Introduction for Cooperative Diversity and Virtual MIMO

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Outline

- Introduction
- Cooperative Diversity and Virtual MIMO
- Cooperative MIMO
- Cooperative FEC
- Conclusions

Introduction

- MIMO: degree-of-freedom gain & diversity gains
  - However, MIMO requires multiple antennas at sources and receivers

- **Cooperative diversity** => achieve spatial diversity with even one antenna per-node (eg: MISO, SIMO, MIMO)

- **Cooperative *MIMO***: special case of coop. diversity
  - Achieve MIMO gains even with one antenna per-node.
  - Eg: open-spectrum meshed/ad-hoc networks, sensor networks, backhaul from rural areas

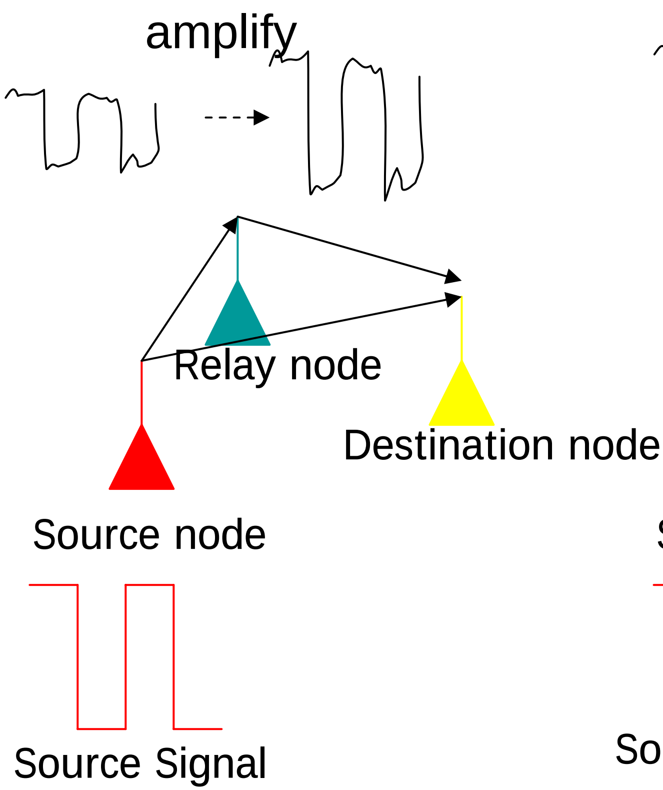
- **Cooperative *FEC*:** link layer cooperation scheme for multi-hop wireless networks and sensor networks

Cooperative Diversity

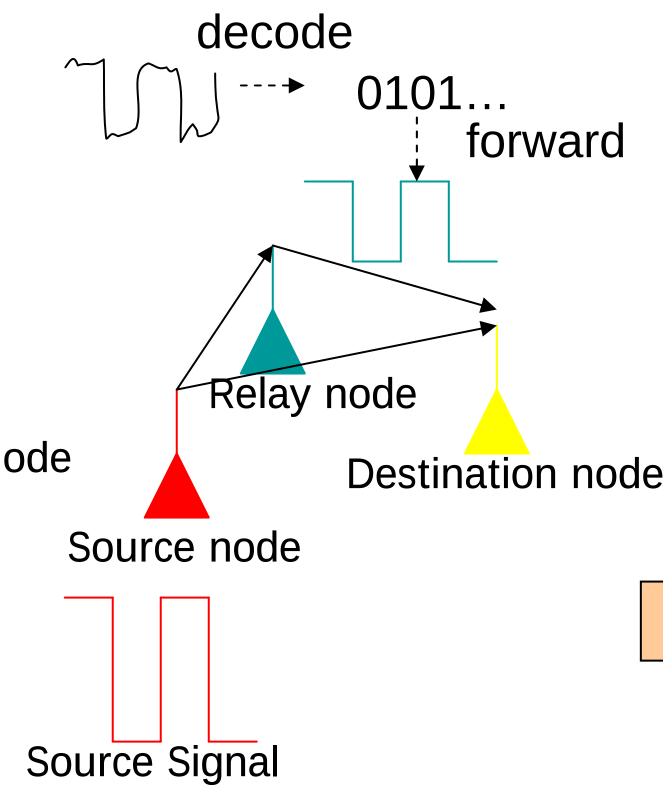
- Motivation
  - In MIMO, size of the antenna array must be several times the wavelength of the RF carrier
  - unattractive choice to achieve receive diversity in small handsets/cellular phones
- Cooperative diversity: Transmitting nodes use idle nodes as relays to reduce multi-path fading effect in wireless channels
- Methods
  - Amplify and forward
  - Decode and forward
  - Coded Cooperation

Cooperative Diversity Schemes

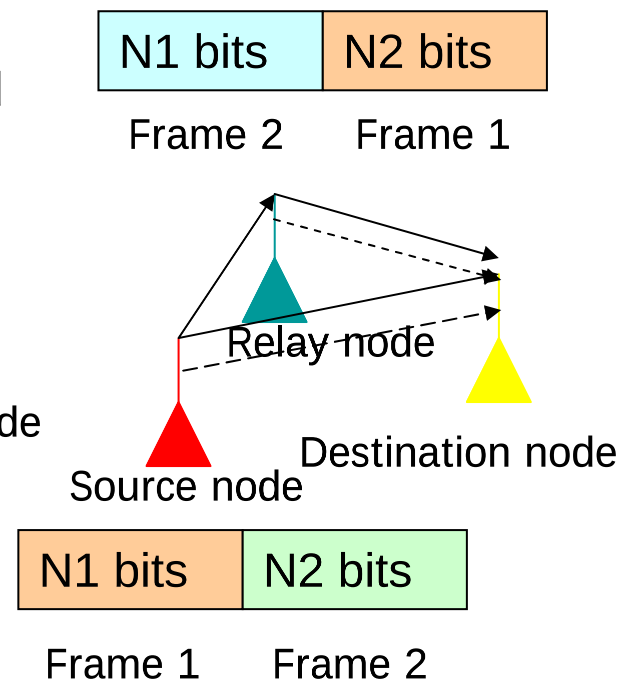
Amplify and forward



Decode and forward



Coded cooperation



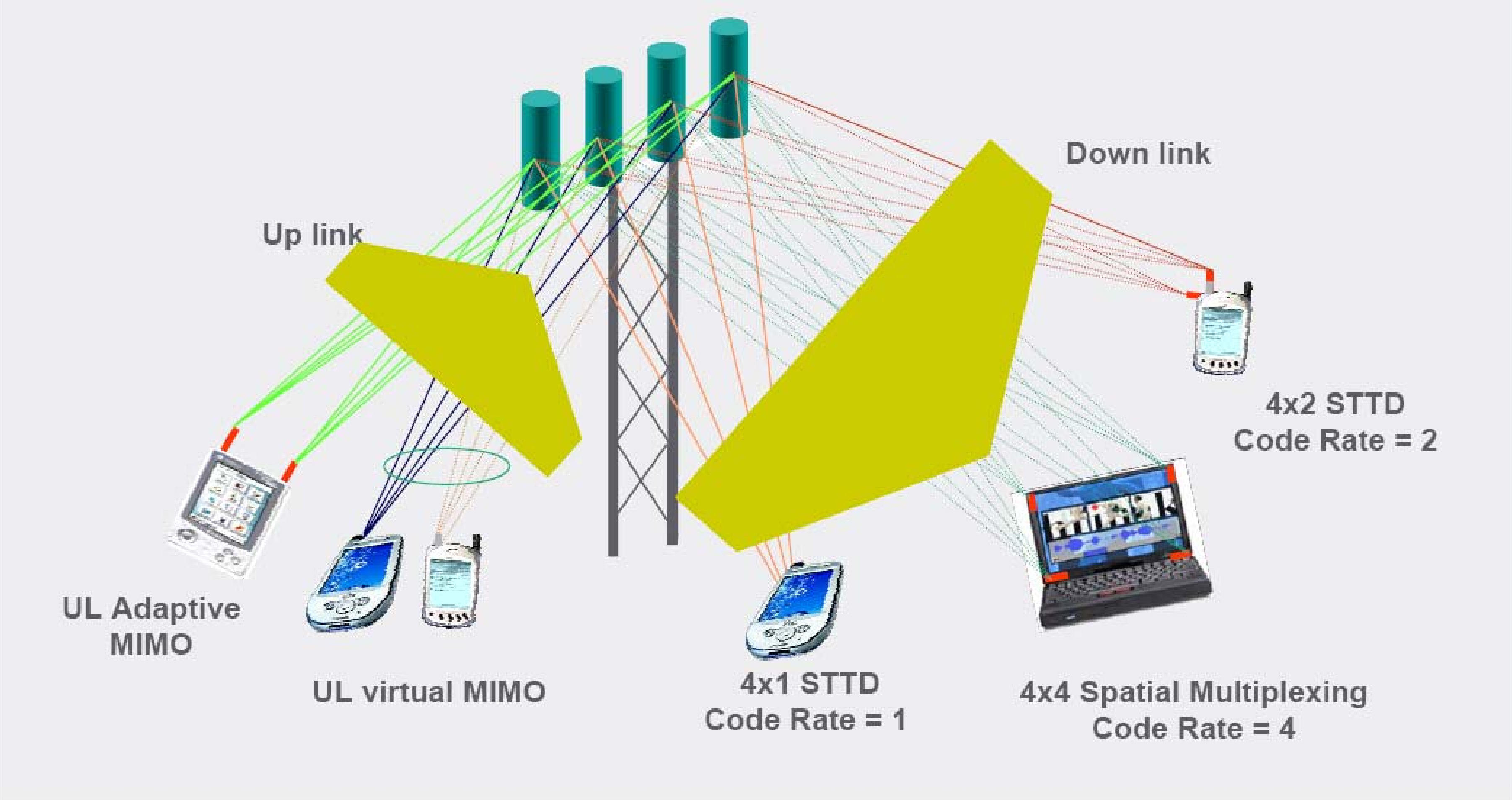
Comparison of Cooperative Diversity Scheme

- Decode and Forward
  - Simple and adaptable to channel condition (power allocation)
  - If detection in relay node unsuccessful => detrimental for detection in receiver (adaptive algorithm can fix the problem)
  - Receiver need CSI between source and relay for optimum decoding
- Amplify and Forward
  - Achieve full diversity
  - Performance better than direct transmission and decode-and-forward
  - achieve the capacity when number of relays tend to infinity
- Coded Cooperation
  - transmit incremental redundancy for partner
  - Automatic manage through code design
  - no feedback required between the source and relay
  - Rely on full decoding at the relay => cannot achieve full diversity!
  - Not scalable to large cooperating groups.

Virtual MIMO

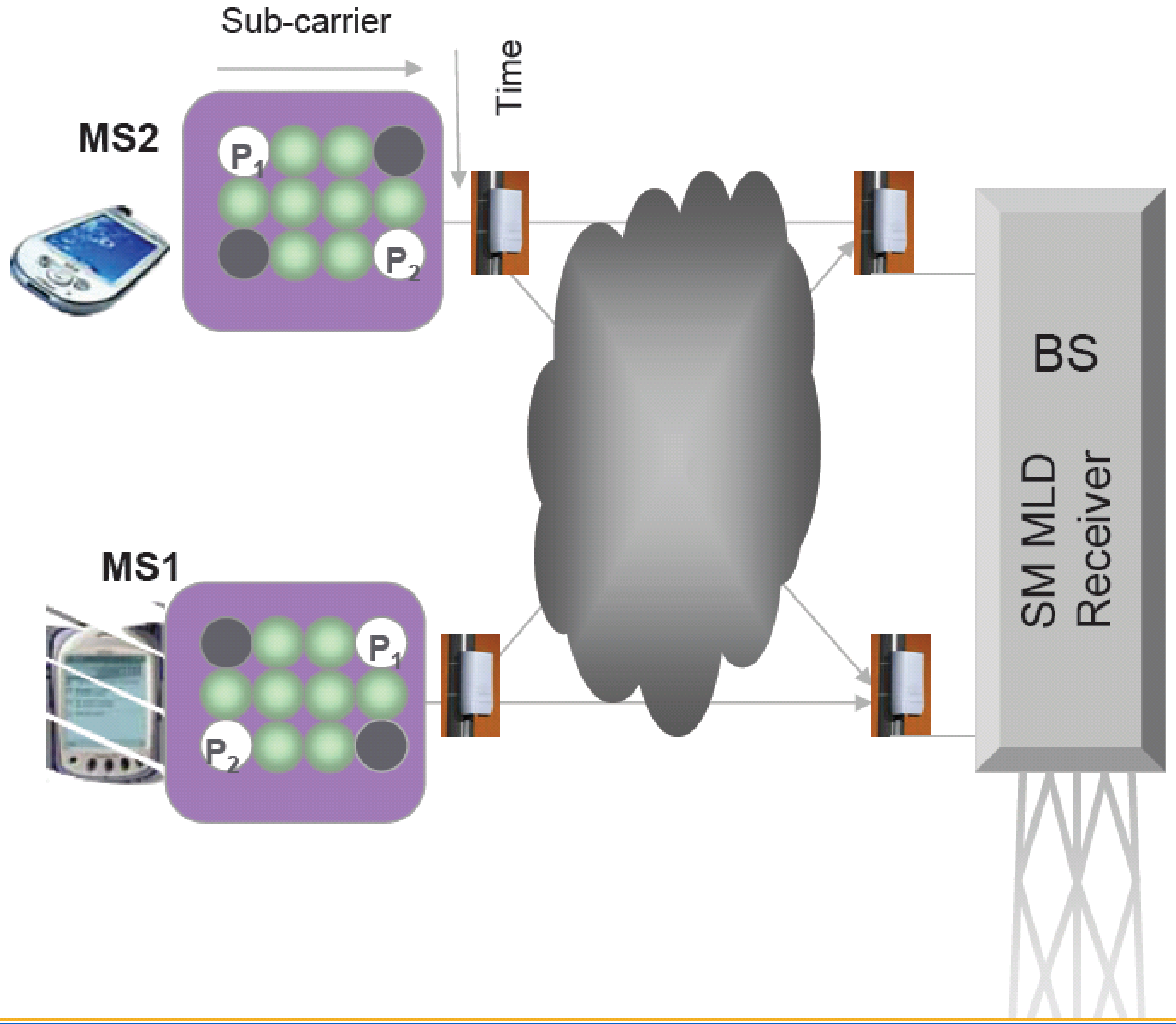
- Proposed by Intel in 2006
- Compatible with WiMax
- Improves uplink capacity by simultaneous uplink by simultaneous uplink from 2 different users

Application for Virtual MIMO



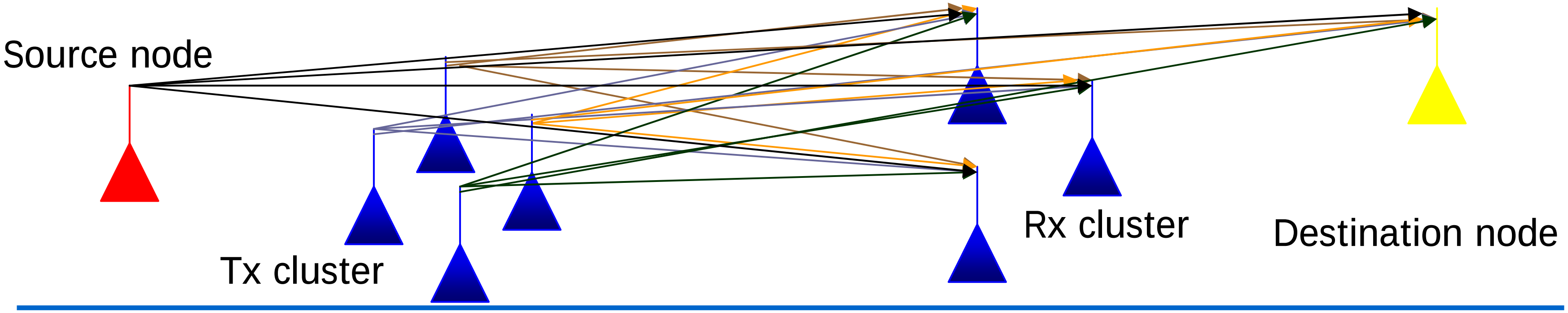
MIMO solutions for both DL and UL to deal with diverse BTS and device antenna capabilities and enable ubiquitous interoperability

Uplink Virtual MIMO



Cooperative MIMO

- Both diversity in transmitter and receiver
- Form sending group and receiving group
- Three phase transmission
  - Broadcasting
  - Inter-cluster transmission
  - Intra-cluster transmission in destination cluster



Analysis of capacity ratio- Phase I

- Phase I: Broadcasting

$$\begin{aligned} C_1 &= Wlog(1+SNR) \\ &= Wlog(1+\frac{P}{N_0W(M+1)}\sum_{i=1}^{M}\frac{\lambda_i^2}{d_{Si}^{\alpha}}), i=1,2,\cdots,M \\ &\geq Wlog(1+\frac{P}{N_0W(M+1)}\sum_{i=1}^{M}\frac{\lambda_i^2}{r^{\alpha}}) \end{aligned}$$

Transmission time for Phase I

$$\rightarrow \quad t_1 = \frac{K}{C_1} \leq \frac{K}{Wlog(1+\frac{P}{N_0W(M+1)}\sum_{i=1}^{M}\frac{\lambda_i^2}{r^{\alpha}})}$$

Analysis of capacity ratio -Phase II

- Phase II: Inter-Cluster Transmission

Transmission time for Phase II

$$
\begin{aligned}
C_{2j} &= Wlog(1 + \frac{P}{N_0 W(M+1)} \sum_{i=1}^{M+1} \frac{\lambda_{ij}^2}{d_{ij}^{\alpha}}) \\
&\geq Wlog(1 + \frac{P}{N_0 W(M+1)} \sum_{i=1}^{M+1} \frac{\lambda_{ij}^2}{(d_{SD} + 2r)^{\alpha}})
\end{aligned}
\longrightarrow
t_2 = \frac{K}{C_2} \leq \frac{K}{\sum_{j=1}^{N+1} Wlog(1 + \frac{P}{N_0 W(M+1)} \sum_{i=1}^{M+1} \frac{\lambda_{ij}^2}{(d_{SD}+2r)^{\alpha}})}
$$

Analysis of capacity ratio -Phase III

- Phase III: intra-cluster transmission in destination cluster

$$C_{3j} = W log(1 + \frac{P\lambda_{jD}^2}{NN_0 W d_{jD}^{\alpha}})$$

$$t_{3j} = \frac{KQ}{W log(1 + \frac{P\lambda_{jD}^2}{NN_0 W d_{jD}^{\alpha}})}$$

→

Transmission time for Phase III

$$t_3 = \sum_{j=1}^{N} t_{3j} = \frac{KQ}{W}(\sum_{j=1}^{N} \frac{1}{log(1 + \frac{P\lambda_{jD}^2}{NN_0 W d_{jD}^{\alpha}})})$$

Capacity ratio

- Total transmission time and the capacity is

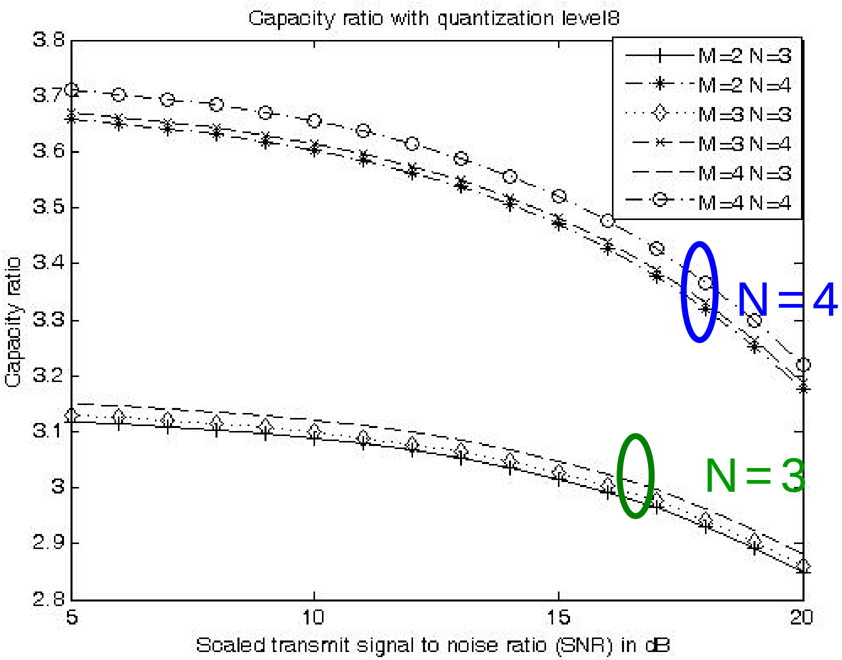
$$
\begin{aligned}
T &= t_1 + t_2 + t_3 \\
&\leq \frac{K}{Wlog(1+\frac{P}{N_0W(M+1)}\sum_{i=1}^{M}\frac{\lambda_i^2}{r^\alpha})} \\
&+\frac{K}{\sum_{j=1}^{N+1} Wlog(1+\frac{P}{N_0W(M+1)}\sum_{i=1}^{M+1}\frac{\lambda_{ij}^2}{(d_{SD}+2r)^\alpha})} \\
&+\frac{KQ}{W}(\sum_{j=1}^{N}\frac{1}{log(1+\frac{P\lambda_{jD}^2}{NN_0Wd_{jD}^\alpha})})
\end{aligned}
$$

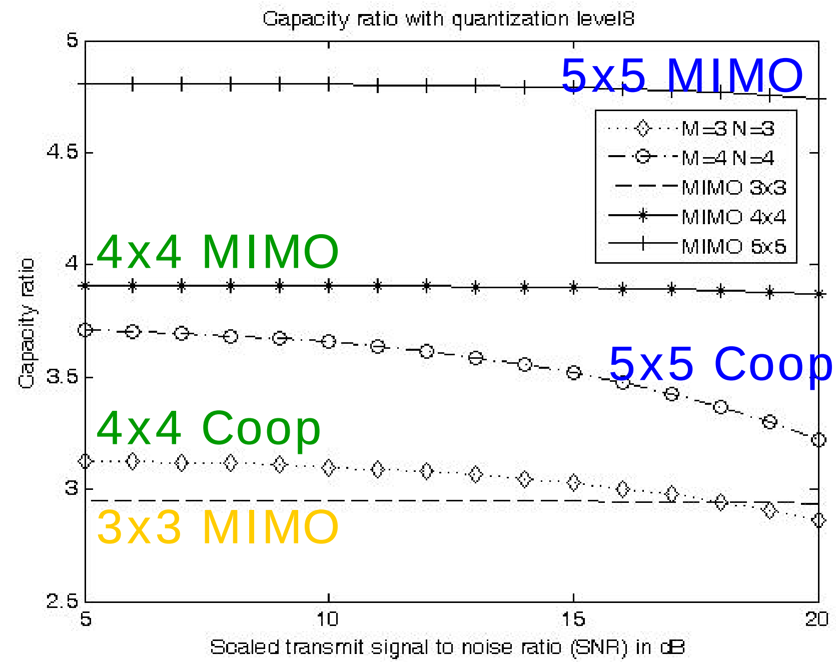
$$
\begin{aligned}
C_{coop} &= \frac{K}{T} \\
&= W/(\frac{1}{log(1+\frac{P}{N_0W(M+1)}\sum_{i=1}^{M}\frac{\lambda_i^2}{r^\alpha})} \\
&+\frac{1}{\sum_{j=1}^{N+1} log(1+\frac{P}{N_0W(M+1)}\sum_{i=1}^{M+1}\frac{\lambda_{ij}^2}{(d_{SD}+2r)^\alpha})} \\
&+Q(\sum_{j=1}^{N}\frac{1}{log(1+\frac{P\lambda_{jD}^2}{NN_0Wd_{jD}^\alpha})})) \qquad (8)
\end{aligned}
$$

- Thus the system capacity ratio is

$$
\frac{C_{coop}}{C_{DT}} = 1/(\frac{log(1+\frac{P\lambda^2}{N_0Wd_{SD}^\alpha})}{log(1+\frac{P}{N_0W(M+1)}\sum_{i=1}^{M}\frac{\lambda_i^2}{r^\alpha})} + \frac{log(1+\frac{P\lambda^2}{N_0Wd_{SD}^\alpha})}{\sum_{j=1}^{N+1} log(1+\frac{P}{N_0W(M+1)}\sum_{i=1}^{M+1}\frac{\lambda_{ij}^2}{(d_{SD}+2r)}} + \sum_{j=1}^{N}\frac{Qlog(1+\frac{P\lambda^2}{N_0Wd_{SD}^\alpha})}{log(1+\frac{P\lambda_{jD}{}^2}{NN_0Wd_{jD}^\alpha})})
$$

The relation of capacity ratio and major system factors





The size of receiving cluster (N+1) more important factor for capacity ratio (than Tx cluster size M+1)

Capacity ratio **decreases** as SNR increases.

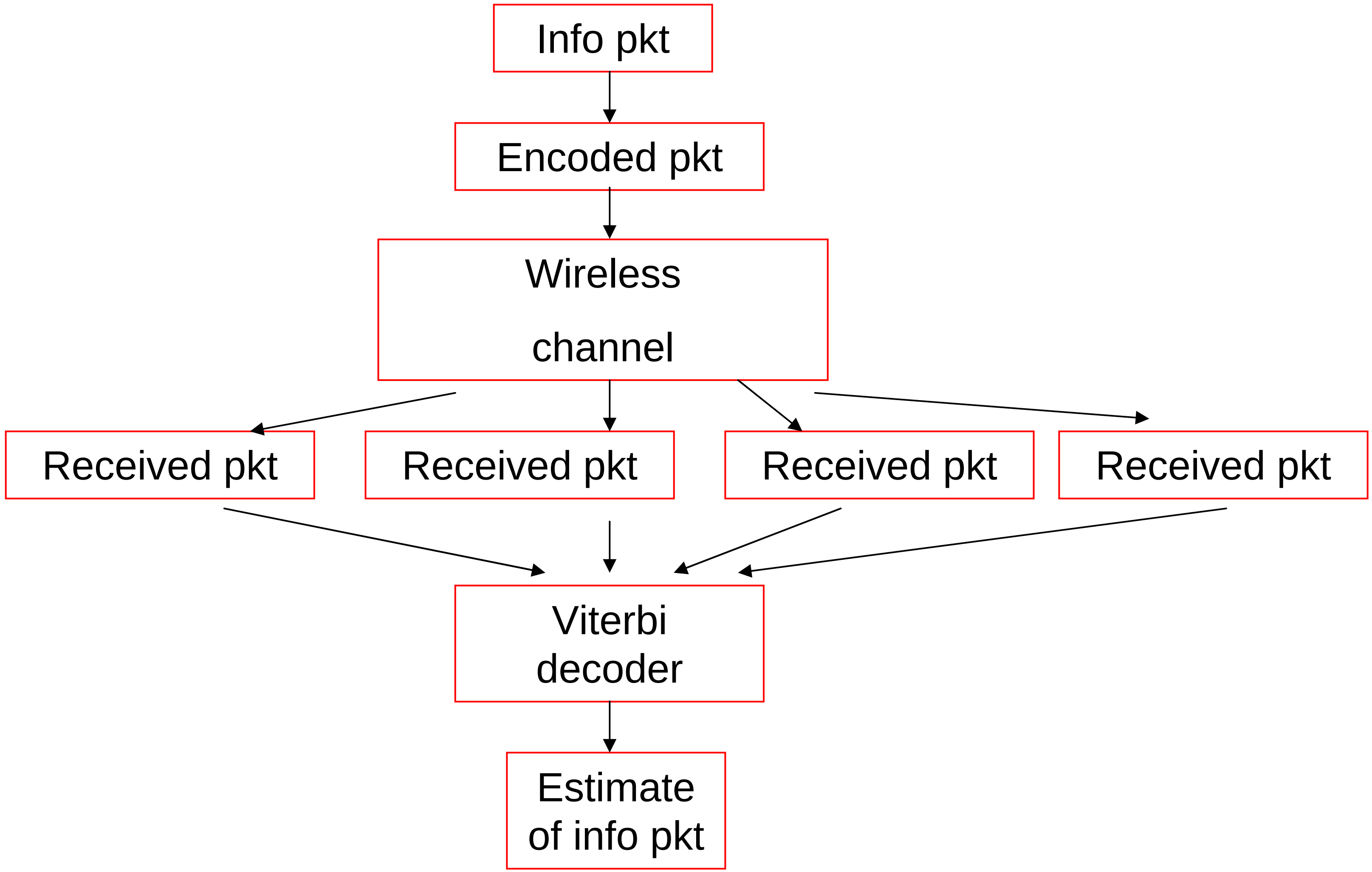
Compared to the equivalent MIMO case, the capacity ratio is smaller due to node cooperation overheads

Note: Tx cluster size (M+1) & Rx cluster size (N+1), incl. of src/dest

Cooperative FEC

- effective in improving the link performance and reducing the energy consumption
- Less power leads to less interference among nodes, thus can improve the capacity of the wireless networks.
- Link layer cooperation
  - Stage 1: Cluster head decides if cooperation is necessary
  - Stage 2: FEC and Code combining among cluster nodes
  - Stage 3: Use ARQ or transmit diversity if else fail

Code Combining Procedure



Code Combining Technique

- Combine *L* repeated packets encoded with a code of rate *R*
- Thus obtain a lower rate *R/L* and more powerful
- Viterbi (maximum-likelihood) decoding
- The decoding function:

$$\max_m \left\{ \Pr[r \mid v_m] = \prod_{i=1}^{L} (1 - p_i)^{N - d_{mi}} \, p_i^{\,d_{mi}} \right\}$$

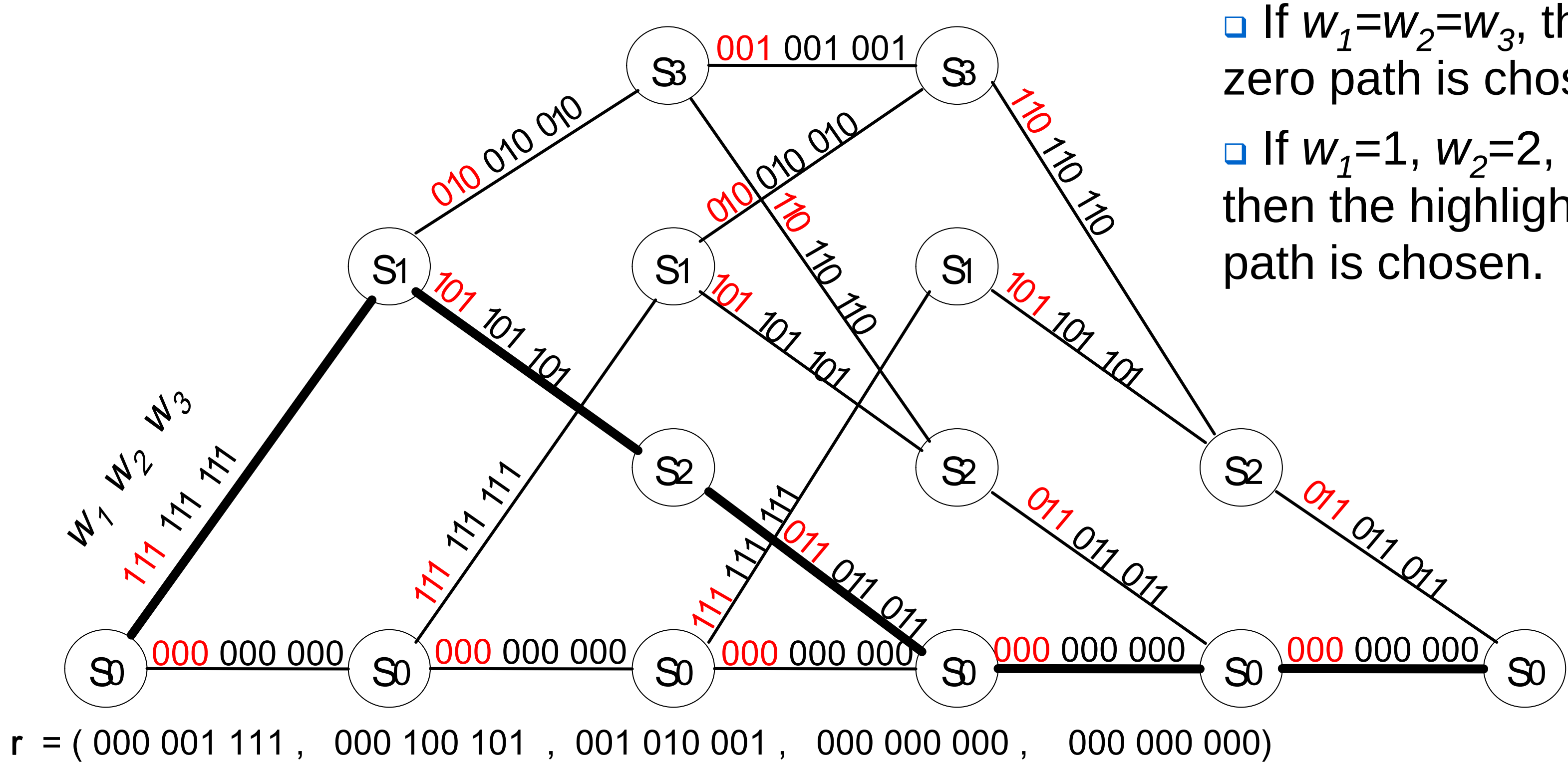
- An alternate way is: $$\min_m \sum_{i=1}^{L} w_i d_{mi}$$

where weight for the *i* th channel

$$w_i = \log \frac{1 - p_i}{p_i}$$

Code Combining with Convolutional Codes: An Example

- A (3,1,2) code with an information sequence *h* =3
- Cooperative nodes *L*=3
- Weight for each channel is w_1, w_2, w_3



- If w_1=w_2=w_3, the all zero path is chosen.
- If w_1=1, w_2=2, w_3=3, then the highlighted path is chosen.

Conclusion

- Cooperative diversity techniques provide diversity gain for single-antenna devices
- Three basic model for cooperative diversity scheme
  - Amplify and Forward
  - Decode and Forward
  - Coded Cooperation
- Application: Virtual MIMO in WiMAX
- Cooperative MIMO: cluster-based, provide MIMO gain
- Cooperative FEC: cooperation in link layer
  - Combine erroneous packets
  - Reduce energy consumption