ADVANCED MAC/PHY DESIGN:
A COOPERATION CASE STUDY

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(work available in CISS 2010 proceedings)
• MIMO boosts speed/reliability
• Requires an antenna array
  • Impractical for some applications (e.g. cellphones)
• Pitfalls:
  • In high-SNR situations, “Relay Phase” is pure overhead
  • How do you synchronize source and relay?
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  • In high-SNR situations, “Relay Phase” is pure overhead
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**Distributed On-demand Cooperation (DOC)**
• Completely severed from centralized scheduling
• Only cooperates when it can help
• Emphasis on practicality; we’ve built it
• MAC Details
• PHY Details
• Implementation Details
• Measurement Results
• CSMA/CA assumes *every* packet loss is due to a collision
Transmission Success

Transmission → Success

Failure

NACKs

Collision Detection

Random Backoff

Retransmission

Collision

No Collision

Cooperative Retransmission
Initial Transmission

Header ✔️
Payload ✔️

Header ✔️
Payload ✗
NACK Transmission

Coop. Retransmission
Broadcast Phase

Relay Phase

\[
\text{ANT}_A = [s_0, -s_1^*, s_2, -s_3^*, \ldots]
\]
Distributed Alamouti STBC

Broadcast Phase

\[ \text{ANT}_A = [s_0, -s_1^*, s_2, -s_3^*, \ldots] \]

Relay Phase

\[ \text{ANT}_A = [s_0, -s_1^*, s_2, -s_3^*, \ldots] \]
Distributed Alamouti STBC

Broadcast Phase

ANT_A = \[ s_0, -s_1^*, s_2, -s_3^*, \ldots \]  
ANT_B = \[ s_1, s_0^*, s_3, s_2^*, \ldots \]

Relay Phase
DOCIIMPLEMENTATION
PowerPC

Logic
Solution: Harden packet responses to fabric
Source Tx:

Relay Tx:

200ns
Computer

Ethernet Switch

Source WARP Node

Relay WARP Node

Destination WARP Node

Wireless Channel Emulator

HSD

HSR

HRD
DOC mimics multihop routing. The exchanges in Figures demonstrate the sufficiency of either the source or relay by packet losses due to channel fades. The labels highlight various channel conditions where the source-destination link does not require help from the relay where the SzD channel degrades sufficiently that the relay actively participates in fewer than 58% of packet exchanges. The peak performance improvement is significant, exceeding 52%, even though the transmission of a two-antenna node also presents measurements of two non-cooperative schemes.

Figures also present results of throughput and throughput improvement of a DOC link over a non-cooperative SISO link, while Figure shows throughput improvement relative to a non-cooperative SISO link as a function of relay location. The DOC throughput improvement relative to a non-cooperative SISO link as a function of relay location is significant, exceeding 52%. The SISO line corresponds to a source-destination link running on a link connecting the source and destination. The throughput plot lines tracing constant paths through values interpolated between theElementException values. The SISO line shows the throughput of a non-cooperative link where the relay does not participate in that exchange.

**Graphical Elements**

- **Throughput Improvement over CSMA/CA**
  - **Y-Axis**: Relay Location Y (meters)
  - **X-Axis**: Relay Location X (meters)
  - **Color Bar**: 0% - 20%
  - **Markers**: Probability of cooperation
  - **Legend**: Throughput Improvement over CSMA in 2D Topology
  - **Legend Labels**: 10%, 15%, 20%

**Experimental Results**

- 2452 MHz RF
- AF relay
- 1400 byte packets
- TGn B channel model
- BPSK/QPSK header/payload
- No synchronization “cheats”
The labels highlight various channel events showing on-demand cooperation initiated in delivering the full payload to the destination. DOC mimics multihop routing. The exchanges in Figures show the probability of the relay participating in a given packet exchange at each location. It is clear from these plots that the relay provides the most benefit when located near the peak performance of a two-antenna node. This is an intuitive result, as this proximity mimics the random channel coefficients imposed by the emulator.

At this scale, it is possible to visualize channel variations viewed over a much longer time scale (approximately 658 ms). The line shows the throughput of a noncooperative link where the relay participates in fewer than 5% of packet exchanges. Thus, the 2x1 MISO line represents an upper bound to the expected throughput. Branching, which leads to fewer retransmissions and hence increased end-to-end throughput, presents results of throughput and is a function of relay location. Figure shows throughput improvement of a relay-aided DOC link over a noncooperative SISO link, while Figure presents experimental results for DOC. Each dot presents measurements of two noncooperative schemes.

The SISO line corresponds to a source-destination link running in the absence of a relay. The 2x1 MISO and the DOC MAC/PHY in the absence of a relay also presents results. The throughput plot lines tracing constant paths through values interpolated between two antennas at the source. The multiplexing gain of 3 in Alamouti MISO mode, transmitting simultaneously from the source uses the DOC MAC protocol but the PHY operates.
sustain any communication or cooperate and where the link degrades to the point that it cannot relay where the channel degrades sufficiently that the relay actively conditions where the source-destination link does not require help from the relay due to packet losses due to channel fades. The labels highlight various channel transmission in delivering the full payload to the destination.

DOC mimics multihop routing. The exchanges in Figures demonstrate the sufficiency of either the source or relay for transmission. In this exchange, the relay retransmits the DATA packet it received previously. The exchanges in Figures also present measurements of two noncooperative schemes. The SISO line corresponds to a source-destination link running the same slope [59]. However, at the finite SNRs of interest, the asymptotic growth of capacity for MISO and SISO have the same slope. The MISO system is the same as a SISO system, which implies that the 3 × 3 MISO reduces packet losses due to added diversity.

The peak performance probability of cooperation, for 62 relay locations along the line, shows the throughput of a noncooperative link where the relay participates in fewer than 58% of packet exchanges. The SISO line shows the throughput of a noncooperative SISO link, while the 5 × 3 MISO line represents an upper bound to the DOC performance. As a true MISO link realizes full diversity, the relay provides the most benefit when located near the source node. This is an intuitive result, as this proximity mimics the transmission of a two-antenna node. The multiplexing gain of 5 in Alamouti MISO mode, transmitting simultaneously from two antennas at the source, uses the DOC MAC protocol but the PHY operates in the absence of a relay.

The throughput plot also presents results of throughput and shows the probability of cooperation, u, for 62 relay locations along the line. Figure shows throughput improvement of a relay-aided DOC link over a noncooperative SISO link, while Figure , presents experimental results for DOC.

Figure uses the same four signals as the previous figures, and the resulting node transmissions. The node behaviors in the view over a much longer time scale (approximately 658 ms) are the real-time reactions of the DOC MAC-PHY to the random channel coefficients imposed by the emulator. How does the throughput of a noncooperative SISO link compare to 5 × 3 MISO line? It shows the throughput of a noncooperative SISO link, while the 5 × 3 MISO line represents an upper bound to the DOC performance. As a true MISO link realizes full diversity, the relay provides the most benefit when located near the source node. This is an intuitive result, as this proximity mimics the transmission of a two-antenna node. The multiplexing gain of 5.5 in Alamouti MISO mode, transmitting simultaneously from two antennas at the source, uses the DOC MAC protocol but the PHY operates in the absence of a relay. The SISO line corresponds to a source-destination link running the same slope [59]. However, at the finite SNRs of interest, the asymptotic growth of capacity for MISO and SISO have the same slope. The MISO system is the same as a SISO system, which implies that the 3 × 3 MISO reduces packet losses due to added diversity.
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