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Cooperation and Opportunism

Finding a Suitable Balance

VDE/ITG-Fachgruppe 5.2.4
30. Treffen

Mobilität in IP-basierten Netzen

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Internet Architectures and Networking

R&D Tracks and Major Partners (Since November 2007)

Cooperative Networking
- Dynamic management of available spectrum
- Social networking, trust management

Disruptive Internet Paradigms
- Scalable, low-cost architectures
- Autonomic, user-provided network integration

Advanced R&D

(30%)

Applied R&D

(70%)

Mobility Management
- End-user as micro-operator
- Radio interworking, intelligent connectivity

Advanced Forwarding and Routing
- Robust forwarding
- Routing for intermittent connected networks

Academy   Industry

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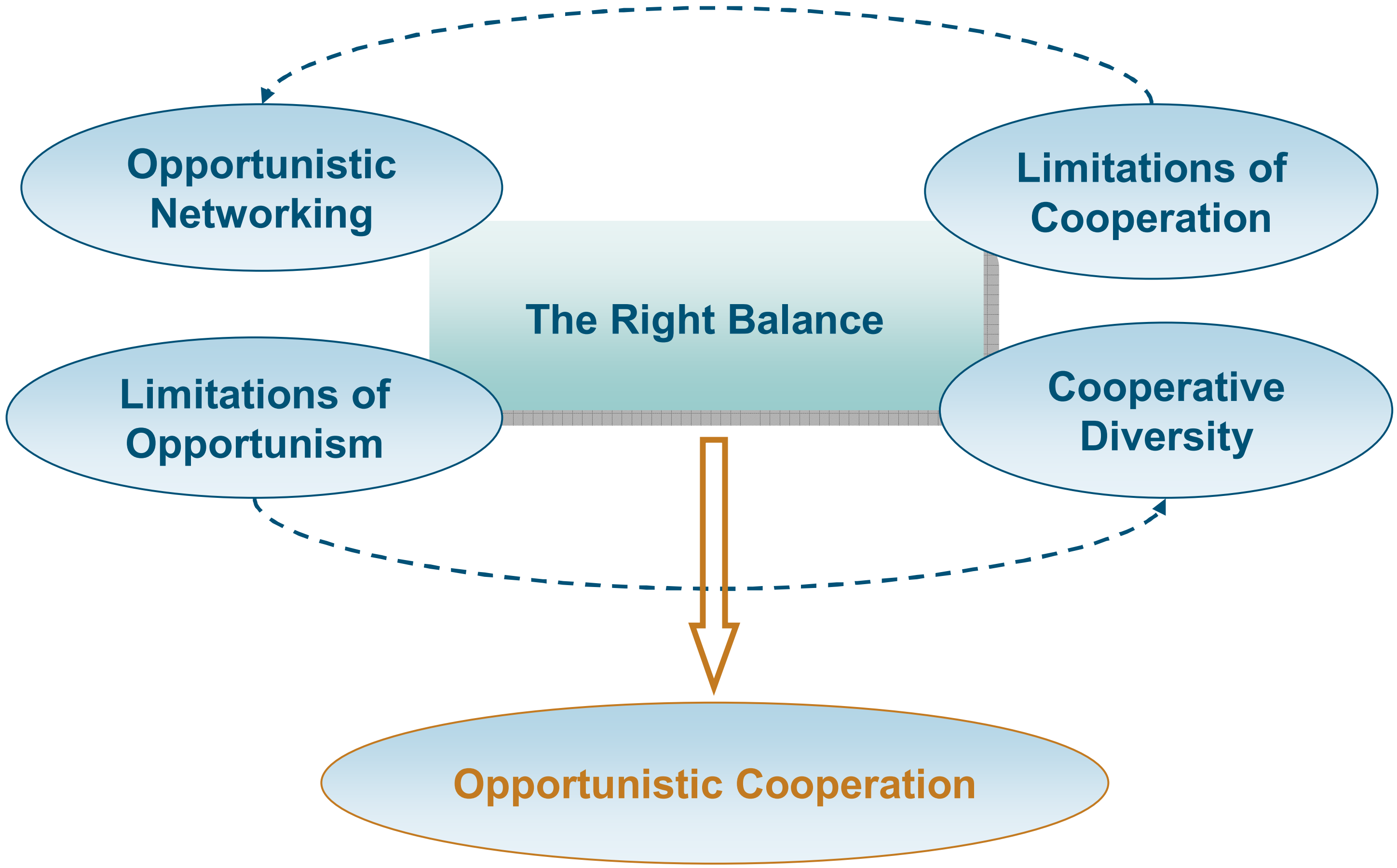
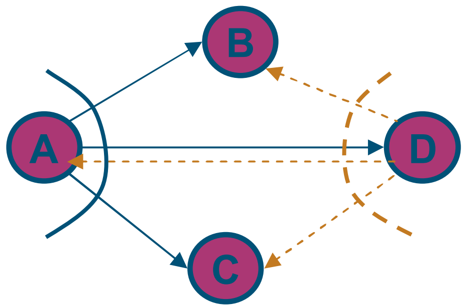
Overview

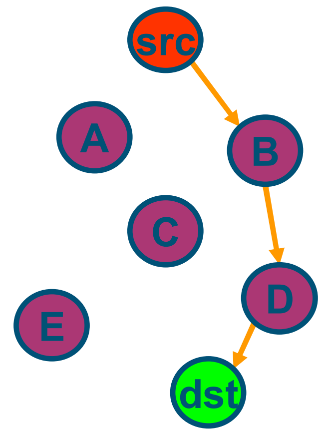

Opportunistic Networking
Limitations of Cooperation
The Right Balance
Limitations of Opportunism
Cooperative Diversity
Opportunistic Cooperation

Opportunistic Networking

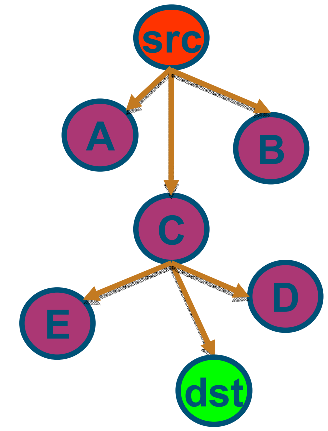
Opportunistic Relaying



Traditional Routing



Opportunistic Routing



Major Characteristics

- Only <u>single</u> “best” relay forwards
  - Only <u>correct</u> messages
  - No combination at destination
- Full diversity requires
  - Knowledge about end-to-end channel
  - Requires feedback from destination

Major Characteristics

- Traditional routing
  - Suffers high overhead because of much retransmission
  - Next hop: long enough to make good progress but short enough for low loss rate
- Opportunistic routing
  - Take advantage of ***multiple user diversity***
  - Multi-hop **opportunistic relaying**

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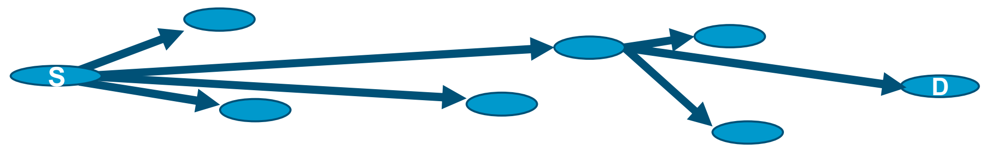
Extremely Opportunistic Routing

ExOR: a primer [ACM SIGCOMM 2005]

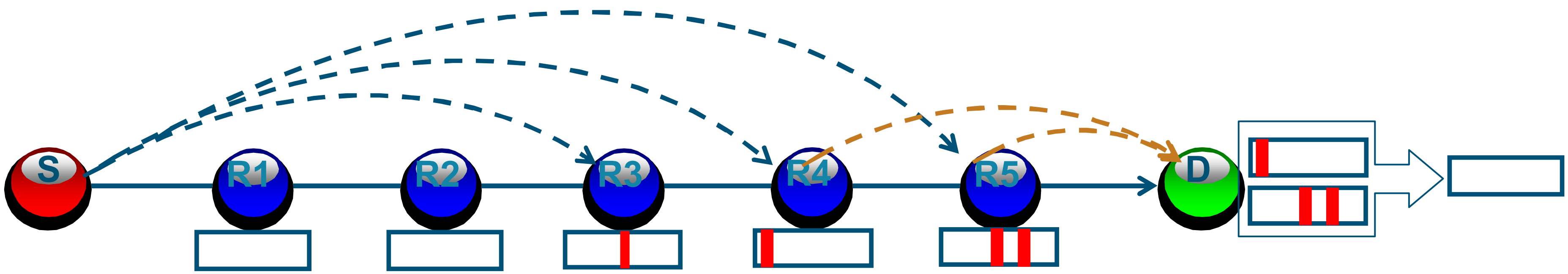


Major Characteristics

- Relaying Algorithm
  - Source includes in each packet a sub-set of candidate forwarders (to decrease overhead)
  - Highest priority forwarder broadcasts the packets in its buffer (and batch map)
- Nodes intercommunication
  - Agreement on which received each packet
- Cost metric (similar to ETX)
  - Knowledge of the set of inter-node loss rates
    - Source gets periodic per-node link-state
  - Value inverse to link's delivery probability

Major Limitations

- Removes spatial reuse
  - Only one node transmits at a time, others listen
- Resources allocated based on current channel state
  - Quasi-static fading assumption
  - Channel state information may not be accurate
- Global scheduler
  - Feedback consumes network capacity
- Relay selection requires full coordination
  - Every node must know who received what
  - No guarantees of coordination sucess



Leverage longer opportunistic receptions of partially correct packets! [ACM SIGCOMM 2008]

Limitations of Opportunistic Scheduling

- Opportunistic scheduling:
  - Dynamically assigns resources to nodes based on their current Channel State Information (CSI)
  - CSI has to be made available at points in the system where opportunistic decisions are made.
    - CSI has to be transported to a (centralized?) scheduler.
  - CSI may not be accurate
    - It may take to long for that information to be available to the scheduler

- Current methods (none or them are acceptable):
  - Schedulers ignore errors by choosing the right set of assumptions
    - Quasi-static fading assumption
    - Perfect feedback of CSI information (does not consumes network capacity)
  - Capacity allocation (over-provisioned fashion even for a resource-scarce wireless channel)

Alternative Method

- Compensation for wrong opportunistic scheduling decisions
- Employing **cooperative diversity** between wireless nodes
  - Allows the exploitation of independent realizations of the received signal (e.g. spatial diversity)

Cooperative Diversity
Motivation, Goal and Realization

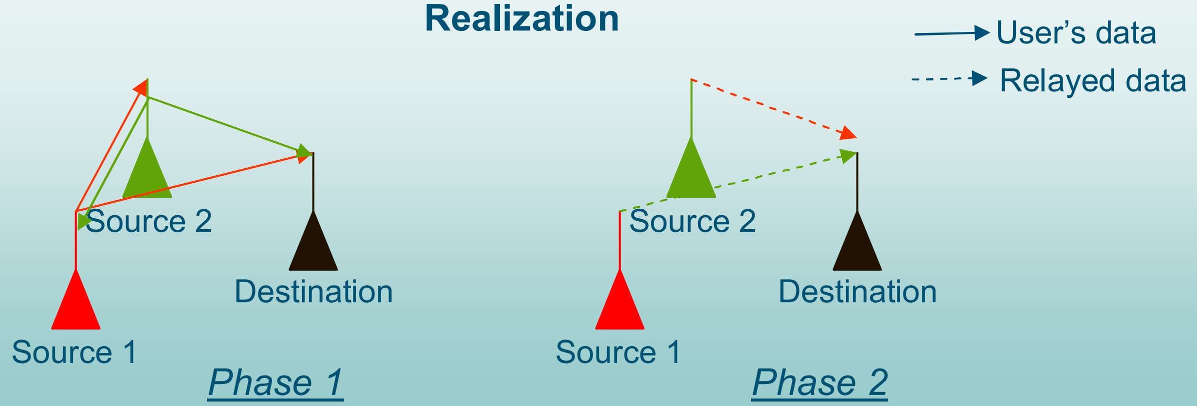
Motivation

- Fading nature of wireless systems (e.g. shadowing) tend to reduce system performance
  - The presence of reflectors create multiple paths
- Combat fading by exploiting multiple channels with independent fading
- Reduce the risks inherent to opportunistic relaying and routing

Goal

Multiple users cooperate in by providing different spatial and temporal transmission paths

Realization

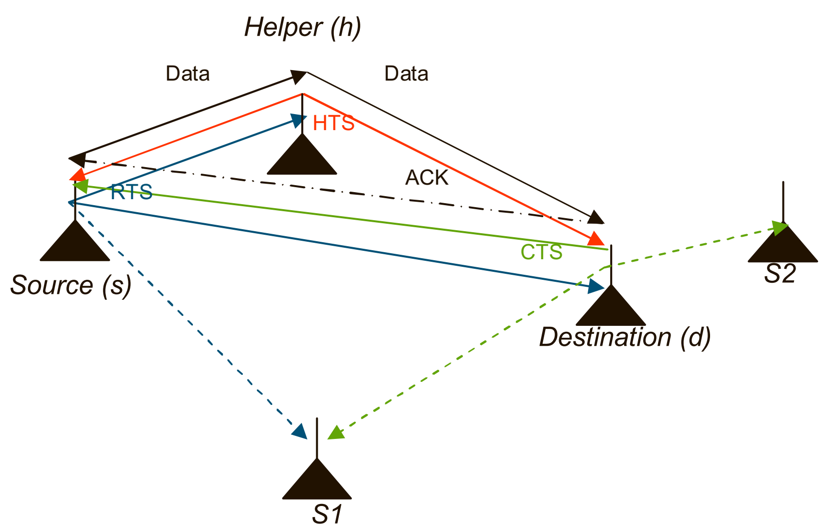


Cooperative Relaying: a special case

Cooperative MAC agnostic of Wireless Diversity [IEEE JSAC 2007]

CoopTable

- Each entry corresponds to a potential helper:
  - Helper ID (e.g, 48-bit MAC address)
  - Latest time a packet form the helper was overheard
  - Data rate between helper and destination
  - Data rate between source and helper
- Controlled by a set of defined protocols



Helper Selection (SRC with L Octets)

- Look up the Cooperation Table
- Find the one neighbor with minimum:

  $8L/R_{sh}+8L/R_{hd}$
- More than one potential helper have the same minimum
  - Use the one with the latest time field.

When to Cooperate

$$8L/R_{sh}+8L/R_{hd} < 8/R$$

Direct transmission otherwise

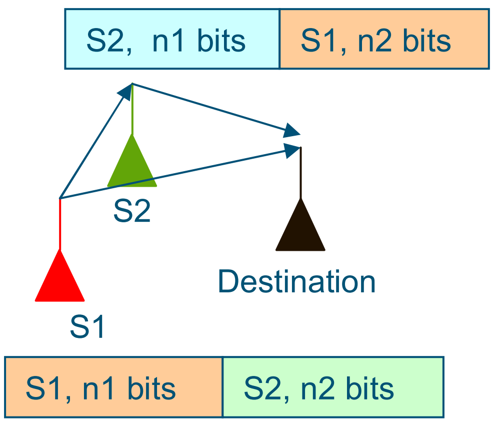
Procedure for Data Transmission

- Handshake
  - RTS (Ready To Send)
    - With: ID of S_h, R_{sh} and R_{hd}.
  - HTS (Helper ready To Send)
  - CTS (Clear To Send)
- Data transmission
- Acknowledgement

Cooperative Relaying: a special case
Cooperative MAC aware of Wireless Diversity

CoopMAC + Coded Cooperation [IEEE WCNC 2008]

- CoopMac used to select best relay
- Combines cooperation with channel coding (cooperative diversity **only** by distributed FEC coding)
    - Relay send FEC and not the source data
- Use of *Cyclic Redundancy Checksum* (CRC) to avoid propagation of errors



Coded cooperation

K bits

FEC r = k /n, r <1

n bits = n1 + n2

k bits plus redundancy

α = n1 / n ← level of cooperation

Spatial diversity

S2 n1	S1 n2
S1 n1	S2 n2

Temporal diversity

CoopMAC + Randomized Distributed Space-Time Coding (R-DSTC) [IEEE Globecom 2008]

- CoopMAC used to select set of relays
- Each relay transmits a random linear combination of antenna waveforms
    - Does not need a deterministic indexed set of helpers.
- Knowing the number of helpers: enable best modulation/coding scheme at the source

Leverage Opportunistic Networking with Cooperation
Motivation

Towards cooperative communications….

- Opportunistic relaying and routing do not leverage an important property of wireless media:
  Wireless Broadcast Advantage (WBA)

- With WBA, cooperative communications allow several nodes to transmit together to a destination.
  Research results show that cooperative communications augment:
  - Performance
  - Network capacity
  - Reliability

… but

With cooperative communications, the sender is not a single node
The concept of a network link needs to be reinvented

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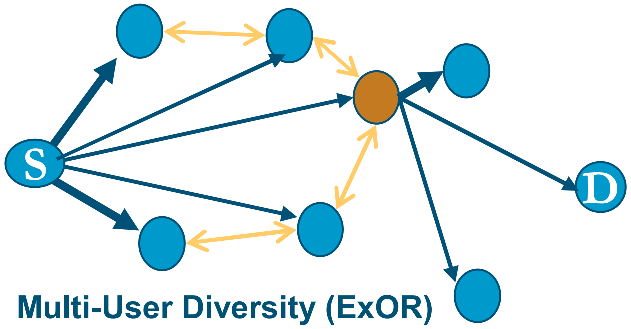
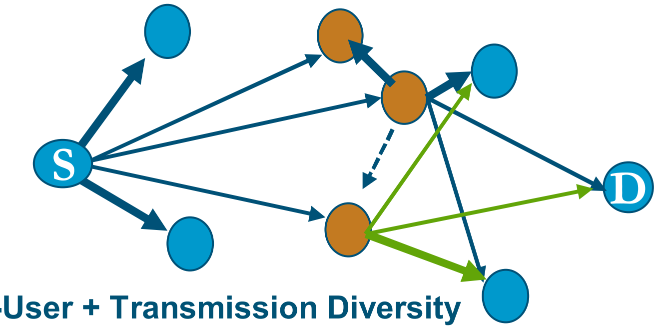
We need to find a good balance between opportunism and altruism

Opportunistic Routing aware of Wireless Broadcast Advantage
But no Cooperation



Multi-User Diversity (ExOR)



Multi-User + Transmission Diversity

Goals

- *<u>Eliminate the coordination overhead of ExOR</u>*
- Take advantage of the spatial diversity of different potential relays
  - Should not be depend from the quality of the source-destination link
- Passive Forward Selection
  - If a node overhears the transmission of a neighbor, it gives up forwarding.
  - May take advantage of partial packet forwarding

Transmit Diversity based on Cooperative Opportunistic Routing **[IEEE INFOCOM 2008]**

- All nodes know and maintain a global topology (e.g. based on proactive routing)
- All potential forwarders have a high-quality link between each other
  - To avoid missing transmissions between candidates leading to packet duplication
- Candidate selection metric is ETX

Opportunism & Cooperation
The right Balance

Goal

Scheduling algorithms able to select from a wide variety of transmissions options, going beyond today's:
- Simpler opportunistic schedulers
- Always-cooperation-based schedulers

Some Design Choices

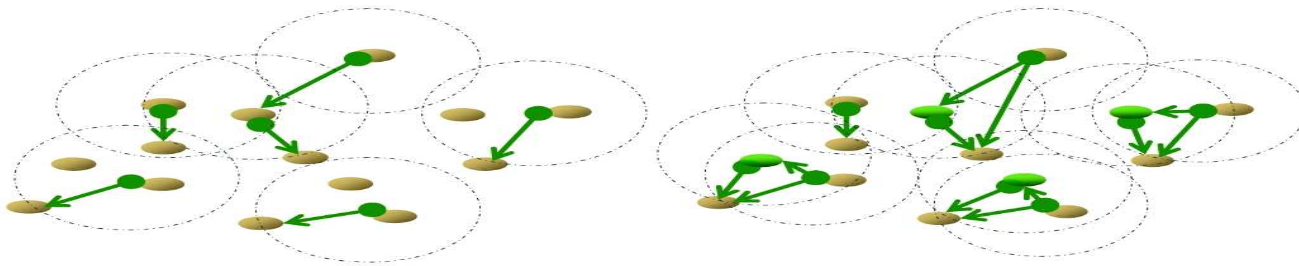
- What is a suitable "risk level" of an opportunistic scheme?
  - Accuracy and delay behaviour of CSI is relevant

- Simplest solutions:
  - Cooperative relaying triggered If the scheduler detects that it operates in a high-risk regime.

Major Open Issues

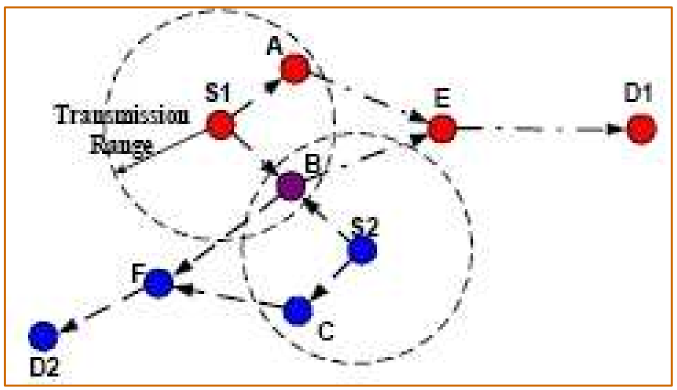
- Metric for opportunism risk level
- Protocols for cooperative vs. opportunistic transmission, allowing adaptation between different schemes
- Tradeoff analysis:
  - Extra resources for cooperation vs. wasted resources in opportunistic incorrect decisions.

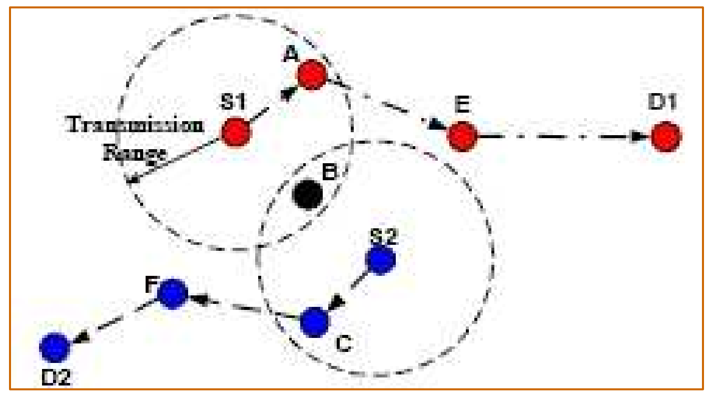
Problems Posed by Cooperative Relaying



Relaying leads to extra transmissions, which means more spatial contention

Opportunistic routing schemes must avoid contention? [IEEE INFOCOM 2008]





And what if….

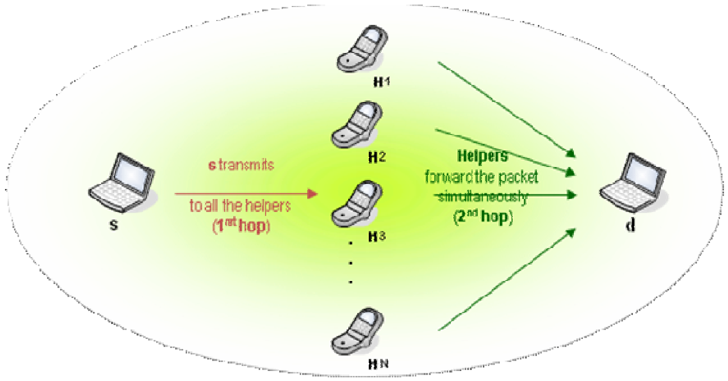
Collision avoidance by keeping cooperation levels:

1. Coordination among S1 and S2 to avoid synchronization of transmissions (e.g. TDD medium access)
2. Allow S1 and S2 data to be coded in B and decoded in E and F.
3. **Take advantage of multiple relays**

Multi-user Cooperation
Taking Advantages of all Possible Cooperative Nodes

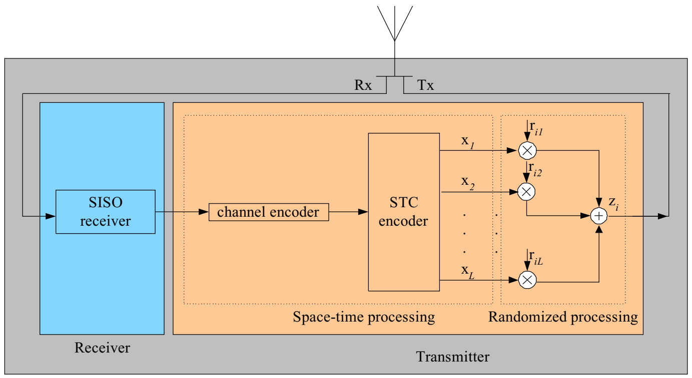
Distributed Space-Time Coding (DSTC)

- Coordinates **M** single antenna relays
  - Emulates antennas of a conventional STC system
- Limitations:
  - Considerable signaling cost.
    - Numbering relays to emulate the right STC antenna element
  - Degraded diversity gain
    - When relays do not correctly decode received signal



Randomized Distributed Space-Time Coding (R-DSTC)

- Relays transmit a random linear combination of antenna waveforms.
  - Eliminates the need of a deterministic indexed set of relays.
- Limitations:
  - For relays with **L** parallel streams, cooperation must involve **N** relays, ensuring N ≥ L
    - Source needs to know approximate number of relays
  - Nodes should transmit coherently
    - Is beyond the foreseeable wireless technologies.



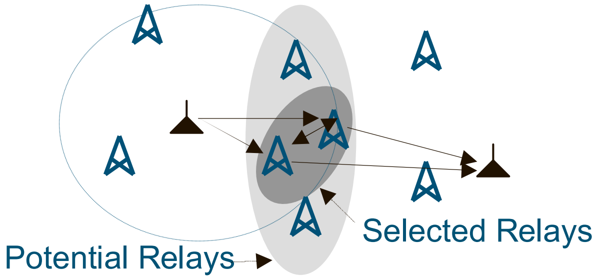
Not all nodes may wish or may be able to be involved in every cooperative transmission

Problem of relay selection

Opportunistic Cooperation
Selecting Relays According to Instantaneous Network Conditions

Major Requirements

- Maintain DSTC diversity with nodes transmit one-at-a-time
  - How many nodes are necessary?
  - CSI needs to be exchanged
- Full diversity on the order of number of relays
  - Low network capacity: multiple transmission of the same message



Limiting the Need for CSI

- Avoiding full CSI at the source
  - Selection based on channel conditions on both sides of the relay
    - Relays must know their outgoing and incoming channel gains
  - Selection based on relay-destination channel conditions
    - High spatial correlation on channels to the destination significantly degrade the performance
- Relay back-off based on relative CSI values

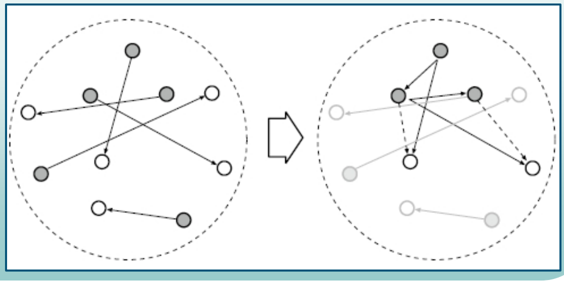
Avoiding Same Problem of Opportunistic Routing?

⇓

Dependency upon CSI

Impact on Network Capacity

- In distributed algorithms nodes make individual decisions on cooperation
  - Non-reciprocal cooperation opportunities
- How the cooperative gain scales with the number of cooperating nodes?
  - How many nodes should a relay help? (relay selection renouncement)
- Multi-hop networks are not considered [IEEE JSAC 2007]



Interesting and Challenging Open Problem

Multi-hop Opportunistic Routes with Cooperative Relay Allocation