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

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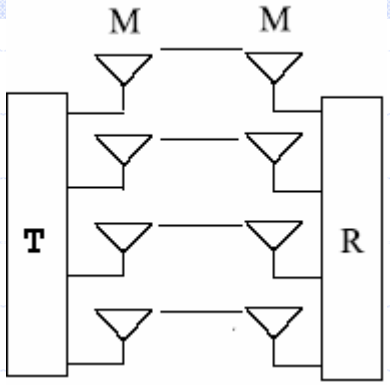
Outline

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

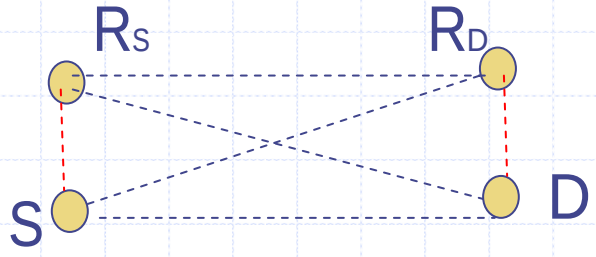
Introduction

- 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

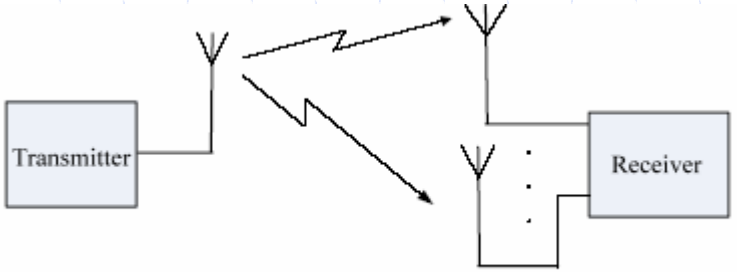
- Cooperative Diversity
- Cooperative Diversity in Wireless Ad Hoc Networks

Cooperative Diversity

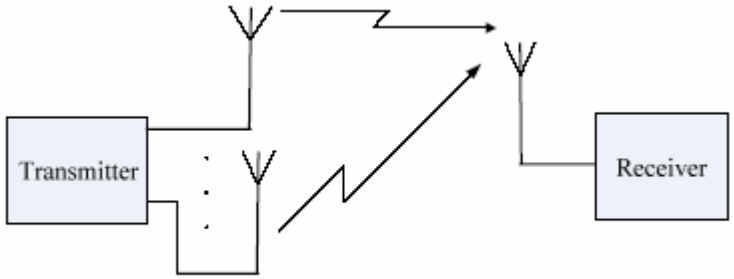
- Several cooperative signaling or relaying methods have been studied, there are two well-known techniques, called repetition-based cooperative algorithms:
  - Amplify-and-forward
  - Decode-and-forward
- The corresponding benefits come at a price of decreasing bandwidth efficiency because each relay 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



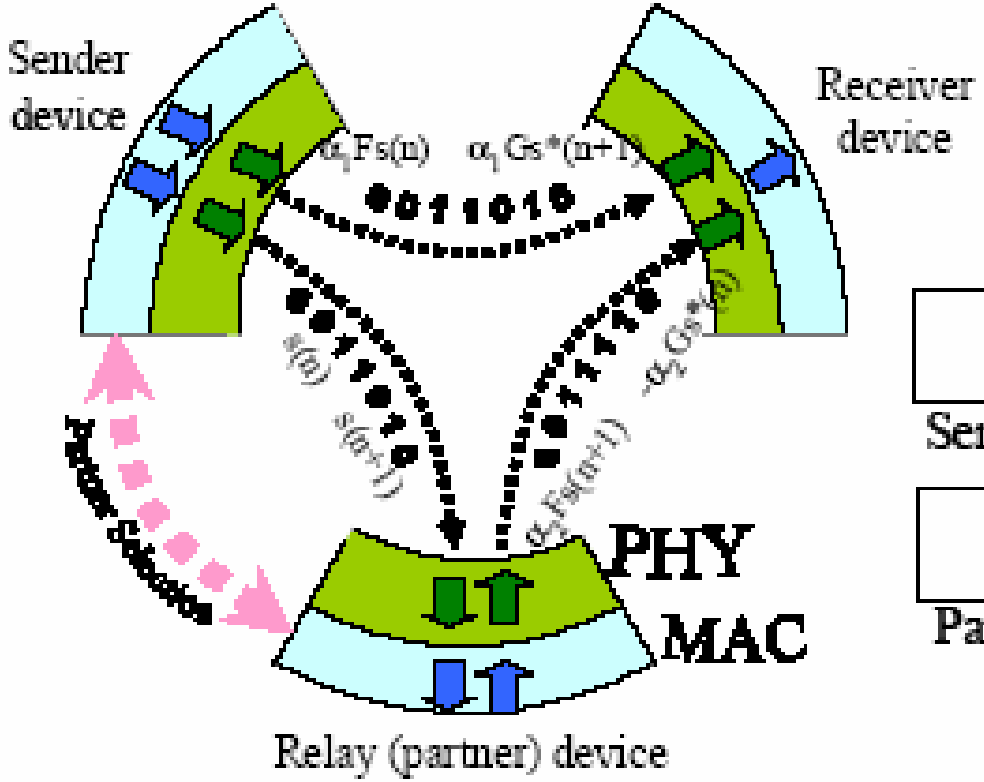
Receive diversity system.



Transmit diversity system.

Distributed space-time coding

- Consider a simple three-node example with sender, relay (partner) and receiver devices as in Fig. 1.



	Time slot 1	Time slot 2
Sender	s(n) s(n+1)	$\alpha_1 Fs(n)$ $\alpha_1 Gs^*(n+1)$
Partner		$\alpha_2 Fs(n+1)$ $-\alpha_2 Gs^*(n)$

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

COOPERATIVE DIVERSITY MAC

- 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 *ri* retransmit the packet cooperatively.
- Note that the relay *ri* 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 *rj*.
- 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.

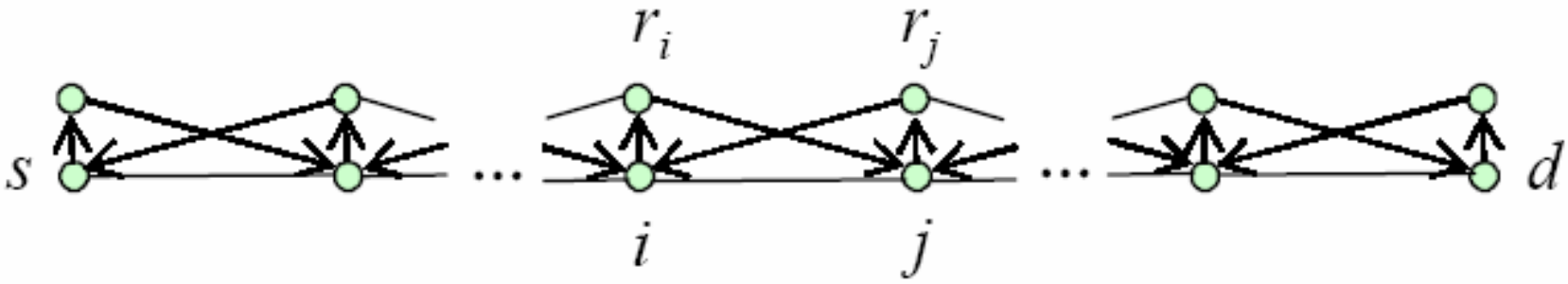
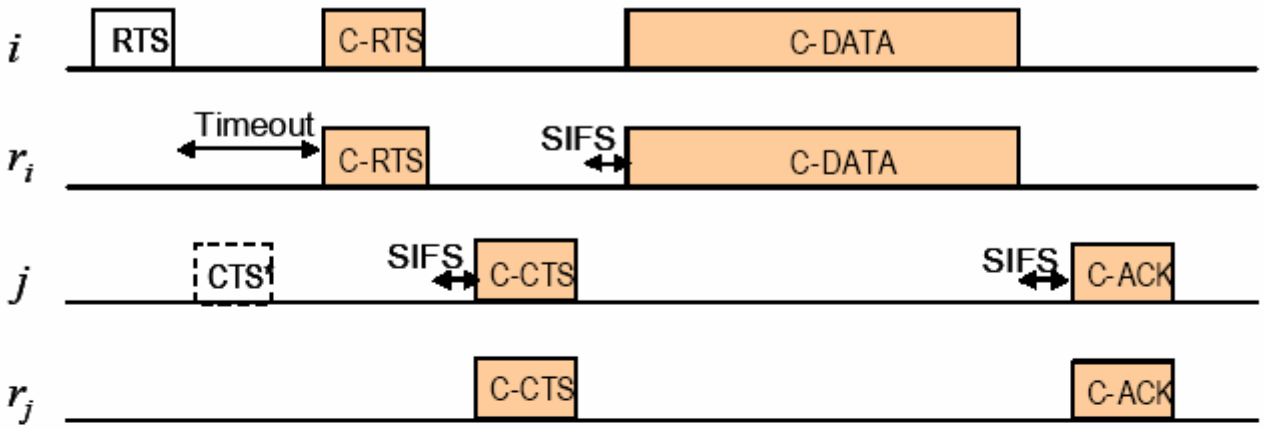
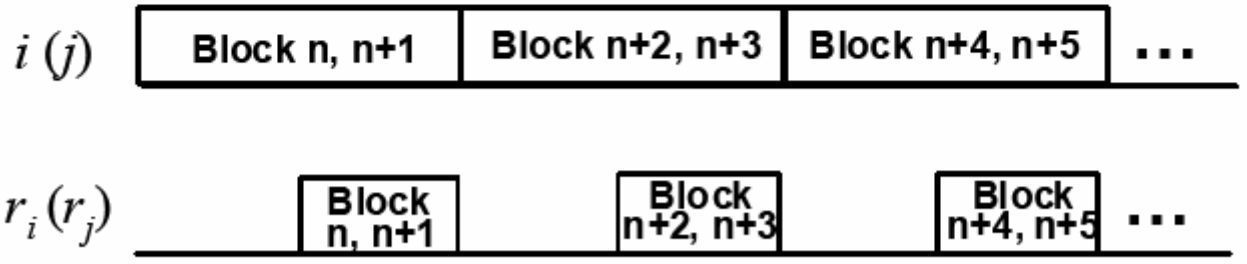


Fig. 2. Cooperative transmission with relays along a routing path.

COOPERATIVE DIVERSITY MAC



(a) Four-way handshaking



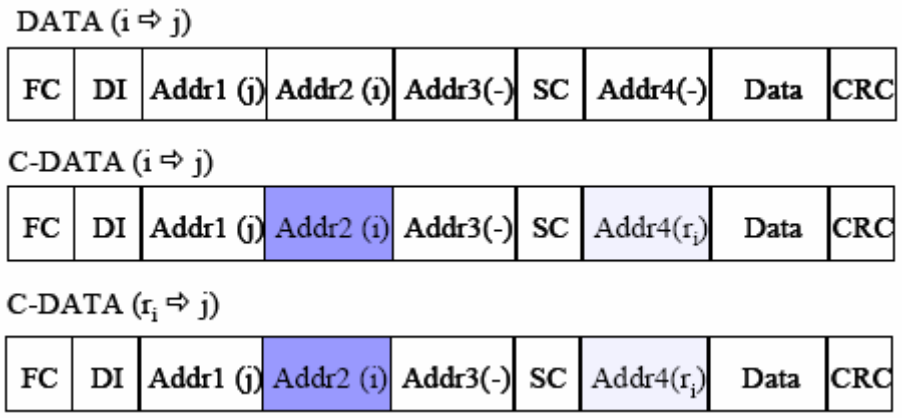
((b) Transmission blocks of C-RTS, C-CTS, C-DATA and C-ACK

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



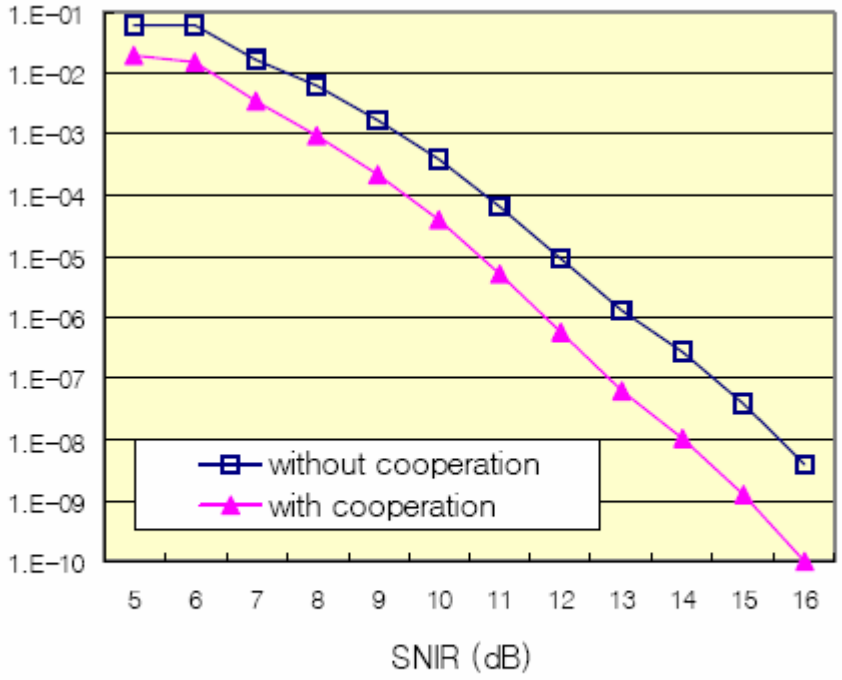
Performance

- Reception Model
- Simulation Environment

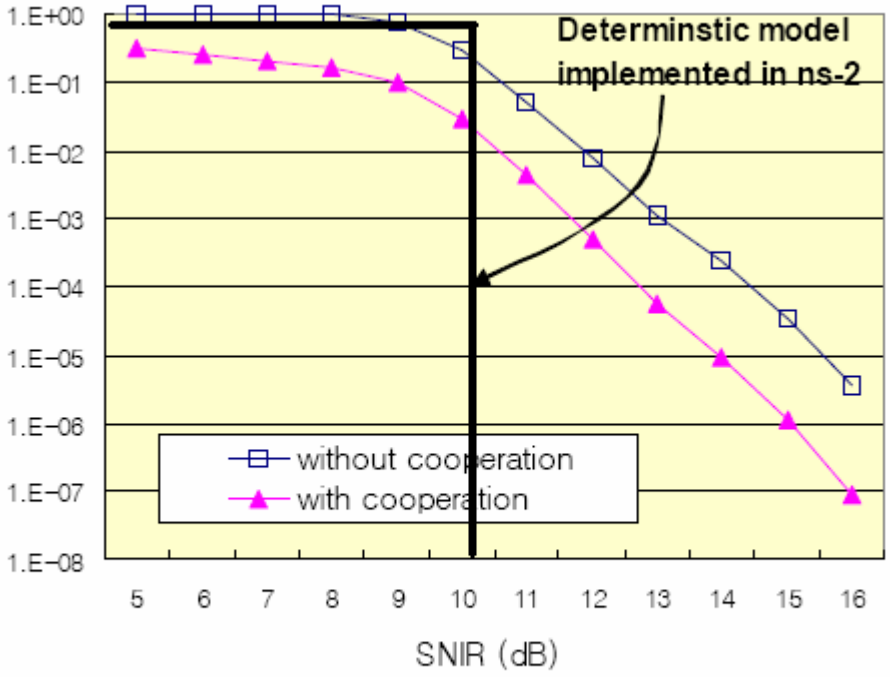
Reception Model

- 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

Simulation Environment

- 50 mobile nodes move over a square area of $300 \times 1500m2$
- Source-destination pairs are randomly selected
- ***Random waypoint model*** with the node speed of 0 ~ 5 m/sec and pause time between moves varies from 0 to 900 seconds.

Packet delivery ratio.

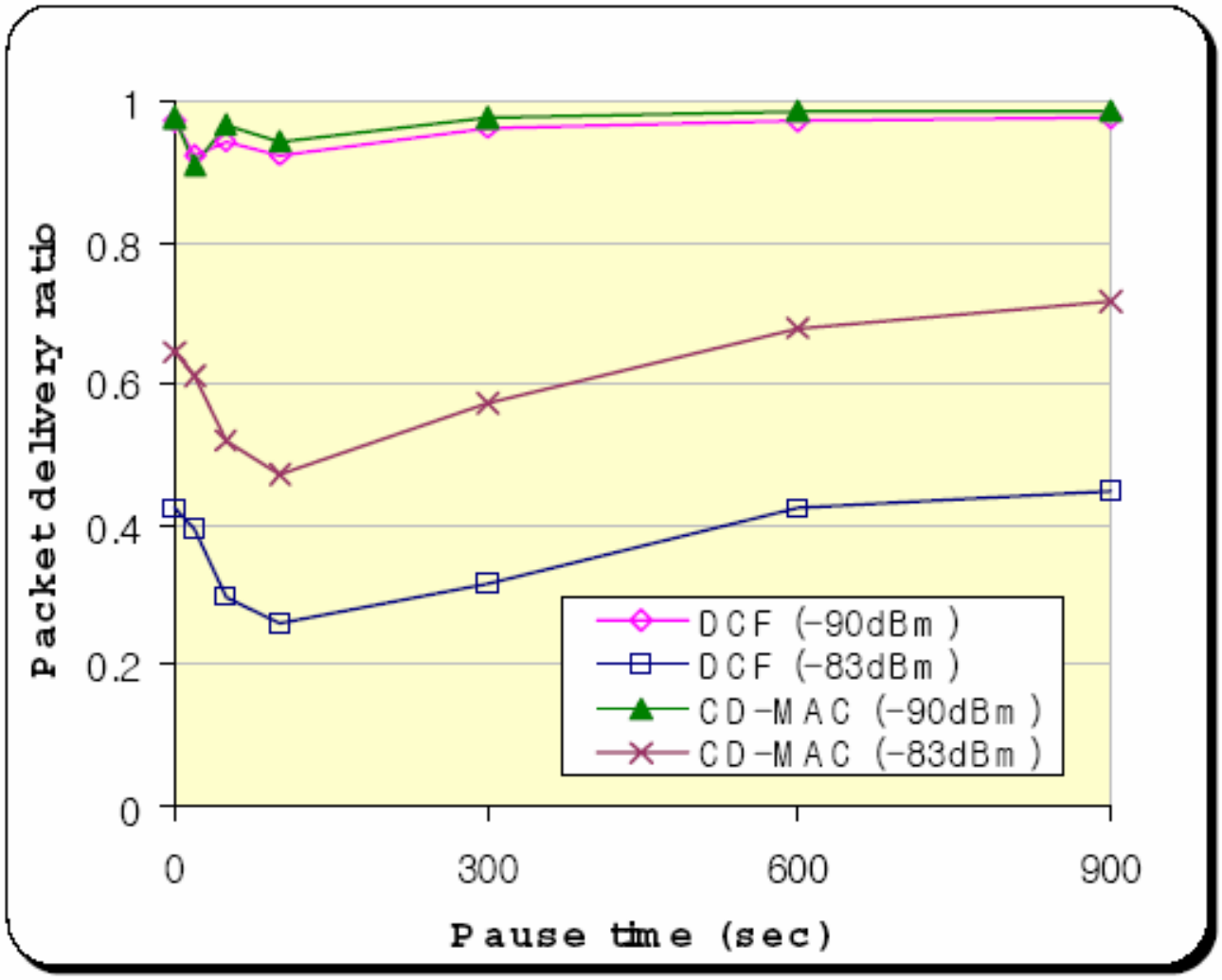


Fig. 4. Packet delivery ratio.

Route discovery frequency.

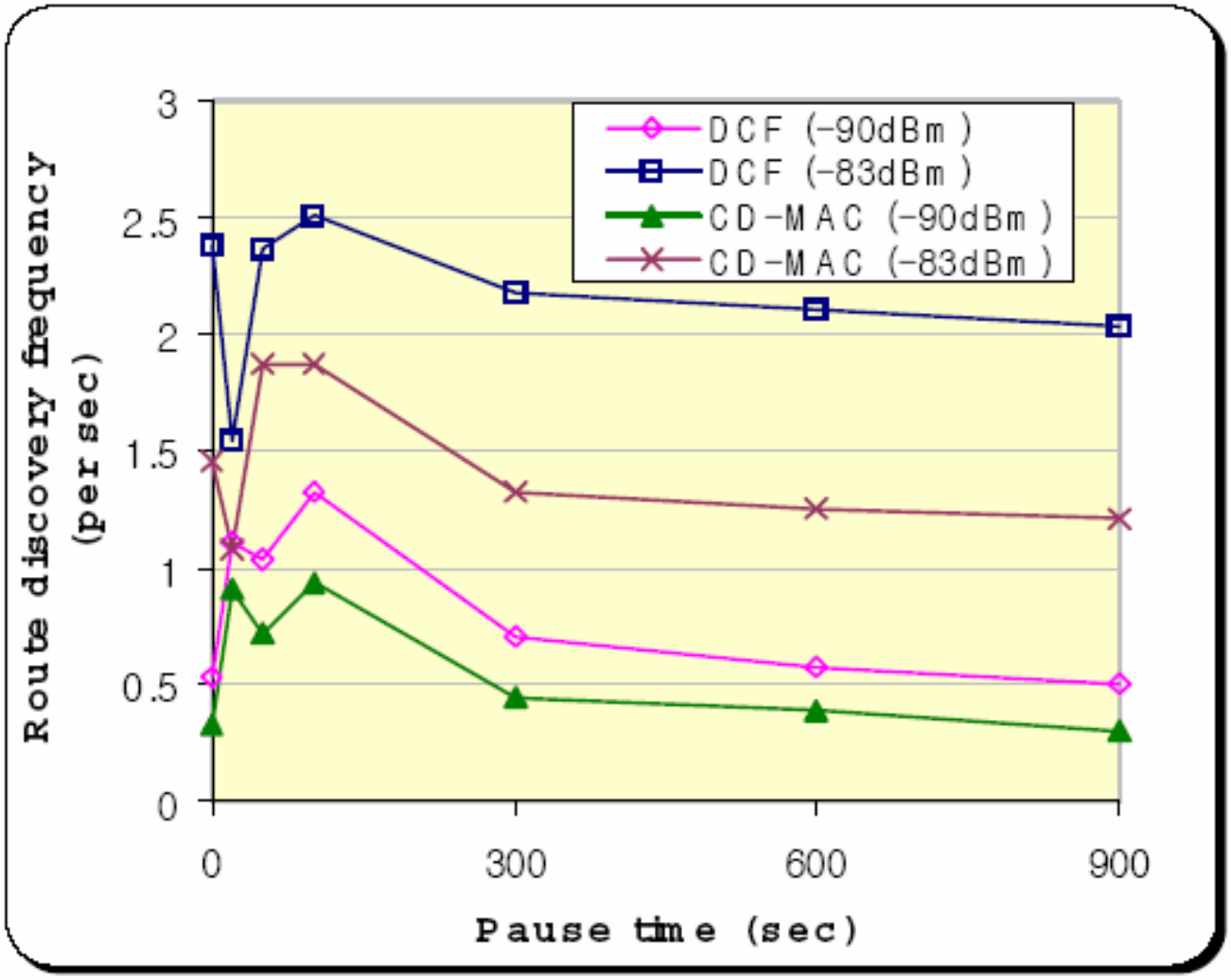


Fig. 5. Route discovery frequency.

Cooperation ratio

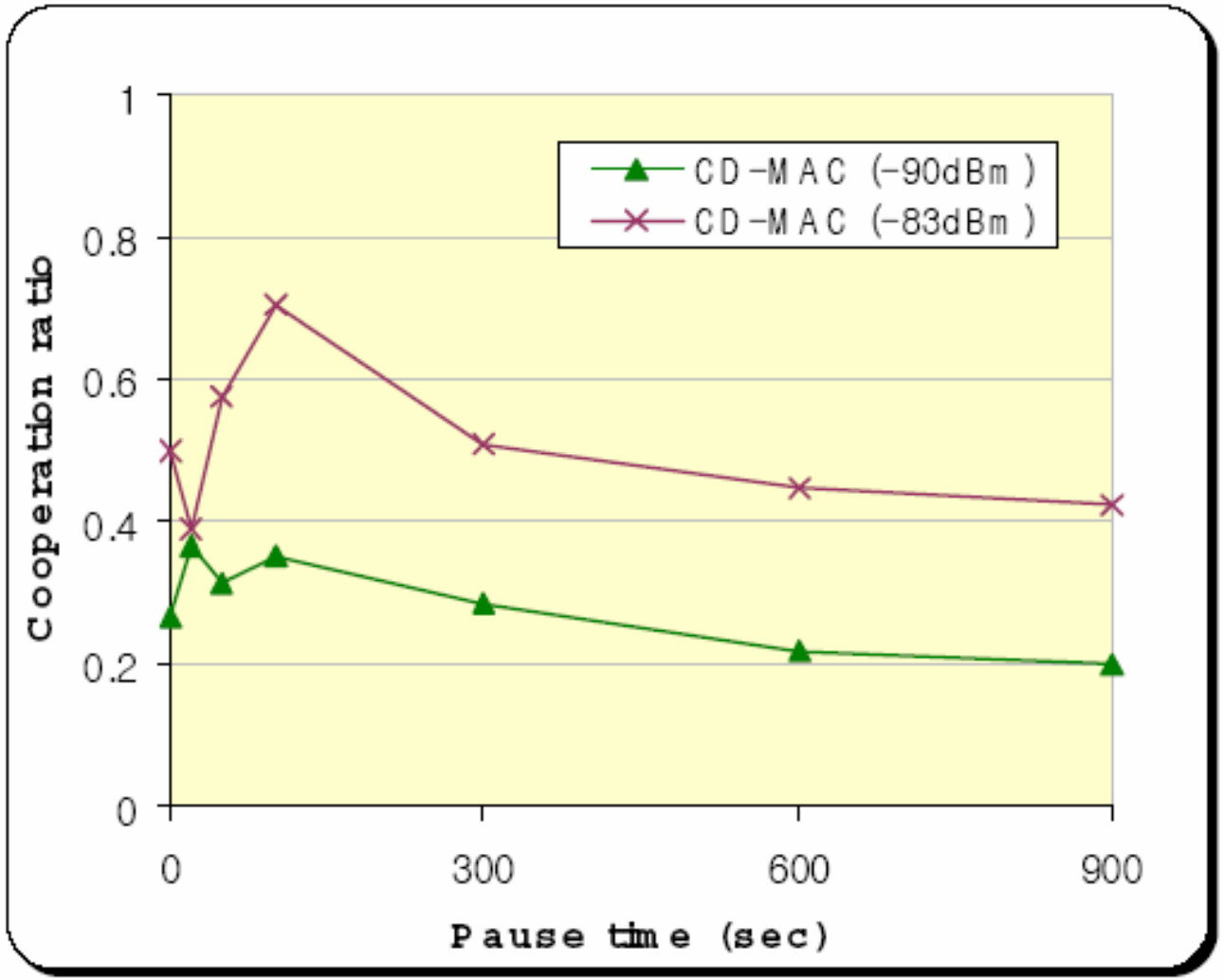


Fig. 6. Cooperation ratio.

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.