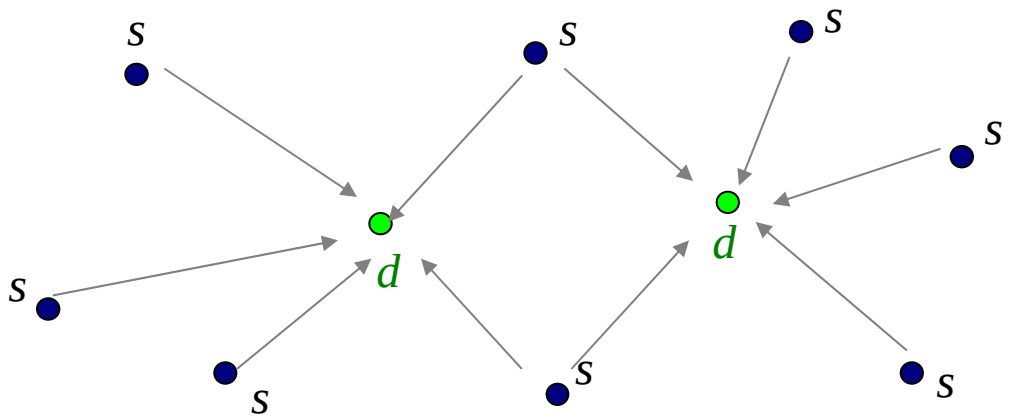
Comparison of User-Cooperation vs. Relay-Cooperation in Multiaccess Channel

Lalitha Sankar
Joint work with G. Kramer, Bell Labs
and N. Mandayam, WINLAB

WINLAB
WIRELESS INFORMATION NETWORK LABORATORY

The Paradigm of Cooperation

- Cooperation results when nodes share their power and bandwidth to mutually enhance transmissions.
- Cooperation induced in at least two ways.
  - User Cooperation: users forward data for each other [Sendonaris, Erkip,Aazhang '98]
  - Hierarchical Relay Networks: relay nodes forward data [Sankar, Kramer,Mandayam '04]
  - Relay introduces hierarchy in the network



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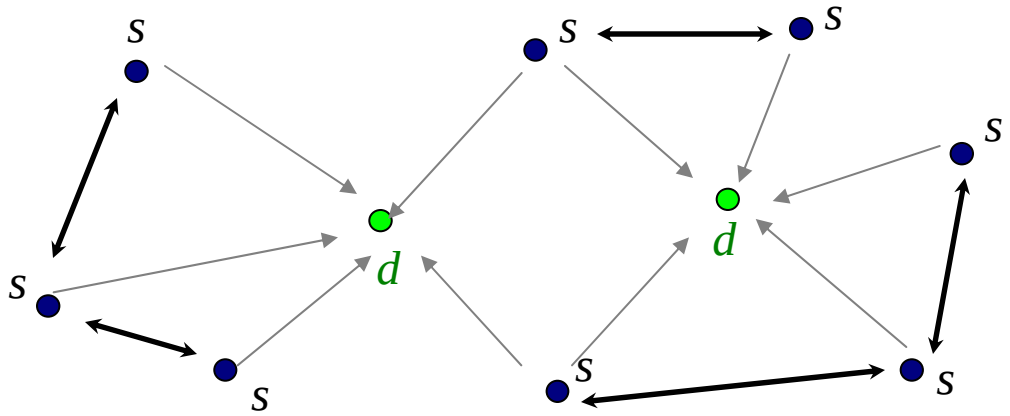

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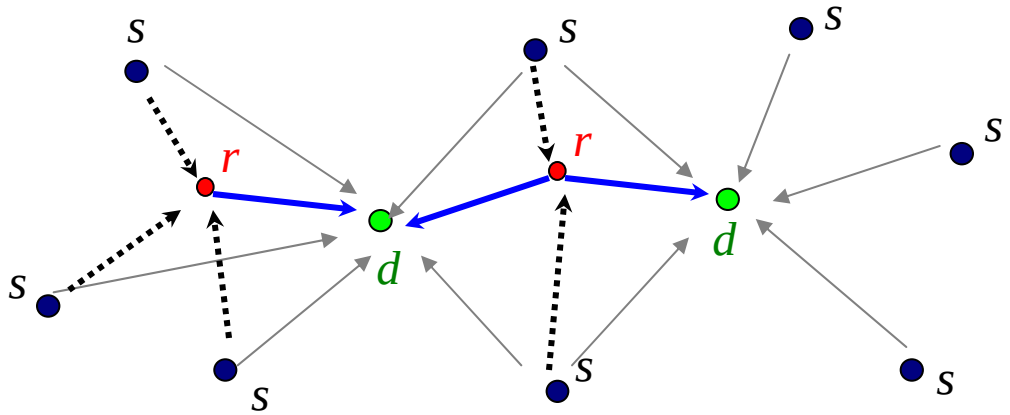

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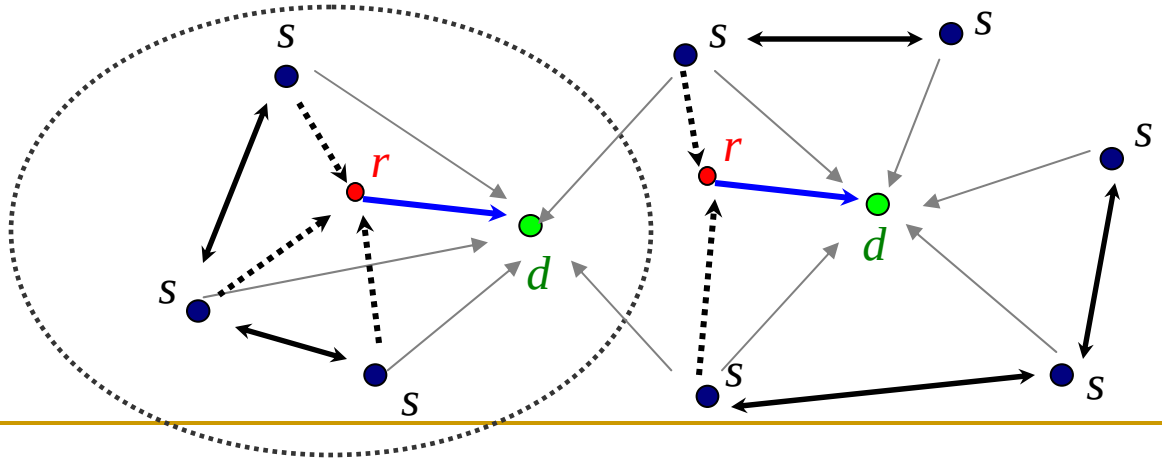


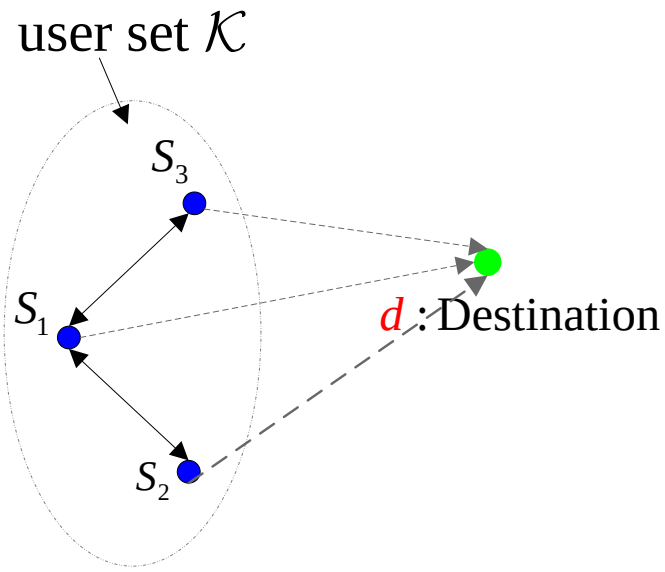
Cost of Cooperation

- A general comparison of the two networks should include cost, power, and bandwidth constraints
- We compare achievable rates and outage for the two networks under a total transmit power constraint P_{tot}
  - Allows fair comparison despite extra node in HN

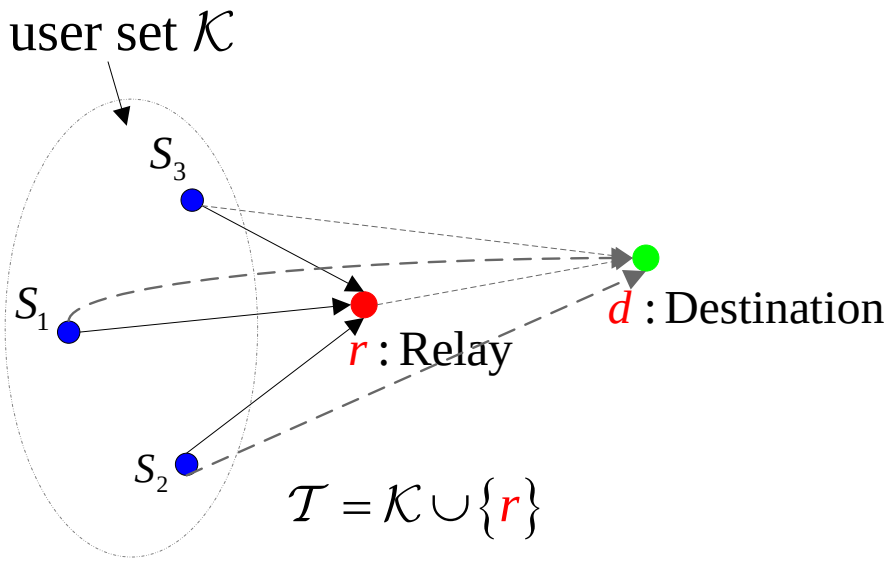
Network Models

- Network of K sources and one destination, node d
- Hierarchical network: introduce relay node r
- Fading AWGN Channel at each receiver

Cooperative Network

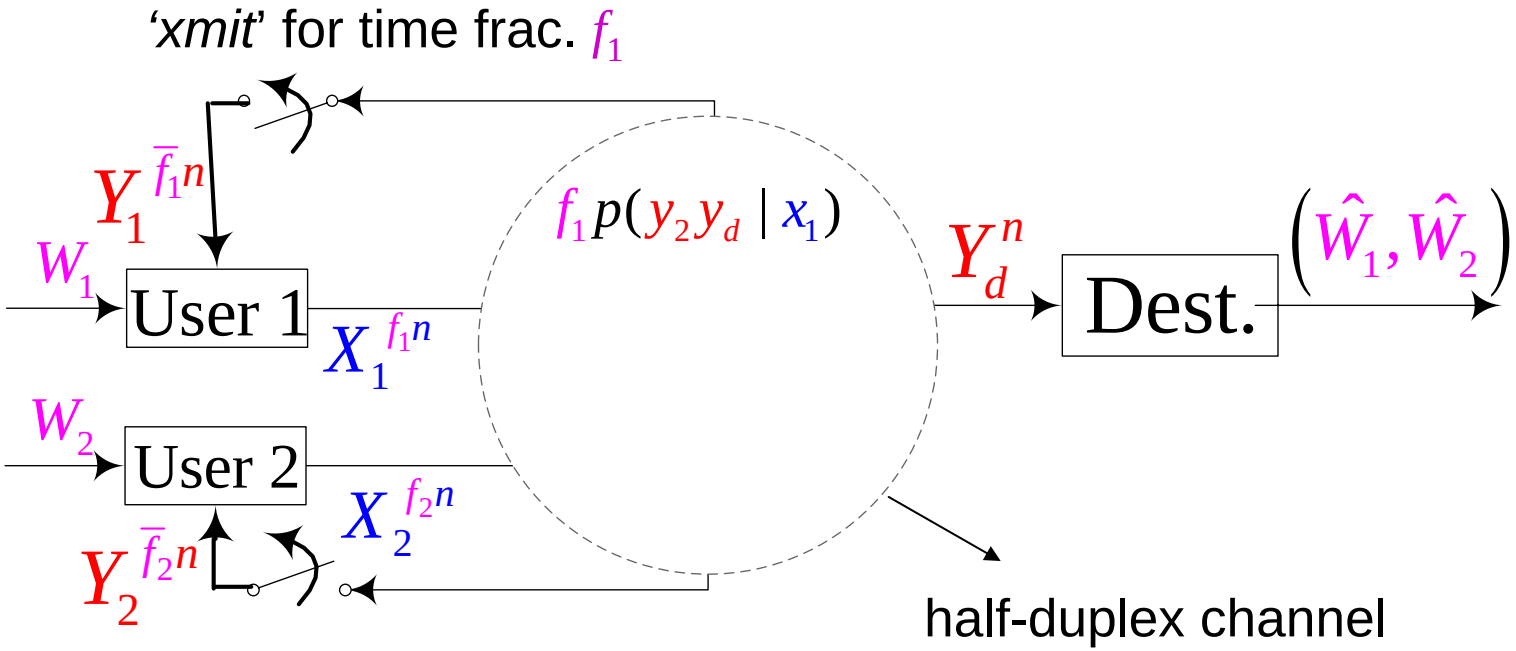


Hierarchical Network



Network Model -- Cooperative

- Sources duplex between '*listen*' and '*transmit*' states



Multi-access Channel with Generalized Feedback (MAC-GF)

Network Model -- Cooperative

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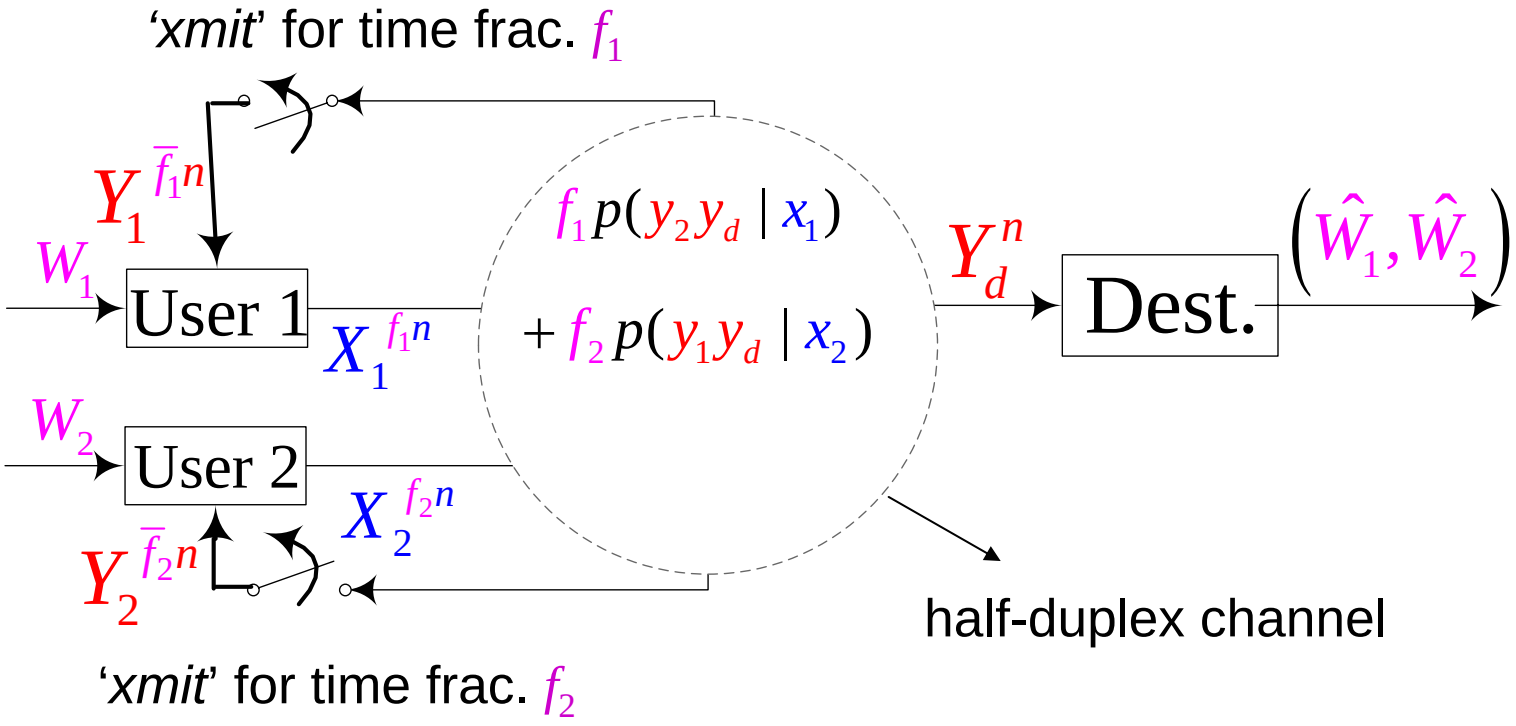

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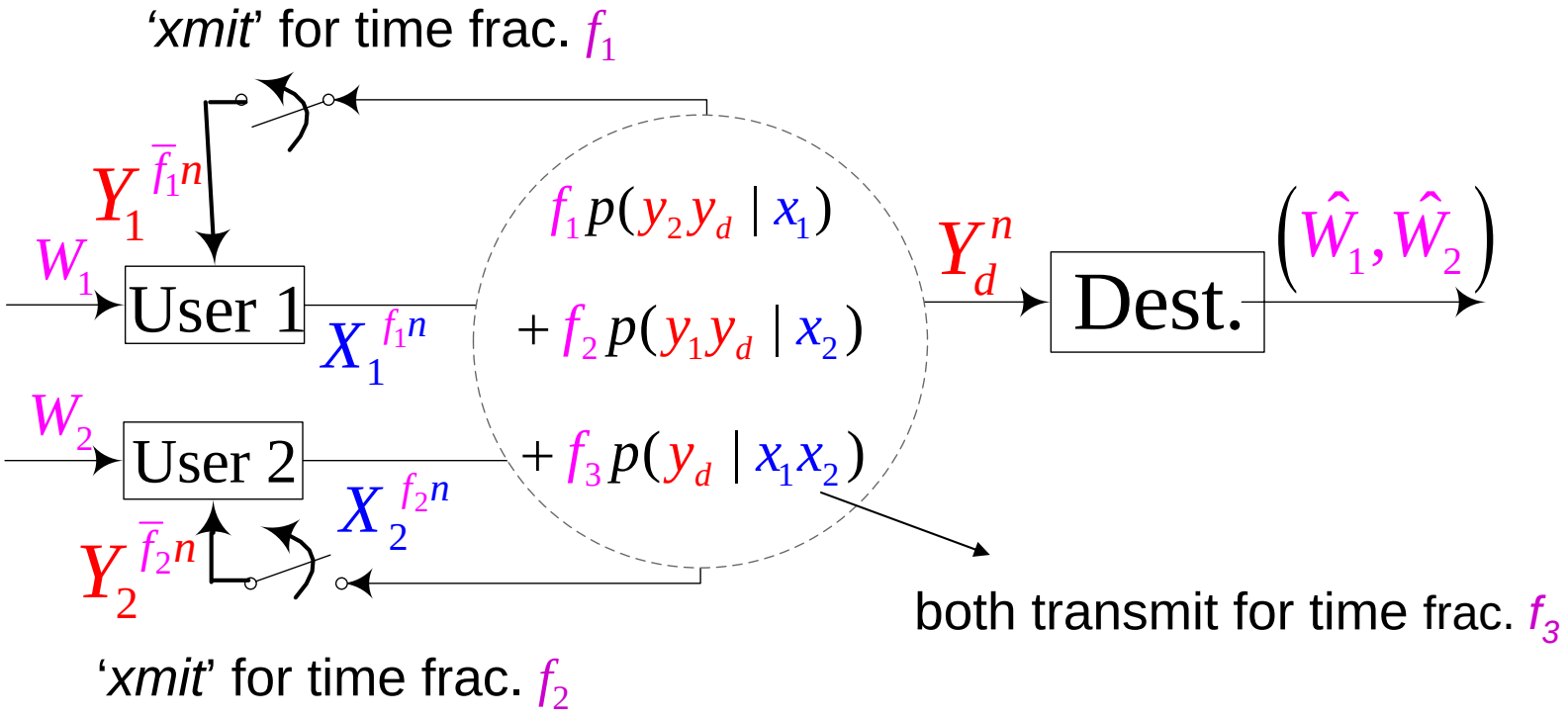
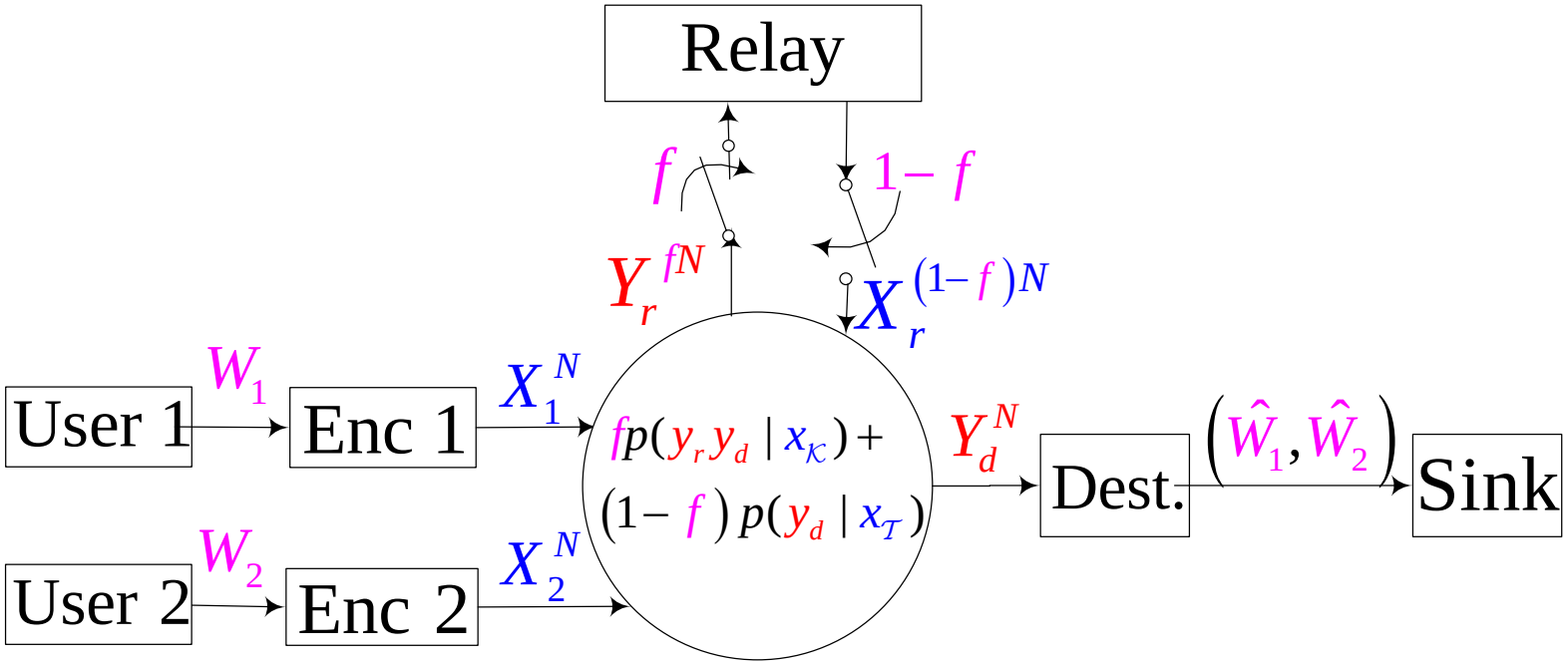


Multi-access Channel with Generalized Feedback (MAC-GF)

Network Model – Hierarchical Relay

- Relay duplexes between '*listen*' and '*transmit*' states



Multi-access Relay Channel (MARC)

Network Constraints

- Cooperative: source and total transmit power constraint

$$P_k^{(C)} \le P_k; \quad k \in \mathcal{K} = \{1, 2, \ldots, K\}$$
$$s.t. \sum_{k \in \mathcal{K}} P_k^{(C)} = P_{tot}$$

- Hierarchical: source, relay, total transmit power constraint

$$P_k^{(H)} \le P_k; \quad k \in \mathcal{T} = \{1, 2, \ldots, K, r\}$$
$$s.t. \sum_{k \in \mathcal{T}} P_k^{(H)} = P_{tot}$$

- For fairness restrict $\boxed{P_{tot} \le \sum_{k \in \mathcal{K}} P_k}$

Transmission Strategy

- Consider a decode-and-forward (DF) strategy where the relay decodes only part of the information (partial DF or PDF)
- Strategy allows for a partial use of a cooperative resource subject to cost per usage
- Introduced in [Cover,El Gamal ’79]

PDF for Cooperative Networks

- Willems presented a PDF strategy for $K = 2$
- Consider case where all nodes cooperate
- Only source k transmits in k^{th} slot for time-fraction f_k
- All sources cooperate to transmit in the $(K+1)^{th}$ slot

PDF for Hierarchical Networks

- Relay decodes only one of the two message streams from any source.
- Relay listens in time fraction f and transmits in (1–f)
- All sources transmit in both slots

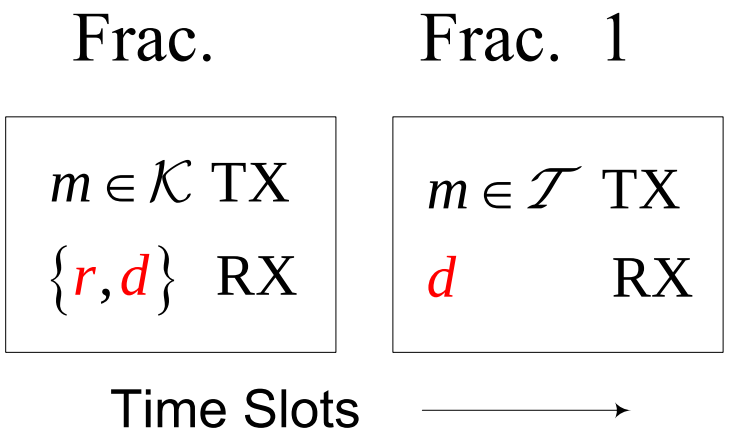
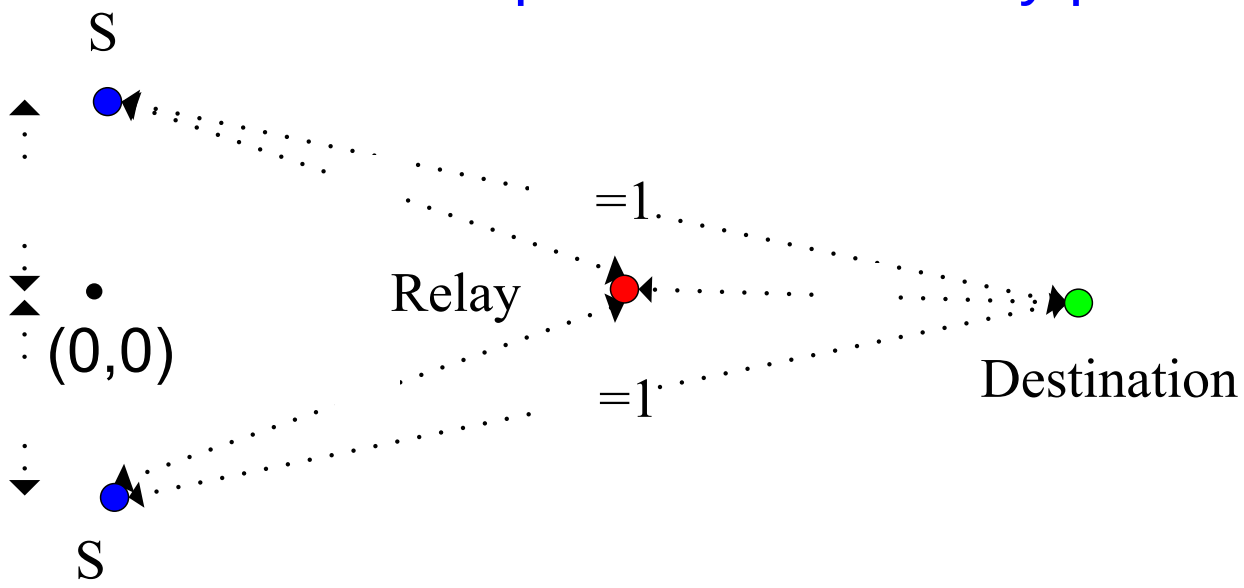


Illustration : Network Geometry

- $K = 2$ symmetric planar network
- Choose total power $P_{tot} = 8$ (normalized w.r.t. noise var.)
- Node power constraints: $P_1 = P_2 = 4$, and $P_r = 6$
- Define $P_{ratio} = P_r^{(H)} / P_{tot}$
- MARC rates can be optimized over relay position



Channel Models

- Channel state information known only at the k^{th} receiver

$$h_{m,k} = A_{m,k} \Big/ \sqrt{d_{m,k}^{\gamma}}$$

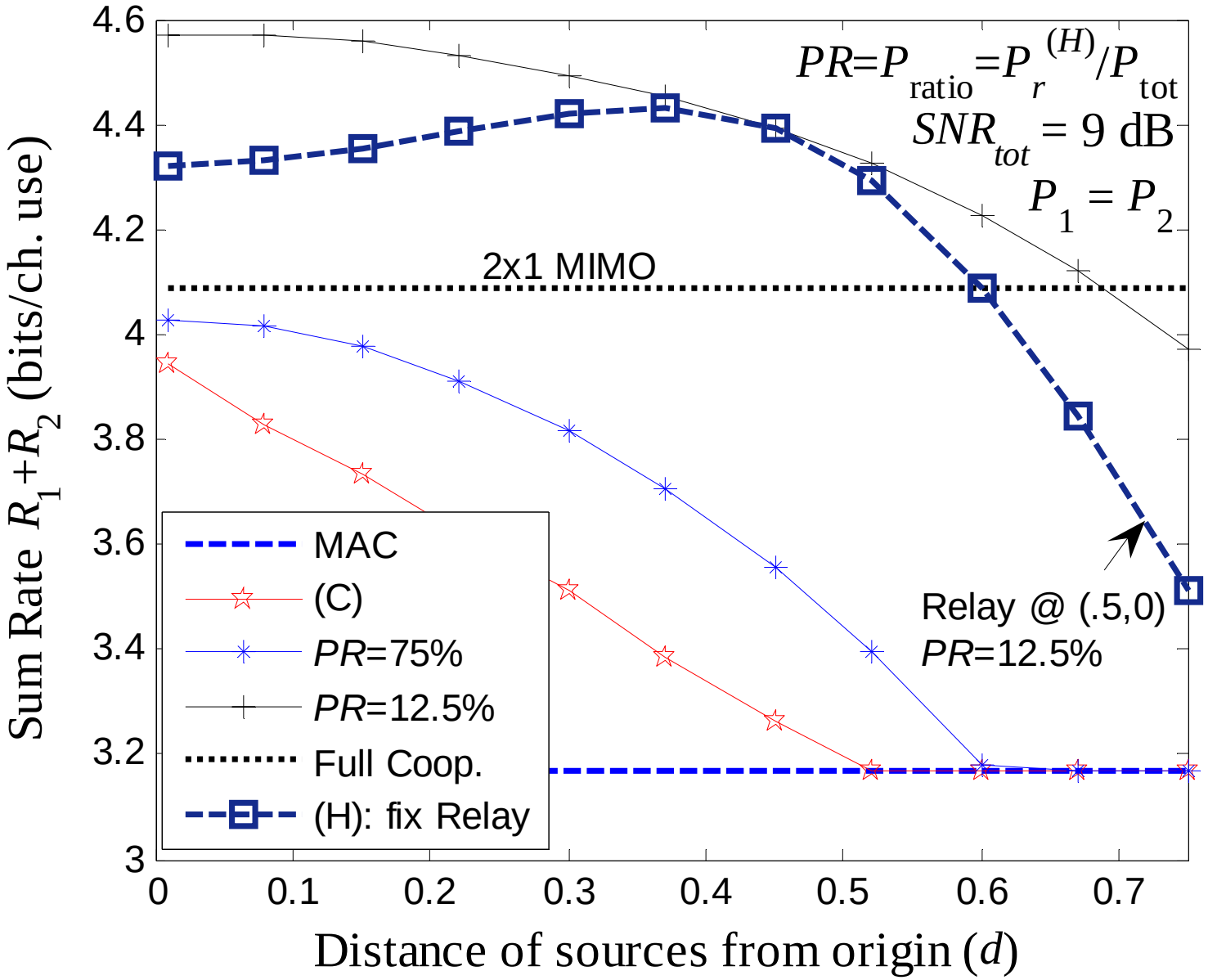
where $d_{m,k}$: m-k distance; γ : path-loss exponent

- Two models for channel gains for $\gamma = 4$:
  - No Fading : $A_{m,k} = 1$
  - Quasi-static Rayleigh fading: $A_{m,k} \sim \mathcal{CN}(0,1)$

No Fading

- Sum-rate for both networks optimized over
  - Half-duplex time fractions
  - Node power in all fractions
  - Convex optimization
- MARC sum rate optimized over relay position
- Compare with MAC (no coop.) sum capacity for same P_{tot}

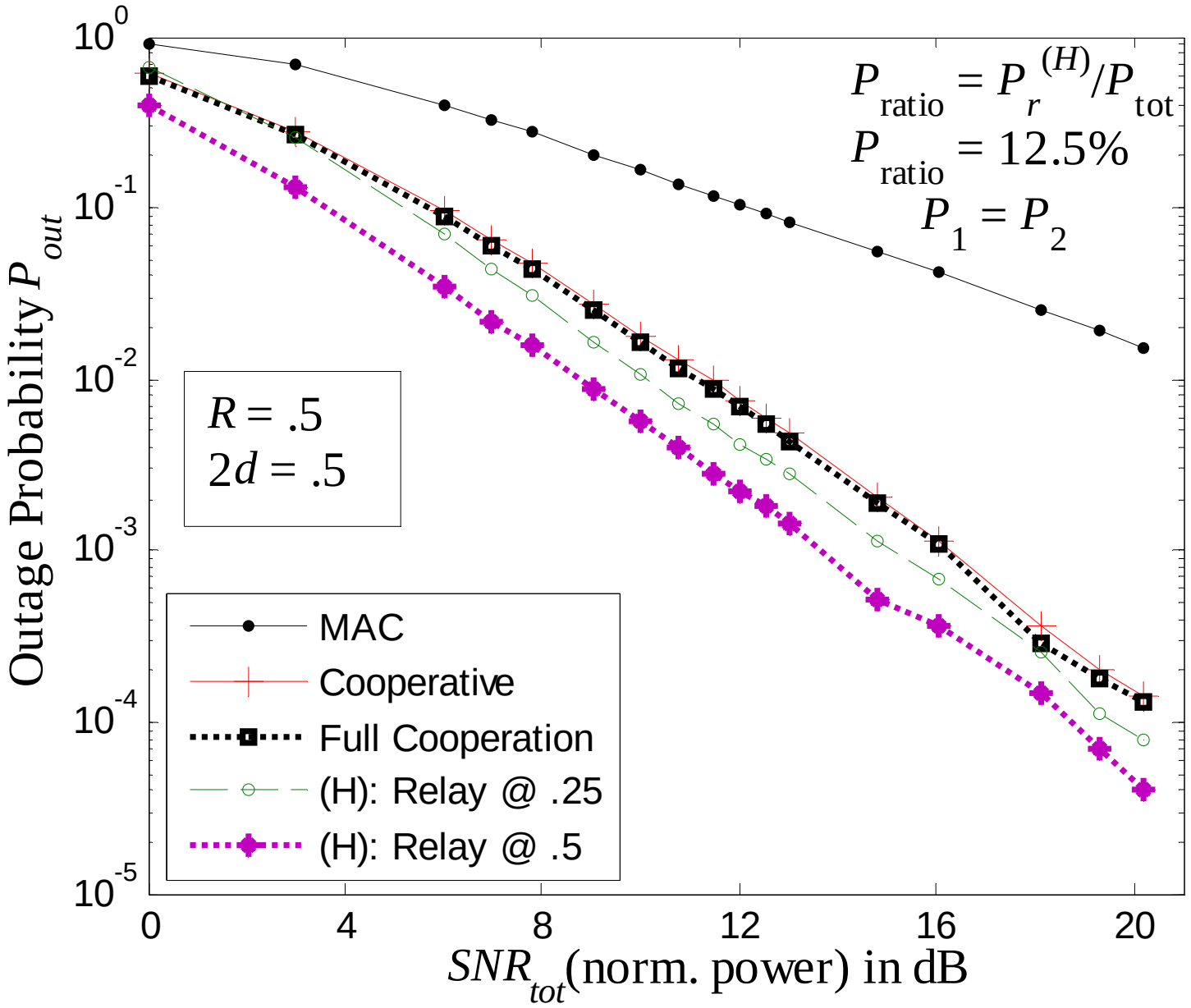
Sum Rate R_1+R_2 - No Fading with $\gamma = 4$



Cooperative: Gains from coherent combining at dest.

Hierarchical: Gains from coherent combining and relay Power at dest.

Outage Probability P_{out} vs. SNR



Sources in Cooperative and Hierarchical network achieve diversity 2

Sources in MAC (no coop.) achieve diversity 1

Summary

- Rate gains due to coherent combining at destination :
  - User cooperation requires synchronization to achieve gains
  - Relay cooperation can achieve gains without coherent combining for path-loss (fading) models
- User-cooperation diversity gains : for K-users
  - maximum diversity K
  - Require SNR > 100 dB to achieve diversity K – due to decoding requirement at all K users
  - Practical SNR range: diversity ~ 2
- Relay cooperation: max. diversity 2.

Thanks!