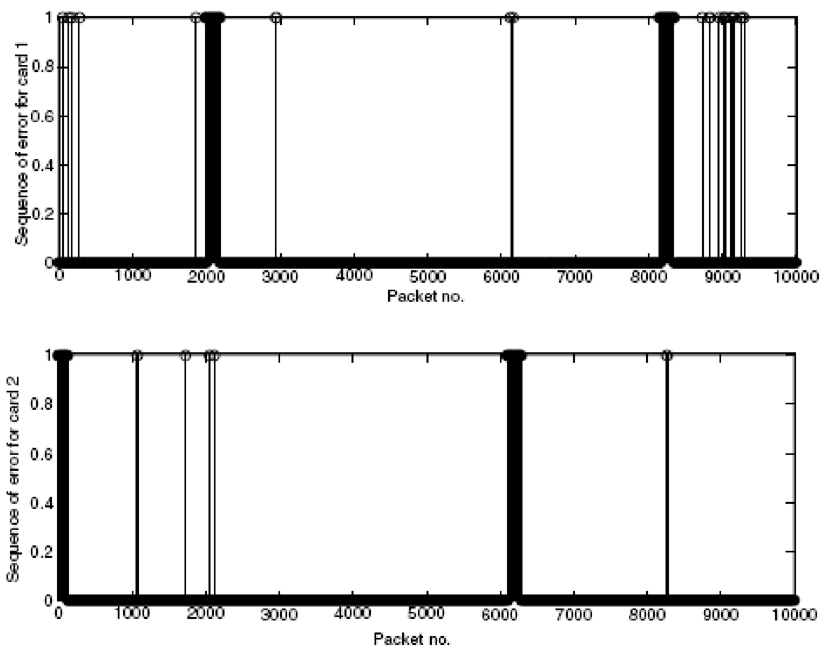
where $k_1 = \frac{\beta N_o r_{sd}^{\gamma}}{1-\alpha}$, $k_2 = \frac{\beta N_o r_{sl}^{\gamma}}{1-\alpha}$, and $k_3 = \frac{\beta N_o r_{ld}^{\gamma}}{1-\alpha}$.

Experimental Results

- Assumptions
  - Channel independence
  - Channel error exhibits strong time correlation

Office Environment





Simulation Results

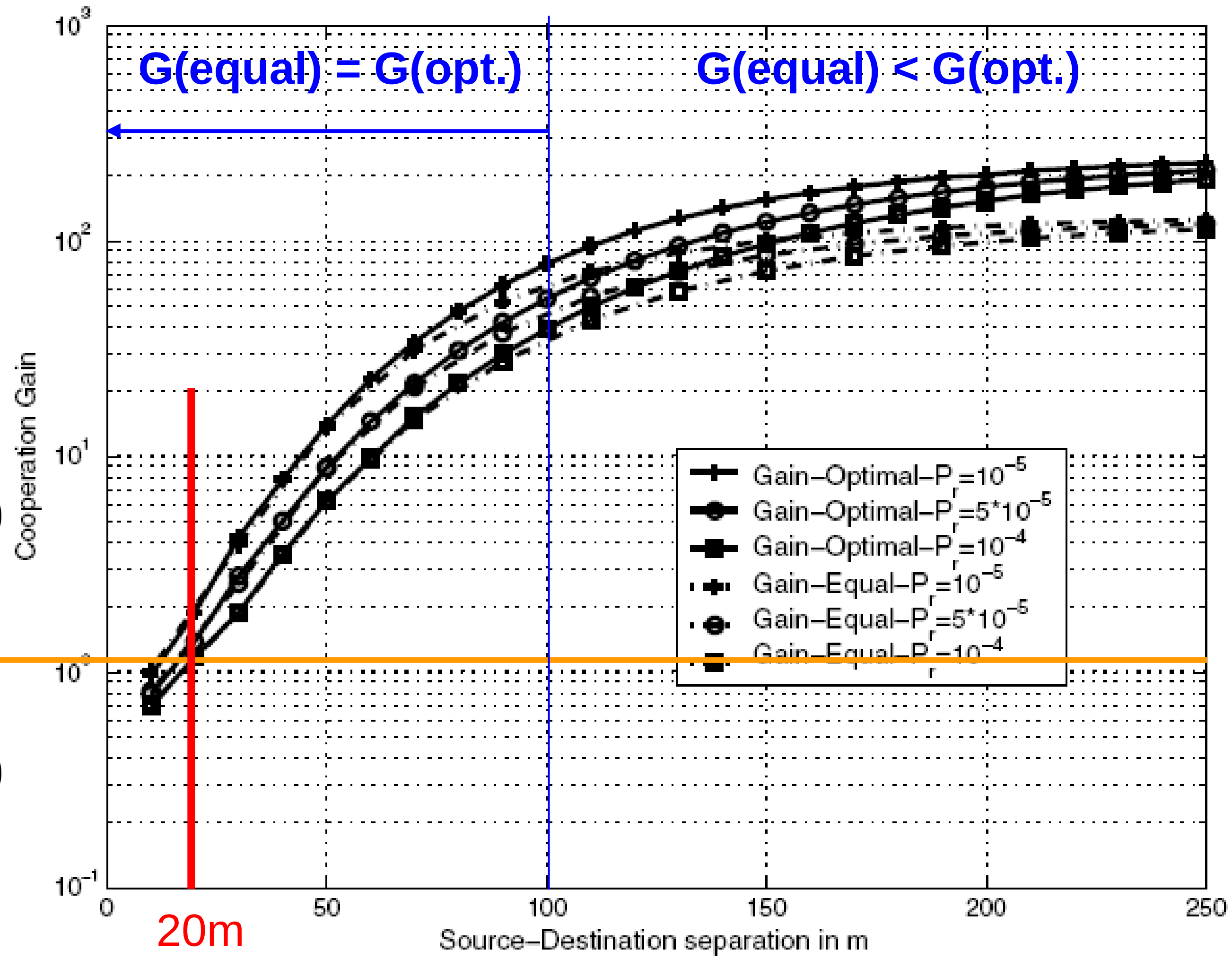
- Parameters
  - α =0.3, β =10
  - $N_0=10^{-3}$
  - $P_c= 10^{-4}$ watts
  - $P_r= 5*10^{-5}$ watts
  - Qos= $P_{outage}= 10^{-4}$
  - Coop. Gain = $P_{coop.}/P_{direct}$

Simulation Results

- Different P_r

Gain(coop.) > Gain(direct)

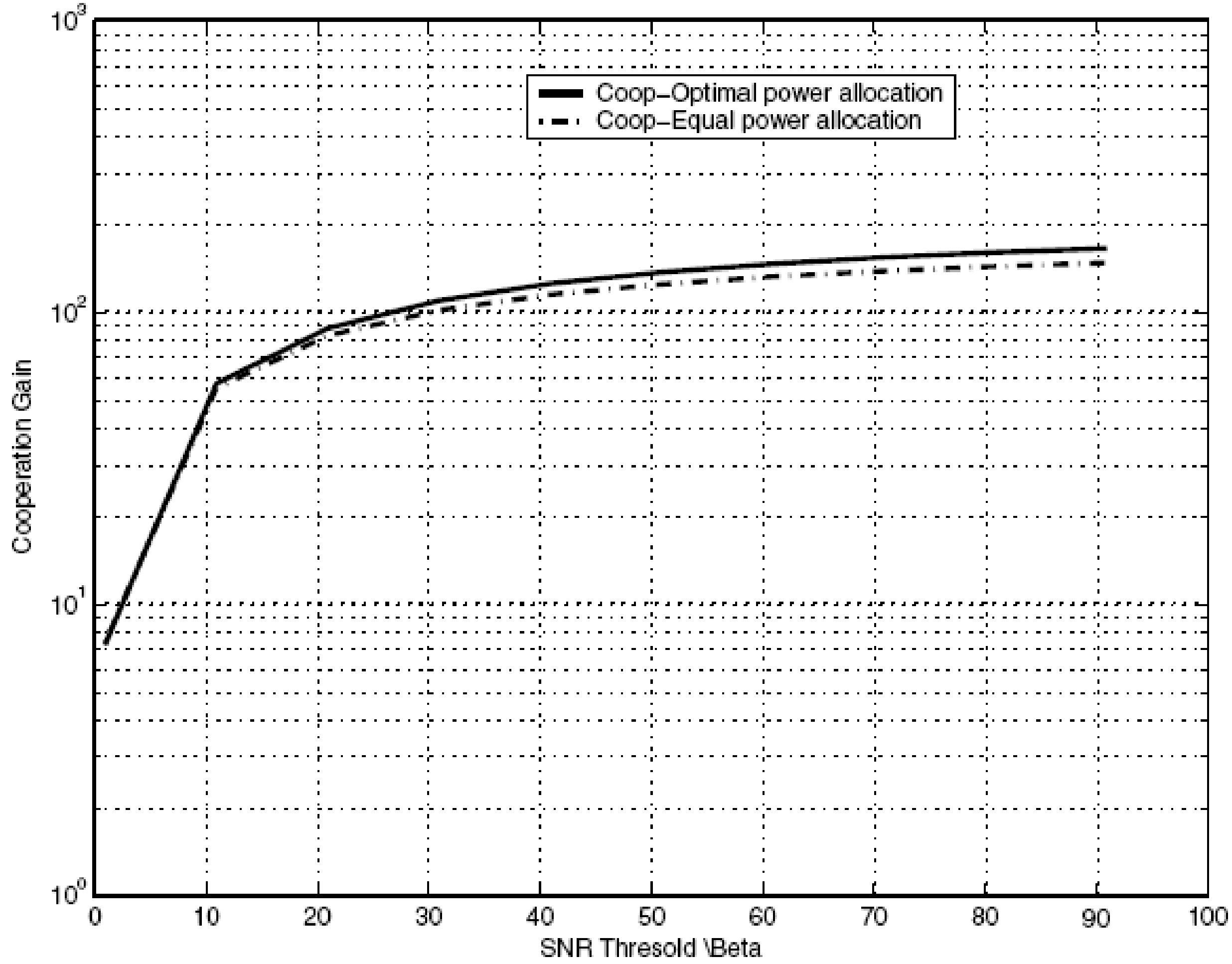
Gain(coop.) < Gain(direct)



Simulation Results

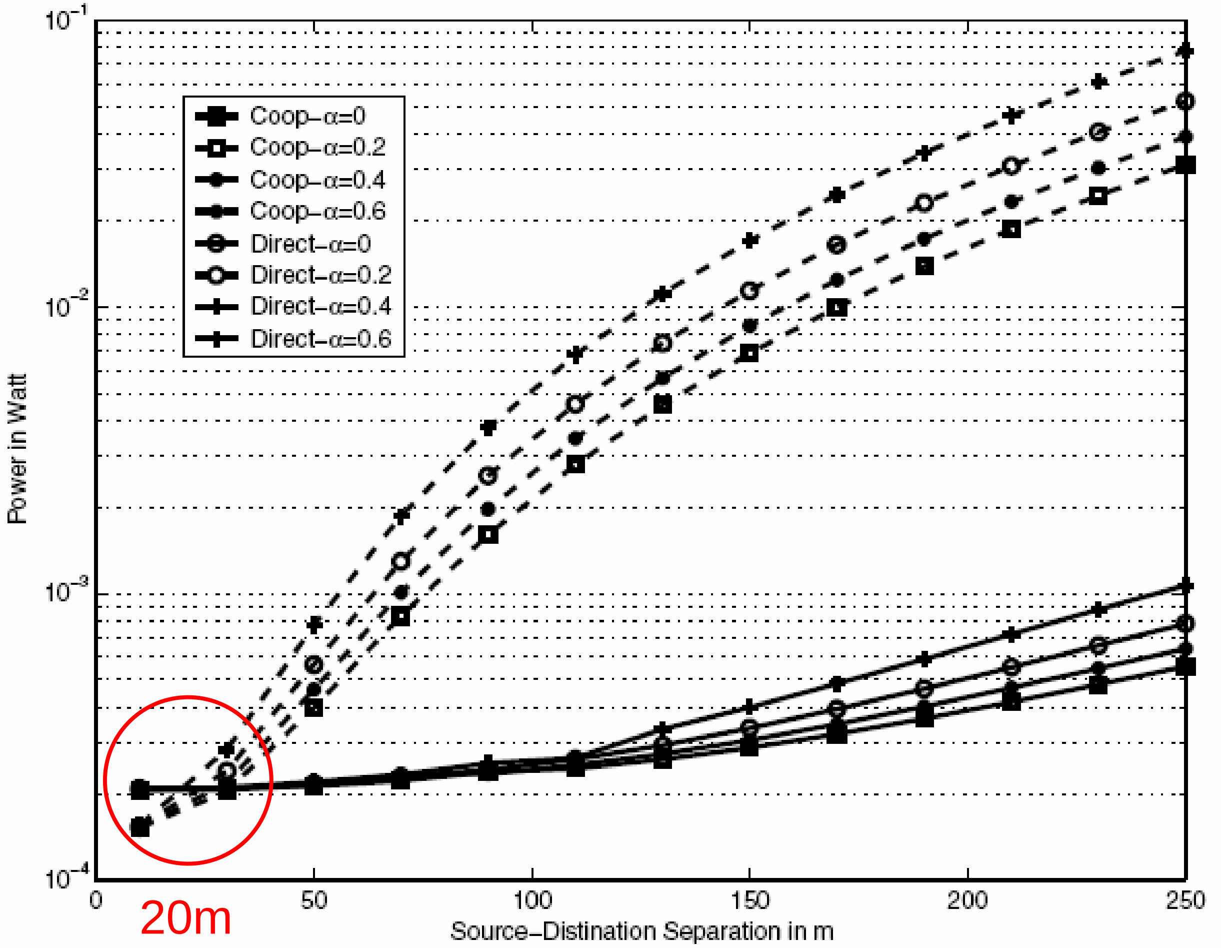
- The effect of SNR threshold β

γ_{sd} = 100m



Simulation Results

- Power amplifier loss α
- Direct transmission is more sensitive to variations in α



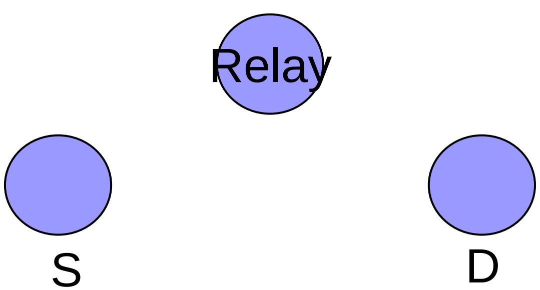
Simulation Results

- The effect of the relay location
- 3 cases

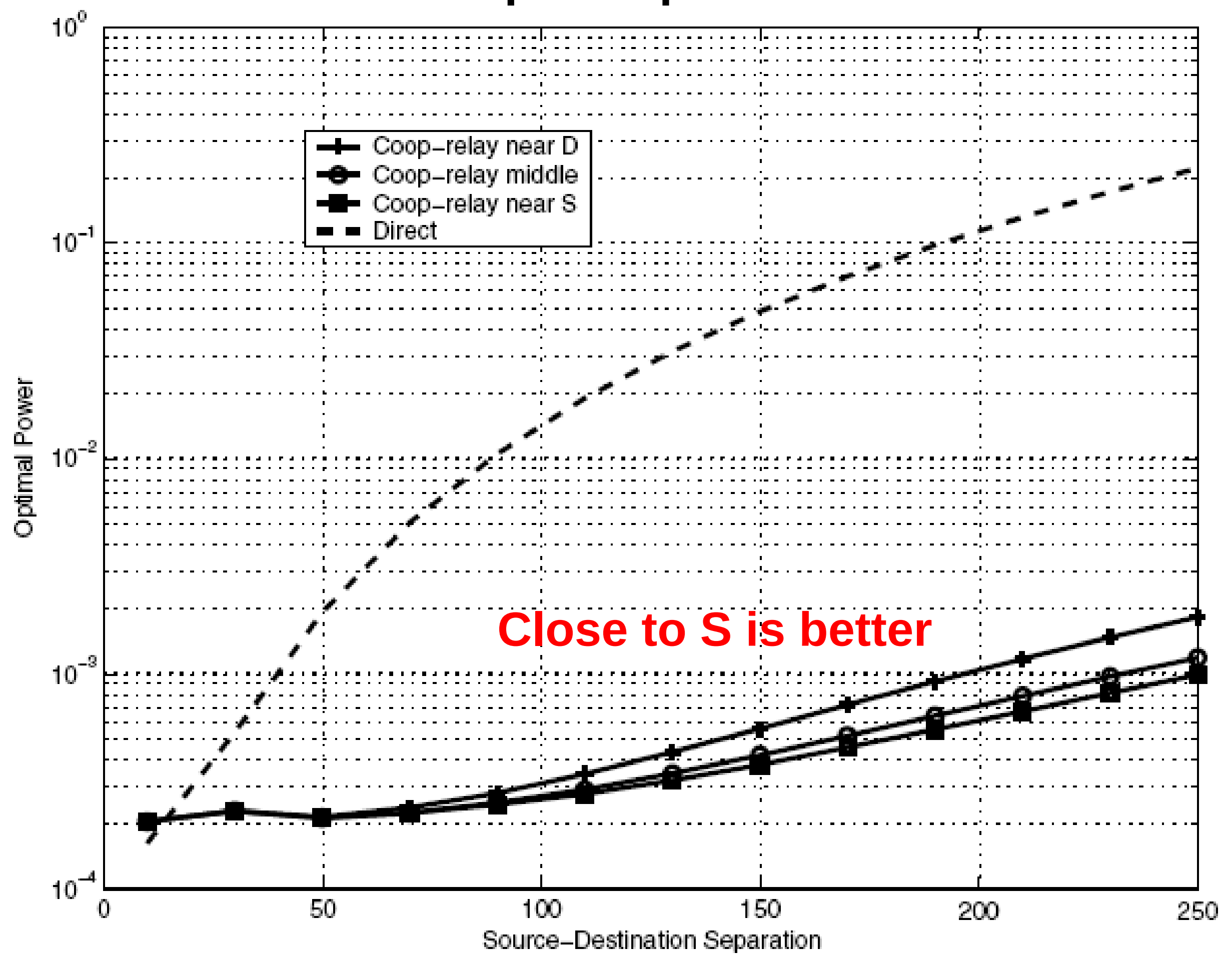
Close to S: 1:4

Middle:1:1

Close to D: 4:1

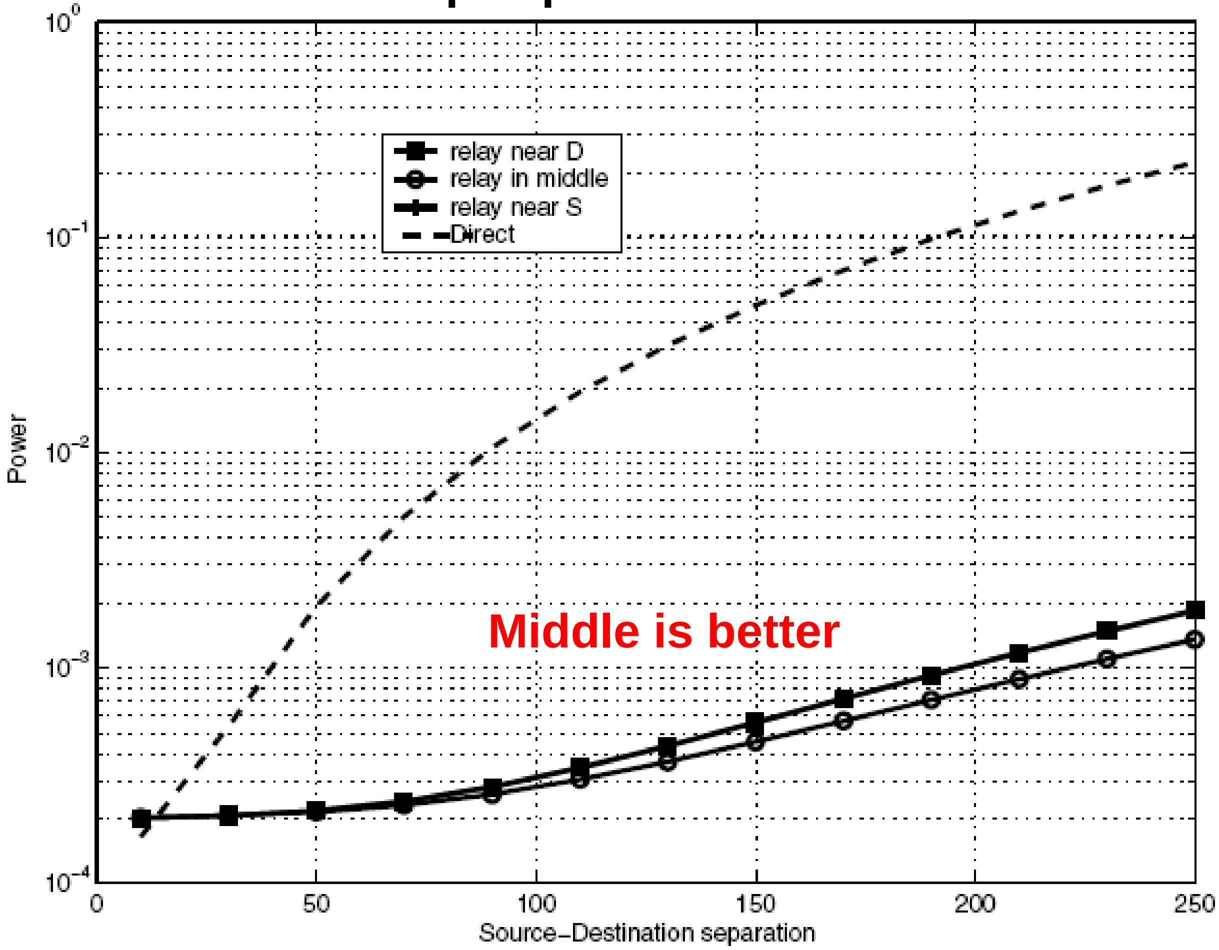


Optimal power allocation



Simulation Results

Equal power allocation



Summary

- The r_{sd} will affect the cooperation gain
  - <20m, direct transmission is better
  - <100m, the equal power allocation can approximate the optimal power allocation
- The relay location also affects the cooperation gain.
  - Closing to the source has better performance
  - <100m, the relay location does not affect the performance much

Conclusions

- This paper investigates the gains of cooperation in WSNs by taking the extra overhead of cooperation into account.
- It formulates a constrained optimization problem to minimize the total consumed power.
- It shows that the distance between source and destination, and the relay location will affect the cooperation gain.