Evaluation of Turbo H-ARQ Schemes for Cooperative MIMO Transmission

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Outline

- Cooperative transmission schemes
- Distributed space-time codes
- Retransmission protocols
- Results
- Conclusions and trend lines
Cooperation for an ad-hoc multihop scenario

[Barbarossa03, Sendonaris03]

Source node

Destination node

MAC
- TDD/TDMA operation

Twice the physical resources used
- Resource allocation in the relay slot crucial is for high network capacity
Cooperation for an ad-hoc multihop scenario

Source node

Destination node

MAC
- TDD/TDMA operation

Equivalent to a MIMO system

TDD/TDMA frame

[LaNeman03]
Capacity gains of the cooperative schemes

Creates a “virtual” multiple input-multiple output (MIMO) transmission scheme ⇒ Capacity gains!

Operating modes for cooperative schemes:

- **Amplify and forward (AF)**
  The relay amplifies and retransmits the received signal

- **Decode and forward (DF)**
  The relay decodes and transmits the decoded symbols

**Capacity** is close to a $M \times 2N$ MIMO system

**Capacity** is close to a $(M + R) \times 2N$ MIMO system
Cooperation in a cellular system: DL

**MAC**
- TDD/TDMA operation
- One of the time slots shared for cooperation

**PHY**
- Multiple antennas at BS and (possibly) at the RS

**RRM**
- Power allocation for the relay slot
- Scheduling based on the cooperative channel state
Particularities of cooperative schemes

Difficulties

- Erroneous reception at the relay channel
- Number of physical resources: reuse of relay channel
Cellular reuse of the relay channel

- Game theoretical approach: *interaction of decision-makers* with conflicting objectives (power selection).

- **Decentralized algorithm**

- Components of the *non-cooperative game*
  - A set of players: \( \text{UE} = \{1,2,...,K\} \)
  - Actions for each player (relay power)
  - Utility function to map actions into the real numbers (maximise the bits/joule)

Single link throughput figures have to be scaled to a factor \( K/(K+1) \)

\[ \text{M}=2, \text{N}=1, \text{R}=1 \quad \text{Max users}=9 \quad \text{case}=10 \quad \text{DF-UC} \quad \text{Users in Cooperation} \]
Particularities of cooperative schemes

Difficulties

- Erroneous reception at the relay channel
- Number of physical resources: reuse of relay channel

Design options:

- Space-time coding: distributed codewords
- A&F or D&F operation
- Combined FEC/Retransmission scheme
- Role of relay node in retransmissions:
  - Incremental
  - Selective
- Receivers: linear vs. optimum
Cooperative transmission (I)

- Turbo coded transmission schemes
  - Non Cooperative
    - Alamouti
  - Cooperative A&F \((R=1)\)
    - Alamouti, VBLAST or QOD
  - Cooperative D&F \((R=2)\)
    - Alamouti, VBLAST or QOD

- Retransmission combining schemes
  - HARQ I
  - HARQ II

\(\sim 2\times2\) MIMO system
Distributed Space Time Coding

D&F implementation

Space-time matrix associated to symbol $q$

$$A_q = \begin{bmatrix}
a_{11} & \cdots & a_{1M} \\
\vdots & \ddots & \vdots \\
a_{T1} & \cdots & a_{TM}
\end{bmatrix}$$

Data associated to M tx antennas

Data associated to R tx antennas

Data associated to one transmitting antenna
Cooperative transmission (II)

- Turbo coded transmission schemes
  - Non cooperative
    - Alamouti
    - Cooperative A&F (R=1)
      - Alamouti, VBLAST or QOD
    - Cooperative D&F (R=2)
      - Alamouti, VBLAST or QOD
  - If the packet is wrongly decoded, incremental information is transmitted and combined at the receiver

2x1 MIMO system
Cooperative transmission (II)

- Turbo coded transmission schemes
  - Non cooperative
    - Alamouti
  - Cooperative A&F (R=1)
    - Alamouti, VBLAST or QOD
  - Cooperative D&F (R=2)
    - Alamouti, VBLAST or QOD

\[ \sim 2x2 \text{ MIMO system} \]
Cooperative transmission (II)

- **Turbo coded transmission schemes**
  - Non cooperative
    - Alamouti
  - Cooperative A&F (R=1)
    - Alamouti, VBLAST or QOD
  - Cooperative D&F (R=2)
    - Alamouti, VBLAST or QOD

- RS and BS may use the same ST block code (for Alamouti or VBLAST), or different (for QOD)
- RS transmits uncorrelated symbols: *different transmitted parity from BS and RS*
Turbo Codes for FEC/HARQ II

- Turbo Encoder implementation

Input packet → systematic

RSC → parity

Puncturing

Input packet → output packet

rate ~ 1/3

Turbo - Encoder

Puncturing

Space-Time encoder

Improving diversity → Change puncturing
- From the relay node
- Between different retransmissions

Concatenation with ST codes

Input packet

Turbo - RSC

Parity

Puncturing output packet

Systematic parity

\[ P_{BS_{1/2}} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \end{bmatrix} \]
HARQ II Retransmission Strategy

- HARQ-II transmission in a cooperative system

\[
P^{(1)}_{BS_{1/2}} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \end{bmatrix}
\]

\[
P^{(2)}_{BS_{1/2}} = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 \end{bmatrix}
\]

- If RS decodes correctly, retransmits with puncturing matrix:

\[
P^{(2)}_{RS_{1/2}} = \begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 \end{bmatrix}
\]

\[
P^{(2)}_{RS_{1/2}} = \begin{bmatrix} 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}
\]

A new transmission is required?

**Change puncturing at BS and RS**

- Use different puncturing matrices for every retransmitted packet.
Results

- **Scenario**
  - List Sphere Decoder *(near optimum receiver)*
  - **Symmetric configuration.** All links have equal average SNR level
  - **Flat Rayleigh fading channel,** uncorrelated among links
  - 4 QAM constellation
  - **Source:** 2 antennas  **Relay:** 1-2 antennas  **Destination:** 1 antenna
  - **HARQ-II** retransmissions of equal or different size

- **Evaluation of throughput in the downlink**
  - Non cooperative 2 x 1 transmission
  - Cooperative D&F – diversity gain
  - Cooperative D&F – multiplexing gain
  - Cooperative A&F
Non cooperative vs. cooperative

Alamouti coding: Cooperation achieve about 3 dB gain
Rate of codes has no major impact: HARQ-II manages it efficiently
Cooperative D&F – multiplexing gain

Both codes achieve multiplexing gain at high SNR, but poorer performance than Alamouti at low SNR...
Cooperative D&F – multiplexing gain

... this is suggesting the choice of the STBC rate as a parameter for the dynamic link control.
Cooperative A&F

Amplify and forward (A&F) shows about 2 dB loss with respect to D&F, but that the relay may be implemented with a single antenna.
HARQ-I vs. HARQ-II retransmissions

Alamouti is used as ST coder
Retransmissions of shorter duration (in red) ⇒ approaches capacity more closely (at the expenses of higher delay)
Conclusions

- Cooperation schemes are able to provide multiplexing gains even if terminals use a single antenna, by using STBC borrowed from MIMO systems.

- Capacity approaching schemes may be based on:
  - The selection of the STBC or
  - The retransmissions at fractional rate

different implications for the selection of the MAC layer and the latency experienced.

- The A&F solution is a good compromise between performance and complexity of the relay node.
Publications

Evaluation of different ARQ schemes


Linear vs. near-optimum receivers


Design of STBC in distributed operation