

EE360: Lecture 8 Outline

Intro to Ad Hoc Networks

- Announcements
 - Proposal feedback by Wed, revision due following Mon
 - HW 1 posted this week, due Feb. 22
- Overview of Ad-hoc Networks
- Design Issues
- MAC Protocols
- Routing
- Relay Techniques
- Generalized cooperation
- Feedback in Ad-Hoc Networks

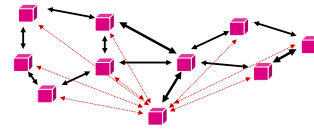
Ad-Hoc Network Design Issues

- Ad-hoc networks provide a flexible network infrastructure for many emerging applications.
- The capacity of such networks is generally unknown.
- Transmission, access, and routing strategies for ad-hoc networks are generally ad-hoc.
- Crosslayer design critical and very challenging.
- Energy constraints impose interesting design tradeoffs for communication and networking.

Frequency Reuse

- More bandwidth-efficient
- Distributed methods needed.
- Dynamic channel allocation hard for packet data.
- Mostly an unsolved problem
 - CDMA or hand-tuning of access points.

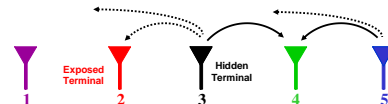
Ad-Hoc Networks



- Peer-to-peer communications
 - No backbone infrastructure or centralized control
- Routing can be multihop.
- Topology is dynamic.
- Fully connected with different link SINRs
- Open questions
 - Fundamental capacity
 - Optimal routing
 - Resource allocation (power, rate, spectrum, etc.) to meet QoS

Medium Access Control

- Nodes need a decentralized channel access method
 - Minimize packet collisions and insure channel not wasted
 - Collisions entail significant delay
- Aloha w/ CSMA/CD have hidden/exposed terminals

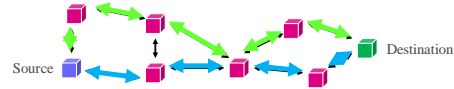


- 802.11 uses four-way handshake
 - Creates inefficiencies, especially in multihop setting

DS Spread Spectrum: Code Assignment

- Common spreading code for all nodes
 - Collisions occur whenever receiver can “hear” two or more transmissions.
 - Near-far effect improves capture.
 - Broadcasting easy
- Receiver-oriented
 - Each receiver assigned a spreading sequence.
 - All transmissions to that receiver use the sequence.
 - Collisions occur if 2 signals destined for same receiver arrive at same time (can randomize transmission time.)
 - Little time needed to synchronize.
 - Transmitters must know code of destination receiver
 - Complicates route discovery.
 - Multiple transmissions for broadcasting.

Introduction to Routing



- **Transmitter-oriented**
 - Each transmitter uses a unique spreading sequence
 - No collisions
 - Receiver must determine sequence of incoming packet
 - ┆ Complicates route discovery.
 - ┆ Good broadcasting properties
 - Poor acquisition performance
- **Preamble vs. Data assignment**
 - Preamble may use common code that contains information about data code
 - Data may use specific code
 - Advantages of common and specific codes:
 - ┆ Easy acquisition of preamble
 - ┆ Few collisions on short preamble
 - ┆ New transmissions don't interfere with the data block

- Routing establishes the mechanism by which a packet traverses the network
- A “route” is the sequence of relays through which a packet travels from its source to its destination
- Many factors dictate the “best” route
- Typically uses “store-and-forward” relaying
 - Network coding breaks this paradigm

Relay nodes in a route



- Intermediate nodes (relays) in a route help to forward the packet to its final destination.
- Decode-and-forward (store-and-forward) most common:
 - Packet decoded, then re-encoded for transmission
 - Removes noise at the expense of complexity
- Amplify-and-forward: relay just amplifies received packet
 - Also amplifies noise: works poorly for long routes; low SNR.
- Compress-and-forward: relay compresses received packet
 - Used when Source-relay link good, relay-destination link weak

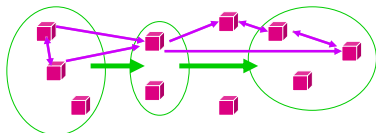
Often evaluated via capacity analysis

Routing Techniques

- **Flooding**
 - Broadcast packet to all neighbors
- **Point-to-point routing**
 - Routes follow a sequence of links
 - Connection-oriented or connectionless
- **Table-driven**
 - Nodes exchange information to develop routing tables
- **On-Demand Routing**
 - Routes formed “on-demand”

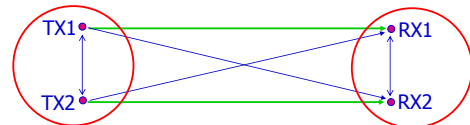
“E.M. Royer and Chai-Keong Toh, “A review of current routing protocols for ad hoc mobile wireless networks,” IEEE Personal Communications Magazine, Apr 1999.”

Cooperation in Wireless Networks



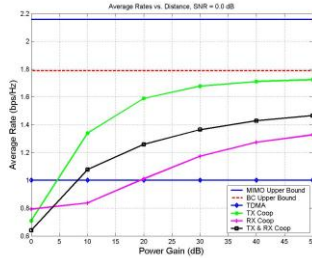
- Routing is a simple form of cooperation
- Many more complex ways to cooperate:
 - Virtual MIMO, generalized relaying, interference forwarding, and one-shot/iterative conferencing
- Many theoretical and practice issues:
 - Overhead, forming groups, dynamics, synchronism, ...

Virtual MIMO



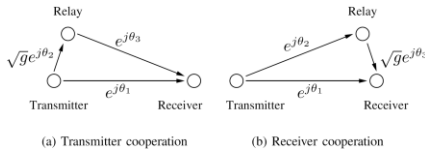
- TX1 sends to RX1, TX2 sends to RX2
- TX1 and TX2 cooperation leads to a MIMO BC
- RX1 and RX2 cooperation leads to a MIMO MAC
- TX and RX cooperation leads to a MIMO channel
- Power and bandwidth spent for cooperation

Capacity Gain with Cooperation (2x2)



- TX cooperation needs large cooperative channel gain to approach broadcast channel bound
- MIMO bound unapproachable

Relative Benefits of TX and RX Cooperation

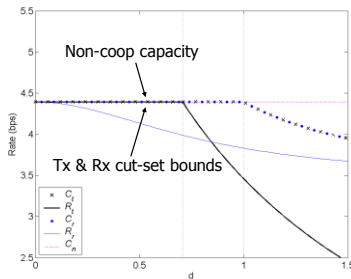


- Two possible CSI models:
 - Each node has full CSI (synchronization between Tx and relay).
 - Receiver phase CSI only (no TX-relay synchronization).
- Two possible power allocation models:
 - Optimal power allocation: Tx has power constraint aP , and relay $(1-a)P$; $0 \leq a \leq 1$ needs to be optimized.
 - Equal power allocation ($a = 1/2$).

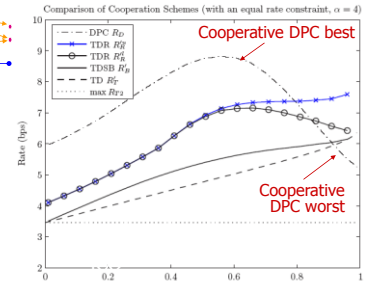
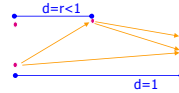
Joint work with C. Ng

Example 2: Equal power allocation with RX phase CSI

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



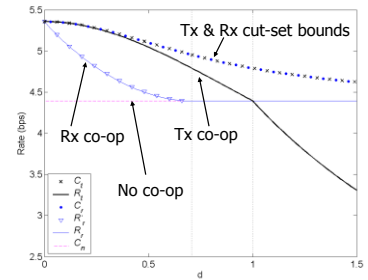
Capacity Gain vs Network Topology



Optimal cooperation coupled with access and routing

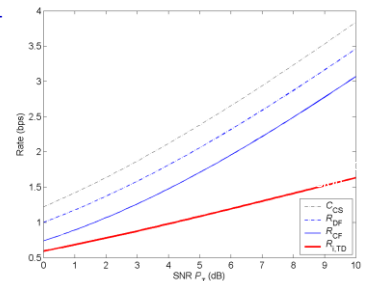
Example 1: Optimal power allocation with full CSI

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



Capacity: Non-orthogonal Relay Channel

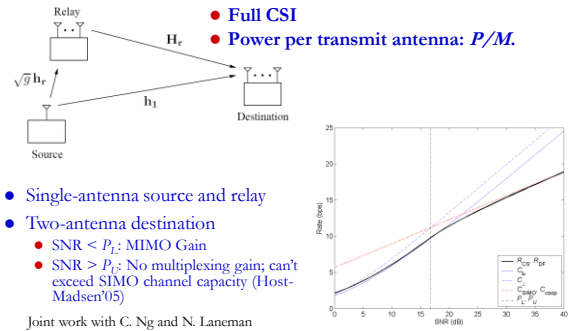
- Compare rates to a full-duplex relay channel.
- Realize conference links via time-division.
- Orthogonal scheme suffers a considerable performance loss, which is aggravated as SNR increases.



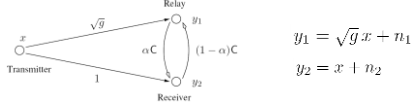
Transmitter vs. Receiver Cooperation

- Capacity 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 allocation and Rx phase CSI, cooperation offers no capacity gain.
- Similar observations in Rayleigh fading channels.

Multiple-Antenna Relay Channel

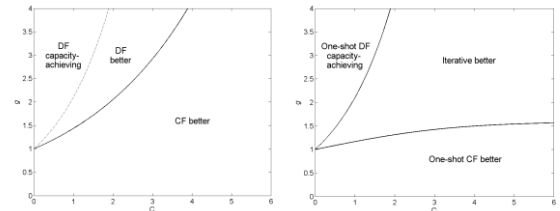


Conferencing Relay Channel



- 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

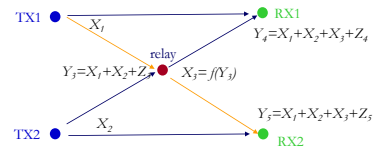


- Weak relay channel: the iterative scheme is disadvantageous.
- Strong relay channel: iterative outperforms one-shot conferencing for large C .

Lessons Learned

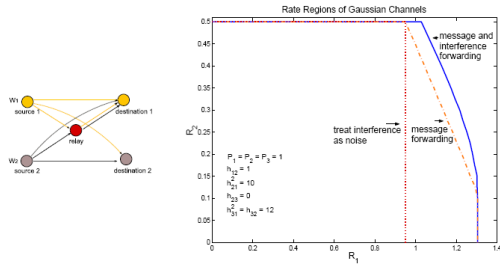
- Orthogonalization has considerable capacity loss
 - Applicable for clusters, since cooperation band can be reused spatially.
- DF vs. CF
 - DF: nearly optimal when transmitter and relay are close
 - CF: nearly optimal when transmitter and relay far
 - CF: not sensitive to compression scheme, but poor spectral efficiency as transmitter and relay do not joint-encode.
- The role of SNR
 - High SNR: rate requirement on cooperation messages increases.
 - MIMO-gain region: cooperative system performs as well as MIMO system with isotropic inputs.

Generalized Relaying

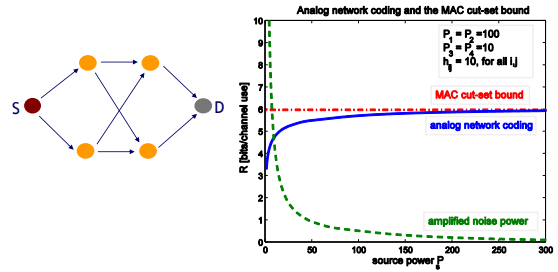


- Can forward message and/or interference
 - Relay can forward all or part of the messages
 - Much room for innovation
 - Relay can forward **interference**
 - To help subtract it out

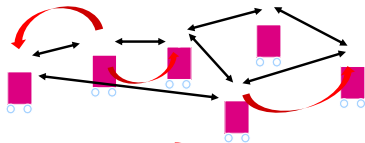
Beneficial to forward both interference and message



In fact, it can achieve capacity

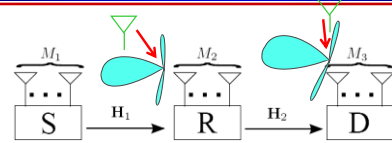


How to use Feedback in Wireless Networks



- Output feedback
 - CSI
 - Acknowledgements
 - Network/traffic information
 - Something else
- Noisy/Compressed

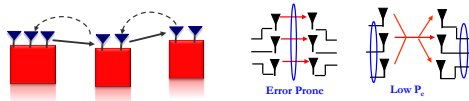
MIMO in Ad-Hoc Networks



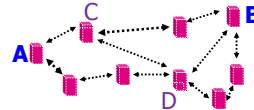
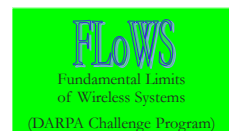
- Antennas can be used for multiplexing, diversity, or interference cancellation
- Cancel $M-1$ interferers with M antennas
- What metric should be optimized?

Cross-Layer Design

Diversity-Multiplexing-Delay Tradeoffs for MIMO Multihop Networks with ARQ

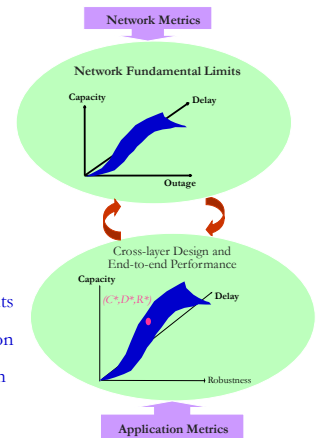


- MIMO used to increase data rate or robustness
- Multihop relays used for coverage extension
- ARQ protocol:
 - Can be viewed as 1 bit feedback, or time diversity,
 - Retransmission causes delay (can design ARQ to control delay)
- Diversity multiplexing (delay) tradeoff - DMT/DMDT
 - Tradeoff between robustness, throughput, and delay



Research Areas

- Fundamental performance limits and tradeoffs
- Node cooperation and cognition
- Adaptive techniques
- Layering and Cross-layer design
- Network/application interface
- End-to-end performance optimization and guarantees



Today's presentation

- *Apurva will present* “User cooperation diversity: Part I. System description”, Sendonaris, A. ; Erkip, E. ; Aazhang, B. ; *IEEE Transactions on Communications*, vol. 51, pp. 1927-1938, 2003
- Required reading (forgot to post)