Information flow and Resource allocation in Wireless Networks

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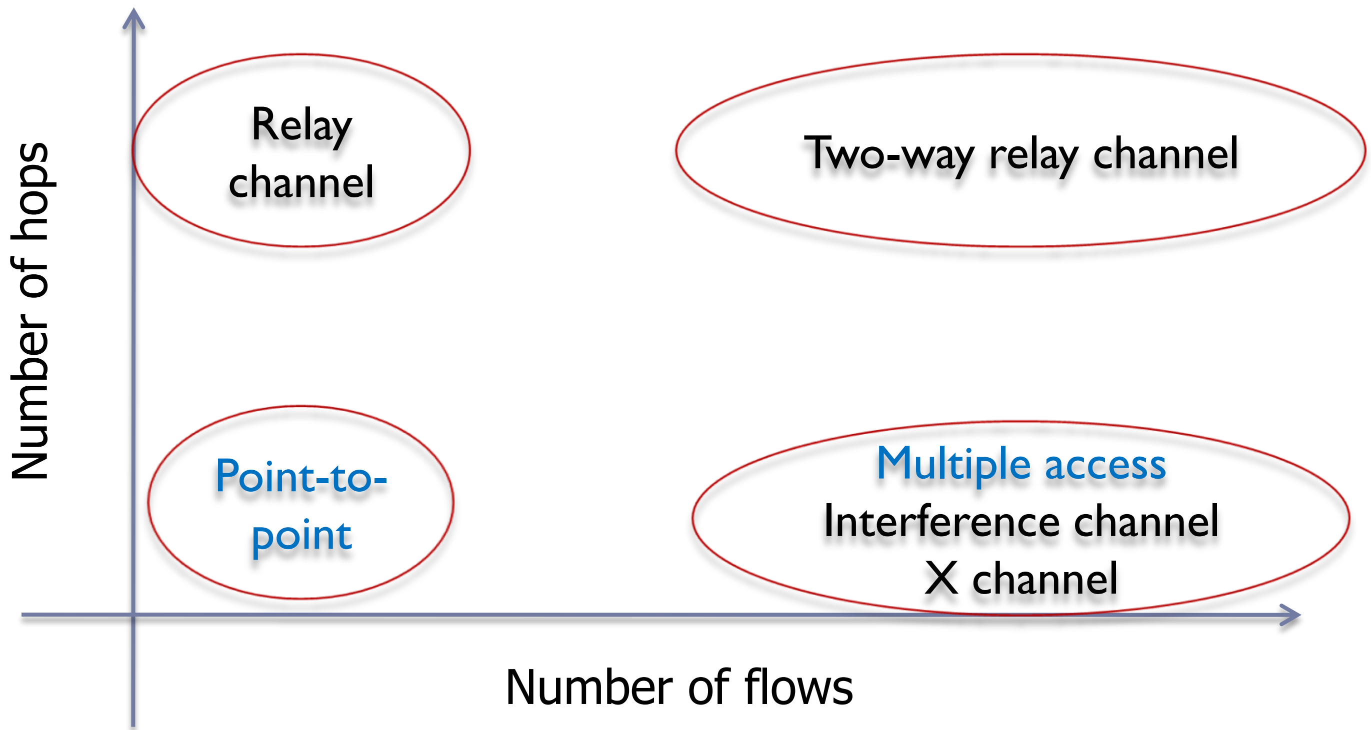
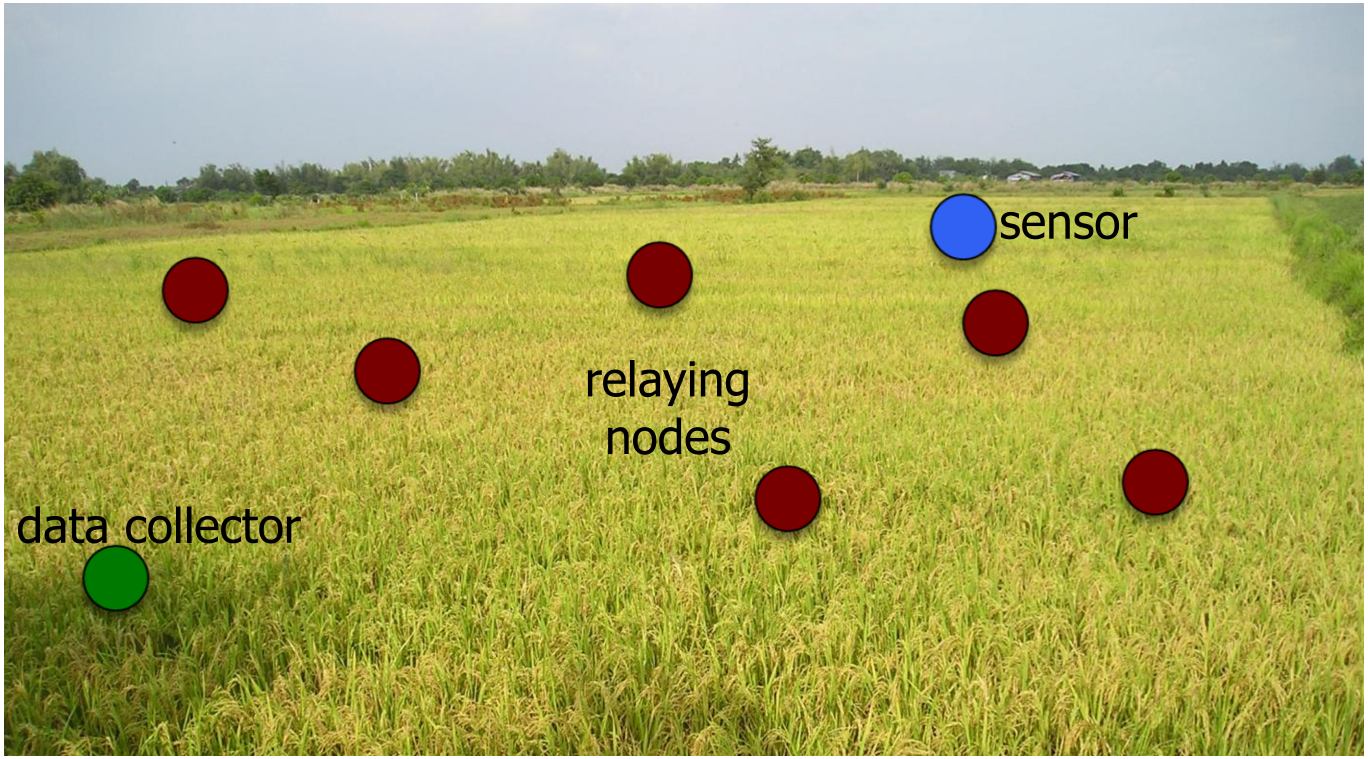
Multi-hop multi-flow wireless networks



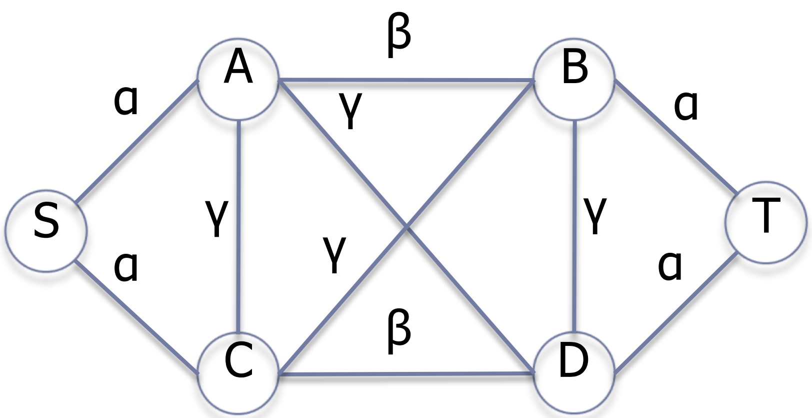
- Challenges
  - Wireless channel: time-varying, shared medium
  - Multiple flows (S-D pairs): Interference
  - Multiple hops: Information flow problems
- Evolution of design approaches
  - Interference: Avoidance → Processing
  - Resource allocation: Static →Dynamic

Multi-hop Gaussian Relay Networks

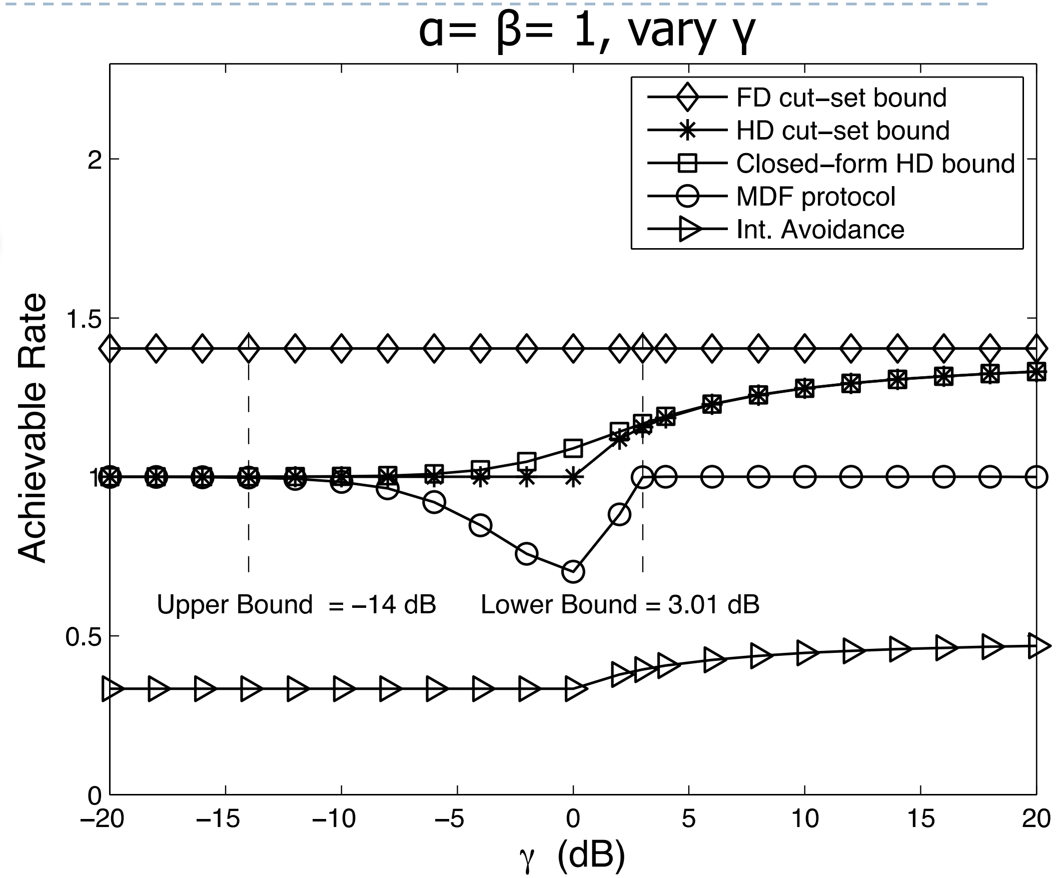


How to efficiently send data from sensor over multiple hops to the data collector?

Two-stage Gaussian Relay Network



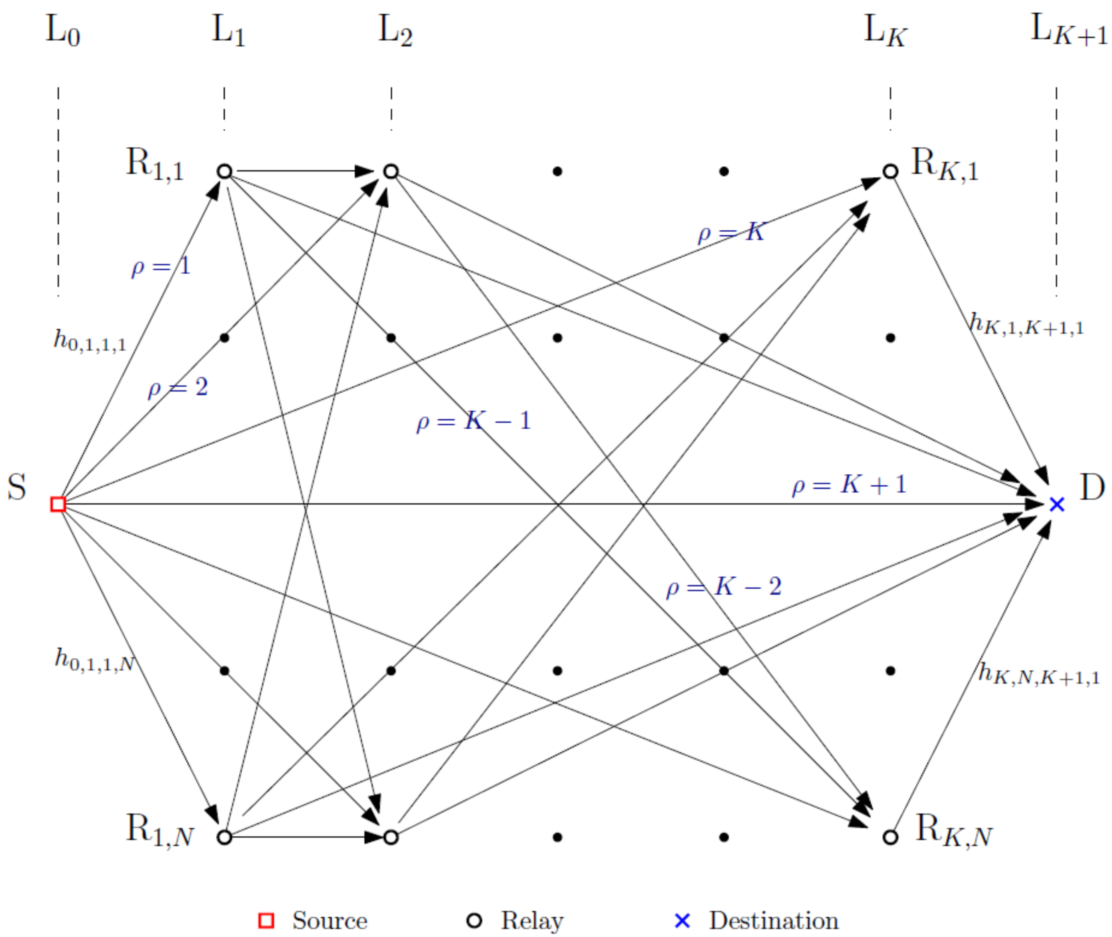
- S: source
  T: sink
  A,B,C,D: half-duplex relays
- Cutset upper bound on rate from S to T
- Our work:
  - Achievable scheme that is close to cutset bound in some channel regimes
  - Scheme uses DPC and superposition coding



Our idea: use multi-terminal rate regions in flow optimization

B. Muthuramalingam, S. Bhashyam, A. Thangaraj, "A Decode and Forward Protocol for Two-stage Gaussian Relay Networks," IEEE Transactions on Communications, col. 60, no. 1, pp. 68-73, January 2012.

Multi-hop Amplify and Forward Relaying



System:

- Multiple layers of relays
- Amplify and forward (AF)

Problem:

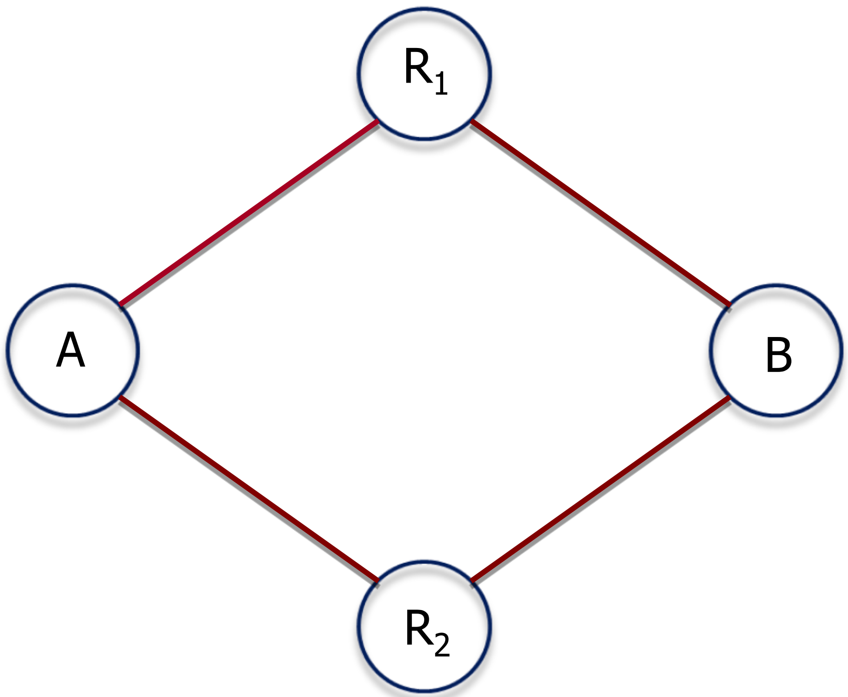
- Design AF coefficients
- Sum power constraint for each layer

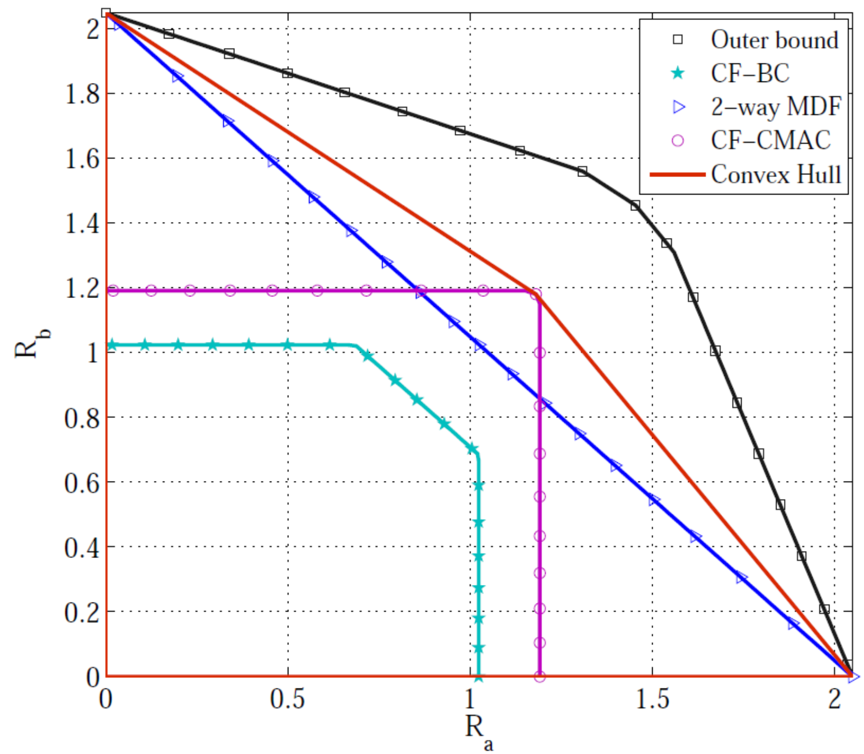
Our work:

- Layer-wise MMSE vs. Global MMSE
- Avoid using forward channel information
- Use leaked/overheard signals

P. S. Elamvazhuthi, B. K. Dey, S. Bhashyam, An MMSE strategy at relays with partial CSI for a multi-layer relay network, To appear in IEEE Transactions on Signal Processing.

Two-way relaying

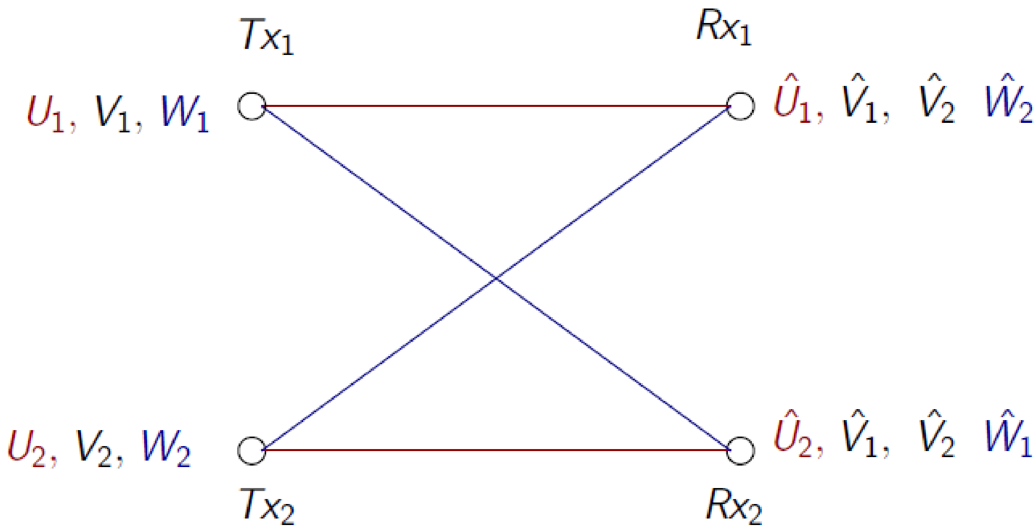




- Diamond network
- New outer bound: linear program
- New relaying protocols better than time-sharing one-way protocols
- Gain from physical layer network coding (or) compute-and-forward

Prathyusha V, S. Bhashyam, A. Thangaraj, The Gaussian Two-way Diamond Channel, Proceedings of Allerton conference on Communication, Control, and Computing, Monticello, IL, Oct. 2013.

Interference networks: Gaussian X channel



- 6 possible messages
- Which messages are useful for sum rate maximization?

- Choice of messages depends on channel coefficients
- Obtained sum capacity for a sub-region of mixed interference region
  - Optimal strategy: MAC transmission to one of the receivers

M. Sridhar, S. Bhashyam, "On the Sum Rate of a 2 x 2 Interference Network," Proceedings of ICC 2012, Ottawa, Canada, June 2012.

Multicast over random networks

- Random graph model (eg. Erdos-Renyi random graph G(n,p))
- Allcast: Each node's data sent to all other nodes
- Multicast: Subset of nodes in session
- Our work:
  - Capacity in the limit of large number of nodes (almost surely)

$$\left\{ (r_1, r_2, \ldots) \ : \ \limsup_{n \to \infty} \frac{1}{n} \sum_{i=1}^{k_n} r_i \leq \left(1 - \frac{\alpha}{2}\right) \mathbb{E}[C]. \right\}$$

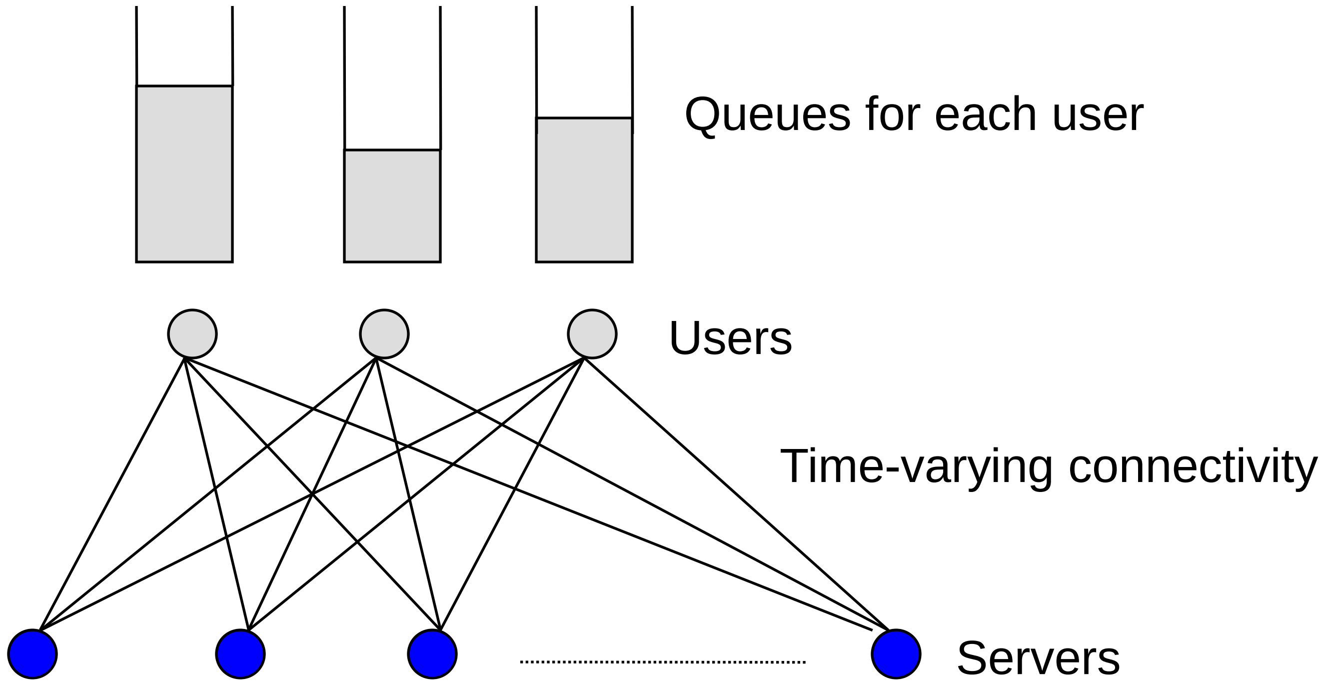
  - What is the network coding advantage?
    - Sub-linear in number of nodes
  - Are there decentralized algorithms that are optimal in the limit?
    - Push-pull algorithm

V. N. Swamy, S. Bhashyam, R. Sundaresan, P. Viswanath, "An asymptotically optimal push-pull method for multicasting over a random network," IEEE Trans. on Information Theory, Vol. 59, No. 8, pp. 5075-5087, Aug. 2013.

Summary:
Multi-hop networks and information theory

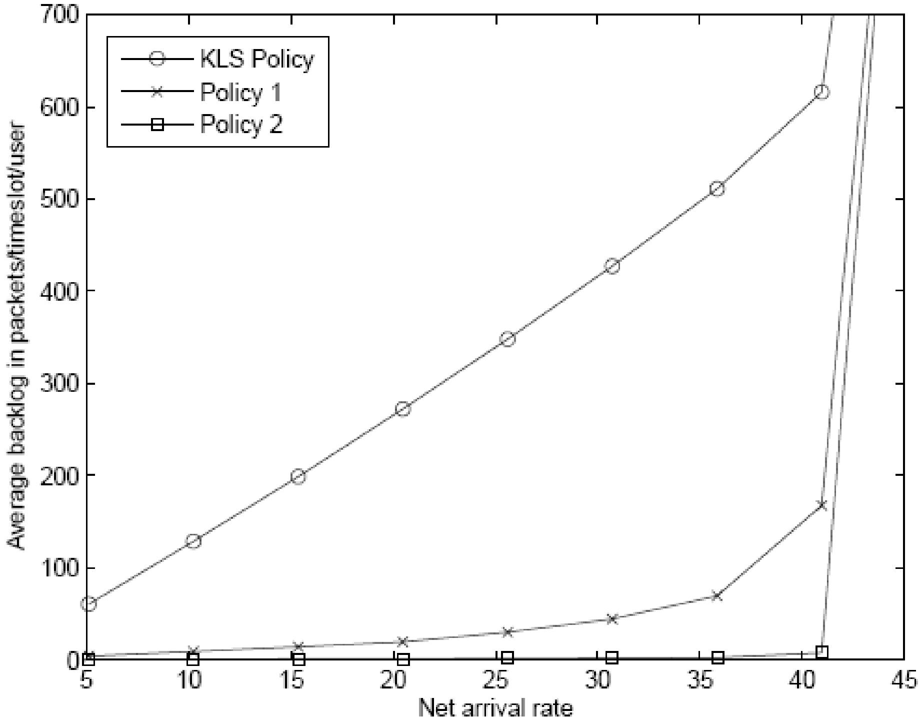
- Multi-hop relaying
  - P. S. Elamvazhuthi, B. K. Dey, S. Bhashyam, *An MMSE strategy at relays with partial CSI for a multi-layer relay network*, To appear in IEEE Transactions on Signal Processing.
  - B. Muthuramalingam, S. Bhashyam, A. Thangaraj, *"A Decode and Forward Protocol for Two-stage Gaussian Relay Networks,"* IEEE Transactions on Communications, col. 60, no. 1, pp. 68-73, January 2012.
- Random networks
  - V. N. Swamy, S. Bhashyam, R. Sundaresan, P. Viswanath, *"An asymptotically optimal push-pull method for multicasting over a random network,"* IEEE Transactions on Information Theory, Vol. 59, No. 8, pp. 5075-5087, Aug. 2013.
- Two-way relaying
  - Prathyusha V, S. Bhashyam, A. Thangaraj, *The Gaussian Two-way Diamond Channel*, Proceedings of Allerton conference on Communication, Control, and Computing, Monticello, IL, Oct. 2013.
- Interference networks
  - M. Sridhar, S. Bhashyam, *"On the Sum Rate of a 2 x 2 Interference Network,"* Proceedings of ICC 2012, Ottawa, Canada, June 2012.

Cross-layer scheduling for OFDM



- Channel and queue aware scheduling
- Joint subcarrier and power allocation
- Stabilizing (throughput optimal) policies
  - Infrequent channel and queue measurements
  - Partial channel information: order statistics (Best M sub-bands)

Cross-layer scheduling for OFDM

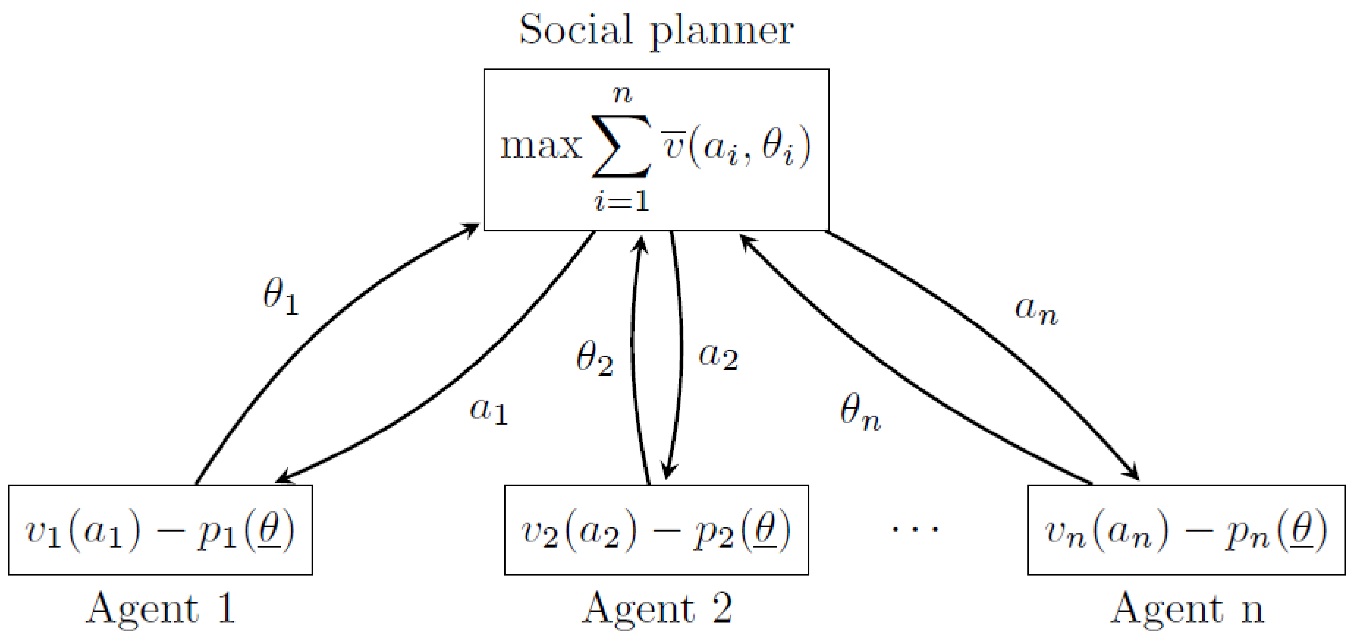


16 servers, 128 users, measurements once every 15 slots, symmetric arrival rates, slow fading

- Supports larger traffic
- Handles infrequent or delayed information

C. Manikandan, S. Bhashyam, R. Sundaresan, "Cross-layer scheduling with infrequent channel and queue measurements," IEEE Transactions on Wireless Communications, vol. 8, no. 12, pp. 5737-5742, December 2009.

Resource allocation and mechanism design



- Allocation of a divisible resource to strategic agents
- Require payments, but not interested in maximizing revenue
- Efficient, strategy-proof, almost budget balanced mechanisms
- Convex optimization framework, constraint sampling approximation

A. K. Chorppath, S. Bhashyam, R. Sundaresan, "A convex optimization framework for almost budget balanced allocation of a divisible good," IEEE Transactions on Automation Science and Engineering, vol.8, no.3, pp.520-531, July 2011.

Summary: Network resource allocation

- Cross-layer scheduling
  - H. Ahmed, K. Jagannathan, S. Bhashyam, "Queue-Aware Optimal Resource Allocation for the LTE Downlink," Proceedings of IEEE GLOBECOM 2013, Atlanta, GA, USA, Dec. 2013.
  - C. Manikandan, S. Bhashyam, R. Sundaresan, *"Cross-layer scheduling with infrequent channel and queue measurements,"* IEEE Transactions on Wireless Communications, vol. 8, no. 12, pp. 5737-5742, December 2009.
  - C. Mohanram, S. Bhashyam, *"Joint Subcarrier and Power Allocation in Channel-Aware Queue-Aware Scheduling for Multiuser OFDM,"* IEEE Transactions on Wireless Communications, vol. 6, no. 9, pp. 3208-3213, September 2007.
  - C. Mohanram, S. Bhashyam, *"A Sub-optimal Joint Subcarrier and Power Allocation Algorithm for Multiuser OFDM,"* IEEE Communications Letters, vol. 9, no. 8, pp. 685-687, August 2005.
- Resource allocation and mechanism design
  - A. K. Chorppath, S. Bhashyam, R. Sundaresan, *"A convex optimization framework for almost budget balanced allocation of a divisible good,"* IEEE Transactions on Automation Science and Engineering, vol.8, no.3, pp.520-531, July 2011.

Summary: Other

- Coding for multi-terminal communication
  - Dirty paper coding for Gaussian BC
  - Dirty paper coding for MIMO Gaussian BC
  - LDPC codes for two-way relaying

- Cooperative communication
  - Coordinated multipoint transmission: selective cooperation and scheduling

- Adaptive MIMO
  - Delayed/imperfect feedback for antenna selection, beam-forming, power control

- Statistical signal processing
  - Channel estimation for OFDM
  - Change detection

Collaborations

- Rajesh Sundaresan, IISc Bangalore
- Bikash Kumar Dey, IIT Bombay
- Ashu Sabharwal, Rice University
- Pramod Viswanath, UIUC
- IITM colleagues