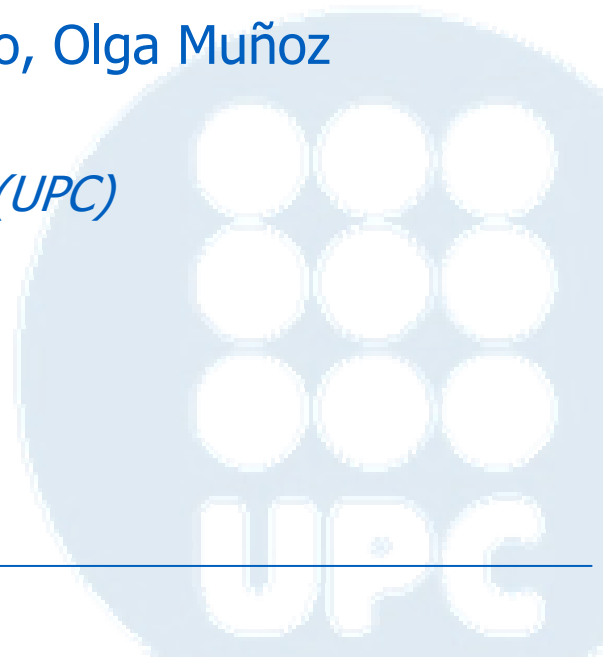


# Evaluation of Turbo H-ARQ Schemes for Cooperative MIMO Transmission

Adrián Agustín, **Josep Vidal**, Eduard Calvo, Olga Muñoz

*Universitat Politècnica de Catalunya (UPC)  
Barcelona, SPAIN*



# Partners in Romantik



**UPC – Universitat Politècnica de Catalunya**  
Prof. Josep Vidal  
Department of Signal Theory and Communications



**UoB – University of Bristol**  
Prof. Andrew Nix  
Centre for Communications Research



**DUN – Dune, Ingegneria dei Sistemi**  
Otello Gasparini



**INFO – Università di Roma "La Sapienza"**  
Prof. Sergio Barbarossa  
INFOCOM Department



**ICOM – Intracom**  
Dr. George Aggelou  
Development Projects Department



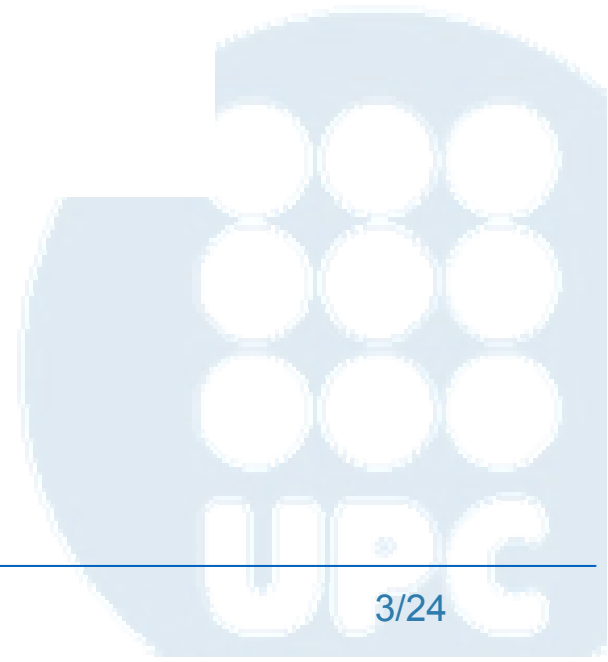
**FLE – Fujitsu Laboratories of Europe**  
Dr. Sunil Vadgama  
Advanced Radio Access Systems



**TELENOR – Telenor Communication II AS**  
Dr. Geoffrey Canright  
Telenor R&D

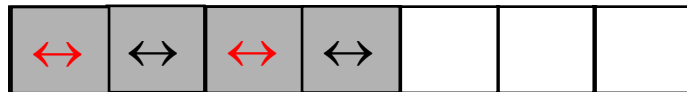
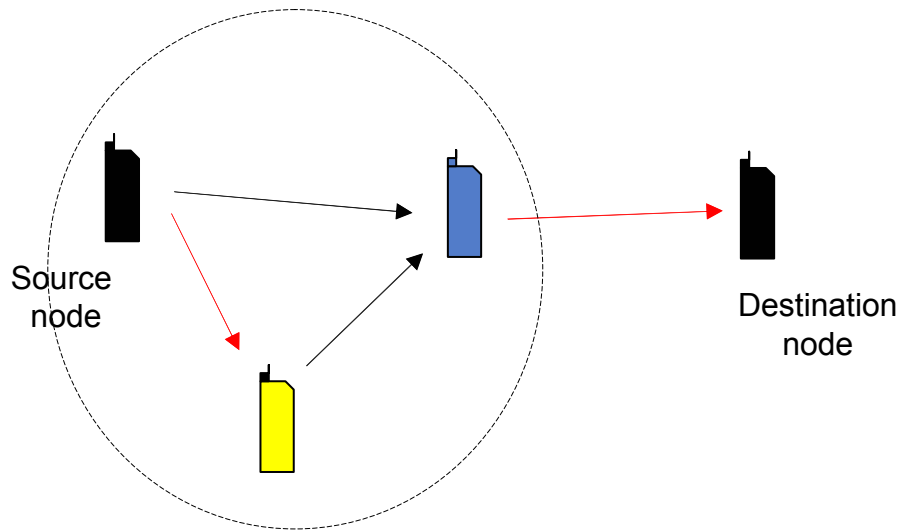
# Outline

- Cooperative transmission schemes
- Distributed space-time codes
- Retransmission protocols
- Results
- Conclusions and trend lines



# Cooperation for an ad-hoc multihop scenario

[Barbarossa03, Sendonaris03]



**TDD/TDMA frame**

## MAC

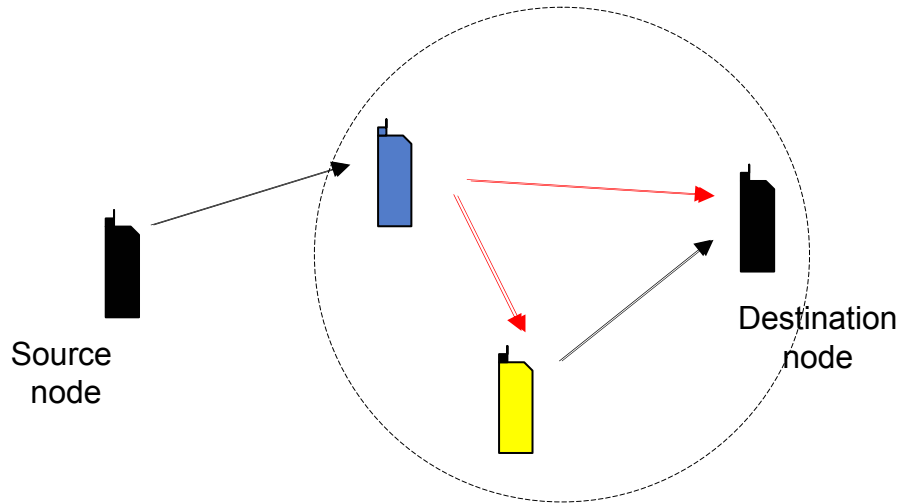
- TDD/TDMA operation

## Twice the physical resources used

- Resource allocation in the relay slot crucial is for high network capacity

# Cooperation for an ad-hoc multihop scenario

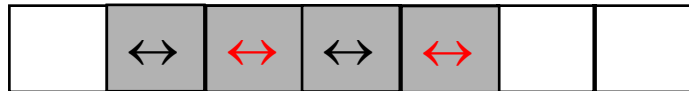
[Laneman03]



MAC

- TDD/TDMA operation

Equivalent to a MIMO system



TDD/TDMA frame

# Capacity gains of the cooperative schemes

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

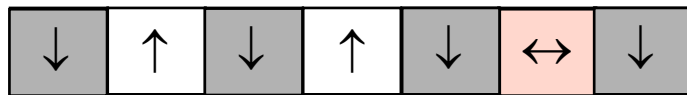
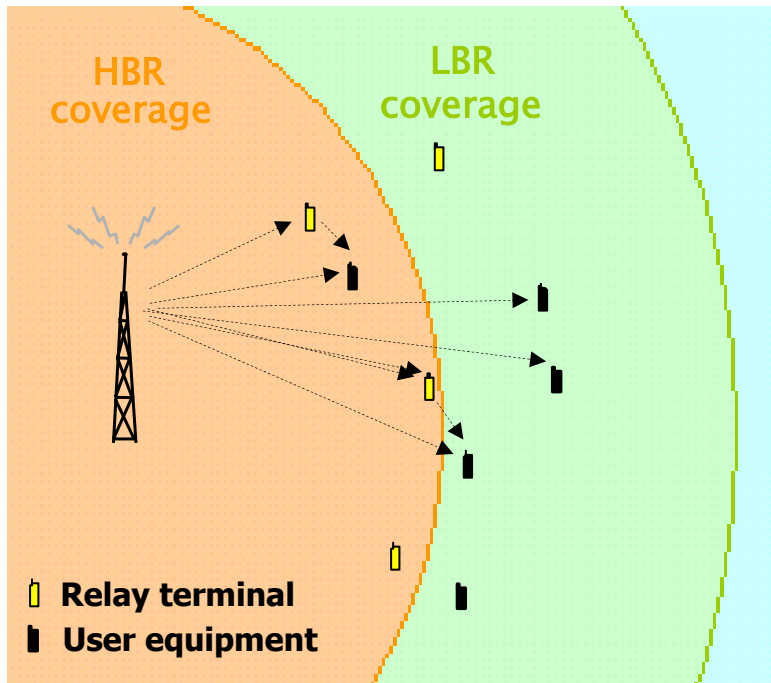
## Operating modes for cooperative schemes:

- **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



TDD/TDMA frame

## MAC

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

## PHY

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

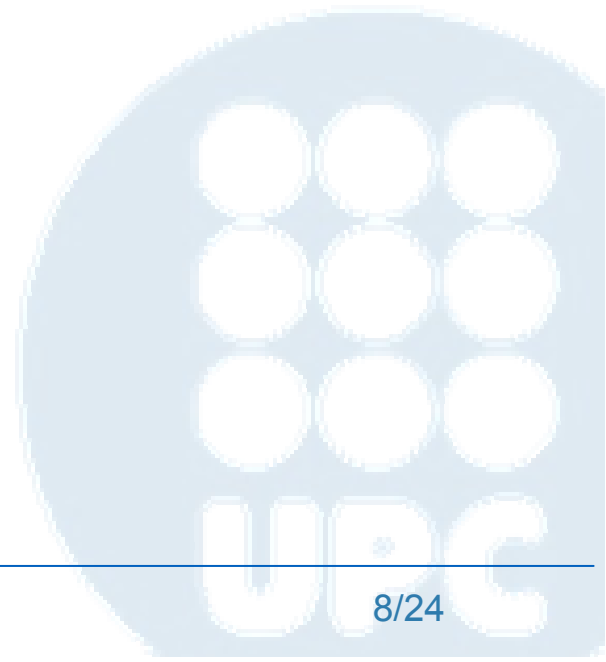
## RRM

- Power allocation for the relay slot
- Scheduling based on the cooperative channel state

# Particularities of cooperative schemes

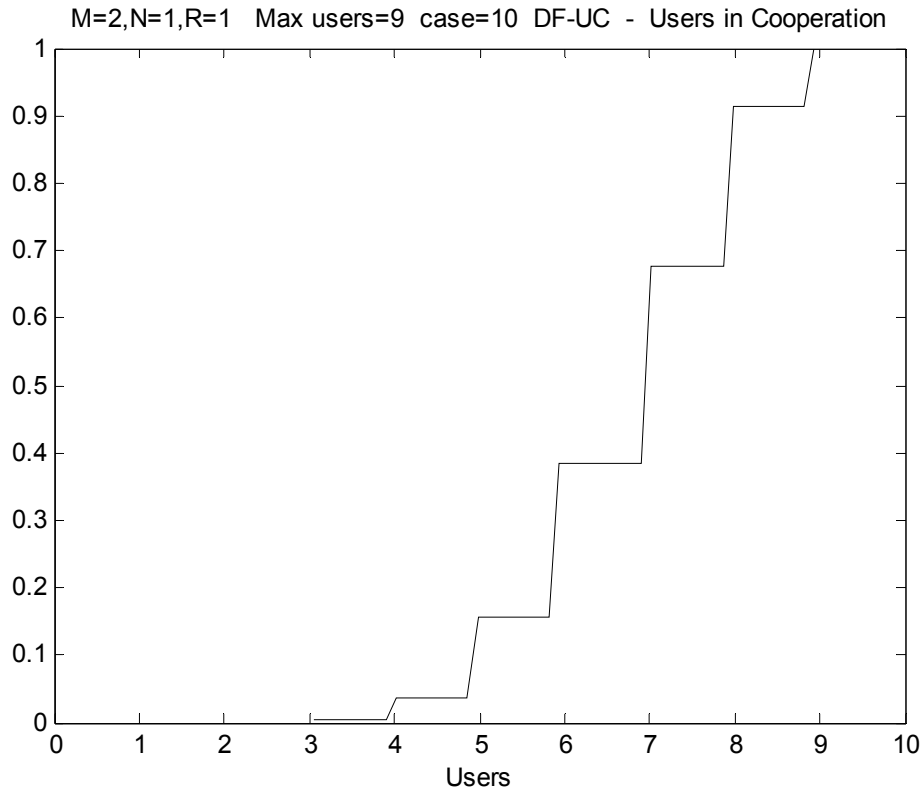
## Difficulties

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



# Cellular reuse of the relay channel

[Agustin04]



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

- Game theoretical approach: **interaction of decision-makers** with conflicting objectives (power selection).
- **Decentralized algorithm**
- Components of the **non-cooperative game**
  - A set of players:  $UE = \{1,2,\dots,K\}$
  - Actions for each player (relay power)
  - Utility function to map actions into the real numbers (maximise the bits/joule)

# Particularities of cooperative schemes

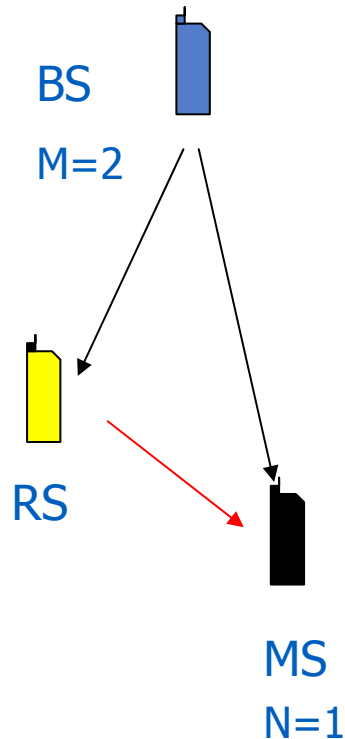
## Difficulties

- 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)



~ **2x2 MIMO system**

- **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*

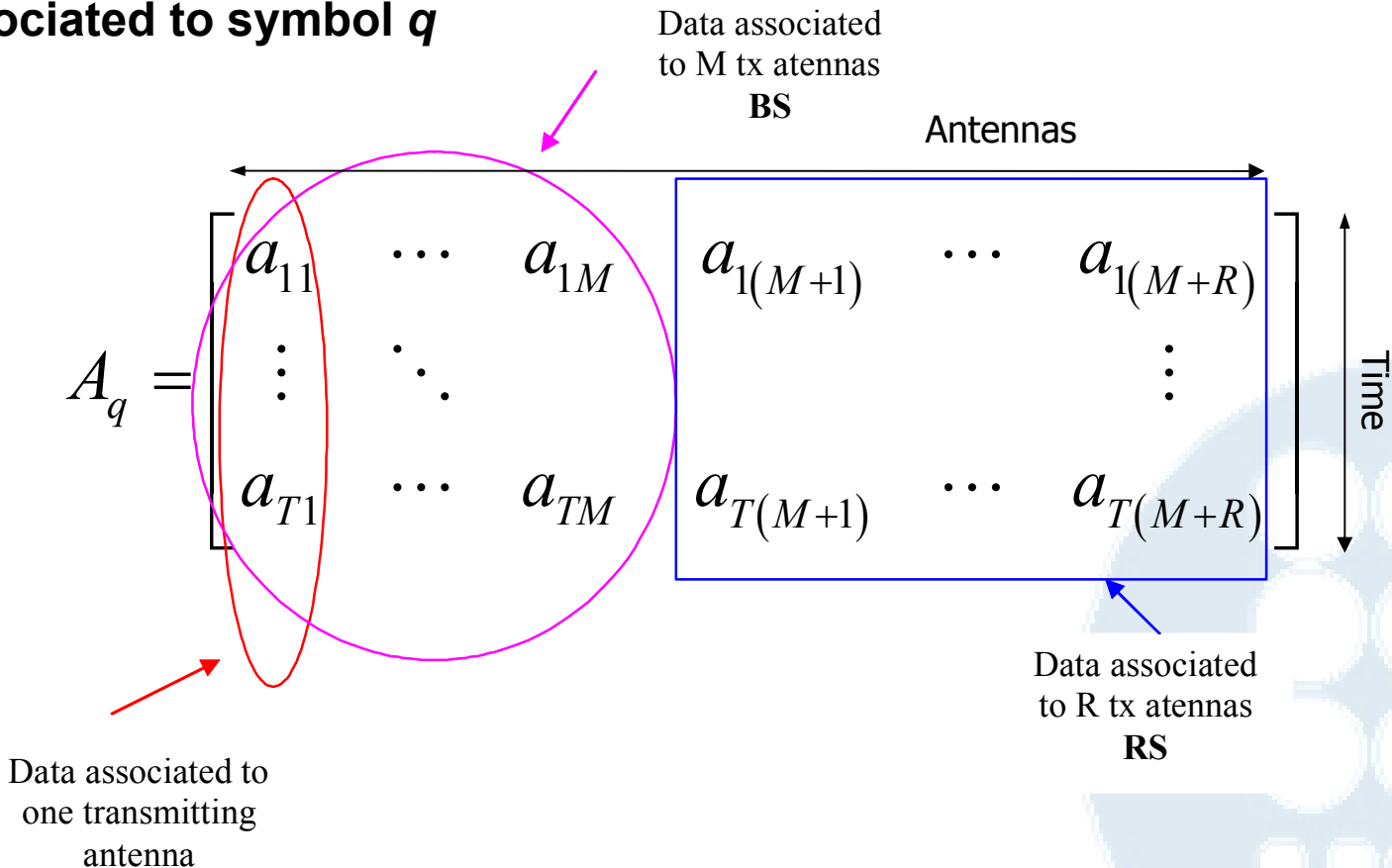
- **Retransmission combining schemes**

- HARQ I
- **HARQ II**

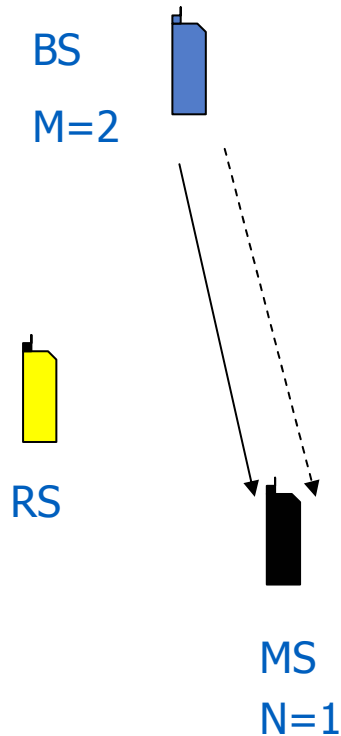
# Distributed Space Time Coding

## D&F implementation

### Space-time matrix associated to symbol $q$



# Cooperative transmission (II)



**2x1 MIMO system**

- **Turbo coded transmission schemes**

- Non cooperative

- *Alamouti*

- Cooperative A&F (R=1)

- *Alamouti, VBLAST or QOD*

- Cooperative D&F (R=2)

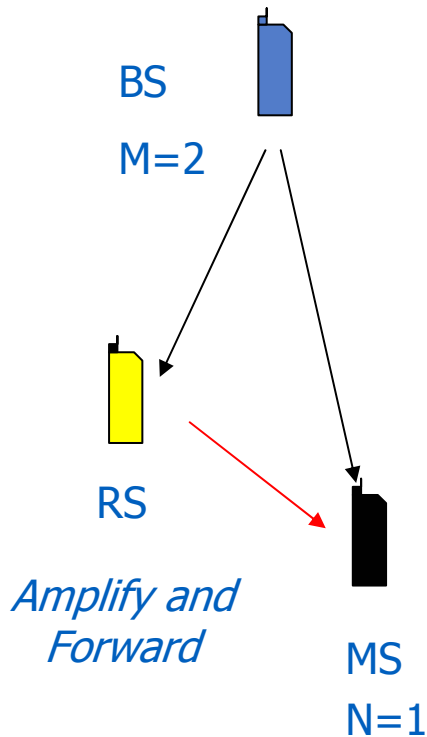
- *Alamouti, VBLAST or QOD*

- **If the packet is wrongly decoded, incremental information is transmitted and combined at the receiver**

# Cooperative transmission (II)

- **Turbo coded transmission schemes**

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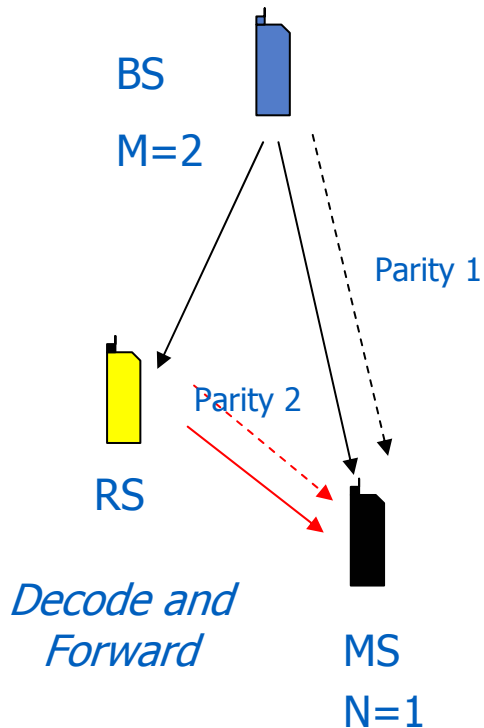


~ **2x2 MIMO system**

# Cooperative transmission (II)

- **Turbo coded transmission schemes**

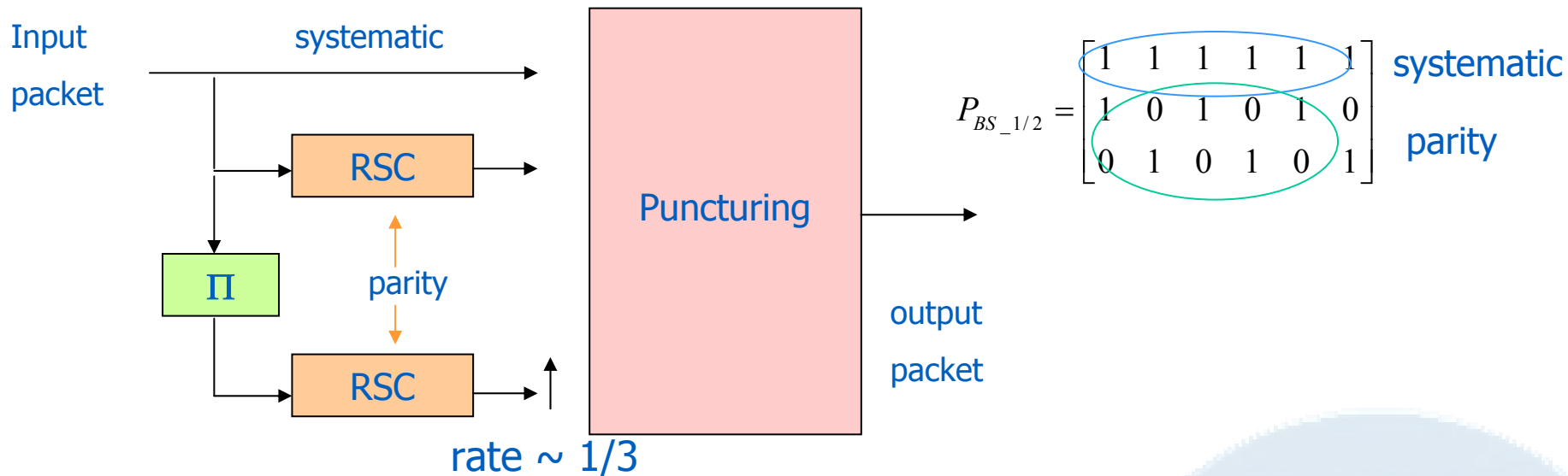
- Non cooperative
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  - *Alamouti, VBLAST or QOD*
- Cooperative D&F ( $R=2$ )
  - *Alamouti, VBLAST or QOD*



- **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

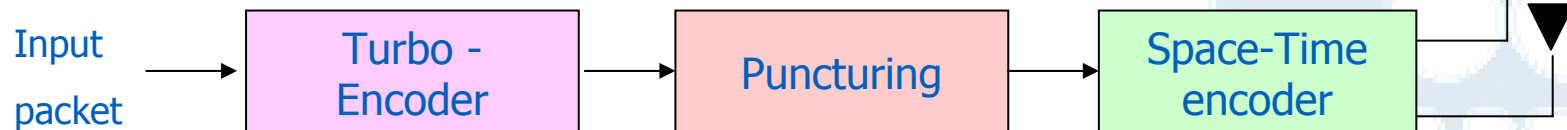
## • Turbo Encoder implementation



Improving diversity  $\rightarrow$  Change puncturing

- From the relay node
- Between different retransmissions

## • Concatenation with ST codes



# HARQ II Retransmission Strategy

- HARQ-II transmission in a cooperative system

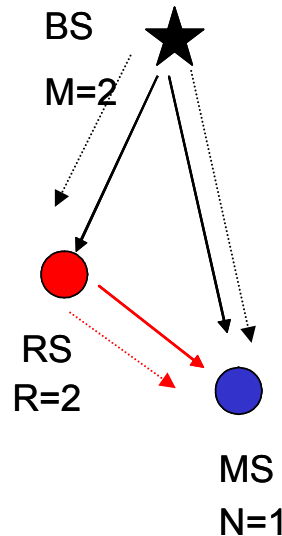
$$P_{BS\_1/2}^{(1)} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \end{bmatrix}$$

$$P_{BS\_1/2}^{(2)} = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 \end{bmatrix}$$

- If RS decodes correctly, retransmits with puncturing matrix:

$$P_{RS\_1/2} = \begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 \end{bmatrix}$$

$$P_{RS\_1/2}^{(2)} = \begin{bmatrix} 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$



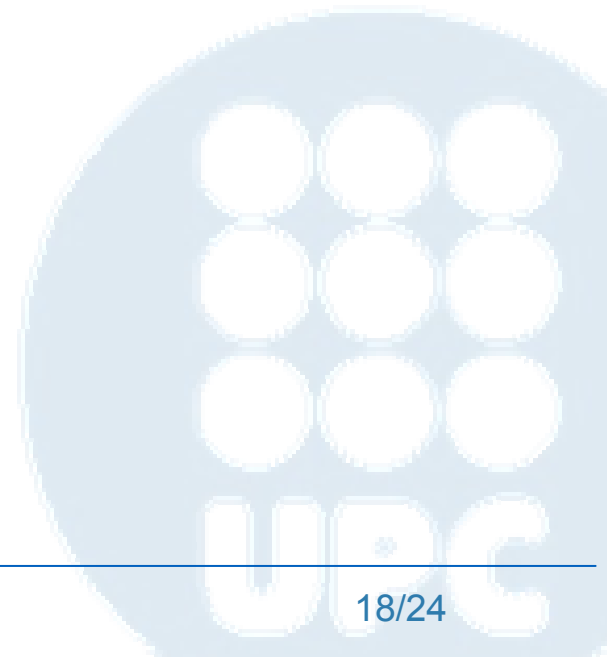
A new transmission is required ?

***Change puncturing at BS and RS***

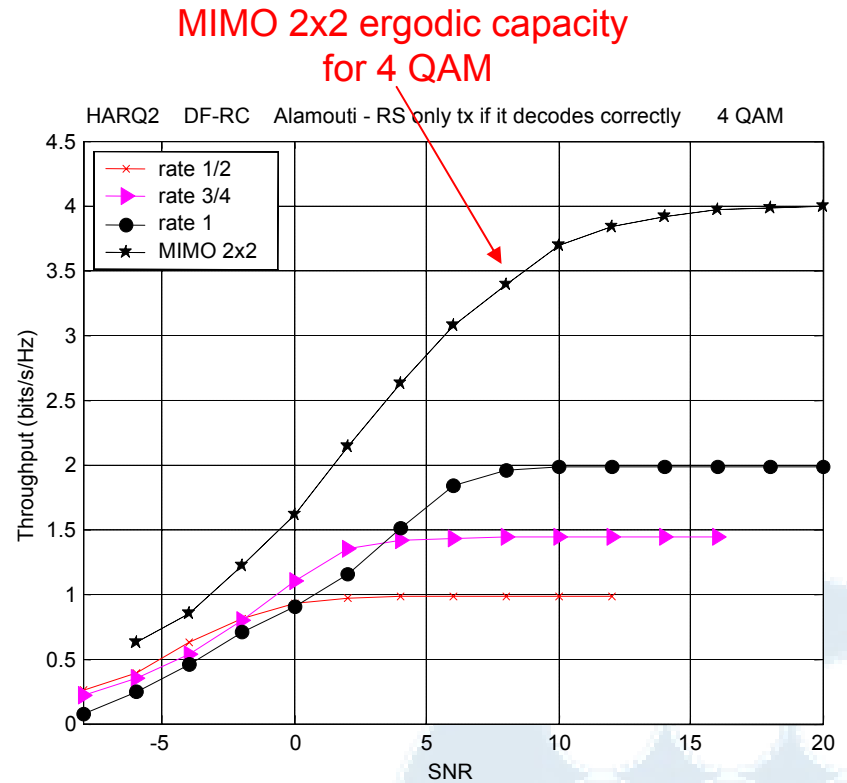
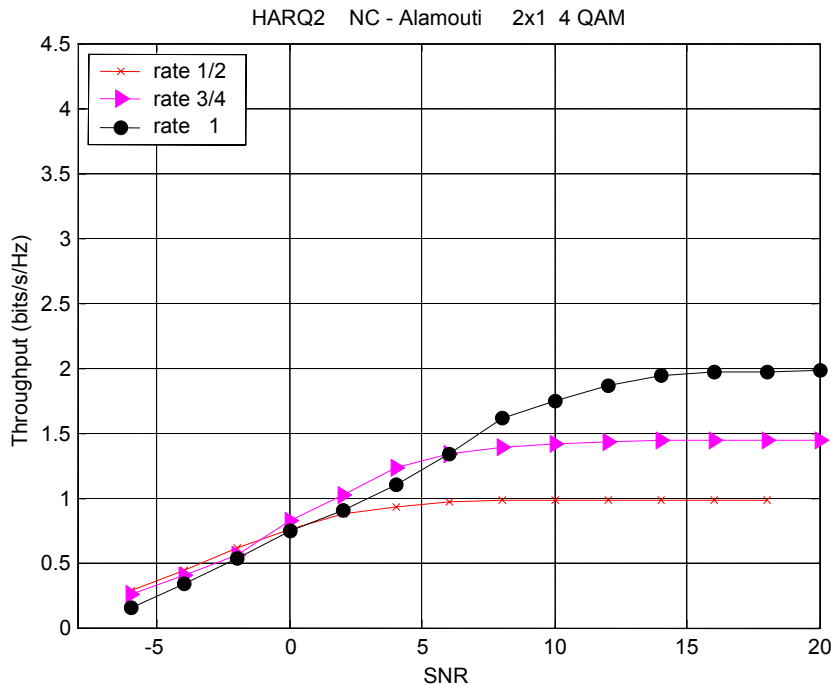
- Use different puncturing matrices for every retransmitted packet

# 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

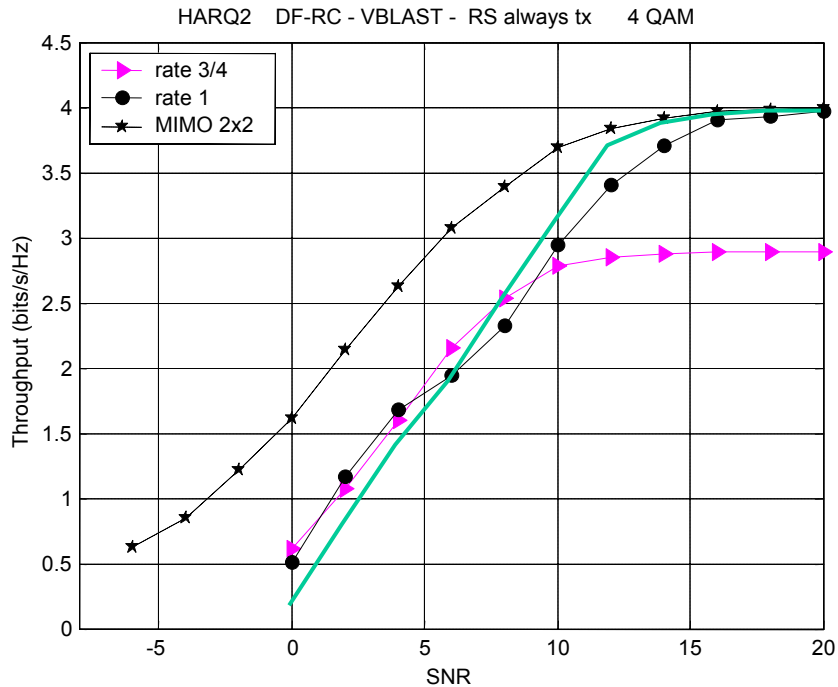


# Non cooperative vs. cooperative

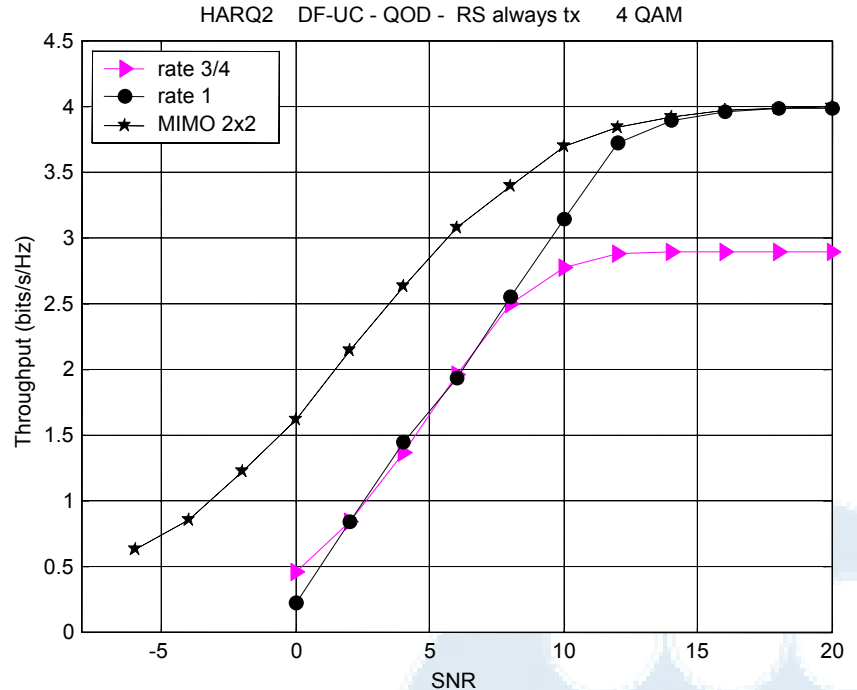


Alamouti coding: Cooperation achieve about 3 dB gain  
 Rate of codes has no major impact: HARQ-II manages it efficiently

# Cooperative D&F – multiplexing gain



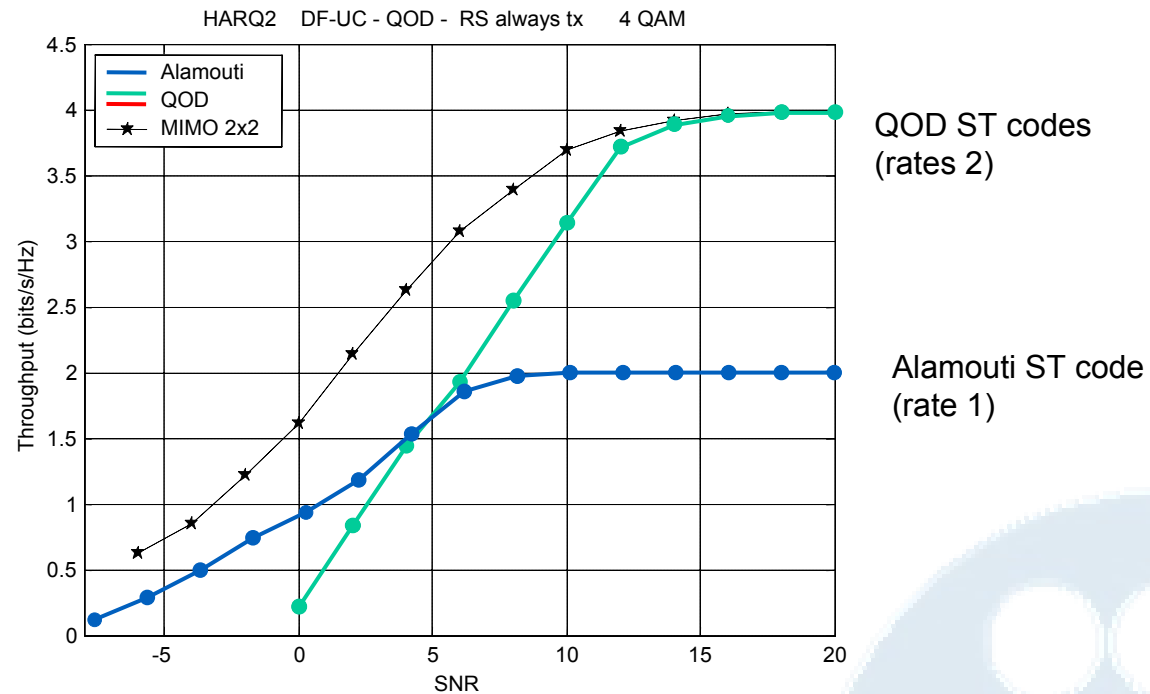
Distributed VBLAST



Distributed Quasi-Orthogonal STC

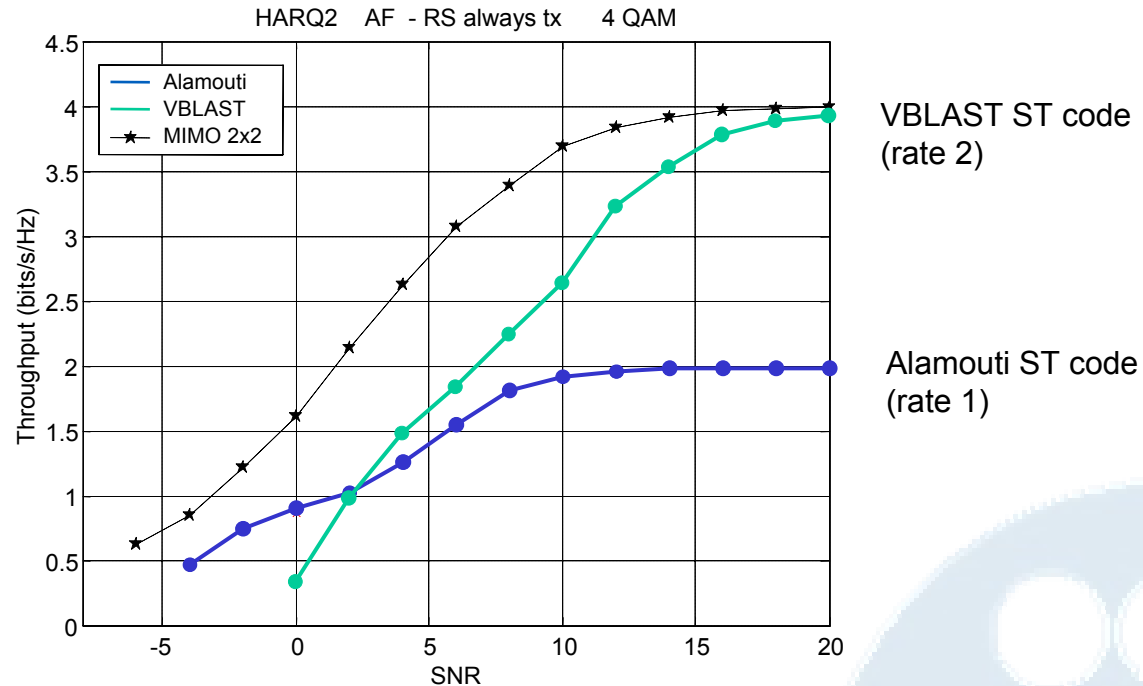
Both codes achieve multiplexing gain at high SNR,  
but poorer performance than Alamouti at low SNR...

# Cooperative D&F – multiplexing gain



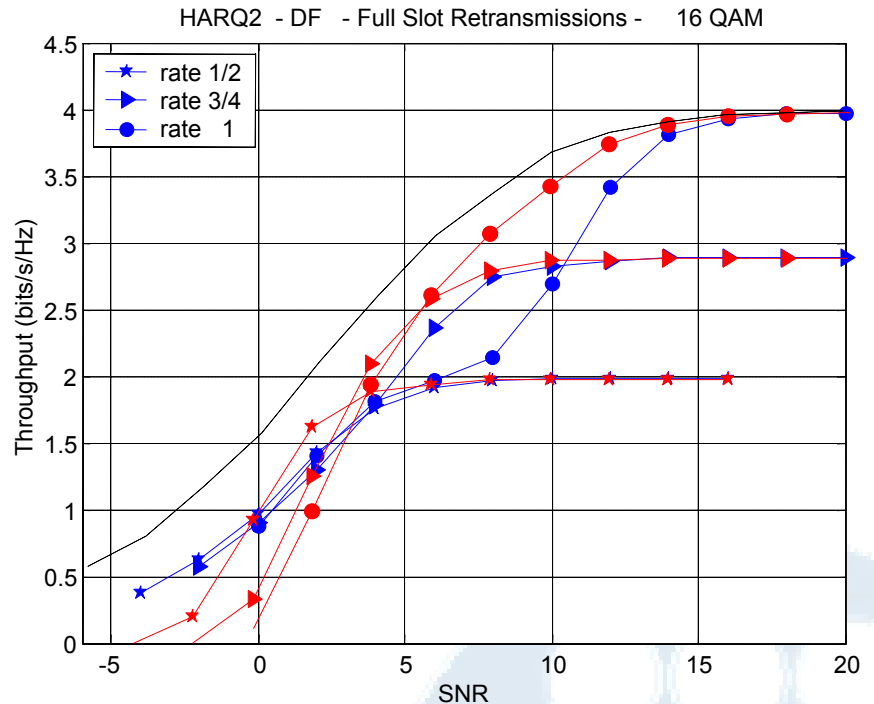
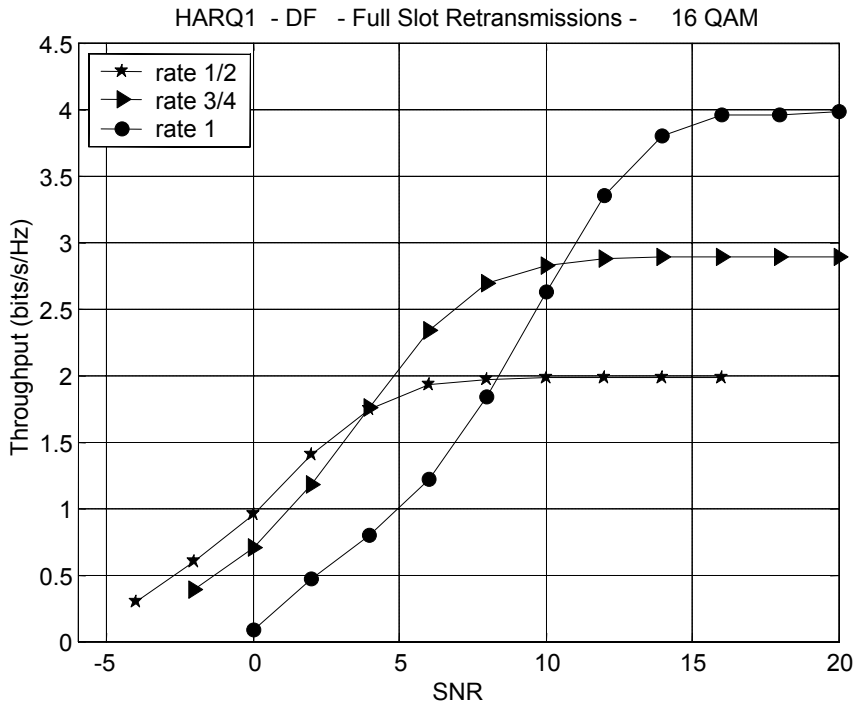
... this is suggesting the choice of the STBC rate as a parameter for the dynamic link control.

# 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)  $\Rightarrow$  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**

Adrian Agustin, Eduard Calvo, Josep Vidal, Olga Muñoz, "Evaluation of Turbo-Coded Cooperative Retransmission Schemes", *IST Mobile Communications Summit 2004*, Lyon, France, 27-30 June 2004.

## **Linear vs. near-optimum receivers**

Adrian Agustin, Josep Vidal, Eduard Calvo, Olga Muñoz, "Evaluation of Turbo H-ARQ Schemes for Cooperative MIMO Transmission", *IEEE IWWAN 2004*, Oulu, Finland, June 2004.

## **Design of STBC in distributed operation**

Adrian Agustin, Josep Vidal, Eduard Calvo, Meritxell Lamarca, Olga Muñoz, "Hybrid Turbo FEC/ARQ Systems and Distributed Space-time Coding for Cooperative Transmission in the Downlink", *IEEE PIMRC 2004*, Barcelona, Spain, September 2004.