Capacity Gain from Transmitter and Receiver Cooperation

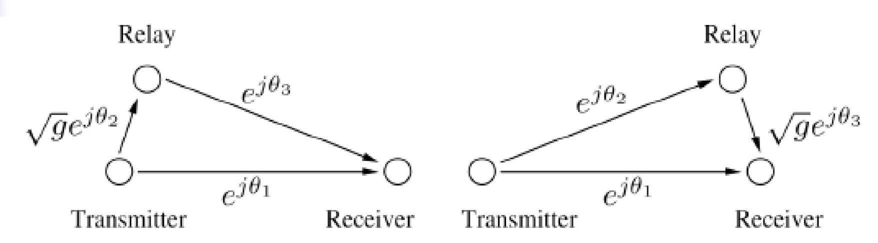
Chris T. K. Ng and Andrea J. Goldsmith

Wireless Systems Lab, Stanford University

Introduction

- Node cooperation can be exploited to increase capacity in wireless networks.
  - But not clear if transmitter cooperation or receiver cooperation offers greater benefits…
- Consider a wireless link, suppose a relay can be deployed either:
  - Near the transmitter, or
  - Near the receiver to form a cooperative cluster.
- Which provides higher capacity improvement?

System Model



(a) Transmitter cooperation (b) Receiver cooperation

- Discrete-time AWGN relay channel.
- Channel power gain between Tx and Rx cluster is normalized to unity, but within cluster it is denoted by *g*.
- Average network power constraint *P*.

Operational Environments

- We consider two models of CSI:
  - Each node has full CSI.
  - Receiver phase CSI only (remote phase information unknown).
- Also two models of power allocation:
  - Optimal power allocation: Tx has power constraint *áP*, and relay (1-*á*)*P* ; 0? *á*? 1 needs to be optimized.
  - Equal power allocation (*á* = ?).
- Combination results in 4 cases to consider.

Receiver cooperation rates

- Cut-set bound:

$$C_r = \max_{0\le\rho\le 1} \min\Big\{\mathcal{C}\Big(2\alpha(1-\rho^2)\Big), \mathcal{C}\Big(\alpha + (1-\alpha)g + 2\rho\sqrt{\alpha(1-\alpha)g}\Big)\Big\}.$$

- Achievable rate:
  - Compress-and-forward achieves the best known rate when Rx and relay are close:

$$R_r = \mathcal{C}\Big(\tfrac{\alpha(1-\alpha)g}{(1-\alpha)g+2\alpha+1/P} + \alpha\Big).$$

- The parameters *á*, *ñ* are to be optimized under each given operational environment.

Transmitter cooperation rates

- Cut-set bound:

$$C_t = \max_{0\le\rho\le 1} \min\Big\{\mathcal{C}\Big(\alpha(g+1)(1-\rho^2)\Big), \mathcal{C}\Big(1 + 2\rho\sqrt{\alpha(1-\alpha)}\Big)\Big\},$$

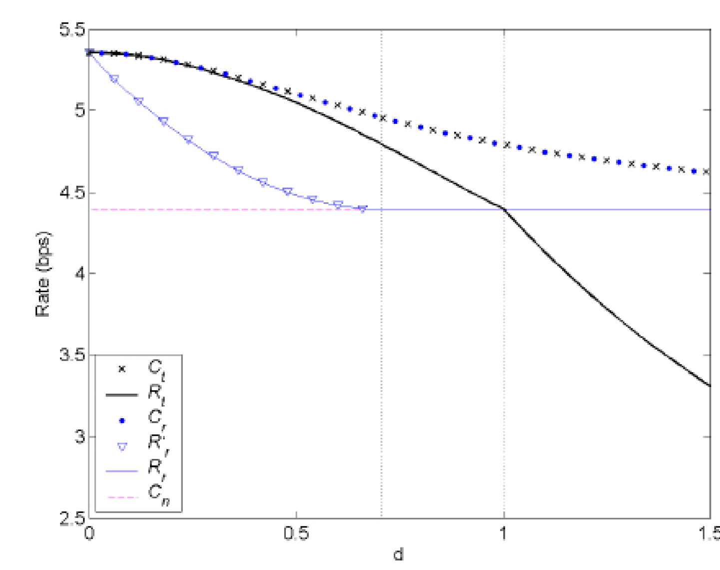
- Achievable rate:
  - Decode-and-forward achieves the best known rate when Tx and relay are close:

$$R_t = \max_{0\le\rho\le 1} \min\Big\{\mathcal{C}\Big(\alpha g(1-\rho^2)\Big), \mathcal{C}\Big(1 + 2\rho\sqrt{\alpha(1-\alpha)}\Big)\Big\},$$

where $\mathcal{C}(x) \triangleq \log_2(1+xP)$.

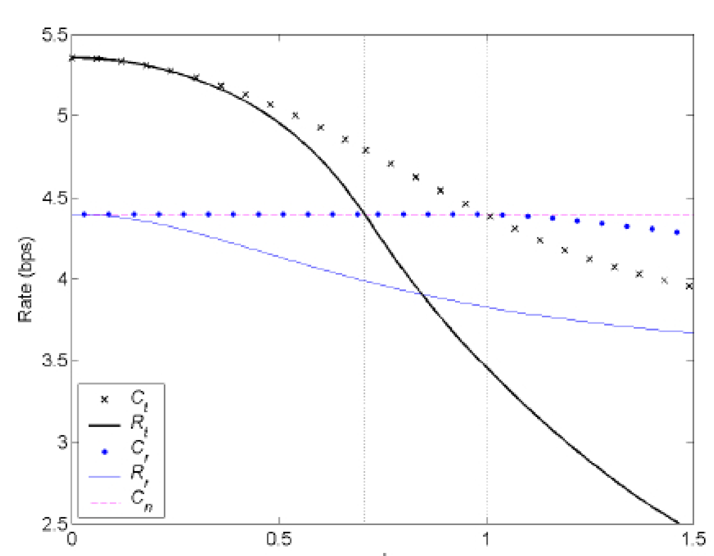
Case 1: Optimal power allocation with full CSI

- Cut-set bounds are equal.
- Tx co-op rate is close to the bounds.
- Transmitter cooperation is preferable.



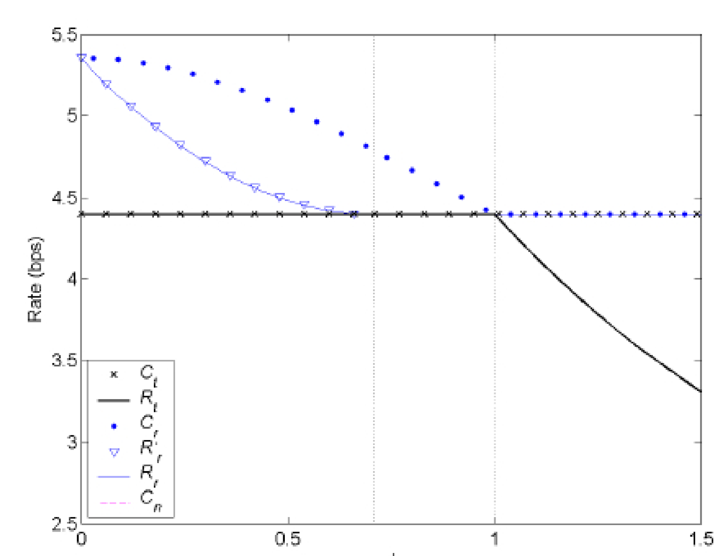
Case 2: Equal power allocation with full CSI

- Tx co-op rate is higher than the cut-set bound of Rx co-op.
- Transmitter cooperation is superior.



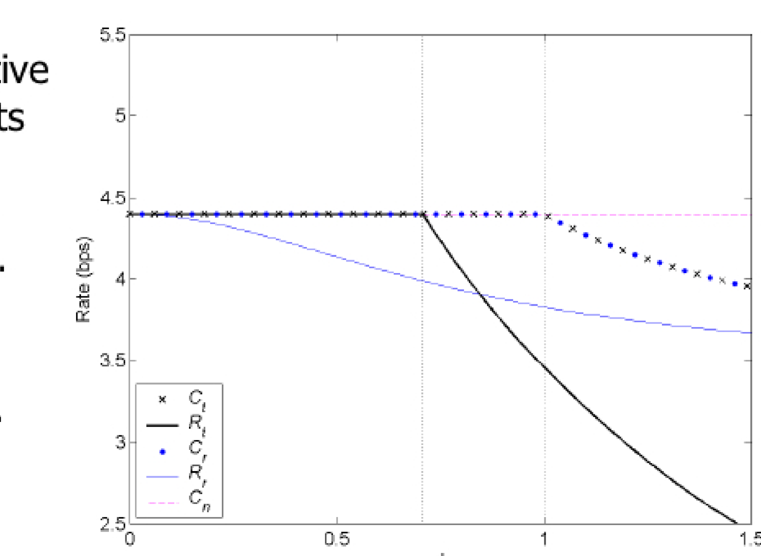
Case 3: Optimal power allocation with receiver phase CSI

- Rx co-op rate is higher than the cut-set bound of Tx co-op.
- Receiver cooperation is superior.



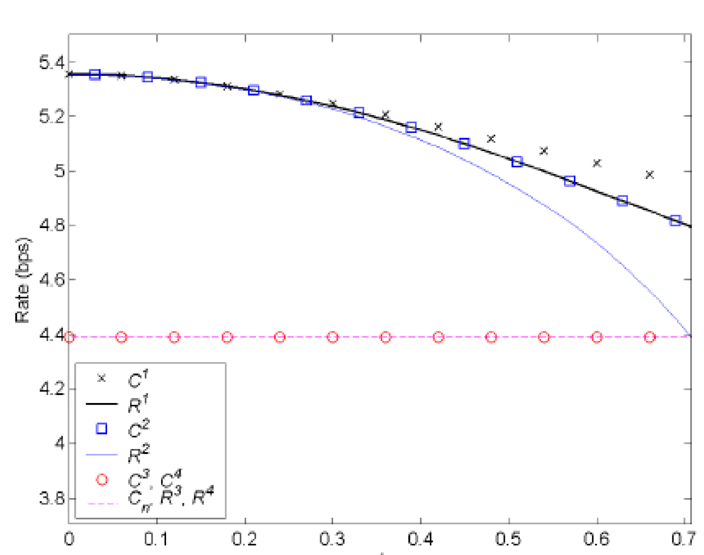
Case 4: Equal power allocation with receiver phase CSI

- Non-cooperative capacity meets the cut-set bounds of Tx and Rx co-op.
- Cooperation offers no capacity gain.



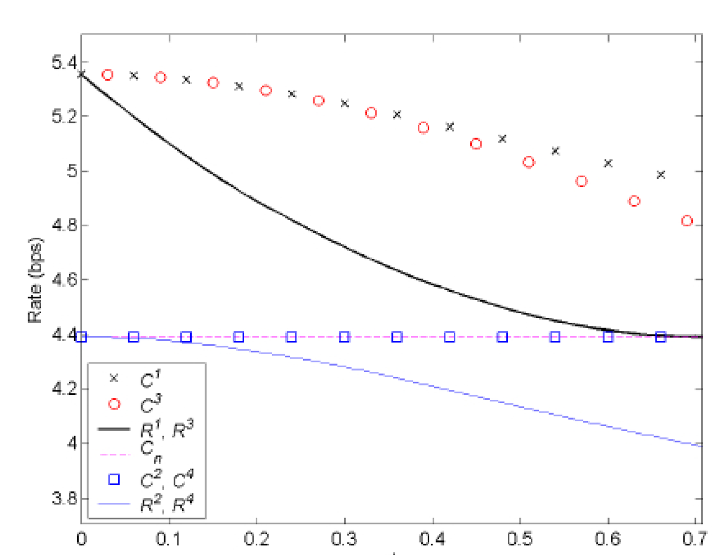
Transmitter Cooperation

- Optimal power allocation contributes only marginal additional capacity gain.
- But full CSI is essential.



Receiver Cooperation

- Compress-and-forward does not require remote phase information.
- But optimal power allocation is essential.



Conclusion

- Proper cooperation strategy is key to realize capacity gain:
  - With full CSI: Tx co-op is preferable.
  - Optimal power allocation and receiver phase CSI: Rx co-op is superior.
  - Equal power allocation and receiver phase CSI: Cooperation offers no capacity gain.
- Implementation strategy to ease deployment of wireless ad-hoc networks:
  - Tx co-op: Homogeneous nodes are deployed, but synchronous-carrier is necessary.
  - Rx co-op: Asynchronous-carrier is used, but optimal power allocation is required.