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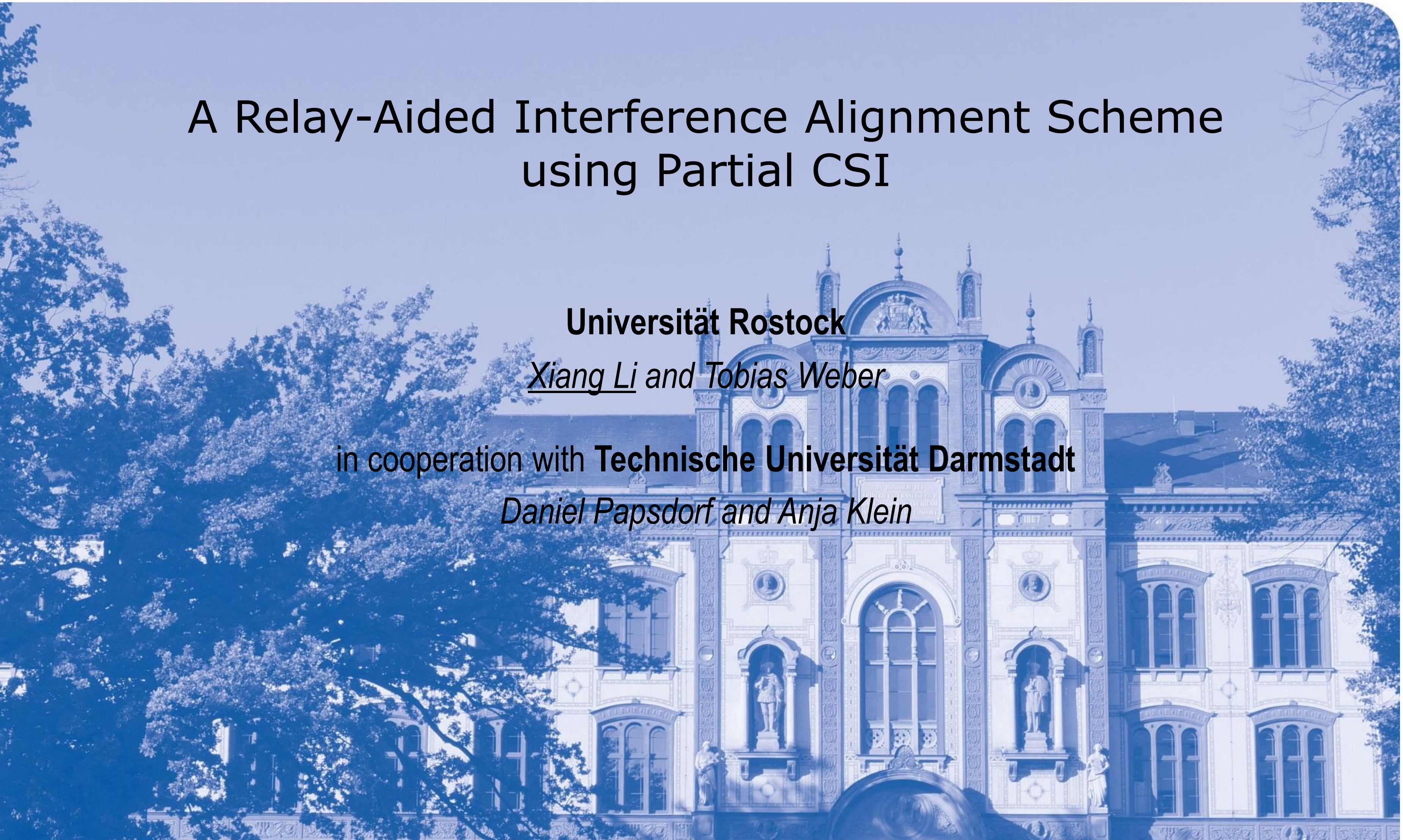

A Relay-Aided Interference Alignment Scheme using Partial CSI

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Motivation

- Interference alignment (IA) usually requires full channel state information (CSI), which increases quadratically with the network size.
- IA schemes without full CSI:
  - topological IA [1]
  - blind IA [2]
  - IA with outdated CSI [3]
  - etc.
- We propose a relay-aided IA scheme with partial CSI exploiting partial connectivity of large networks.

[1] S. A. Jafar, "Elements of cellular blind interference alignment—aligned frequency reuse, wireless index coding and interference diversity," *ArXiv preprint arXiv:1203.2384 [cs.IT]*, 2012.
[2] T. Gou, C. Wang, and S. A. Jafar, "Aiming Perfectly in the Dark-Blind Interference Alignment Through Staggered Antenna Switching," *IEEE Transactions on Signal Processing*, vol.59, no.6, pp.2734-2744, June 2011.
[3] M. A. Maddah-Ali, D. Tse, "Completely Stale Transmitter Channel State Information is Still Very Useful," *IEEE Transactions on Information Theory*, vol.58, no.7, pp.4418-4431, July 2012.

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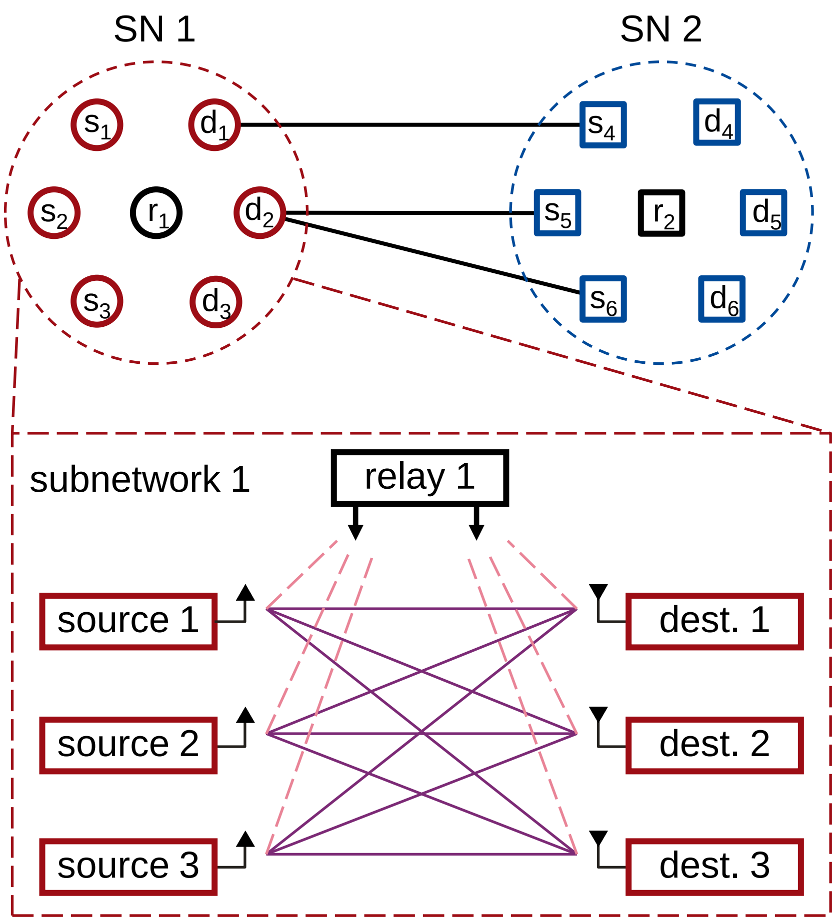
Network Topology



- multiple partially connected synchronized subnetworks (SNs) [4]
- SN q has a single AF relay with R_q antennas and K_q single-antenna node pairs
- two-hop transmission scheme
- IA in the entire network
  - intra-SN interference-nulling
  - inter-SN interference-nulling

[4] X. Li, H. Al-Shatri, R. S. Ganesan, D. Papsdorf, A. Klein, T. Weber, "Relay-aided interference alignment for multiple partially connected subnetworks," in *Proc. 11th International Symposium on Wireless Communications Systems,* pp.121-125, Barcelona, Aug. 2014.

Interference-Nulling Conditions

- channel coefficients

$$h_{DS}^{(k,j)} \in \mathbb{C}$$

$$\mathbf{h}_{DR}^{(k,q)} \in \mathbb{C}^{1\times R_q}$$

$$\mathbf{h}_{DR}^{(k,q)} \in \mathbb{C}^{R_q\times 1}$$

- variables
  - transmit filters

$$\begin{pmatrix} v_1^{(j)} & v_2^{(j)} \end{pmatrix}^{\mathrm{T}}$$

  - receive filters

$$\begin{pmatrix} u_1^{(k)*} & u_2^{(k)*} \end{pmatrix}$$

  - relay processing matrix

$$\mathbf{G}^{(q)} \in \mathbb{C}^{R_q\times R_q}$$

- intra-SN interference-nulling

$$\begin{pmatrix} u_1^{(k)*} & u_2^{(k)*} \end{pmatrix} \begin{pmatrix} h_{DS}^{(k,j)} & 0 \\ \mathbf{h}_{DR}^{(k,q)}\mathbf{G}^{(q)}\mathbf{h}_{RS}^{(q,j)} & h_{DS}^{(k,j)} \end{pmatrix} \begin{pmatrix} v_1^{(j)} \\ v_2^{(j)} \end{pmatrix} = 0$$

  - new variables for linearization

$$v^{(j)} = \frac{v_2^{(j)}}{v_1^{(j)}} \qquad u^{(k)*} = \frac{u_1^{(k)*}}{u_2^{(k)*}}$$

  - linearized as

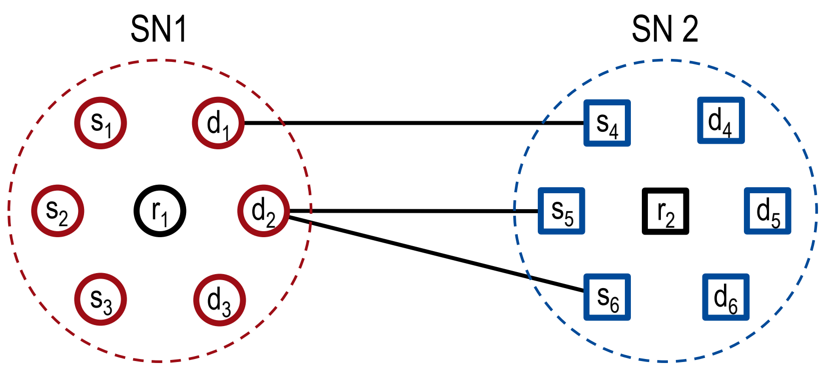
$$\mathbf{h}_{DR}^{(k,q)}\mathbf{G}^{(q)}\mathbf{h}_{RS}^{(q,j)} + h_{DS}^{(k,j)}\left(v^{(j)} + u^{(k)*}\right) = 0$$

- inter-SN interference-nulling

$$\begin{pmatrix} u_1^{(k)*} & u_2^{(k)*} \end{pmatrix} \begin{pmatrix} h_{DS}^{(k,j)} & 0 \\ 0 & h_{DS}^{(k,j)} \end{pmatrix} \begin{pmatrix} v_1^{(j)} \\ v_2^{(j)} \end{pmatrix} = 0$$

$$v^{(j)} + u^{(k)*} = 0$$

A Toy Example (1/4)

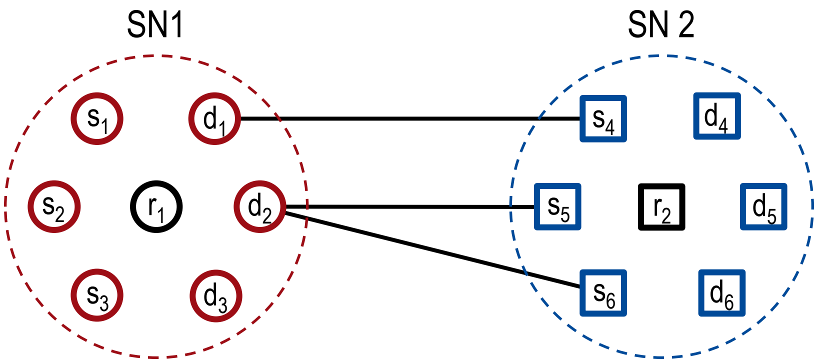


- partial CSI: every node and relay knows
  - the intra-SN CSI of its own SN, and
  - the network topology
- intuitive approach: fixing the filters at the nodes connected by inter-SN links

$$\left.\begin{aligned} u^{(1)*} + v^{(4)} &= 0 \\ u^{(2)*} + v^{(5)} &= 0 \\ u^{(2)*} + v^{(6)} &= 0 \end{aligned}\right\} \text{ i.e. orthogonal signal spaces} \Rightarrow \begin{cases} v^{(4)} = v^{(5)} = v^{(6)} = 1 \\ u^{(1)*} = u^{(2)*} = -1 \end{cases}$$

More relay antennas required!

A Toy Example (2/4)

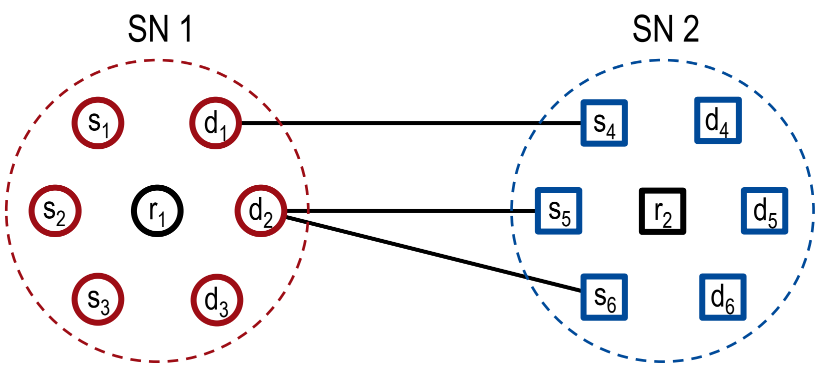


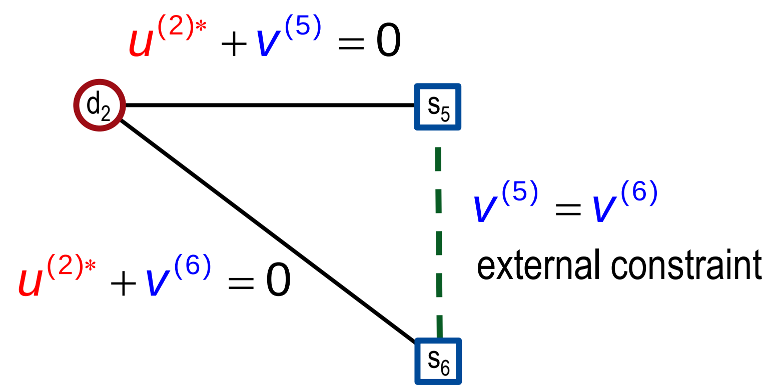
- our approach:
  1. SN 1 solves its intra-SN interference-nulling problem and chooses a solution from the solution space.
  2. SN 1 forwards $u^{(1)*}$ and $u^{(2)*}$ to SN 2.
  3. Given $u^{(1)*}$ and $u^{(2)*}$, SN 2 chooses a solution from its intra-SN interference-nulling solution space which nulls the inter-SN interferences as well.

     $$v^{(4)} = -u^{(1)*}$$

     $$v^{(5)} = v^{(6)} = -u^{(2)*}$$
- $u^{(1)*}$ and $u^{(2)*}$: side information for SN 2

A Toy Example (3/4)





alternative: SN2 $\longrightarrow$ SN1

1. SN 2 solves its intra-SN interference-nulling problem under the external constraint $v^{(5)} = v^{(6)}$ and choose a solution from the solution space.
2. SN 2 forwards $v^{(4)}$ and $v^{(5)}$ (or $v^{(6)}$) to SN 1.
3. Given $v^{(4)}$ and $v^{(5)}$ (or $v^{(6)}$), SN 1 chooses a solution from its intra-SN interference-nulling solution space which nulls the inter-SN interferences as well.

$$u^{(1)*} = -v^{(4)}$$

$$u^{(2)*} = -v^{(5)} = -v^{(6)}$$

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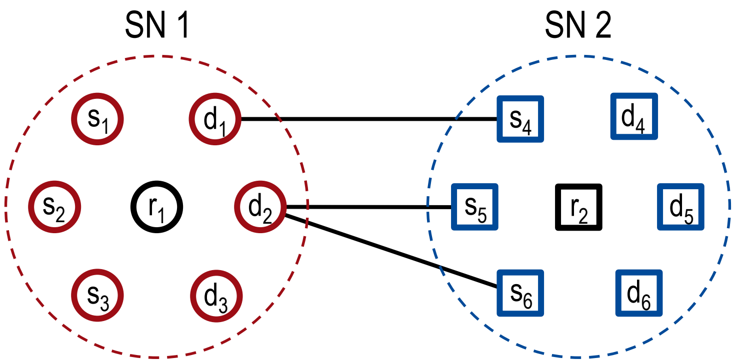
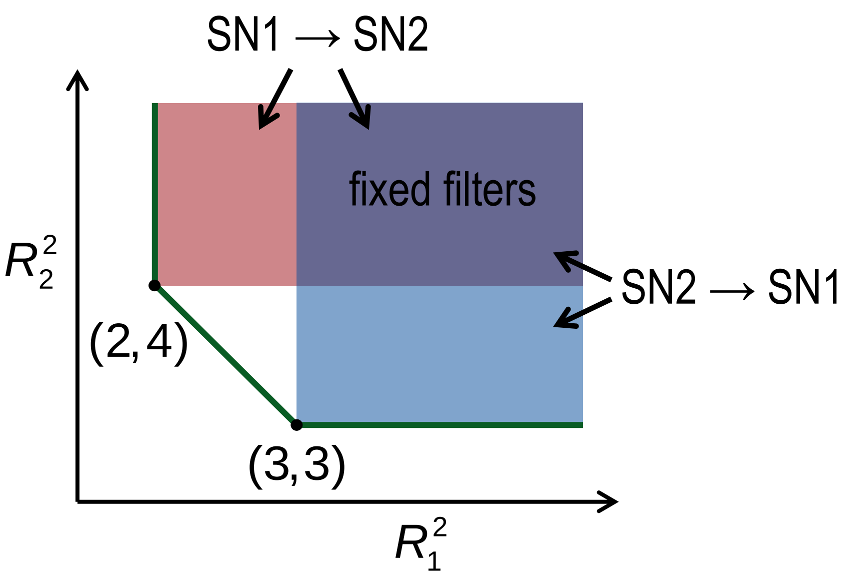
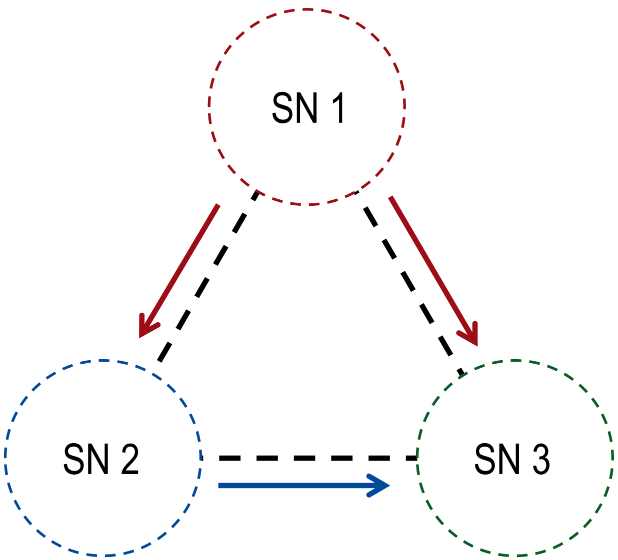
A Toy Example (4/4)





- partial CSI requirement: intra-SN CSI + network topology + side information from other SNs
- low computational complexity: intra-SN interference-nulling problem
- no additional relay antennas

Extension to Large Networks (1/2)

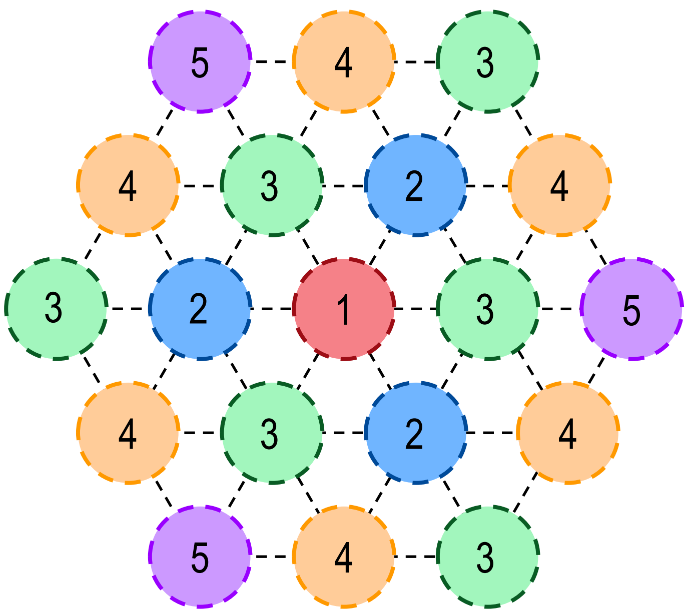


three partially connected SNs

1. intra-SN interference-nulling under the external constraints in SN1
2. SN 1 forwards side information to SN 2 and SN 3
3. SN 2 chooses a solution from its intra-SN interference-nulling solution space under the external constraints
4. SN 2 forwards side information to SN 3
5. SN 3 chooses a solution from its intra-SN interference-nulling solution space

Step 3 and step 5 cannot be done in parallel!

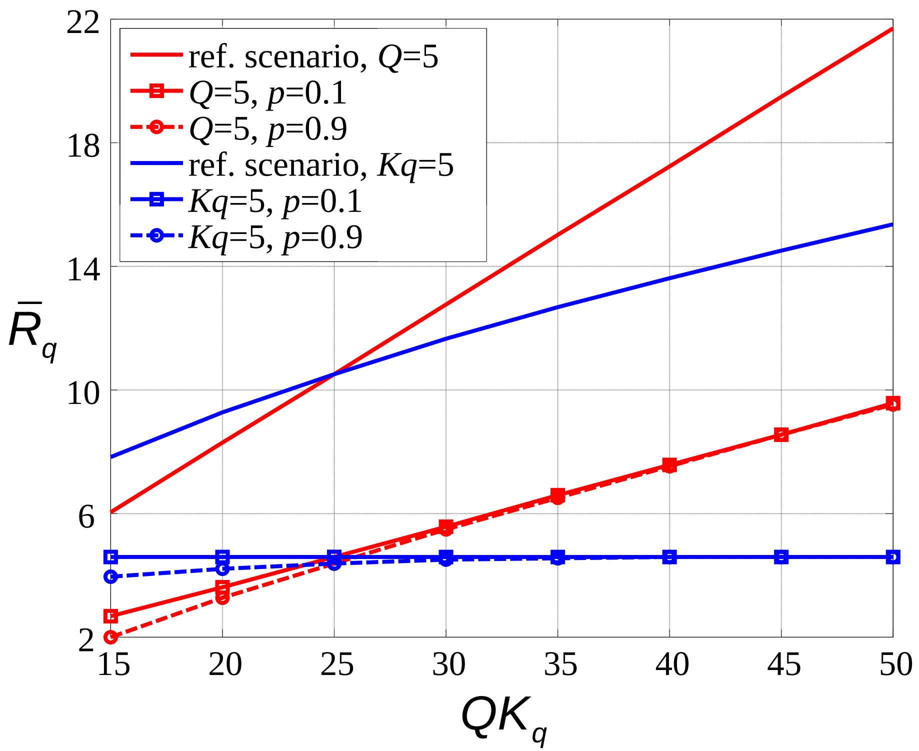
Extension to Large Networks (2/2)



more partially connected SNs

- direct extension
  - Zigzag
  - suitable for dense networks
  - large delay
- parallelization
  - assume inter-SN interference links between neighboring SNs only
  - unconnected SNs can choose theire intra-SN interference-nulling solutions in parallel

Simulation Results: Feasibility Conditions



- QK_q: network size
- $\bar{R}_q$: average number of antennas per relay
- p: probability of inter-SN links being neglected

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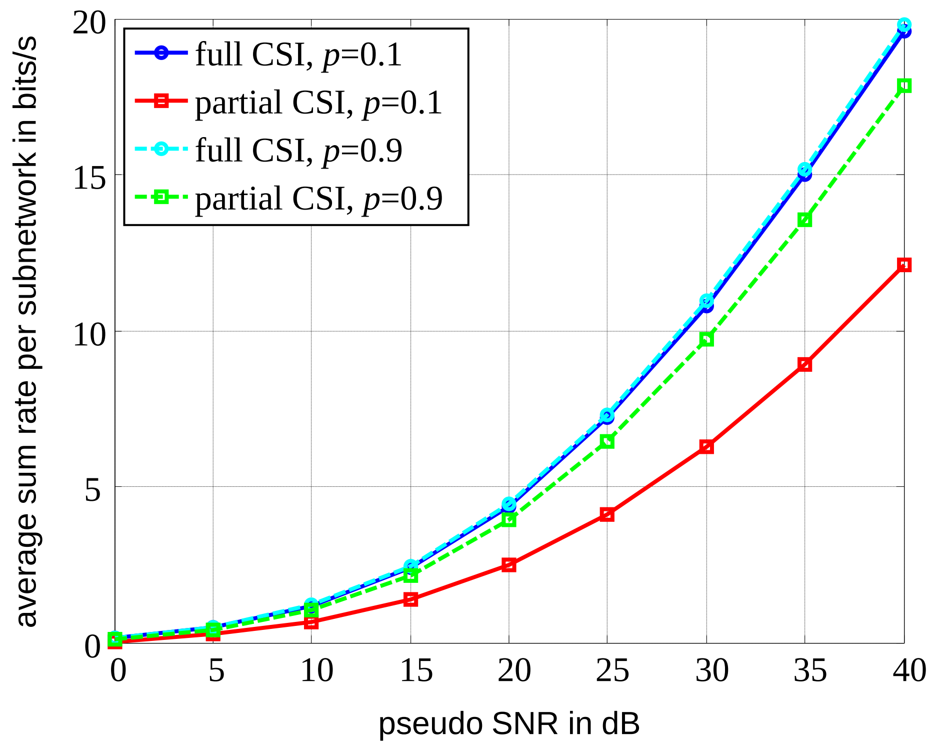
Simulation Results: Sum Rate



- $Q = 3, K_q = 3, R_q = 3$
- pseudo SNR: ratio of the sum transmit power per subnetwork to the noise variance
- p: probability of inter-SN links being neglected

Summary

- IA scheme with partial CSI exploiting the partial connectivity of the network
- side information from other SNs: a few filter coefficients
- no additional relay antennas required as compared to IA with full CSI
- low computational complexity
- parallelization in large networks to reduce the delay