Cooperation and Coding in MANETs

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Vision

- To develop new capacity definitions for the appropriate MANET metrics and models.
- To find novel communication techniques that expand the associated achievable rate regions.
- To exploit network degrees of freedom optimally
- To integrate security and robustness into the information theory of MANETs

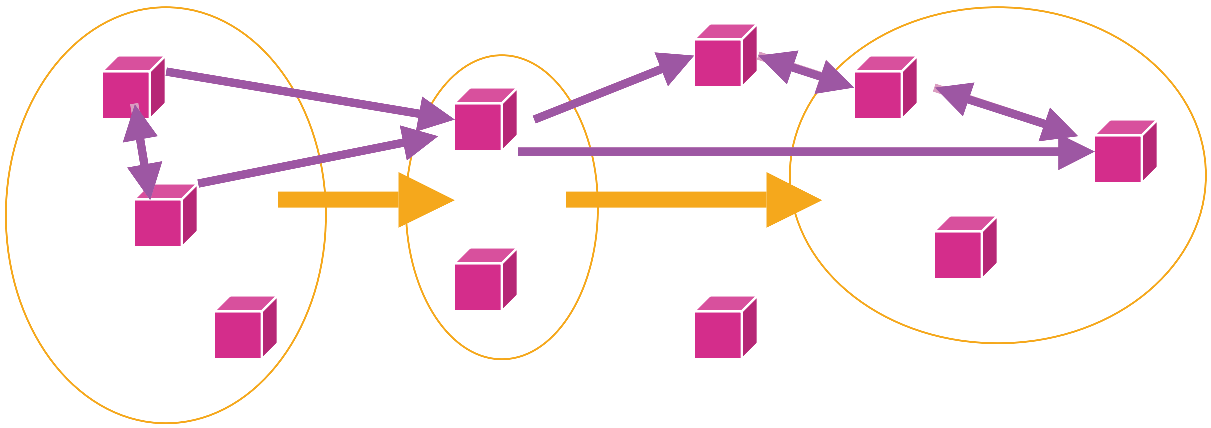
New Theory

- New capacity definitions
- Scaling laws that make sense
- Adaptive coding over degrees of freedom
- Cooperation, relaying and conferencing
- Error exponents
- Mismatch detection
- Capacity with security and robustness

New Capacity Definitions

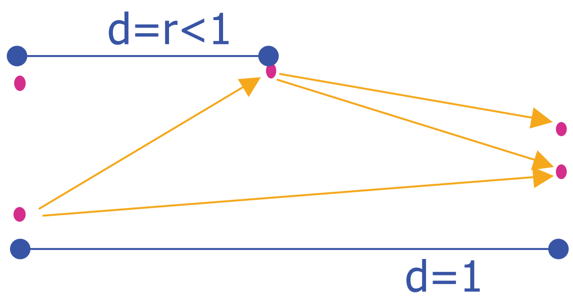
- New capacity definitions needed that allow for dynamics, errors, delay, etc.
  - Capacity with outage
  - Expected capacity
- Coding theorems to achieve capacity under these definitions are fundamentally different.
- The network application(s) dictate the "right" capacity definition

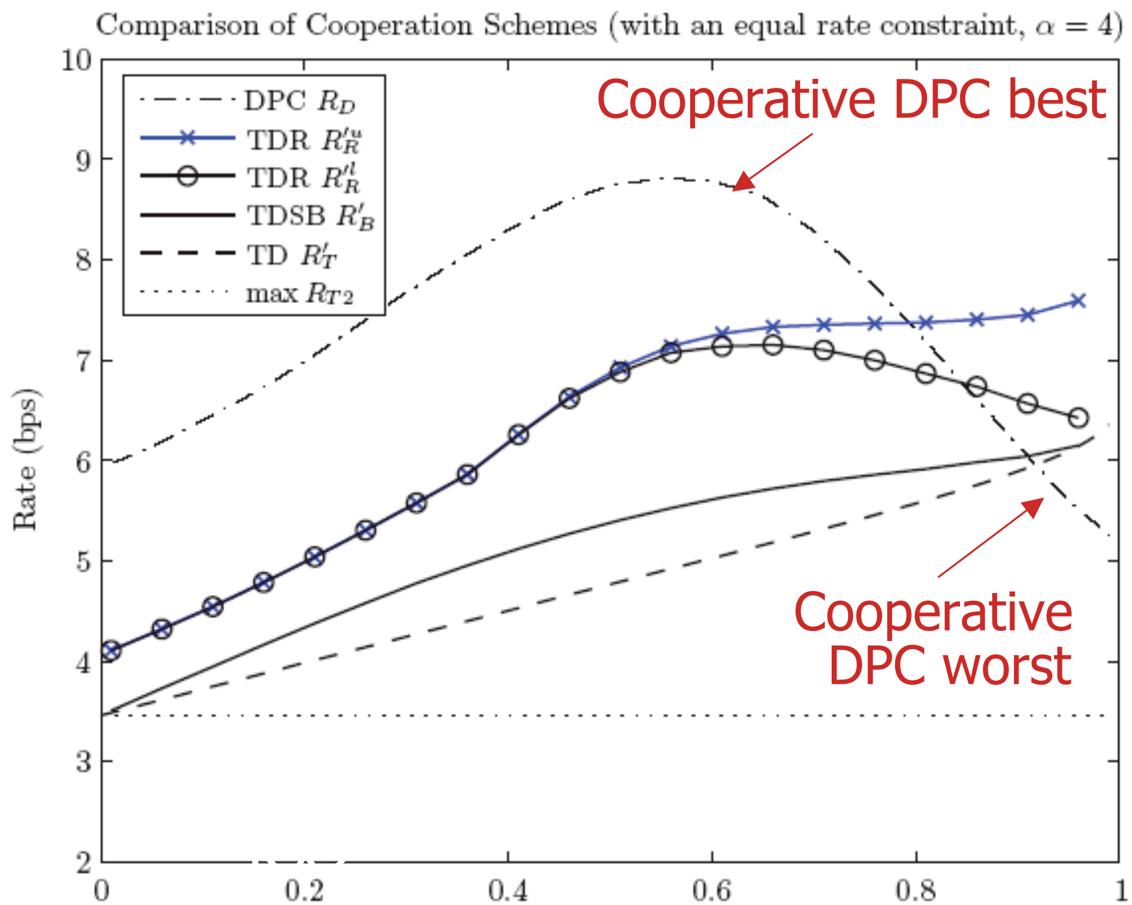
Cooperation in Wireless Networks



- Many possible cooperation strategies:
  - Virtual MIMO with DPC, relaying (DF, CF, AF), one-shot/iterative conferencing, and network coding
  - Nodes can use orthogonal or non-orthogonal channels.
  - Forwarding/routing/network "coding" should not be based on a point-to-point model

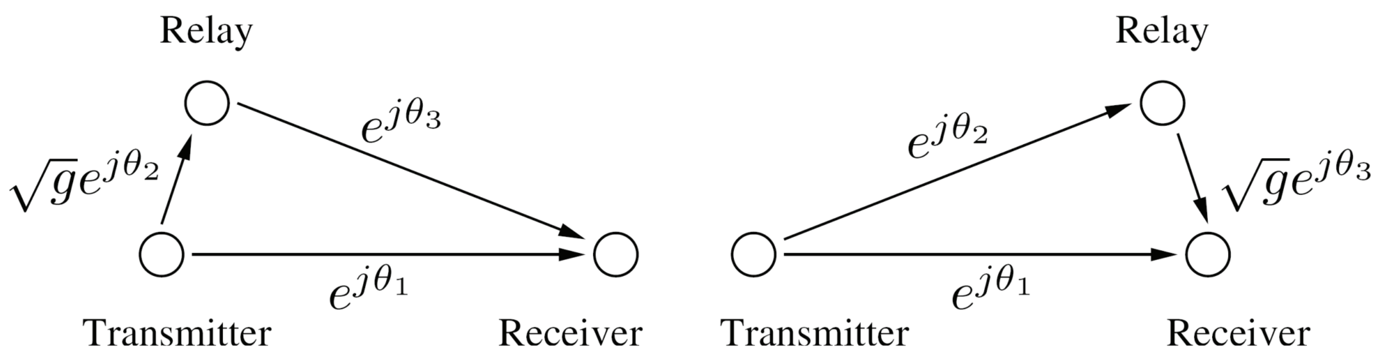
Virtual MIMO vs. Relaying





Must quantify cost of synchronization and CSI

Relative Benefits of TX and RX Cooperation



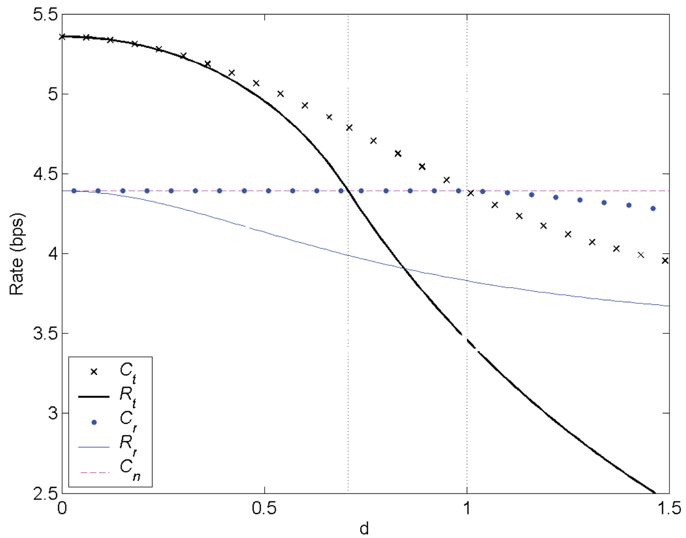
(a) Transmitter cooperation (b) Receiver cooperation

- **Two possible CSI models:**
  - **Each node has full CSI (synchronization between Tx and relay).**
  - **Receiver phase CSI only (no TX-relay synchronization).**

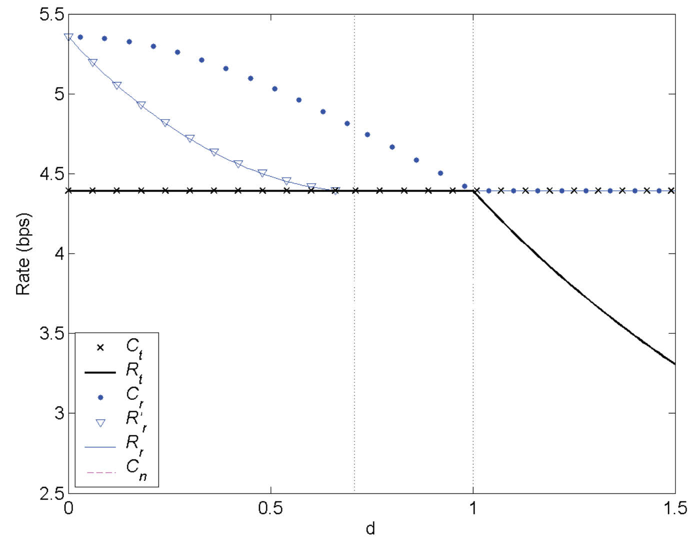
- **Two possible power allocation models:**
  - **Optimal power allocation: Tx has power constraint aP, and relay $(1-a)P$; $0 \leq a \leq 1$ needs to be optimized.**
  - **Equal power allocation ($a = ½$).**

Effective Cooperation

Equal Power Allocation with Full CSI

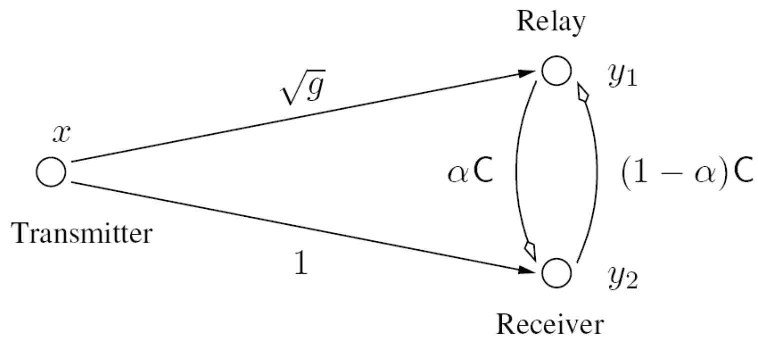


Optimal Power Allocation with Receiver CSI



- **Gain only realized with the right cooperation strategy**
- **With full CSI, Tx co-op is superior.**
- **With optimal power allocation and receiver phase CSI, Rx co-op is superior.**
- **With equal power and Rx phase CSI, no gain from cooperation.**

Conferencing Relay Channel



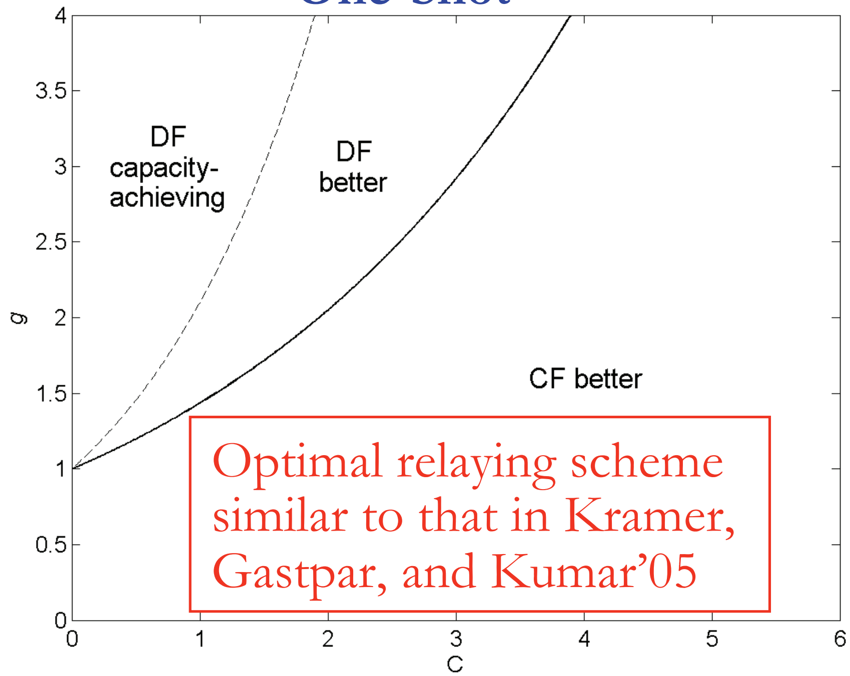
$$y_1 = \sqrt{g}\, x + n_1$$

$$y_2 = x + n_2$$

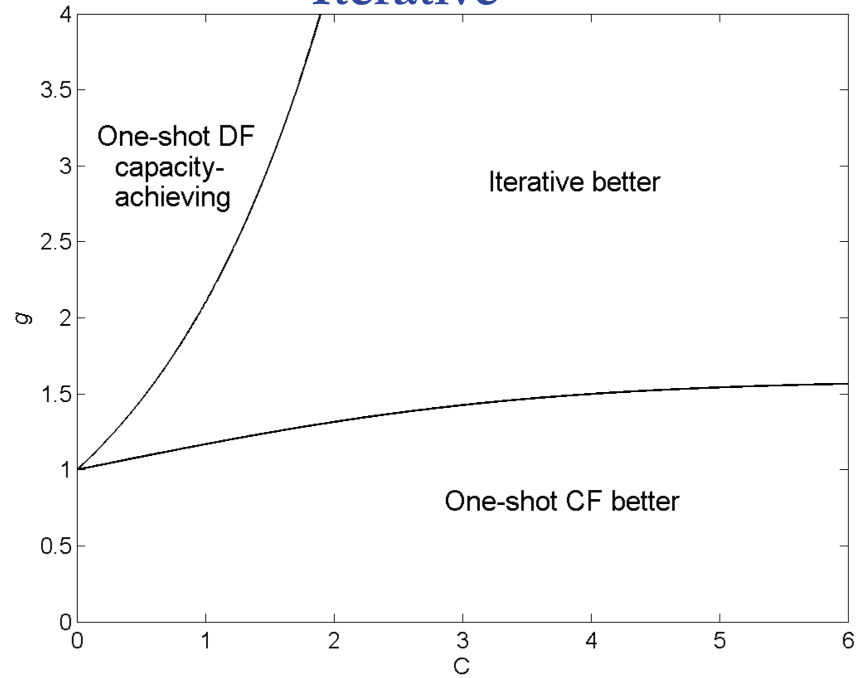
- Willems introduced conferencing for MAC (1983)
  - Transmitters conference before sending message
- We consider a relay channel with conferencing between the relay and destination
- The conferencing link has total capacity C which can be allocated between the two directions

Iterative vs. One-shot Conferencing

One-Shot



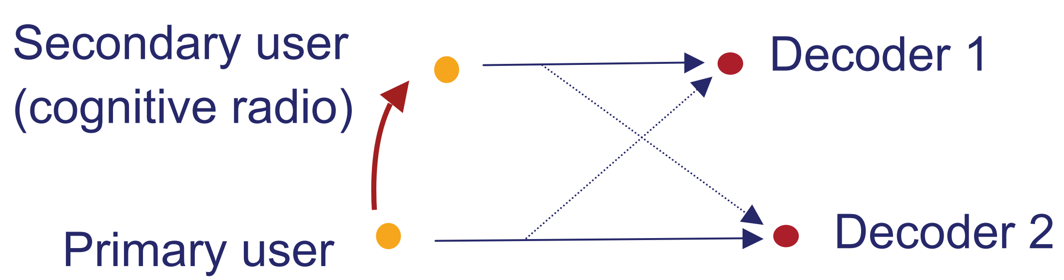
Iterative



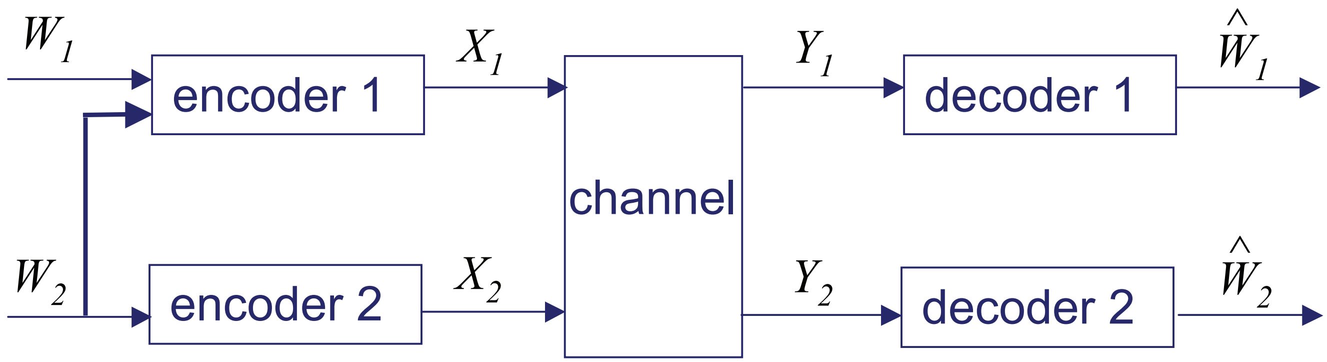
- **Weak relay channel: the iterative scheme is disadvantageous.**
- **Strong relay channel: iterative outperforms one-shot conferencing for large C.**

Cognitive radio cooperation

- One of the transmitters is a cognitive radio
- It "overhears" transmission of primary user
- It *partially* obtains primary user's message
  - it can **cooperate**
- The setting becomes

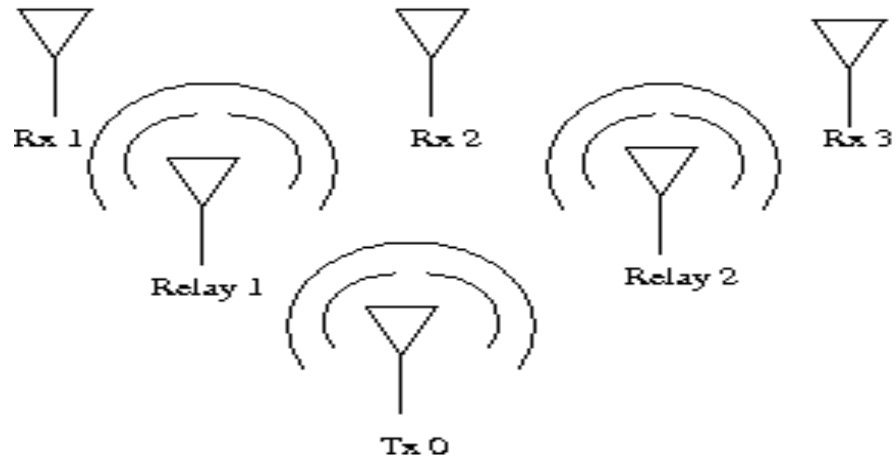


Idealized model



- **Secondary user learns the whole message W_2**
- **Capacity region determined:**
  - **For the Gaussian channel in weak interference** *[Wu, Vishwanath & Arapostathis, 2006]*
  - **For strong interference** *[Maric, Yates & Kramer, 2005]*
- **We have upper and lower bounds on capacity for this model.**

Crosslayer Cooperative Broadcasting via Dualized Erasure Correction Codes



- Major issue in wireless networks: interference.
- High level: noise well understood
- Many network designs suppress interference by orthogonalization and successive cancellation.
- If cooperation is enabled, interference can provide benefits.

Interference has value

- Allow noise to be managed by physical layer, interference info exposed to app layer for handling.
  - *Interference carries information*

(Rel1,Rel2)	Rx1	Rx2	Rx3
(-1,-1)	-1	-1	1
(-1,1)	-1	*	1
(1,-1)	1	*	-1
(1,1)	1	1	-1

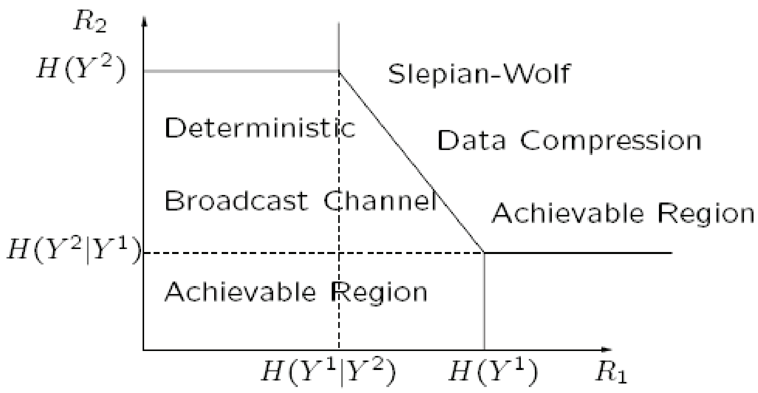
•Rx1 only hears Rel1, Rx3 only hears Rel2, Rx2 hears both

Physical scenarios:

•BPSK with additive combining

•Non-coherent modulation with FSK

Deterministic BC Channel

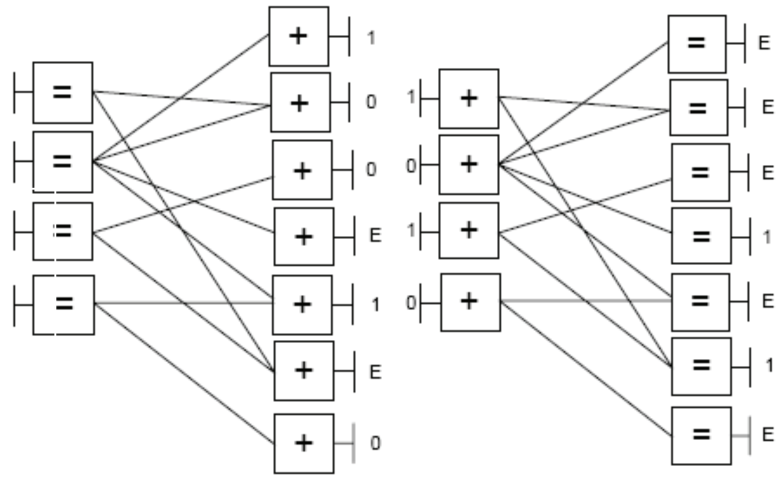


(Rel1,Rel2)	Rx1	Rx2	Rx3
(-1,-1)	-1	-1	1
(-1,1)	-1	*	1
(1,-1)	1	*	-1
(1,1)	1	1	-1

- Although DBC dual to Slepian Wolf, developing practical codes is non-trivial.
- Encoding is hard, decoding easy
- On opposite side of entropy boundary; so using off-the-shelf LDPCs yields exponentially many codewords consistent with what observed.

Rate Splitting Approach

A low-complexity capacity-achieving strategy



- Coding at vertices
- First stage of pipeline, can use Cover's "enumerative source coding" technique
- Later stages: use Luby's generator-form LT codes
- Dualize the algorithm + dualize the linear code
- In 1-to-1correspondence with Digital Fountain coding on the binary erasure channel

Cooperation and Coding Posters

- "Capacity Gain from Transmitter and Receiver Cooperation," C. Ng. and A. Goldsmith
- "Fundamental Limits of Networks with Cognitive Users," I. Maric and A. Goldsmith
- "Capacity Definitions of General Channels with Receiver Side Information," M. Effros, A. Goldsmith, and Y. Liang
- "Crosslayer Cooperative Broadcast Communication via Dualized Erasure Correction Codes", T. Coleman