# Performance of Spatially Distributed Large Interference Relay Networks

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# Outline

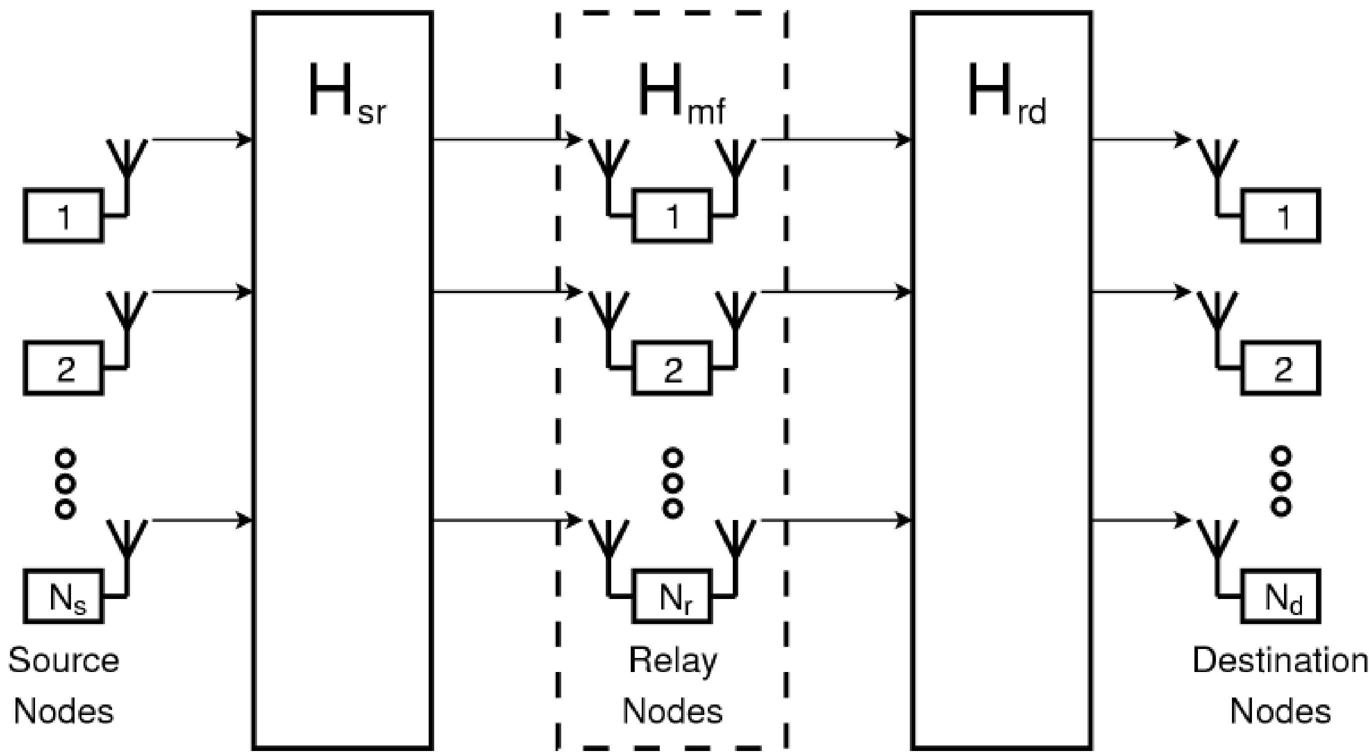
- Introduction
- System model
- Relay allocation
- Power allocation
- Network topologies
- Simulation results
- Conclusion

# Introduction

- The interference relay network concept [1]
- Interference is mitigated by active scatterers [2]
- Matched filtering relay protocol [3]
- Capacity scaling analysis [4]
  - Large number of relays are required
  - Large number of source-destination pairs
  - Not spatially distributed
- Spatially distributed networks
  - Scaling works also with small number of communicating pairs
  - Performance varies significantly depending on the network topology

# Large Interference Relay Network

- Two-hop half-duplex relaying network ($N_s$ x $N_r$ x $N_d$)
- An equal amount of sources and destinations ($N_s$=$N_d$) forming distinct non-cooperative communicating pairs



# System Model

- Sources transmit during the 1st time slot

$$r_k = \sum_{l=1}^{N_s} \sqrt{E_{k,l}}\, h_{k,l} x_l + n_k$$

- Relays amplify-and-forward

$$t_k = \beta_k r_k$$

- Destinations receive combinations of the relayed signals during the 2nd time slot

$$y_l = \sum_{k=1}^{N_r} \sqrt{P_{l,k}}\, f_{l,k} t_k + z_l$$

# New General Weighted Relaying Protocol

- Matched filtering orthogonalizes the channels of distinct communicating pairs in a distributed manner
- The matched filtering AF-gain factor

$$\beta_k = \tau_k \sum_{n=1}^{N_s} \gamma_{k,n} e^{-j\arg(h_{k,n})} e^{-j\arg(f_{n,k})}$$

  - Power normalization factor $\tau_k$
  - Weighting or power allocation coefficient $\gamma_{k,n}$
- The effective channel matrix becomes somewhat diagonal

# Matched Filtering at the Relays

- Previously introduced protocols are special cases of our generalized protocol
- "Protocol 1" [3]: Each relay assists only one source-destination pair

$$\gamma_{k,n} = \begin{cases} 1, & \text{if } n = p(k) \\ 0, & \text{otherwise} \end{cases} \qquad \beta_k = \tau_k e^{-j\arg(h_{k,p(k)})} e^{-j\arg(f_{p(k),k})}$$

- "Protocol 2" [5]: Every relay assists all source-destination pairs using equal gain

$$\gamma_{k,n} = 1, \quad \text{for all } k, n \qquad \beta_k = \tau_k \sum_{n=1}^{N_s} e^{-j\arg(h_{k,n})} e^{-j\arg(f_{n,k})}$$

# Relay Allocation for Protocol 1

- Effective signal-to-noise ratio (SNR) at the destination

$$SNR_{eff} = \frac{SNR_{sr} SNR_{rd}}{SNR_{sr} + SNR_{rd} + 1}$$

- Iterative relay selection
  - First all relays are unallocated
  - Each communicating pair selects in a round robin fashion the relay that offers the highest $SNR_{eff}$
  - The process continues until all relays are allocated
- Not optimal scheme, but gives reasonable results
- Guarantees that none of the communicating pairs is left unassisted
- Left-over relays

# Power Allocation

- Signal to interference and noise ratio (SINR) of the *m*th pair

$$\Gamma_m = A_m + C_m \gamma_m^2$$

- As we assume power normalization and equal weight coefficients for all relays

$$\sum_{n=1}^{N_s} \gamma_{k,n}^2 = 1 \qquad \gamma_m = \gamma_{1,m} = \gamma_{2,m} = \ldots = \gamma_{N_s,m}$$

- The coefficients are

$$A_m = \frac{\sum_{k=1}^{N_r} P_{m,k} E_{k,m} \tau_k^2}{\sum_{l \neq m} \sum_{k=1}^{N_r} P_{m,k} E_{k,m} \tau_k^2 + (1 + \sum_{k=1}^{N_r} P_{m,k} \tau_k^2) \sigma^2} \qquad C_m = \sum_{k_1=1}^{N_r} \sum_{k_2 \neq k_1} \frac{\frac{\pi^2}{16} \sqrt{P_{m,k_1} P_{m,k_2} E_{k_1,m} E_{k_2,m}} \tau_{k_1} \tau_{k_2}}{\sum_{l \neq m} \sum_{k=1}^{N_r} P_{m,k} E_{k,m} \tau_k^2 + (1 + \sum_{k=1}^{N_r} P_{m,k} \tau_k^2) \sigma^2}$$

# Power Allocation (SINR Equalization)

- Optimization problem is a linear programming (LP) problem

$$\boldsymbol{\gamma}_o = \arg\max_{\boldsymbol{\gamma}} \min_{1 \le m \le N_s} \Gamma_m$$

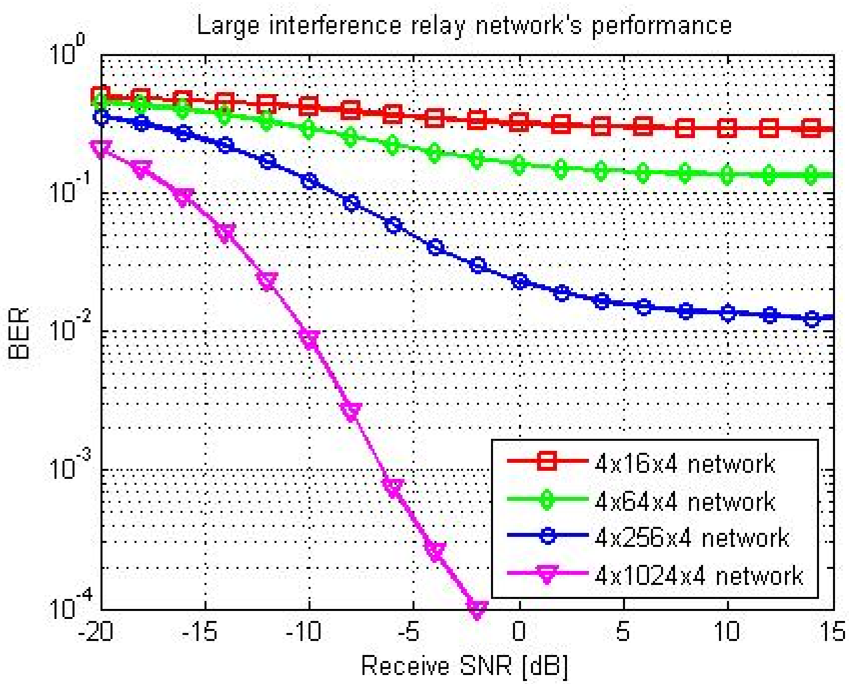
- Solution of the optimization problem equalizes SINRs to $\Gamma_o$

$$\Gamma_o = \Gamma_1 = \Gamma_2 = \ldots = \Gamma_{N_s}$$

- Optimized weights are

$$\gamma_m^2 = \frac{1}{C_m}(\Gamma_o - A_m)$$

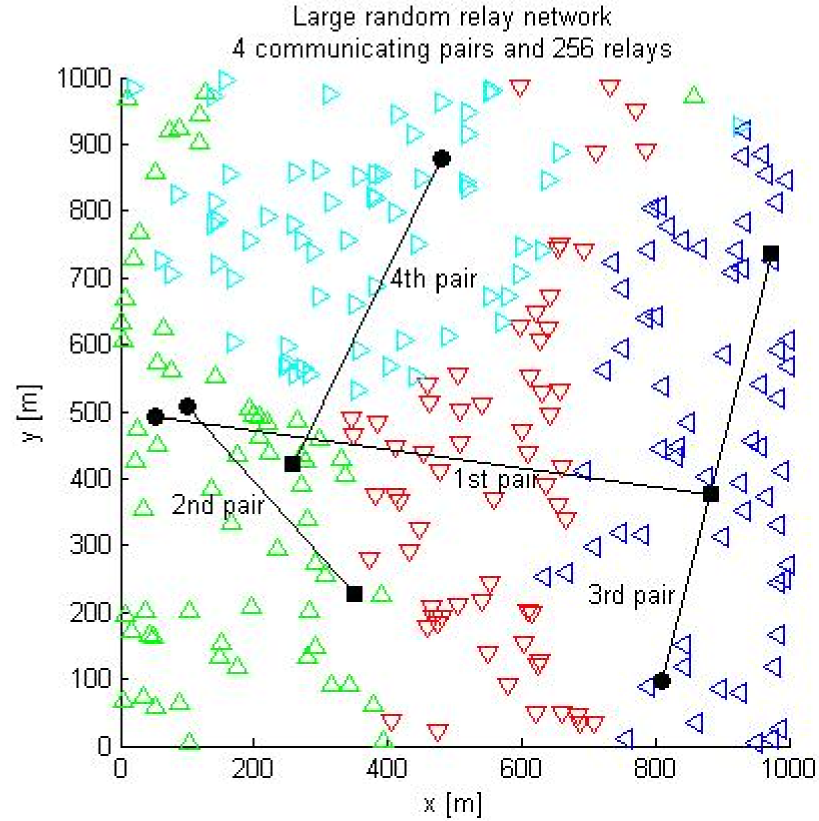
# Performance Scaling without Spatial Separation




- No path loss model used
- No spatial separation in the network
- 4 x $4^{\alpha+3}$ x 4 network using Protocol 1
  - Varying $\alpha$=-1,0,1,2
- Performance scaling is valid also for low number of communicating pairs

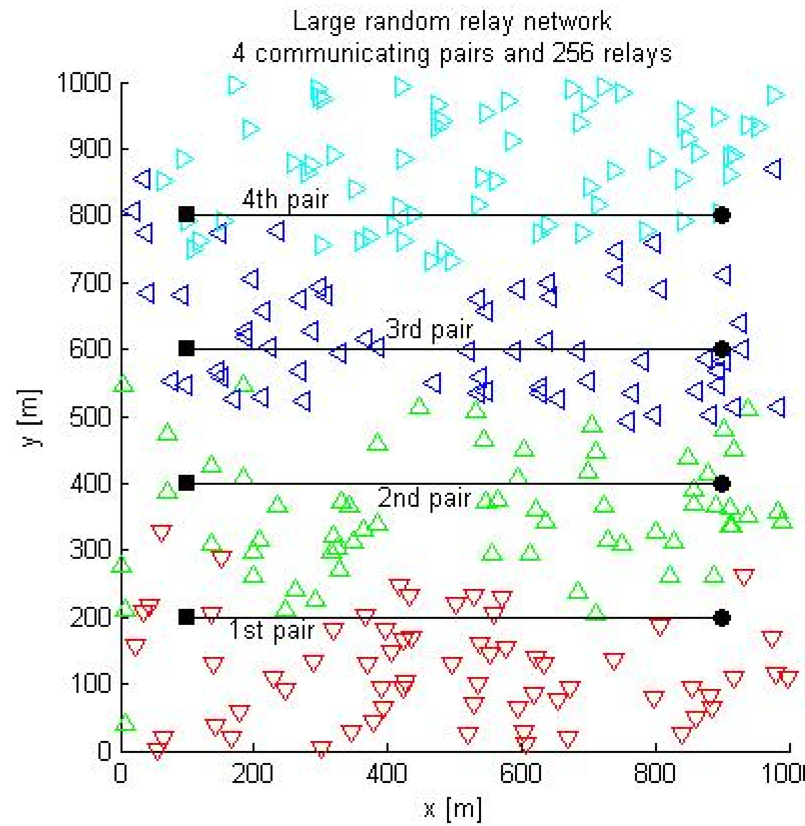
# Random Network

- Spatially distributed
- All nodes are randomly located
- Smallest degree of organization



# Parallel Network

- Spatially distributed
- Fixed source and destination nodes
- Relays are randomly placed
- Some degree of organization





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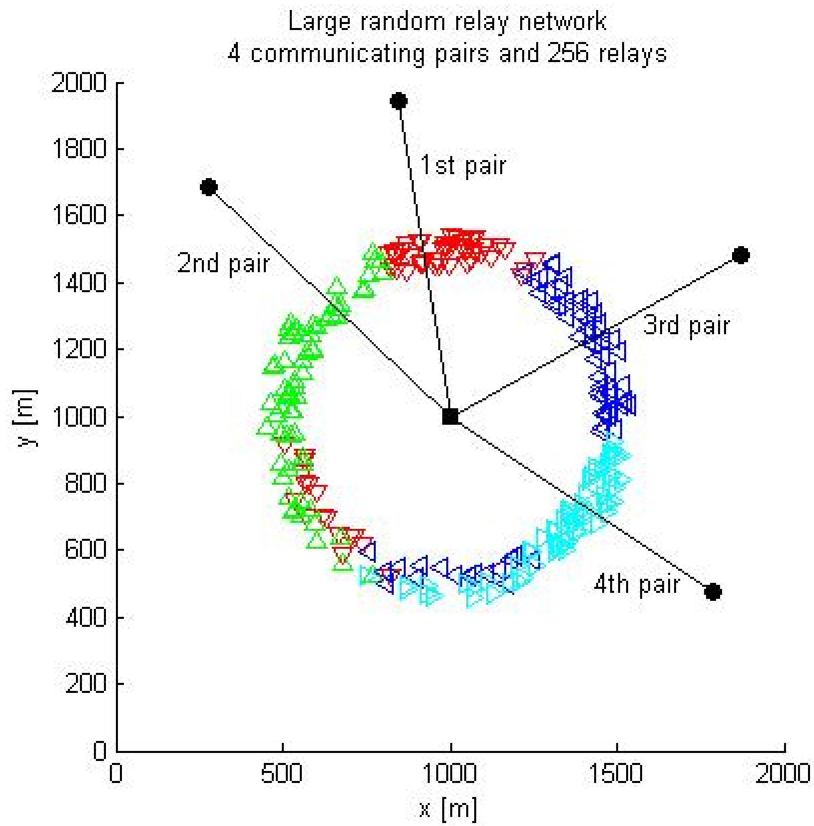
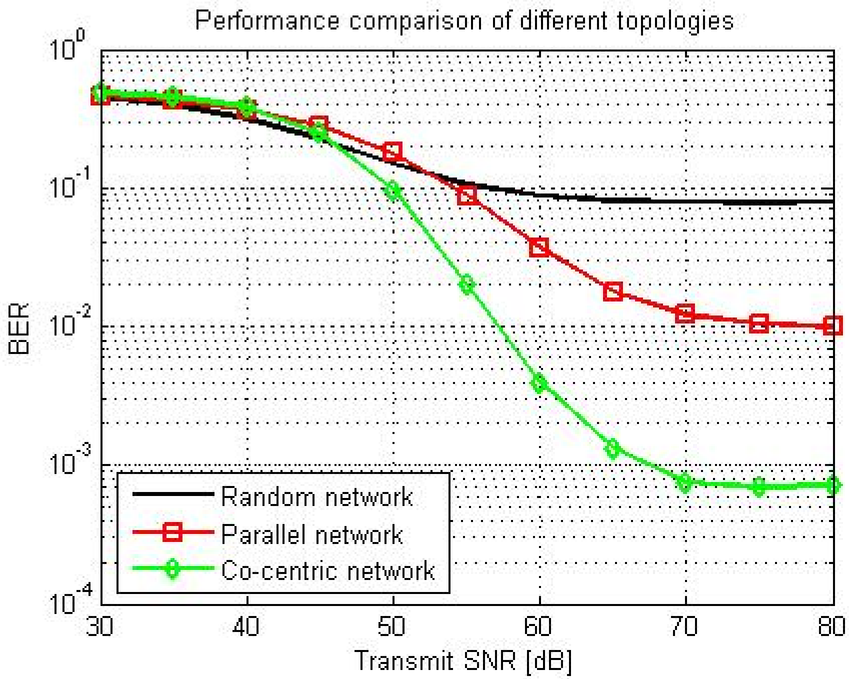
# Co-centric Network

- Spatially distributed
- A ring of relays
- Most organized scenario
- For example, closely placed users communicate to distant base stations

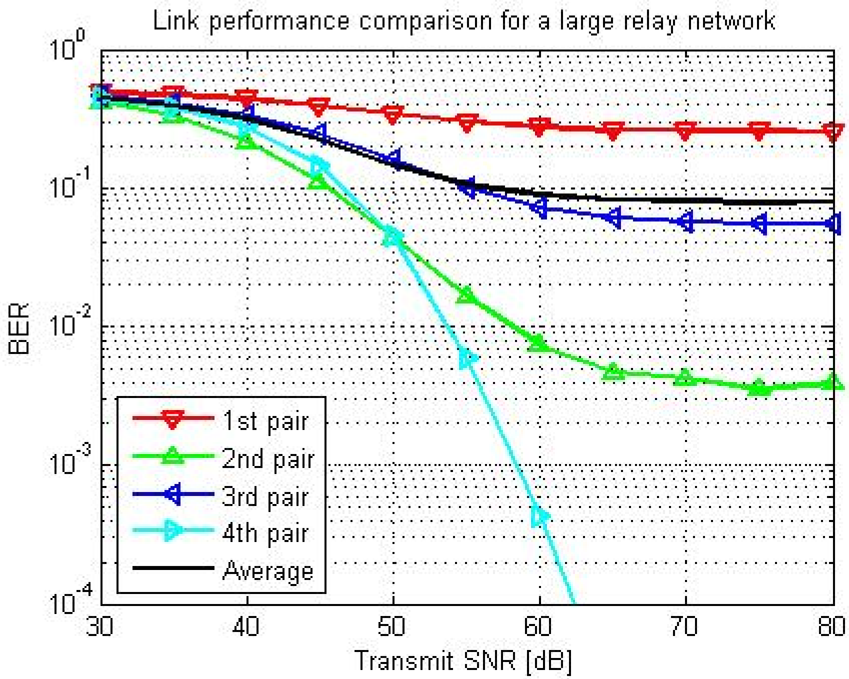


# Comparison of the Topologies




- Performance of parallel network is similar to the same-sized network without spatial separation
- Random topology suffers most from the spatial separation
  - ”Effective number of relays” is decreased by factor of 4

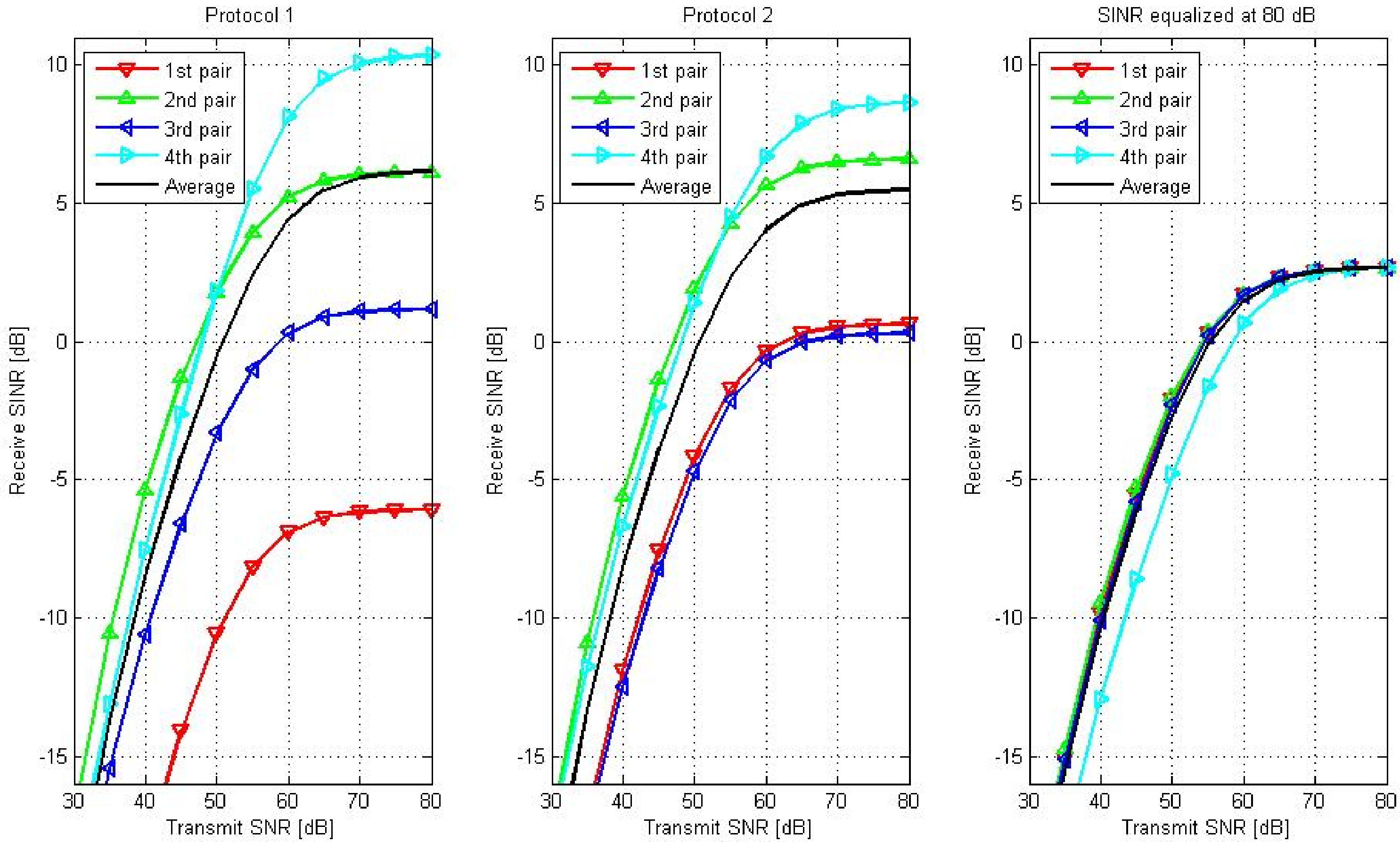
# Link Performances in the Random Network




- Symmetry of the parallel and the co-centric networks makes BER is similar for each communicating pair
  - In the random network the interference situation is different for each link
- The first and third communicating pairs have a high BERs, which dominates the average BER performance
- The 1st pair suffers from having longer link span than the other pairs
- Both the 1st and 3rd pairs suffer from the interfering relays located in the vicinity of the destinations

# SINR Equalization

- Generalized protocol used to equalize SINRs at 80 dB





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# Conclusion

- The experimental behavior of the interference relay network without spatial separation and with low number of communicating pairs is similar to the analytical behavior with high number of communicating pairs analyzed in [4]
- A new generalized relaying protocol
- The network topology has a crucial effect
  - Random networks perform worse
  - More organized networks achieve the same or better performance than a network without spatial separation
  - Spatial separation can be exploited
- For the random network, the distributed orthogonalization did not work well for all communicating pairs
  - the resulting link performances were totally different
- SINR equalization improves performance of the weakest link

# References


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- [3] H. Bölcskei, R. U. Nabar, Ö. Oyman, and A. J. Paulraj, "Capacity scaling laws in MIMO relay networks," *IEEE Trans. Wireless Comm.*, 2006, to appear.
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- [5] A. F. Dana and B. Hassibi, "On the power efficiency of sensory and ad-hoc wireless networks," *IEEE Trans. Inf. Theory*, 2003, submitted.