CD-MAC Cooperative Diversity
MAC for Robust Communication
in Wireless Ad Hoc Networks

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Sangman Moh (Chosun University, Korea); Chansu Yu (Cleveland State University, USA);
Seung-Min Park (ETRI, Korea);
Heung-Nam Kim (Electronics and Telecommunications Research Institute, Daejeon,
Korea); and Jiwon Park (Chosun University, Korea)

Presented by Yu-Chu Chu Chang
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Outline

- Introduction
- Related Work
- Cooperative Diversity MAC
- Performance
- Conclusion
Introduction

In wireless ad hoc networks, *signal fading* and *interference* are two major obstacles in realizing their full potential in delivering signals.

Cooperation among the nodes is considered critically important in addressing these problems.
Introduction

Diversity techniques such as co-located antenna array can mitigate the interference problem by transmitting redundant signals over essentially independent channels.

- But it may not be always feasible in practice for each node to have multiple antennas.

Recently, a new class of diversity techniques called *cooperative diversity* has been proposed, in which distributed radios interact with each other to jointly transmit information exploiting diversity offered by multiple users.
Introduction

Cooperative communication exploits diversity offered by multiple users, known as *cooperative diversity*

- Improve the *bit error rate (BER)*
- More reliable transmission
- Higher throughput

It is important to note that the primary motivation of cooperative diversity is to improve *link reliability* over wireless fading channels rather than lengthen the transmission range
Introduction

There are two types of cooperative diversity algorithms:

- **repetition-based**
  - the sender broadcasting its transmission both to its receiver and potential relays (or partners)
  - these relays repeating the sender’s message individually on orthogonal channels.

- **space–time-coded**
  - all the relays transmit simultaneously on the same channel using a suitable coding scheme such as orthogonal distributed space-time code (DSTC)
Introduction

This paper presents a MAC layer protocol, called *cooperative diversity MAC (CD-MAC)*, that exploits the cooperative communication capability in wireless ad hoc networks:

- Operate on a single channel
- Use a single relay (partner)
  - A key element of the CD-MAC is the selection of relay
- Assume that radio hardware supports cooperative space-time coding (STC)
Related Work

- Cooperative Diversity
- Cooperative Diversity in Wireless Ad Hoc Networks
Cooperative Diversity

Several cooperative signaling or relaying methods have been studied, there are two well-known techniques, called repetition-based cooperative algorithms:

- Amplify-and-forward
- Decode-and-forward

The corresponding benefits come at a price of decreasing bandwidth efficiency because each relay requires its own channel for repetition.
Cooperative Diversity

For realizing cooperative diversity while allowing relays to transmit on the same channel, orthogonal distributed space time coding (DSTC) has been studied, DSTC is a distributed multi-user version of STBC.

Historically, space-time coding (STC) and space-time block coding (STBC) were initially developed to offer transmit diversity in multi-antenna systems.
Distributed space-time coding

Consider a simple three-node example with sender, relay (partner) and receiver devices as in Fig. 1.
Cooperative Diversity in Wireless Ad Hoc Networks

- Distributed Automatic Repeat Request [10] (Kojima et al.)
- Cooperative MAC (C-MAC) and the corresponding routing protocols for wireless ad hoc networks [11] (Azgin et al.)
- A MAC protocol that supports the virtual MISO and multiple relays [12] (Jakllari et al.)
COOPERATIVE DIVERSITY MAC

- Single-channel
- Cooperative diversity via DSTC
- Two-node cooperation
- Four-way Handshaking of CD-MAC
- Relay Selection
The proposed CD-MAC is based on Distributed Coordination Function (DCF) of IEEE 802.11 standard. If a primary link imposed by the upper layer routing protocol is reliable enough to successfully transmit packets, the conventional MAC (i.e., DCF) is used and no cooperative transmission is enabled. If it fails, however, the sender retransmits the packet but cooperatively with its relay.
COOPERATIVE DIVERSITY MAC

- Node $i$ transmits its packet to the next hop node $j$ over the primary link.
- If it fails, node $i$ and its relay $r_i$ retransmit the packet cooperatively.
- Note that the relay $r_i$ decodes the packet received from the sender $i$ in time slot 1, encodes it using DSTC, and transmits in time slot 2.
- Likewise, the node $j$ transmits its packet (e.g., ACK) to node $i$ cooperatively with its relay $r_j$.
- A sender and a relay transmit the exactly same copy at the MAC layer while they are different at the physical layer as they use space-time block code.

![Diagram of cooperative transmission with relays along a routing path.]

Fig. 2. Cooperative transmission with relays along a routing path.
COOPERATIVE DIVERSITY MAC

(a) Four-way handshaking

(b) Transmission blocks of C-RTS, C-CTS, C-DATA and C-ACK
Relay Selection

To exploit cooperative transmission in CD-MAC, every node proactively selects its relay by monitoring or overhearing its neighbors with respect to *link quality*. The one with the best quality is selected as its relay.

Note that metrics that can be used to indicate link quality are distance, load, interference level, signal strength (SS) and *signal-to-interference plus noise ratio* (SINR).
Relay Selection

- If a node receives a frame, it measures and records the link quality between itself and the transmitter.
- And, it looks up the neighbor table and selects a neighbor with the maximum link quality among all neighbors as its relay.
- When it has a packet to send (DATA or C-DATA) or needs to send its own hello packet, it includes its selection in Addr4.

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<th>DATA ( (i \Rightarrow j) )</th>
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<th>C-DATA ( (r_i \Rightarrow j) )</th>
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Performance

- Reception Model
- Simulation Environment
Reception Model

- The signal reception model implemented in ns-2 network simulator is based on three fixed thresholds, i.e., carrier sense threshold (CSThresh), receive threshold (RxThresh) and capture threshold (CPThresh).
- To consider bit error rate (BER) when determining the success or failure of a received signal.
  - Compute SINR
  - Look up the BER-SINR curve to obtain BER
  - Calculate frame error rate (FER) and determine whether to receive or drop the frame
BER versus SNIR

(a) BER versus SNIR  (b) FER versus SNIR
50 mobile nodes move over a square area of $300 \times 1500\, m^2$

Source-destination pairs are randomly selected

*Random waypoint model* with the node speed of $0 \sim 5\, m/sec$ and pause time between moves varies from 0 to 900 seconds.
Packet delivery ratio.

Fig. 4. Packet delivery ratio.
Route discovery frequency.

Fig. 5. Route discovery frequency.
Fig. 6. Cooperation ratio.
Conclusion

This paper proposes *cooperative diversity MAC* (*CD-MAC*) and discusses design issues and performance benefits in wireless ad hoc networks.

The proposed CD-MAC is designed based on the IEEE 802.11 standards and does not require any changes in frame formats, making it amenable to immediate implementation.

For accurate performance study, this paper developed a realistic reception model based on BER and FER, which are derived from Intersil radio hardware specification.