The case for a cooperative stack for wireless multihop networks

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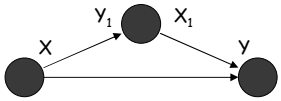
Cooperative protocols

- Cooperative protocol:
  - This is a too vague term: In any communication protocol there is some form of cooperation!.
  - Cooperation is related with who owns the system and who benefits from system's operation.
- Possible (probably unsatisfactory) definition:
  - Protocols which opportunistically exploit broadcast transmission for resource sharing.
  - In other words, they do not use the point-to-point abstraction for wireless links as it is done in most L2-4 current protocols.
- Broadcast transmission is for free. Broadcast reception and promiscuous processing, however, is not for free:
  - eg: typical WiFi NIC power consumption: Tx: 1.5 W, Rx: 1 W, Idle <100mW.

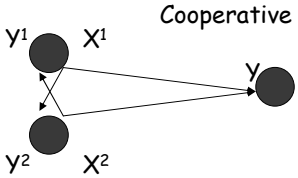
Cooperative protocols

- First proposals come from the Information Theory community:
  - Relay channel
    - '71: Introduced by Van der Meulen.
    - '79: Capacity region for the degraded relay channel found by Cover & ElGamal [Cov79].
  - Renewed interest: Extension to Cooperative Diversity
    - '99: Sendonaris, Erkip & Aazghan [Sen99]
    - '02: Laneman & Wornell [Lan02].

Relay channel



Cooperative diversity



Decode & forward: Relay decodes the signal, and retransmits the same signal or some information extracted from this signal (e.g. parity bits)

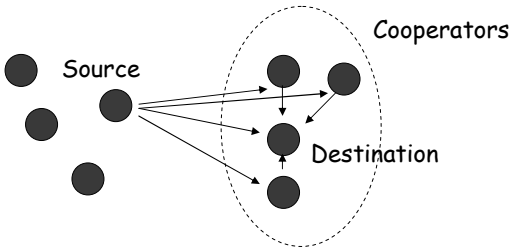
Amplify&forward : Relay amplifies and retransmits the same signal or a quantizied version of the signal.

Cooperative protocols

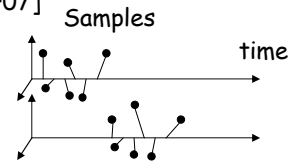
- Some cooperation techniques:
  - Cooperation to improve link quality
    - Cooperative diversity transmission systems
    - C-ARQ, C-ARQ/FC, MASA, etc
  - Cooperation to increase path reliability in presence of mobility
    - C-Relaying
  - Cooperation to increase path reliability in presence of fading
    - Opportunistic Relaying
  - Cooperation to increase network capacity
    - Network coding
  - Cooperation to increase network security
    - Cooperative IDS
  - Cooperation for node location

Cooperation to improve link quality

- Cooperation in Wireless Transmission:
  - Cooperative diversity [Sen99], [Lan02],
  - Virtual MIMO,
  - Virtual antenna arrays
- Cooperation in Link Reliability protocols:
  - Cooperative ARQ [Zha05] [Mon05], [Dia05]
  - Cooperative ARQ/FC [Miu05], [Mor05],[Mor07]



Cooperative diversity



ARQ/FC

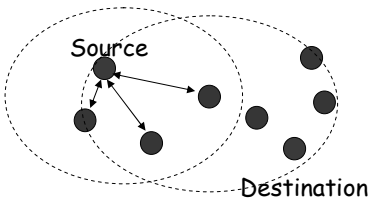
Bits

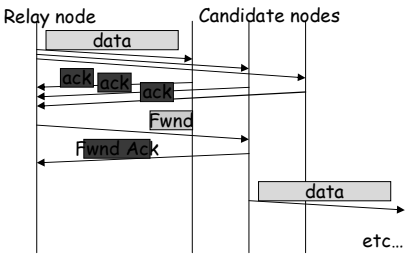
1**01**10010**010**01000111001
1**01**10010**101**01000111001
1**10**10010**010**01000111001

Cooperation to increase path robustness

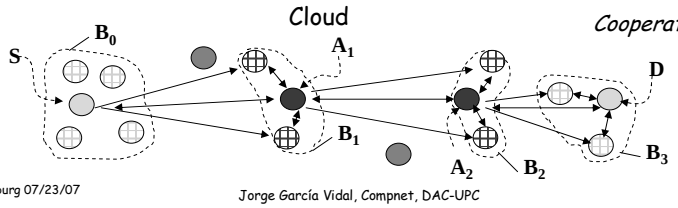
- Cooperation for fixed networks:
  - Opportunistic forwarding: SDF [Lar01], ExOR [Bis05], [Ble06]
- Cooperation for mobile networks:
  - Cooperative Relaying [Gar05]

Opportunistic Forwarding



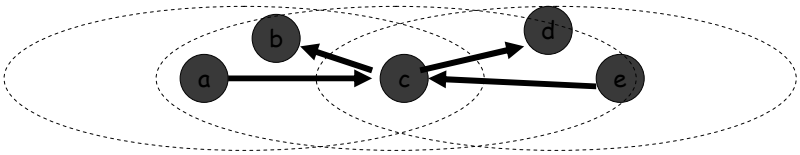


Cooperative Relaying



Cooperation to increase network throughput

- **Cooperation to increase network throughput**
  - Cooperation in Network transport:
    - Network coding [Ahl00] [Kat05]



Node ***a*** sends a packet to ***c*** which has to relay the packet to ***d***.
This packet is also received by ***b***
Node ***e*** sends a packet to ***c***, which has to relay the packet to ***b***.
This packet is also received by ***d***
Node ***c*** XORs both packets and sends them in broadcast.
Nodes ***b*** and ***d*** can recover the intended packet from this
Broadcasted packet, XORing the packet with the stored packet
Throughput increases by 4/3

The benefits of cooperation

C-ARQ

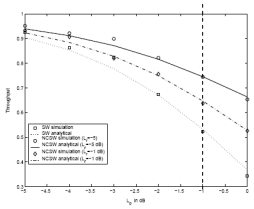


Figure 15: Throughput vs. fading margin of the primary channel

Cooperative Relaying

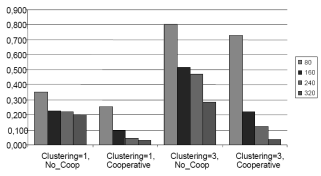


Figure 5: Packet loss rate

Opportunistic forwarding

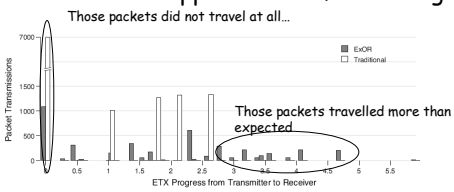


Figure 12: Distance traveled towards N24 in ETX space by each transmission. The X axis indicates the difference in ETX metric between the sending and receiving nodes; the receiver is the next hop for traditional routing, and the highest-priority receiving node for ExOR. The Y axis indicates the number of transmissions that travel the corresponding distance. Packets with zero progress are not received by the next hop (for traditional routing) or by any higher-priority node (for ExOR).

Network Coding

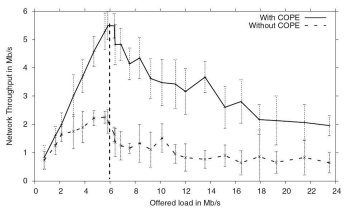


Figure 12—COPE can provide a several-fold (3-4x) increase in the throughput of wireless Ad hoc networks. Results are for UDP flows with randomly picked source-destination pairs, Poisson arrivals, and heavy-tail size distribution.

Cooperative protocols: Cost and barriers

- Cooperation incentives
  - Why should I use my resources for the benefit of the others?
  - Not an issue in some applications
- Processing overload
  - Should I process every packet I hear?
- Cooperation overhead
  - MAC signaling
- Interaction with TCP/IP

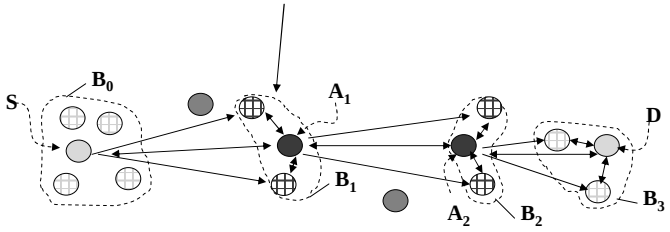
A cooperative stack

- Current communication stacks for ad-hoc networks are not designed to exploit the wireless transmission characteristics:
  - E.g: Broadcast transmission limits multihop wireless network capacity (Gupta, Kumar '00).
  - However, it also presents some benefits that could be exploited.
- Lack of some important issues. Eg:
  - Addressing scheme
  - Forwarding scheme
  - Adequate MAC signalling
  - Protocol stack organization

A cooperative stack

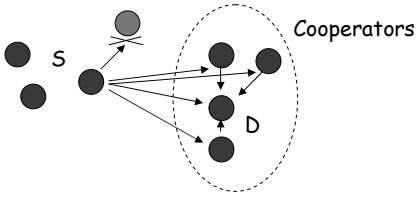
- New abstractions and addressing schemes

Frames can be addressed to a "cloud", i.e. a set of a node and its cooperators.



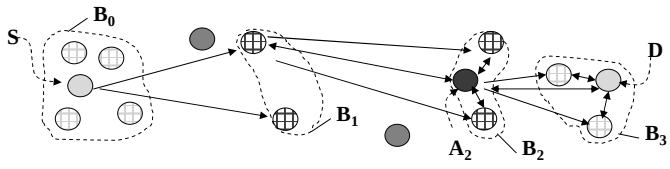
<@A_1,0>: Node A_1
<@A_1,1,n>: Nodes of cloud B_1 (built around A_1). ***n*** is used to keep track of changes in cloud membership.

A cooperative stack



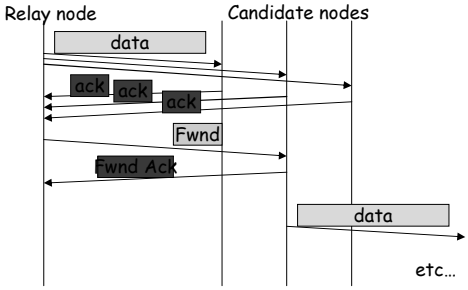
Example: In C-ARQ, S sends frames with destination address <@D,1,n>. D's cooperators keep temporaly these frames, while other nodes discard them.

Example: In C-Relaying, S sends frames with destination address <@A_1,1,n>. A_1's cooperators keep temporaly these frames, while other nodes discard them.



A cooperative stack

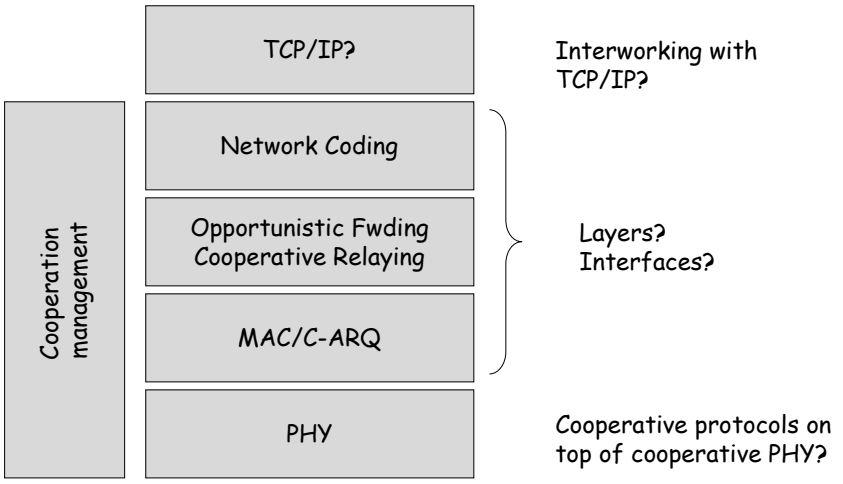
- MAC signaling



- Several ACK packets per data packet
- ACKs generated by nodes which are not the intended receivers
- Coordination overhead

A cooperative stack

- Stack organization



Conclusions

- Cooperation is a promising technique for future (multihop) wireless networks
- Current communication stacks do not incorporate the adequate abstractions, layering, etc to accomodate cooperation
- Challenge: to define a "cooperative stack"
- Some important issues:
  - Addressing scheme
  - Forwarding scheme
  - Adequate MAC signalling
  - Protocol stack organization

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