Cooperative Diversity with Incremental Redundancy (IR) Turbo Coding for Quasi Static Wireless Networks

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IAB, 2005

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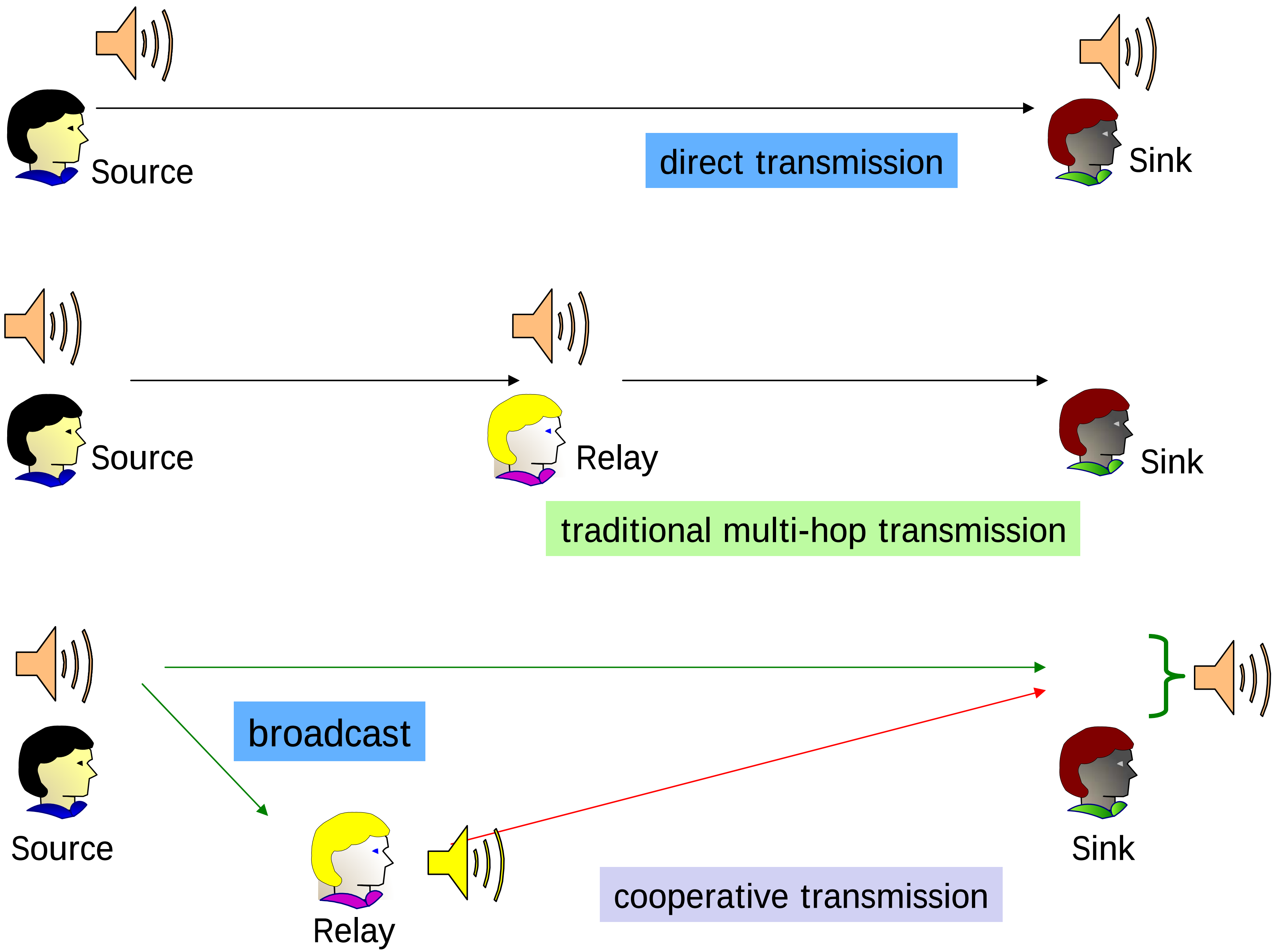
Transmission schemes

- direct transmission
- traditional multihop transmission
- cooperative transmission

Laneman, et. al.

Erkip, et. al.

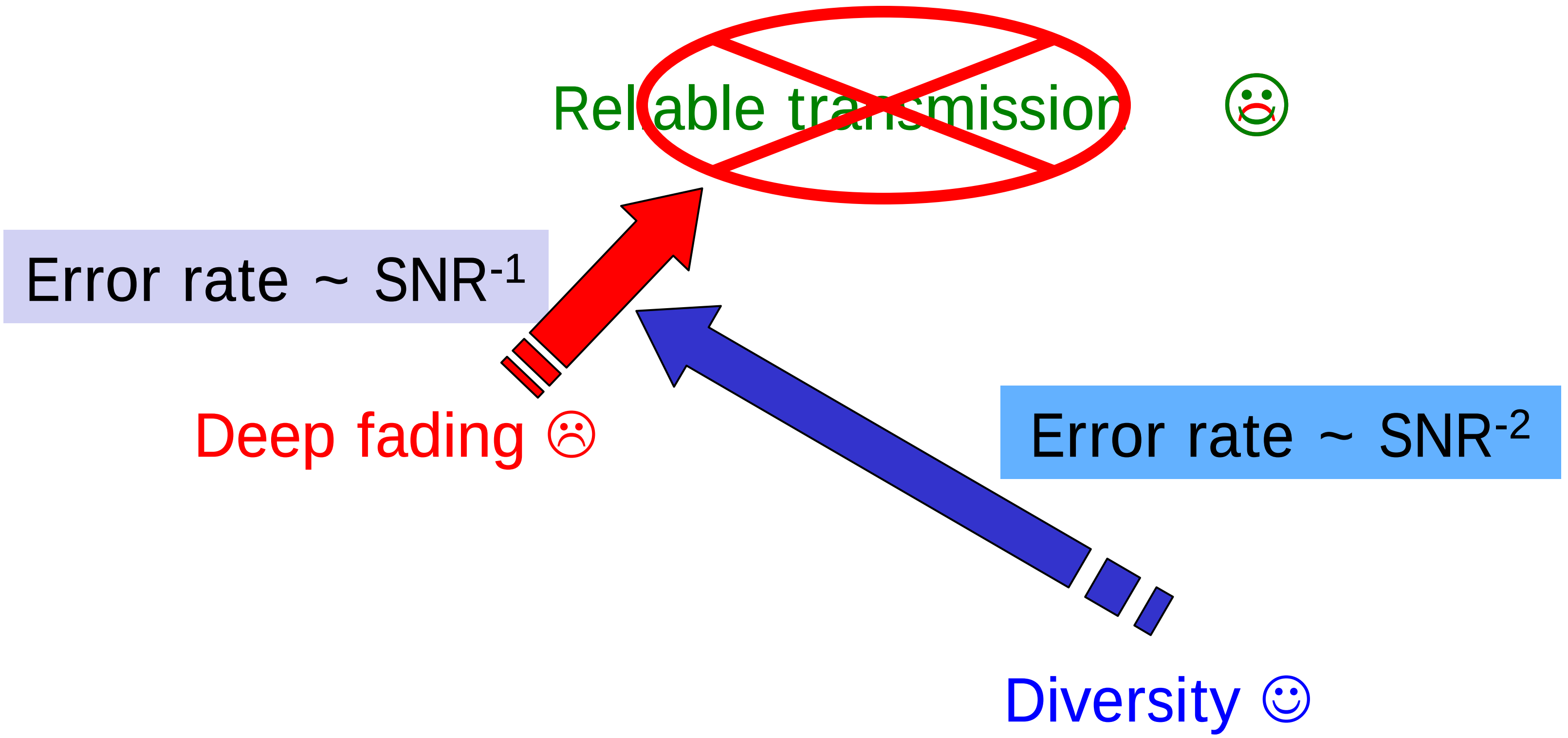

Source
Sink
direct transmission
Source
Relay
Sink
traditional multi-hop transmission
Source
broadcast
Relay
Sink
cooperative transmission

Transmission schemes comparison

- direct transmission
  - sink receives one copy from source
  - diversity order: 1
- traditional multi-hop transmission
  - sink receives one copy from relay
  - diversity order: 1
- cooperative transmission
  - sink receives two copies from source and relay
  - each of links experiences independent fading gain
  - diversity order: 2

Cooperation benefit?

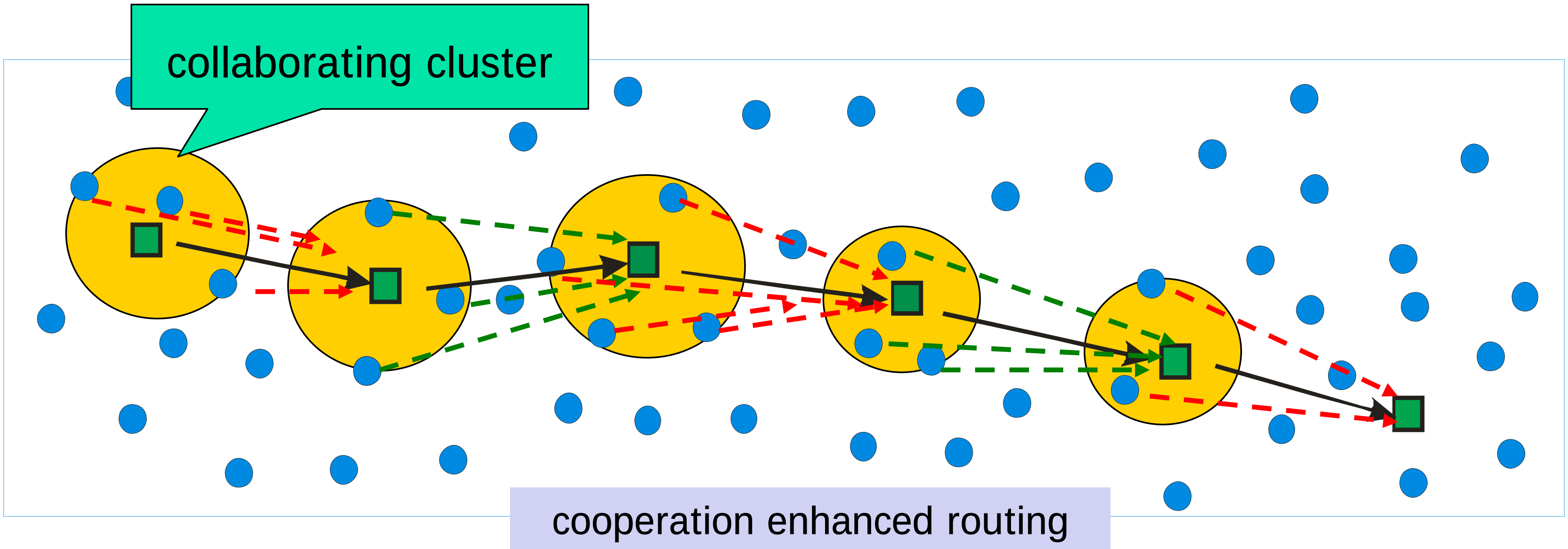
wireless communications



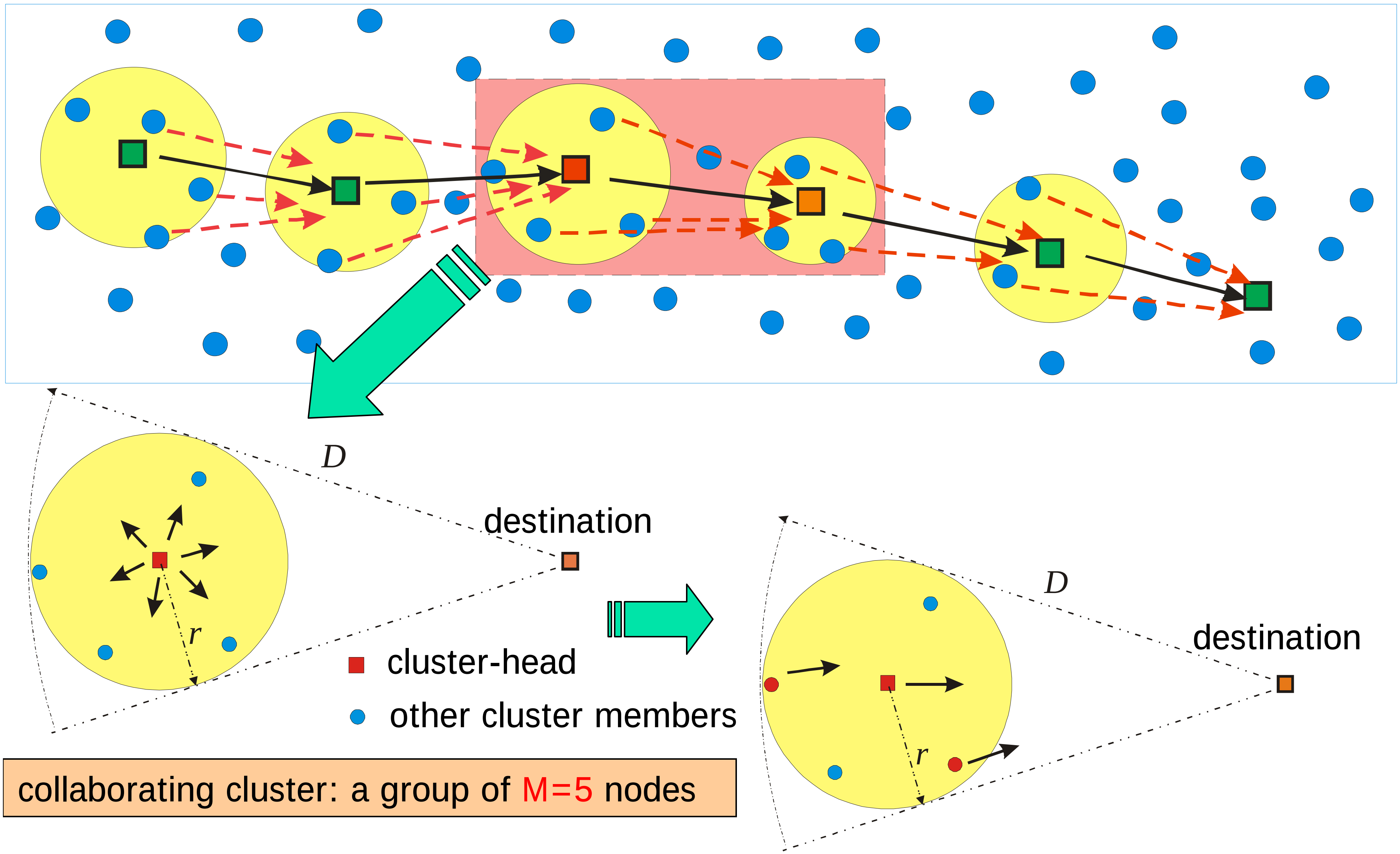
Objective

- develop a practical cooperative coding scheme
  - embed into the current ad-hoc multihop wireless network protocols
- evaluate how much benefit one can get from cooperation

Wireless cooperative routing in ad-hoc networks

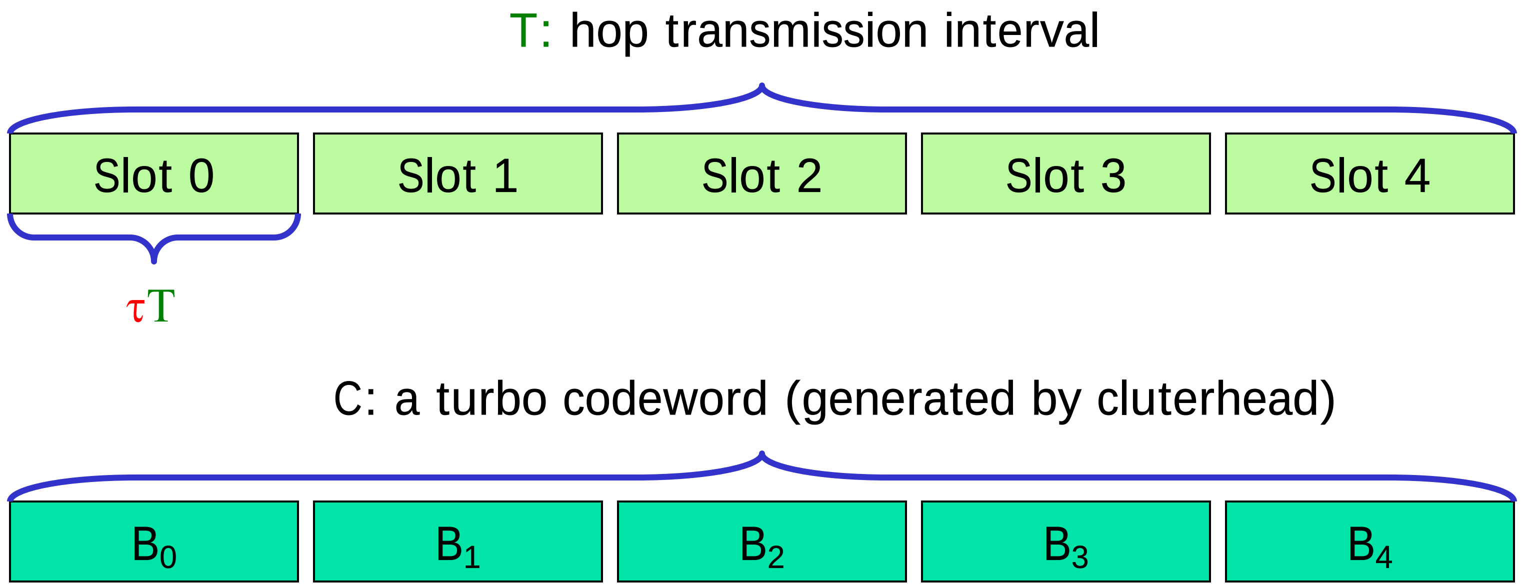


Wireless cooperative routing in ad-hoc networks



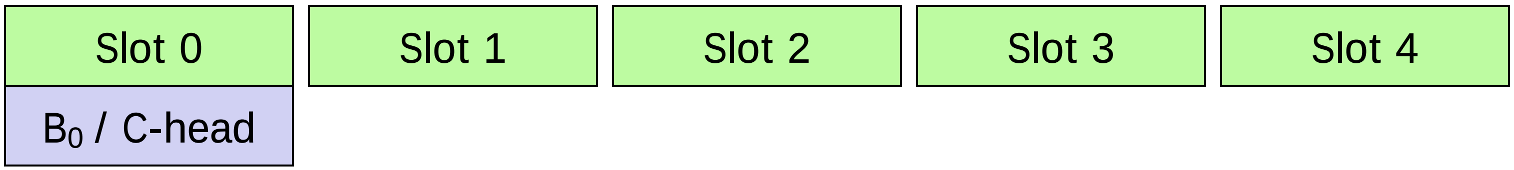
collaborating cluster: a group of M=5 nodes

IR cooperative turbo coding scheme

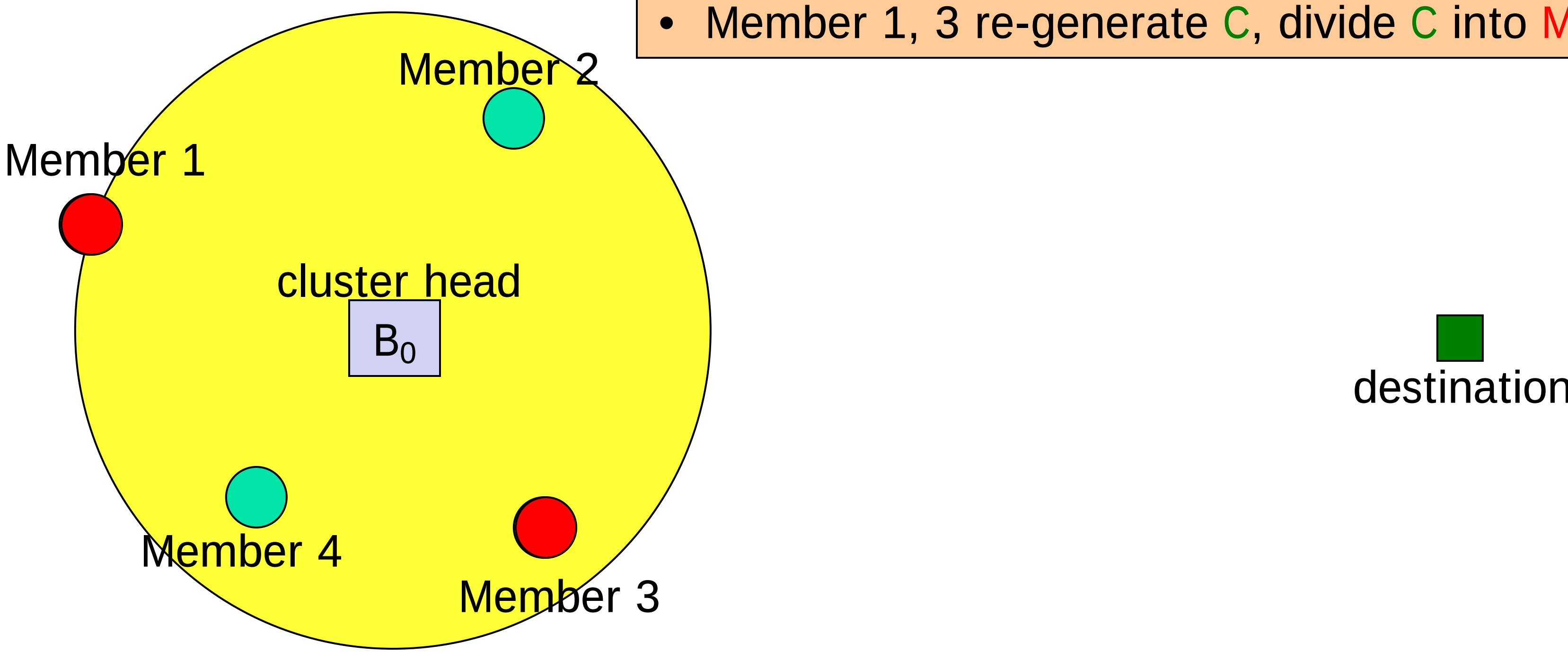


- one hop transmission interval T is partitioned into M non-overlapping slots
- cluster can transmit n symbols during the transmission interval T
- clusterhead encodes the information using mother turbo codeword C of length n
- clusterhead divides C into M blocks, each of them is a punctured codeword B_j

IR cooperative turbo coding scheme



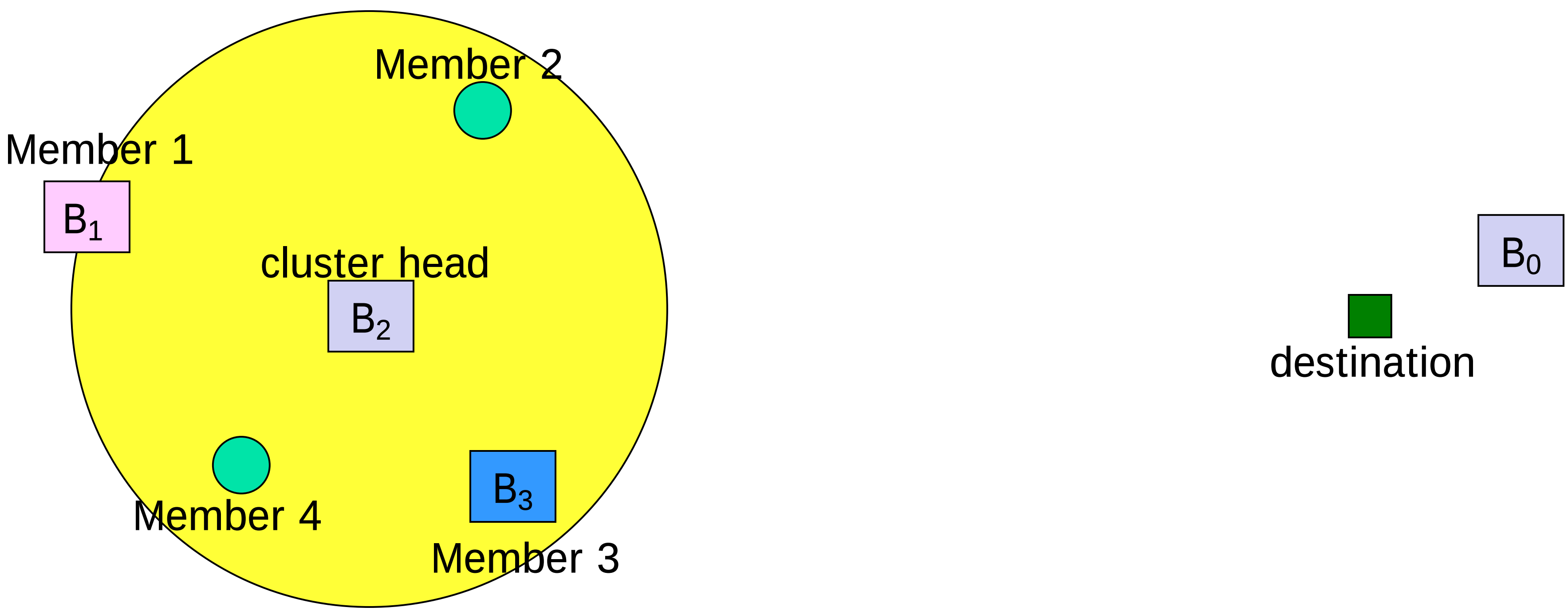
- e.g. reliable set F={Member 1, Member 3}
- reliable nodes send ACK to cluster head
- Member 1, 3 re-generate C, divide C into M block



IR cooperative turbo coding scheme

Slot 0	Slot 1	Slot 2	Slot 3	Slot 4
B_0 / C-head	B_1/Member 1	B_2/ C-head	B_3/Member 3	B_4/C-head

- Member 1 (3) relays block B_1 (B_3) in Slot 1 (3)
- cluster-head transmits the leftover blocks B_2,B_4



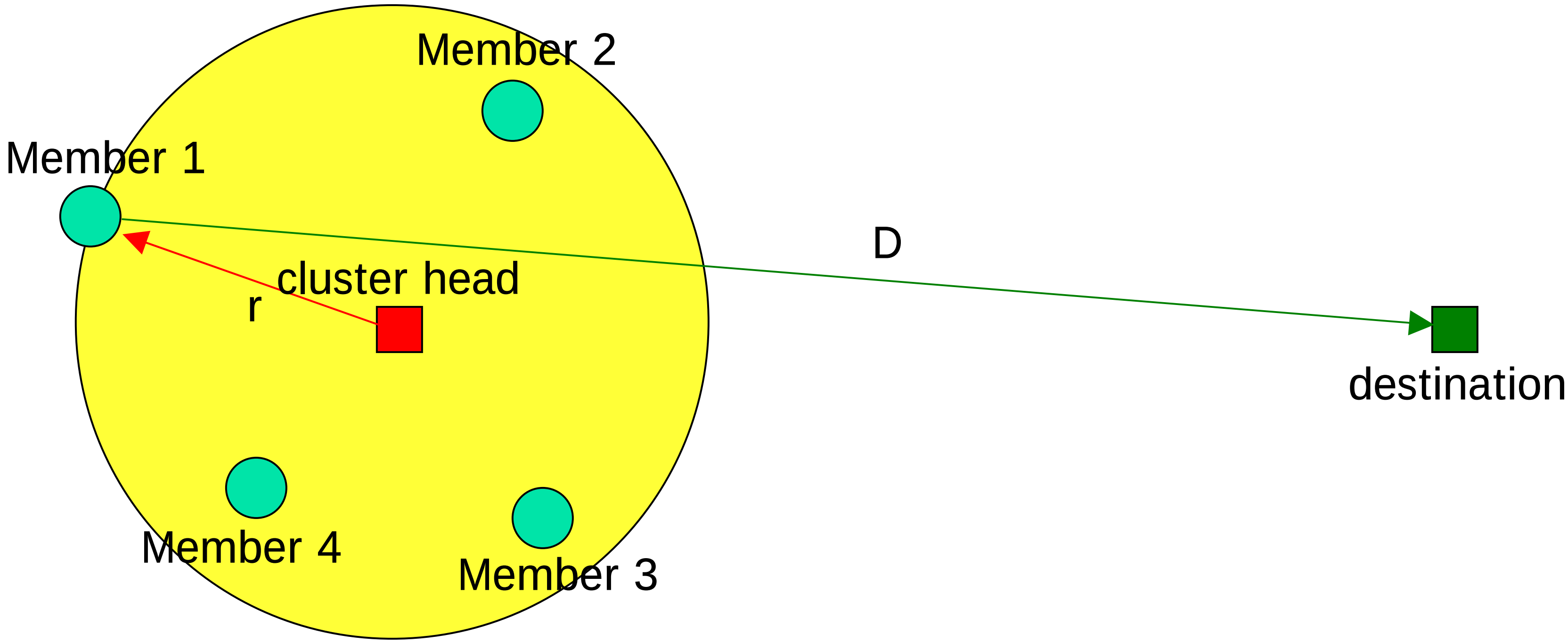
Channel model

- quasi-static Rayleigh fading channel (CSI at receiver ends)

$$y_{i,j} = d_{i,j}^{-\beta/2} a_{i,j} x_i + z_{i,j}$$

  - Nodes 1,...,M cluster members, and Node M+1 destination
  - $i \in \{1,\ldots,M\}$ transmitter index, $j \in \{1, \ldots, M+1\}$ receiver index.
  - transmitted symbol energy: $E=|x_i|^2$
  - $z_{i,j}$ is additive Gaussian noise N(0,1/2)
  - channel power $v_{i,j}=|a_{i,j}|^2$ is exponentially distributed with mean 1
  - $d_{i,j}$ distance from Node i to Node j.
  - β: path loss exponent
  - instantaneous SNRs $\Gamma_{i,j} = E \cdot v_{i,j} \cdot d_{i,j}^{-\beta}$

Collaborating cluster parameters

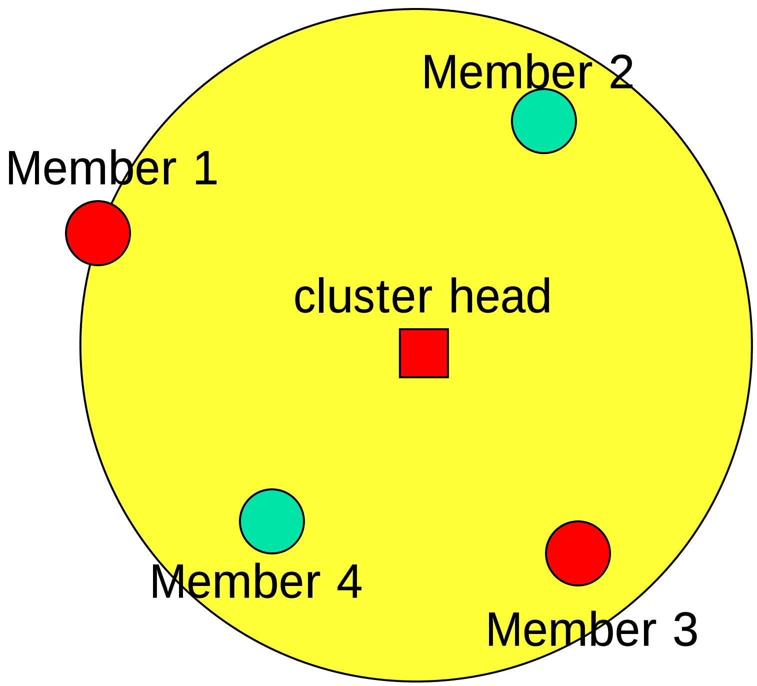


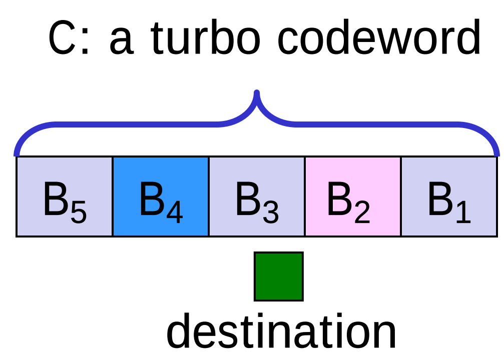
- cluster radius: $r = \max\{d_{1,2}, \ldots, d_{1,M}\}$
- cluster-to-destination distance: $D = \max\{d_{1,M+1}, \ldots, d_{M,M+1}\}$
- inter-cluster SNR: $\rho = E \cdot r^{-\beta}$
- cluster-to-destination SNR : $\lambda = E \cdot D^{-\beta}$

worst channel parameters

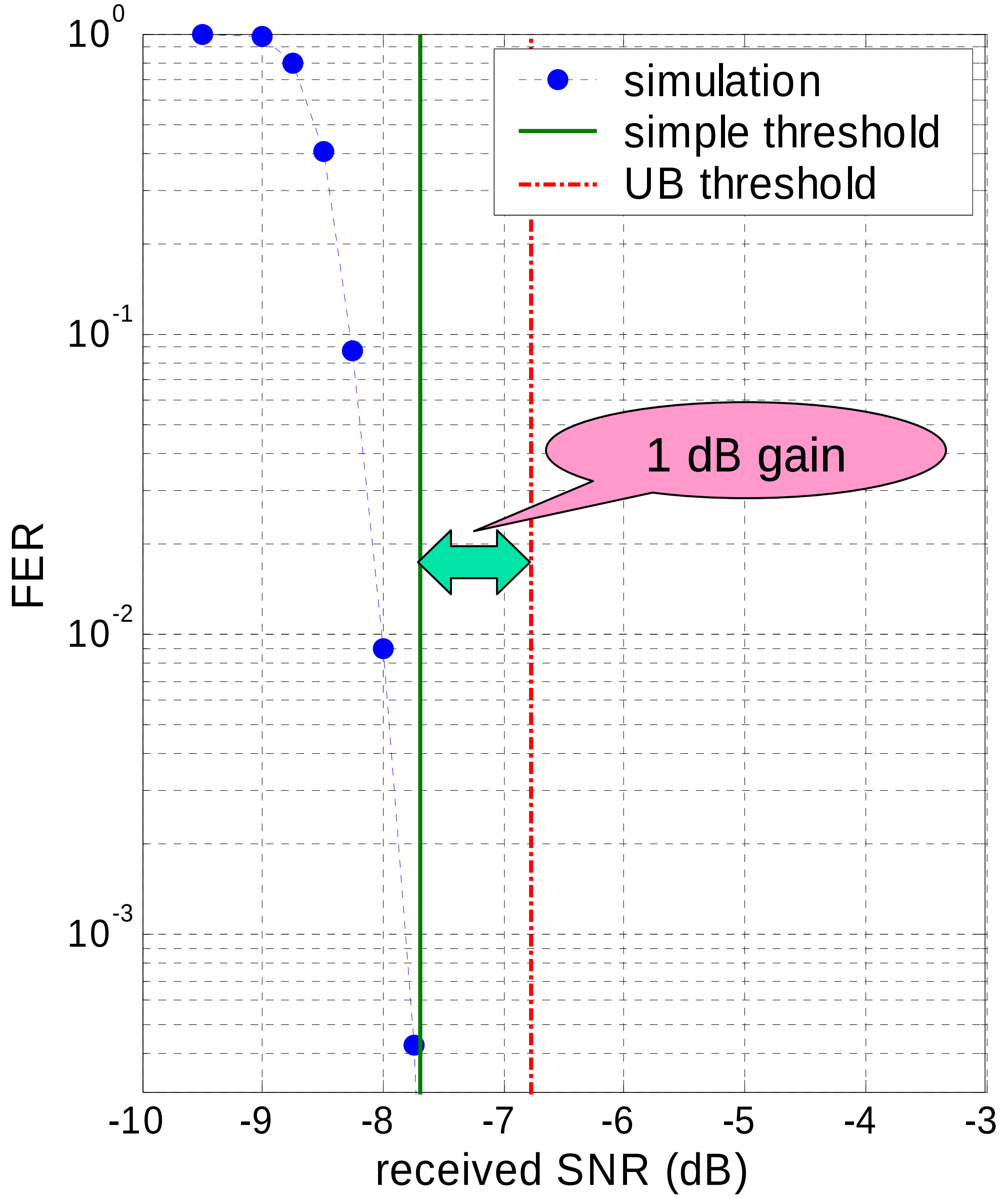
Performance analysis

- decoding is performed at the destination upon completion of M slots.
- received signal is always a mother turbo codeword
- all communication links experience independent Rayleigh fading
- codeword C is equivalently transmitted over M=5 parallel channels, and experiences |F|+1=3 independent channel gains





Simple code threshold



- turbo codes (R=1/7, k=768)
- binary input AWGN channel
- Union Bhattacharyya (UB) threshold

$$c_0^{[TC]} = 0.21 \quad \Rightarrow \quad -6.77dB$$

Jin, McEliece

- simple threshold (this work)

$$c_*^{[TC]} = 0.17 \quad \Rightarrow \quad -7.70dB$$

Frame error rate of the cooperative scheme

- simple threshold upper bound

$$\mathsf{FER}^{(M)} \le \sum_{k=0}^{M-1} \binom{M-1}{k} P(|\mathsf{F}| = k) \cdot P\left\{\theta(\mathsf{F}) \le c_*^{[\mathsf{TC}]} \mid |\mathsf{F}| = k\right\}$$

  - $\theta(\mathsf{F})$: effective cluster-to-destination SNR

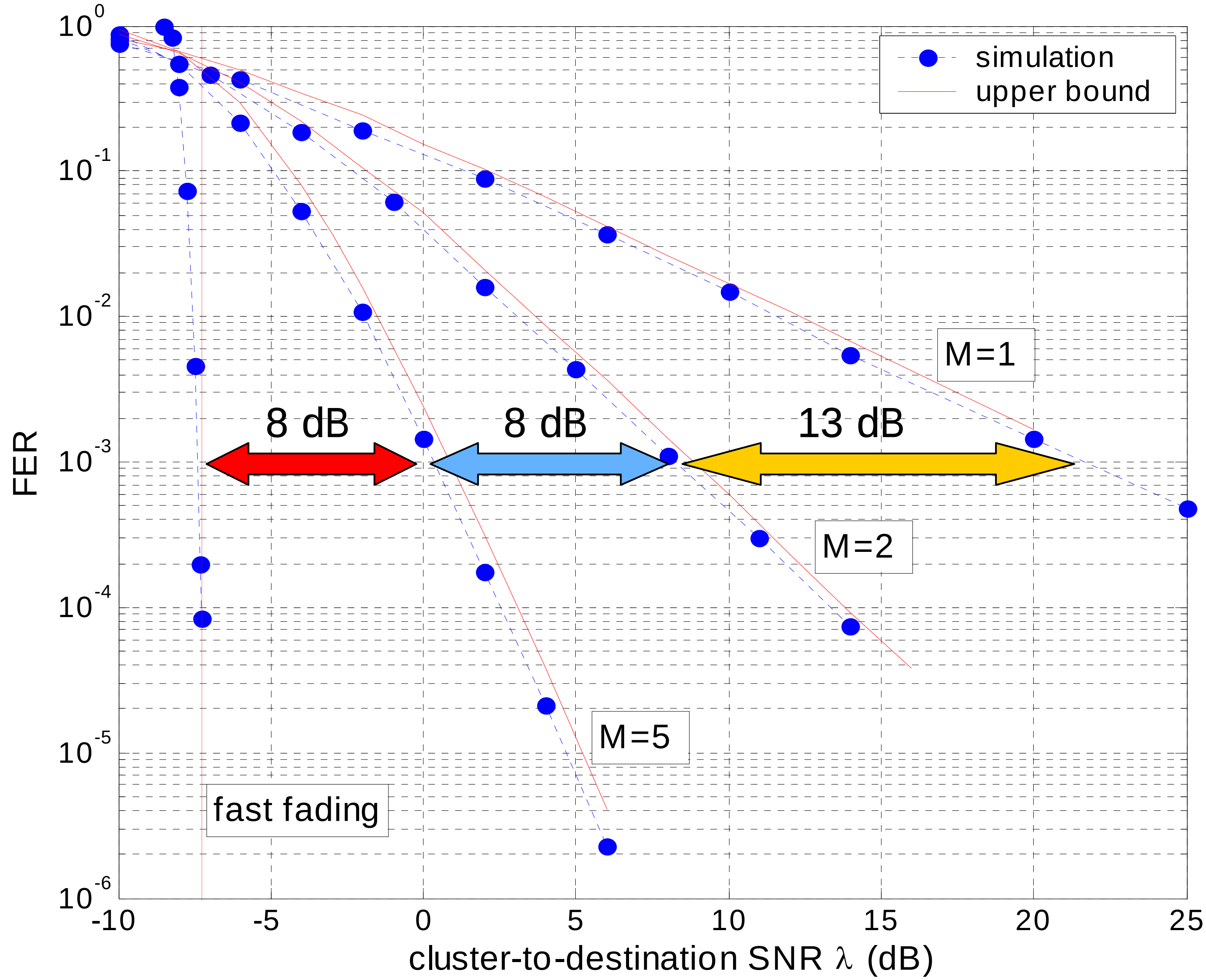
- asymptotic upper bound (small $c_*^{[\mathsf{TC}]}$ and large ρ, λ)

$$\mathsf{FER}^{(M)} \le_{\lambda,\rho,c_*^{[\mathsf{C}]}} \sum_{k=0}^{M-1} \binom{M-1}{k} \frac{(M \cdot c_*^{[\mathsf{TC}]})^M}{(M-k)(k+1)!} \rho^{-M+(k+1)} \lambda^{-(k+1)}$$

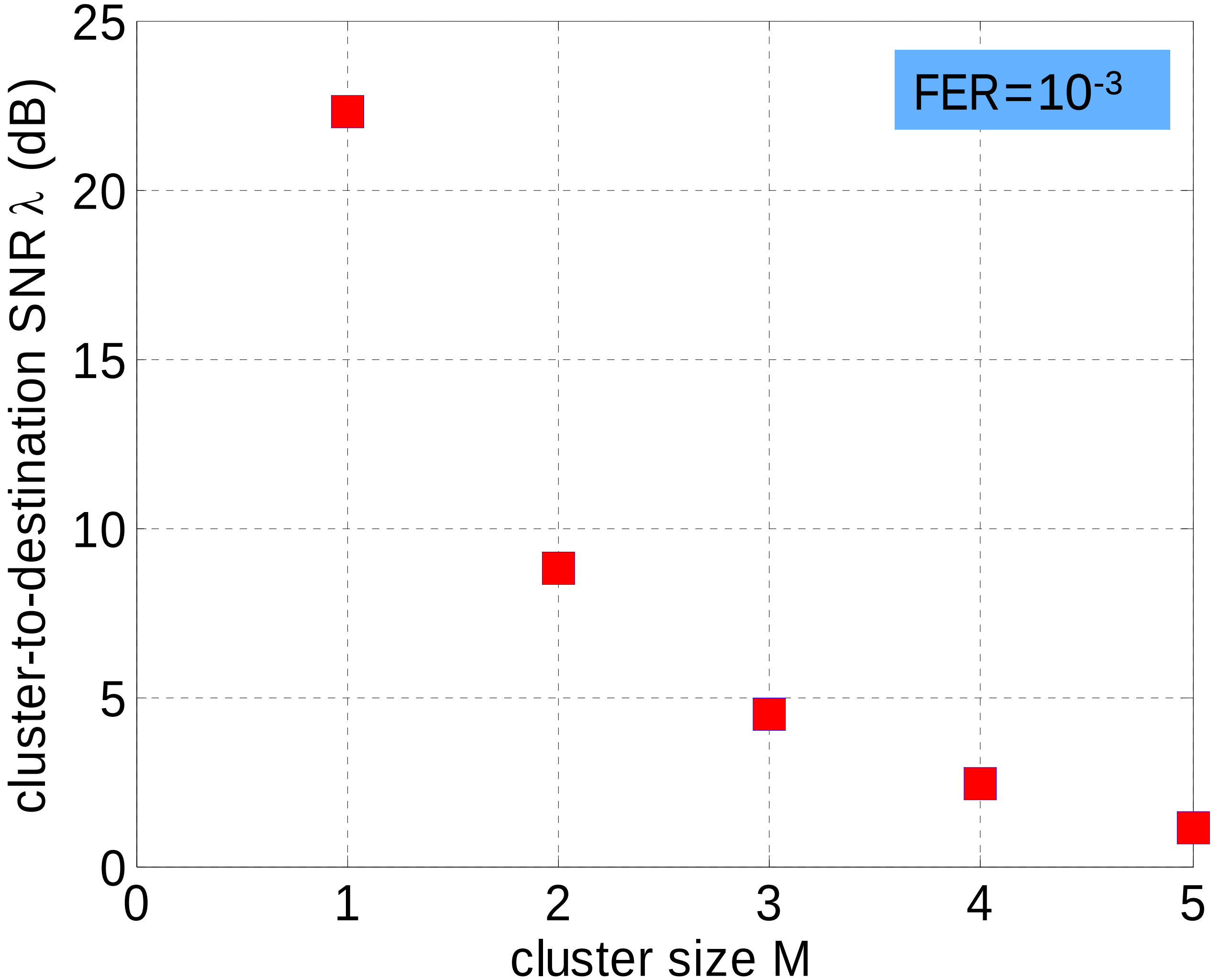
An example

- evaluate error performance of the cooperation scheme
  - mother turbo code R=1/7, n=5376
  - binary antipodal signaling
  - independent flat quasi-static Rayleigh fading channel

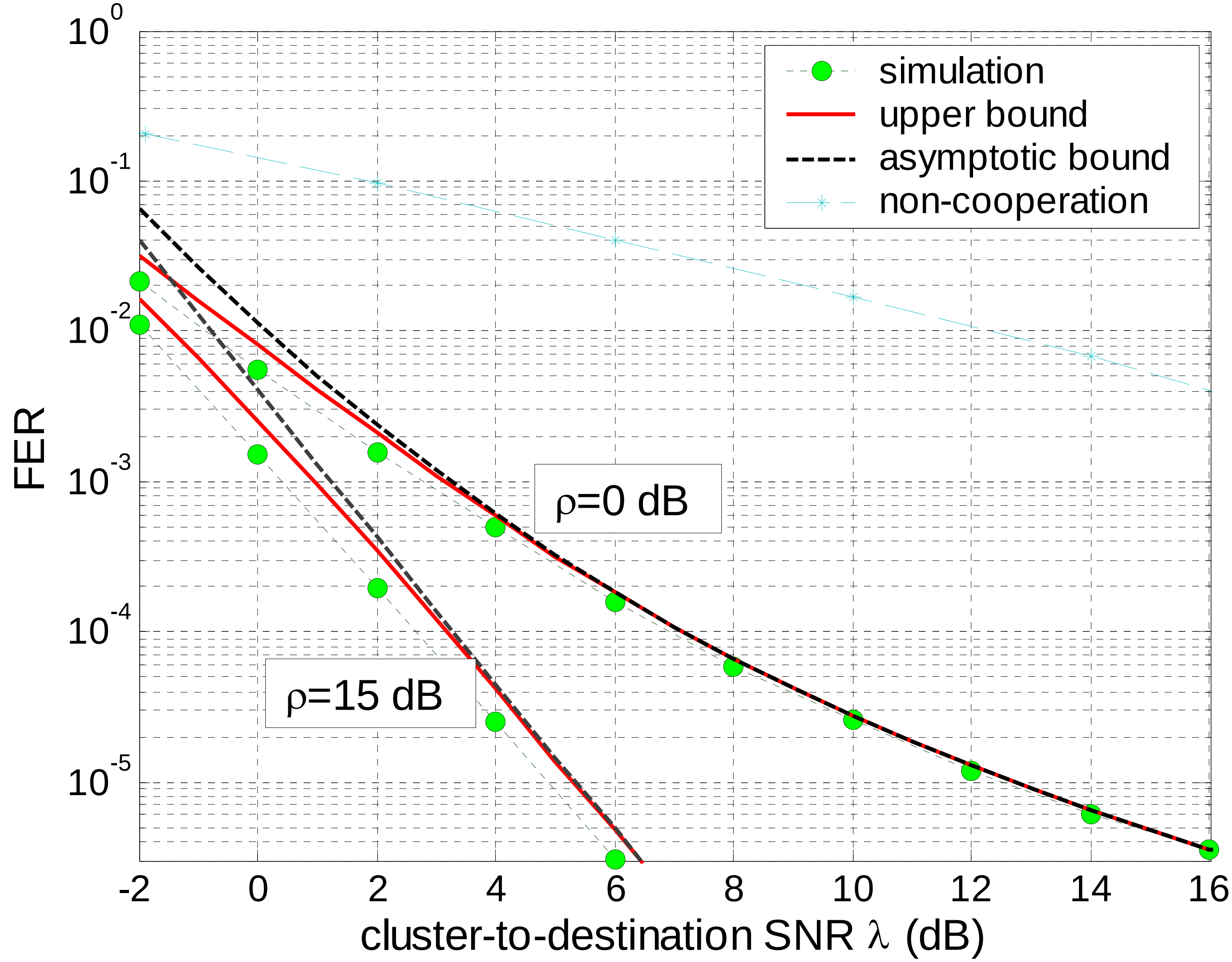
Diversity gain vs cluster size M



Required cluster to destination SNR



FER: fixed inter-cluster SNR (M=5)



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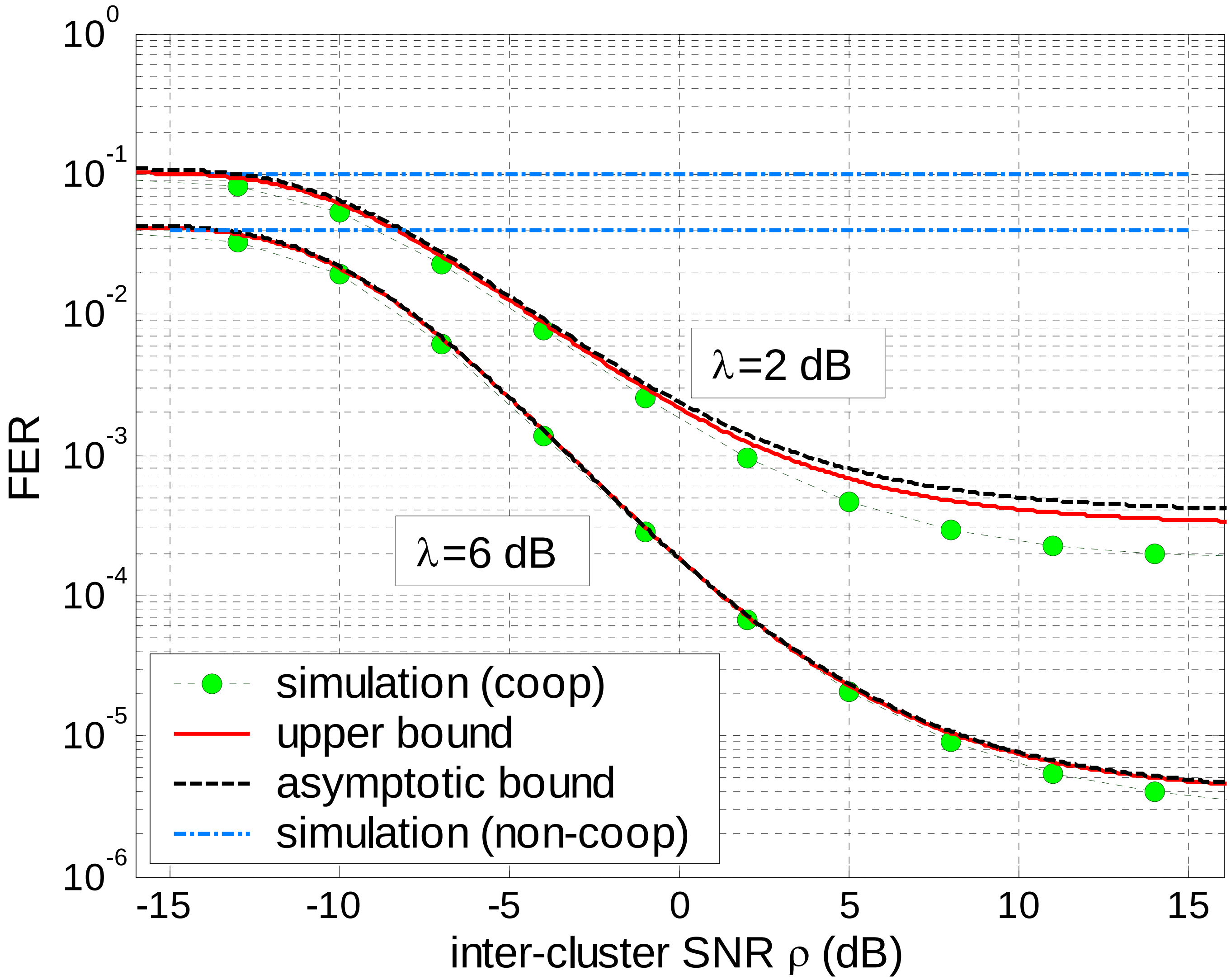
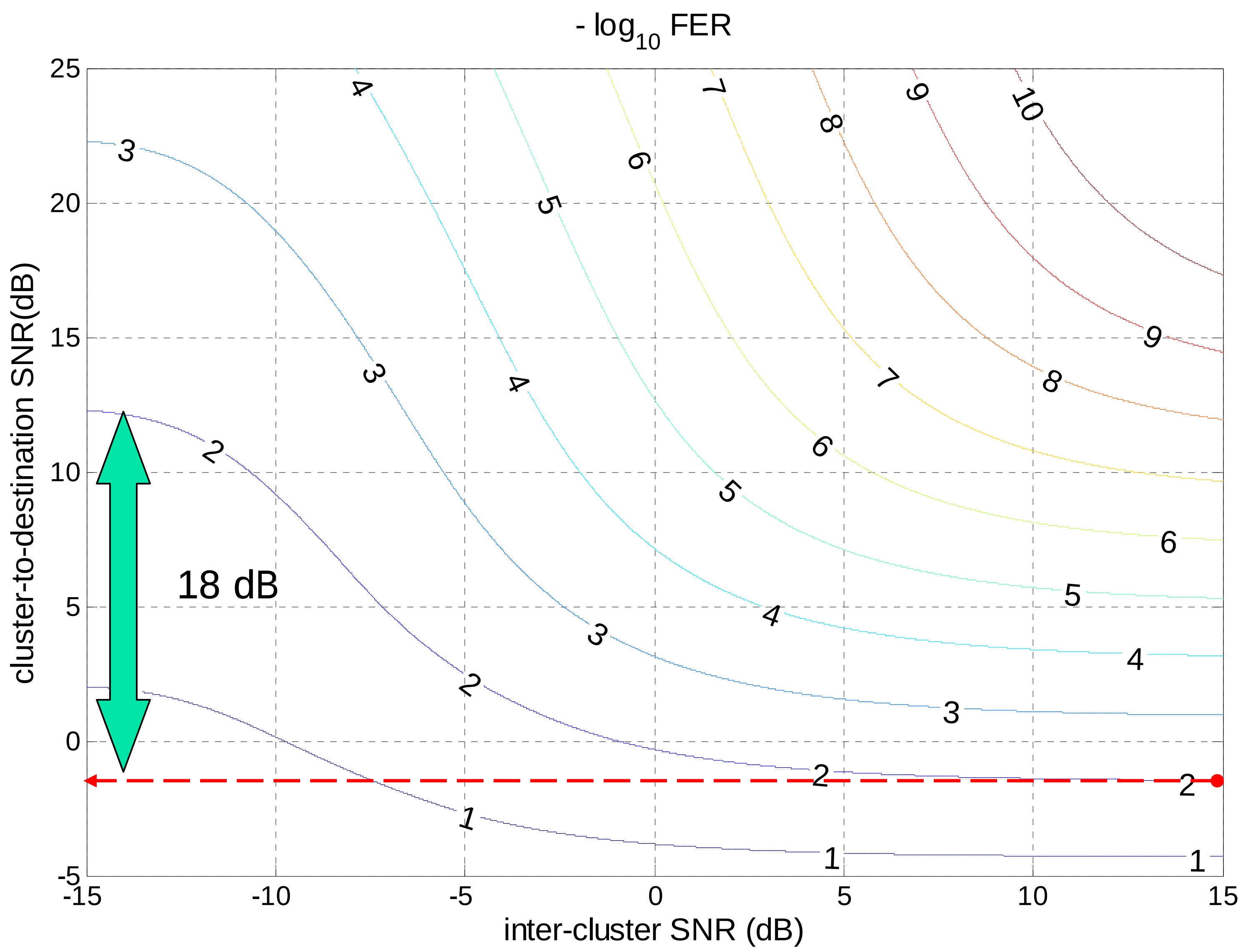


FER performance (M=5)



Summary

- We propose an IR cooperative coding scheme, which can be easily embedded into the current ad-hoc multihop wireless network protocols.

- We derived a FER upper bound on ML decoding performance and its asymptotic versions based on a simple code threshold.

effective cluster-to-destination SNR

$$\theta(\mathsf{F}) = -\ln\left\{\frac{M-|\mathsf{F}|}{M}\exp\left(-v_{1,M+1}\lambda\right)+\frac{1}{M}\sum_{j\in\mathsf{F}}\exp\left(-v_{j,M+1}\lambda\right)\right\}$$

- λ: (average) cluster-to-destination SNR
- F: reliable set
- M: cluster size
- $v_{j,M+1}$: channel power from Node j to Node M+1