Some Networking Aspects of Multiple Access

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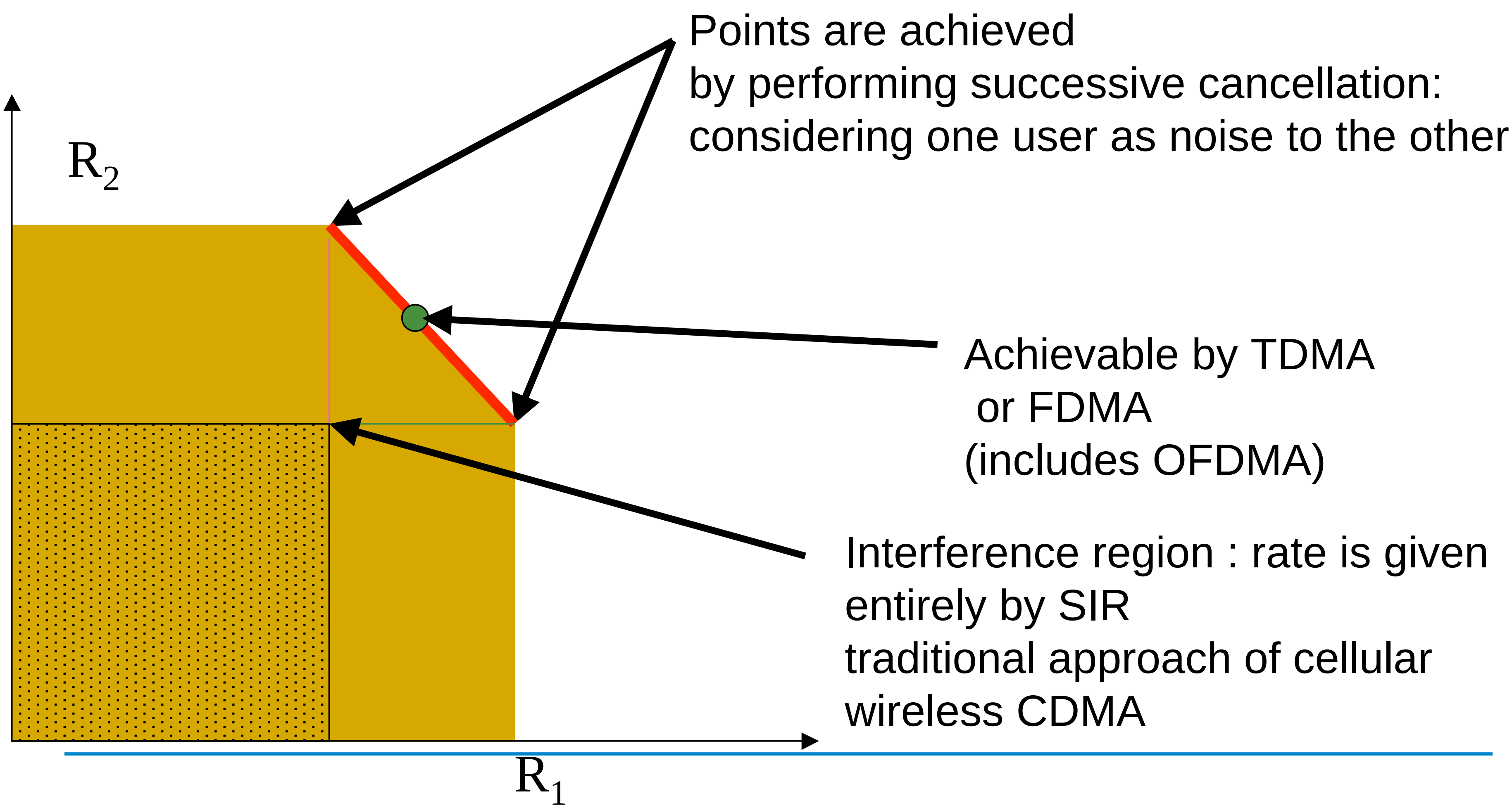
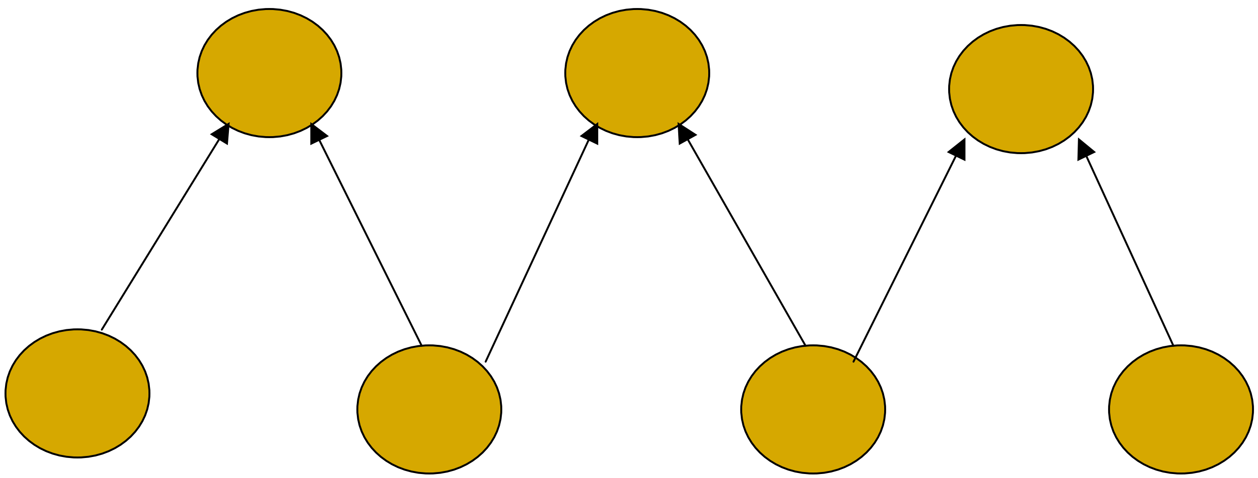
Multiple access

The Cover-Wyner rate region



Multiple access in networks



Problem:

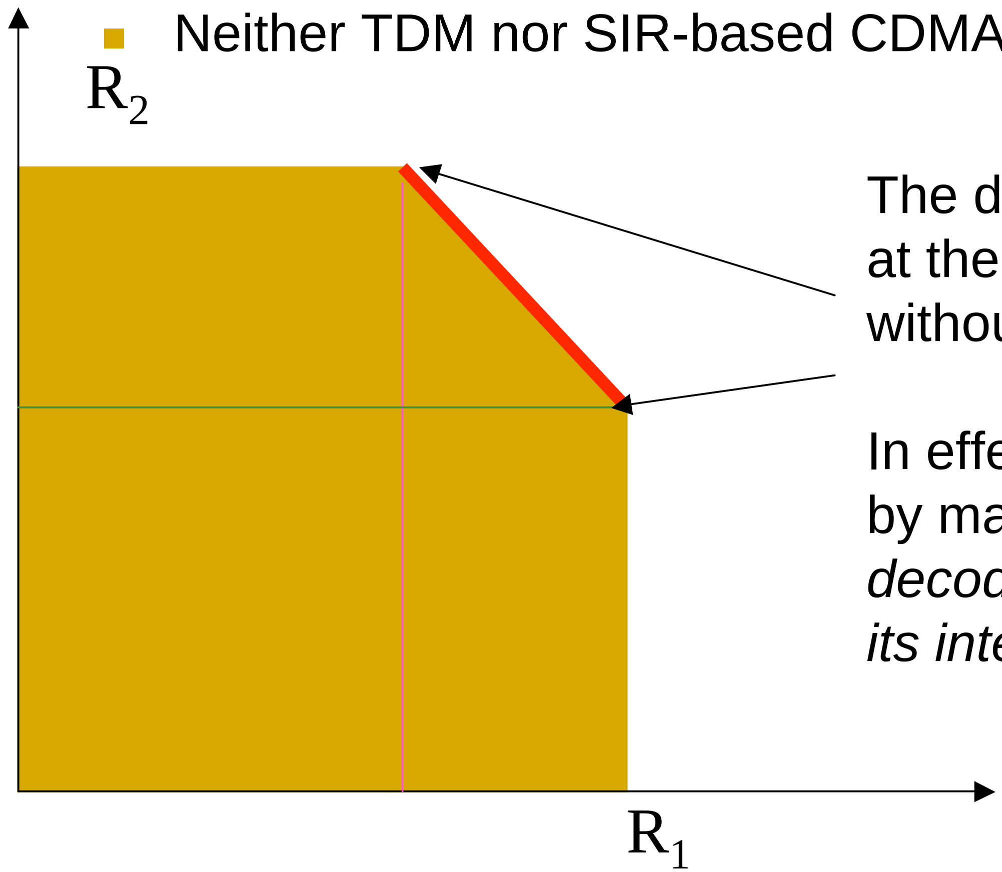
Multiple access in uncertain conditions and channels

Effect of multiple access on the network

Interaction of several multiple access points

Intermediate SNRs

- Neither TDM nor SIR-based CDMA systems are close to optimal



The decoding order changes the rate at the receiver
without requiring a change of power

In effect obviates the near-far problem by making use of SIR differences to *decode stronger user first and remove its interference to the other users*

All rates on the maximum sum rate are achievable using rate-splitting

MAC Resource Allocation

- Utility maximization in non-fading channel
  - Gradient projection-like method with approximate projection
- Dynamic resource allocation in fading channel
  - Greedy vs. Optimal policy
  - Gradient projection method to track the greedy policy
- Two main approaches
  - Communications theory approach
    - No interference cancellation: CDMA [ODW'03], [KH'00]
    - TDMA [WG'05]
  - Information theoretic approach (non-concave utility)
    - Weighted sum rate maximization
      - D. Tse and S. Hanly, "Multi-Access Fading Channels: Part I: Polymatroid Structure, Optimal Resource Allocation and Throughput Capacities".
      - S. Vishwanath, S. A. Jafar, A. Goldsmith, "Optimum Power and Rate Allocation Strategies for Multiple Access Fading channels"

Non-fading channel

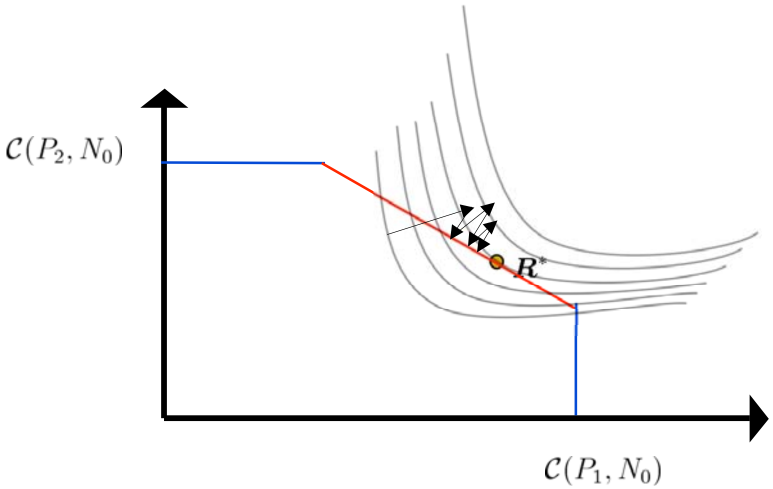
- The utility maximization problem

$$\begin{aligned} &\text{maximize} \quad u(\boldsymbol{R}) \\ &\text{subject to} \quad \sum_{i \in S} R_i \le \mathcal{C}\Big(\sum_{i \in S} P_i, N_0\Big), \quad \text{for all } S \subseteq \{1, \dots, M\} \\ &\qquad\qquad\quad R_i \ge 0 \end{aligned}$$

- Assumption: Let $u: \mathbb{R}^M \to \mathbb{R}$ve, monotonically non-decreasing and has bounded subgradient

- To solve this problem we use gradient projection method

$$\boldsymbol{R}^{k+1} = P(\boldsymbol{R}^k + \alpha^k \boldsymbol{g}^k)$$
$$\boldsymbol{g}^k \in \partial u(\boldsymbol{R}^k)$$



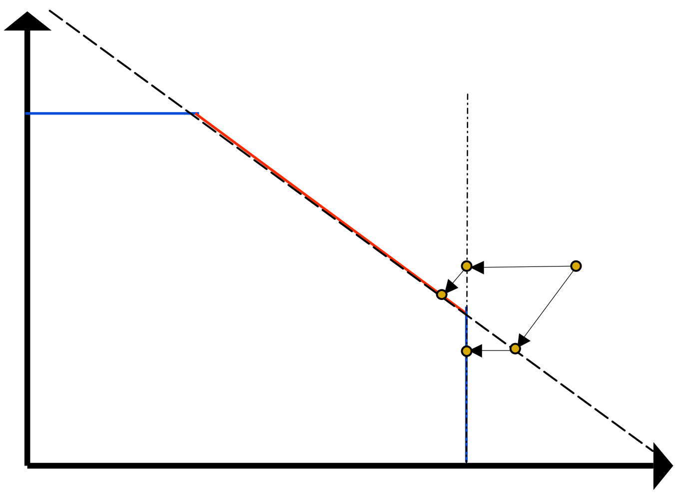
- This method converges to the optimal solution for appropriate stepsize and bounded subgradient,

ParandehGheibi, Ozdaglar, Medard, Eryilmaz

The Projection Problem

- Gradient projection effective when projection is easy
- In our problem, exact projection is hard

- Main novelty: Approximate projection
  - Successively project on the hyper planes corresponding to the violated constraints
  - Terminates after finite iterations
  - Resulting solution not unique



Fading Channel

- Goal: Find rate allocation policy $\mathcal{R}: \mathbb{R}^M \to \mathbb{R}$ s.t.

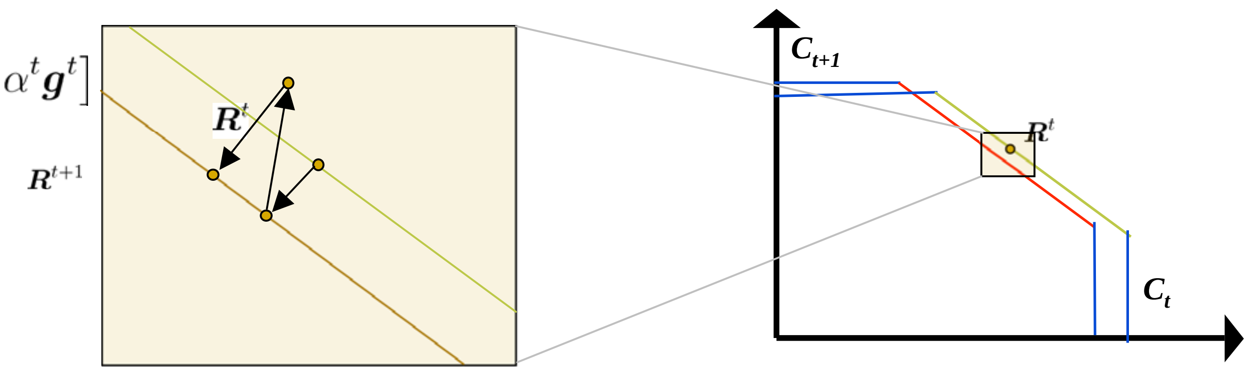
$$\mathbb{E}_{\boldsymbol{H}}\left[\mathcal{R}^*(\boldsymbol{H})\right] = \operatorname{argmax}\ \mathrm{u}(\boldsymbol{R}) \quad \text{subject to } \boldsymbol{R} \in \mathrm{C_a}(\boldsymbol{P})$$

- There exists a greedy policy closely approximates the optimal policy.
- The greedy policy needs to solve the utility maximization problem at any time instant

  ⇨ Not computationally efficient

- Under slow fading condition we can track the greedy policy by taking one iteration of the gradient projection method

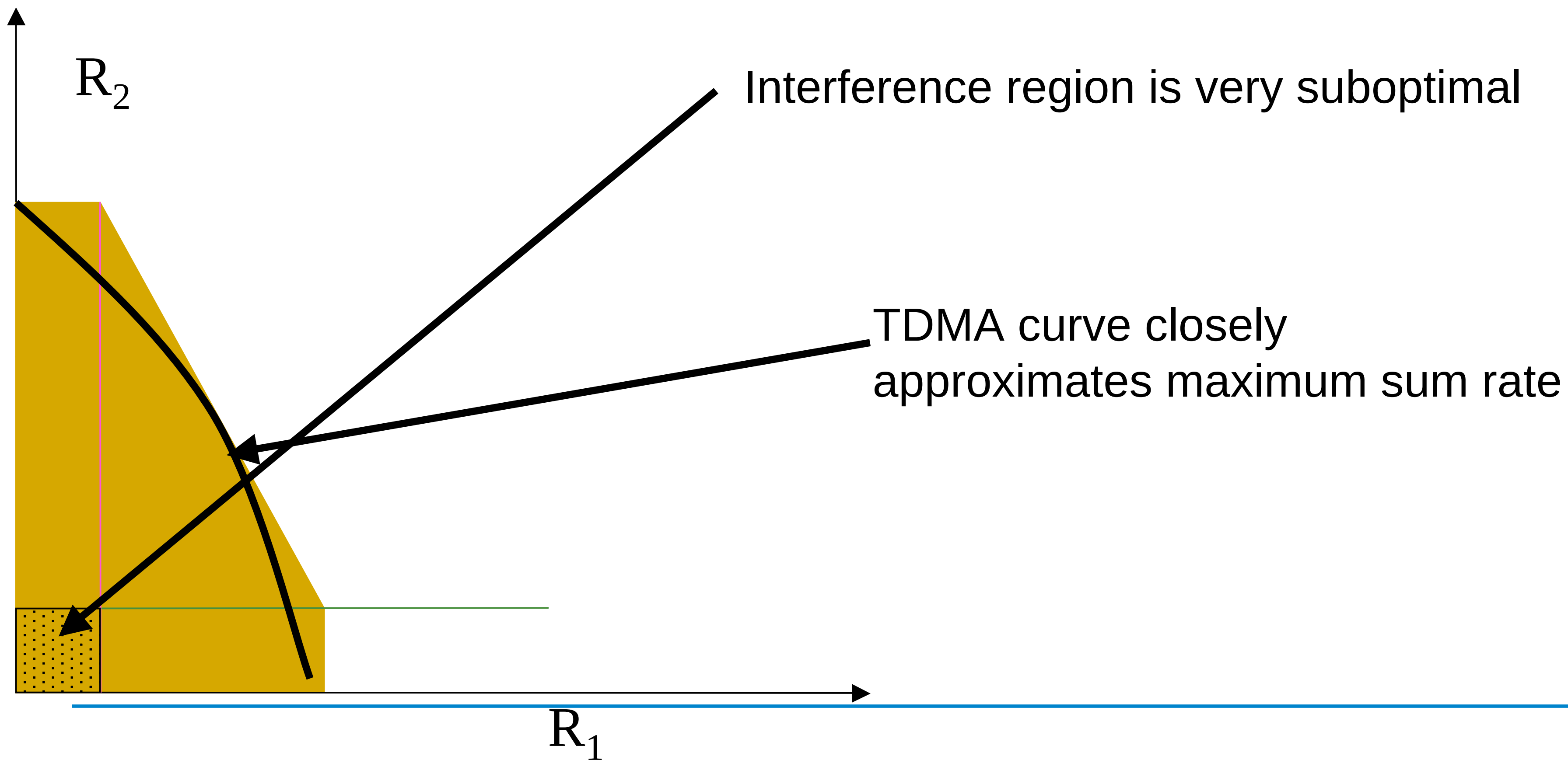
$$\boldsymbol{R}^{t+1} = \tilde{P}_{t+1}\left[\tilde{P}_{t+1}[\boldsymbol{R}^t] + \alpha^t \boldsymbol{g}^t\right]$$



- The rate allocation policy: $\tilde{\mathcal{R}}(\boldsymbol{H}(t)) = \boldsymbol{R}^t$

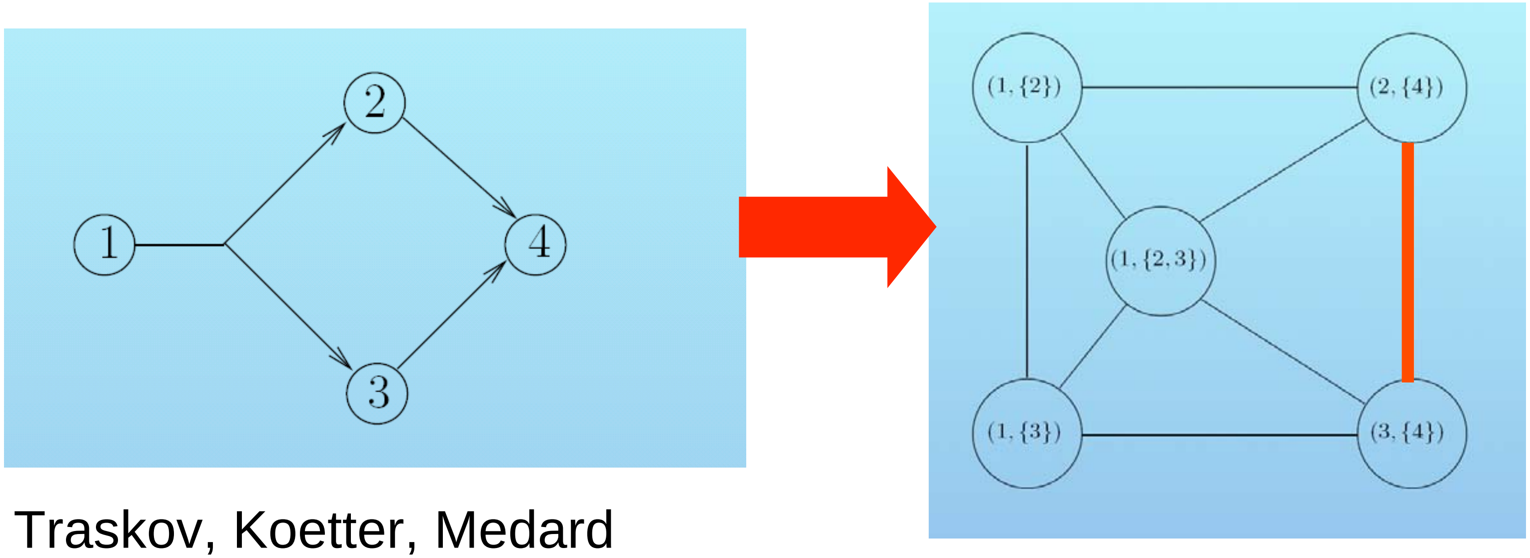
High SNR Case

In the case of high SNR, system is quasi-optimal if run as a TDMA system



Multiple access as a conflict

- A vertex represents a configuration of the network in terms of codes among components of the network
  - An edge between two vertices if the two configuration cause conflict (i.e. They cannot be served simultaneously).
- Stable Set: no edge connecting any pair of vertices in the set
  - Stable set of G → valid network configuration

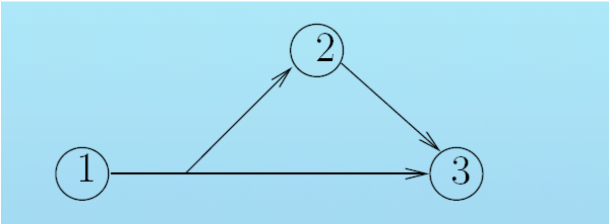


Traskov, Koetter, Medard

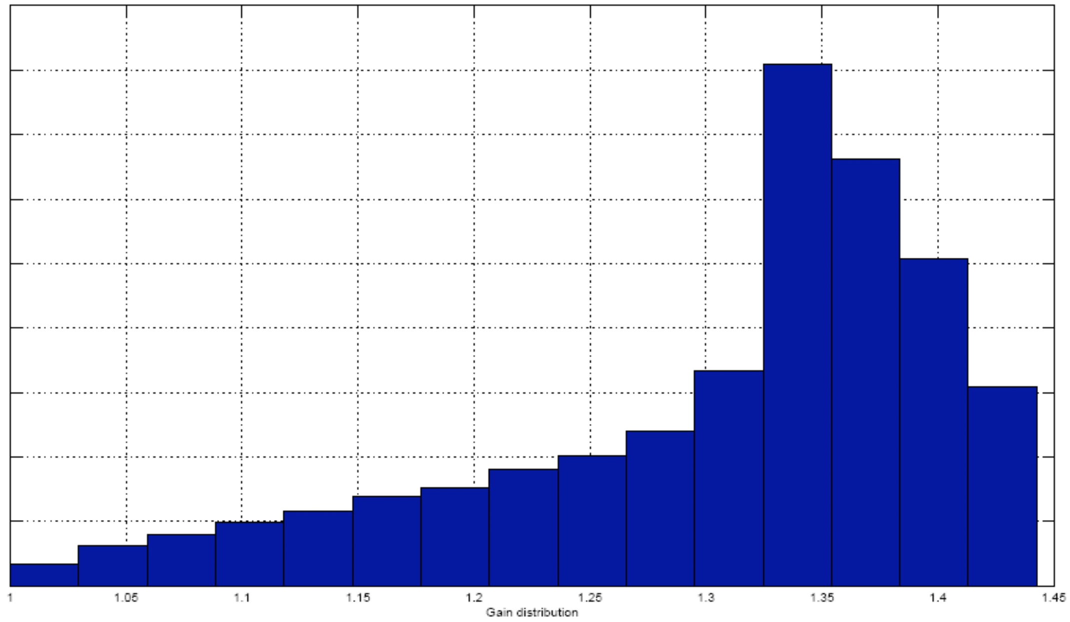
Multiple access as a conflict

- A valid transmission schedule is an *independent set* in the conflict graph.
- The rate region is the convex hull of the *independent set polytope*.
- In general this is computationally very demanding, however in certain graphs (perfect graphs) maximum independent sets can be computed efficiently (in polynomial time).
- Examples of perfect graphs are *bipartite graphs* (e.g. layered networks), *fully connected graphs* (cluster networks), ...

Network coding in a relay with conflicts

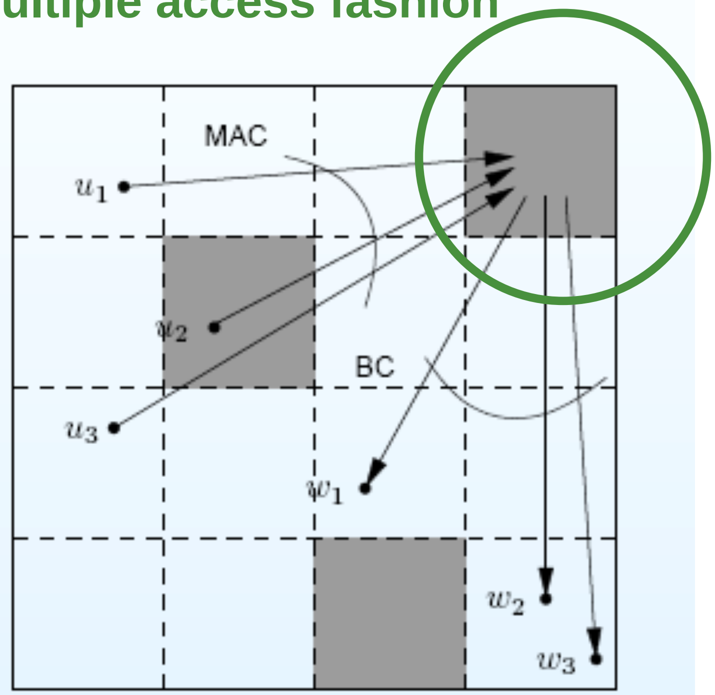


Take two nodes S and T at unit distance and place a relay randomly in the circle with midpoint (S+T)/2.
We assume the erasures due to distance attenuation follow a square law rule.
We compare the performance of network coding using the relay as opposed to routing.



Scaling laws using multiple access

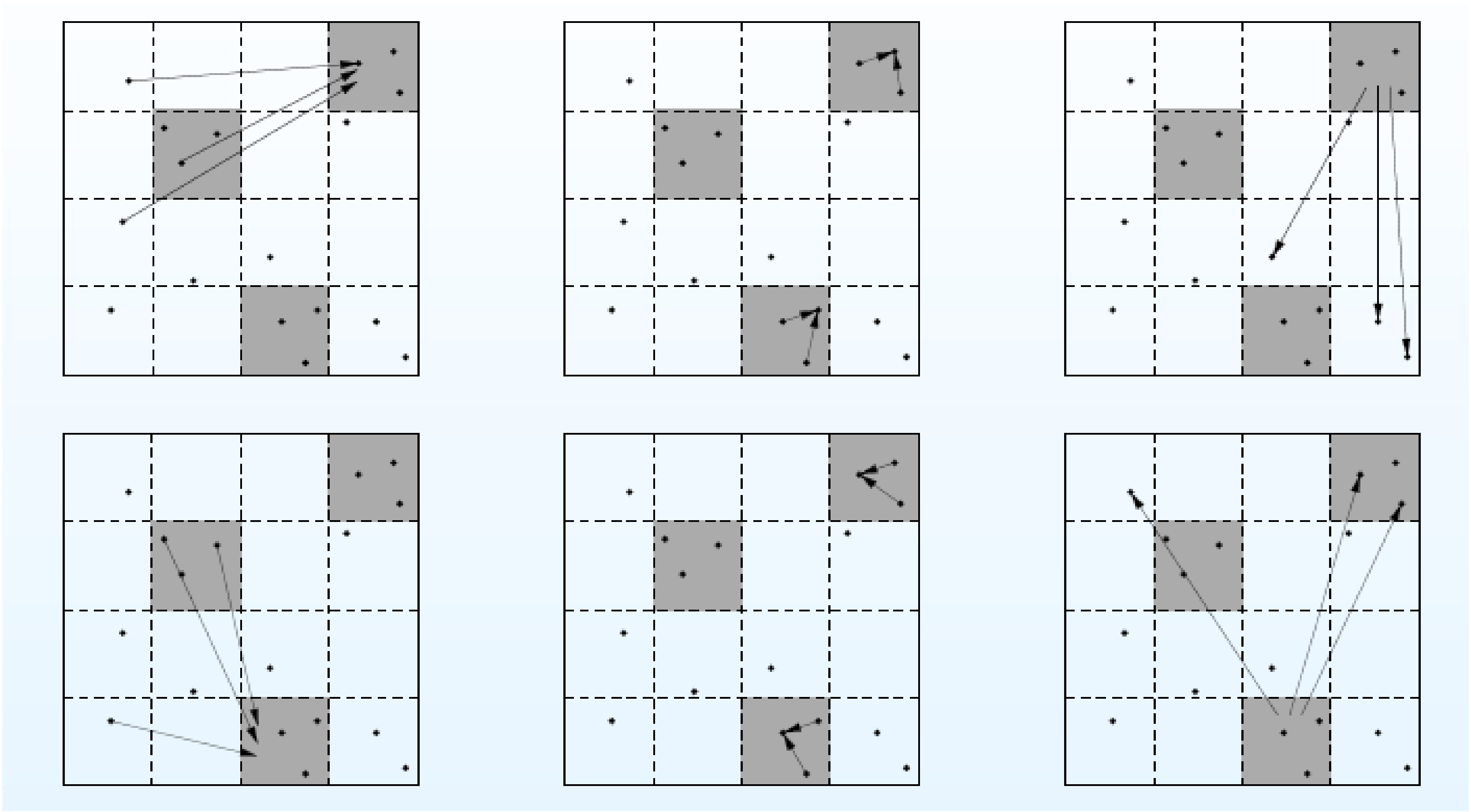
Squarelet acts as a component and interconnections occur among components, albeit in a multiple access fashion



- Example of granularity in systems
- Divide into squarelets
- Constant fraction of squarelets are dense (contain many nodes)
- Source-destination pairs relay traffic over dense squarelets
- Induces virtual multiple antenna multiple access and broadcast channels

Niessen, Shah, Gupta

Further hierarchical interaction



Consequences

- A hierarchical cooperative communication scheme, achieving a per node rate

$$\rho^{HR}(n) \geq n^{1-\frac{\alpha}{2}-o(1)}$$

for any α > 2, attenuation exponent

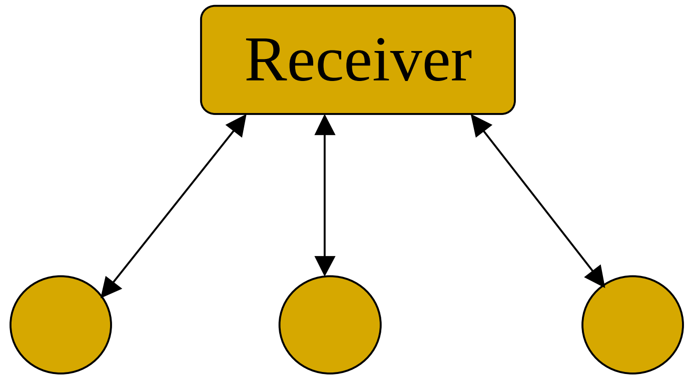
- For the best communication scheme

$$\rho^{*}(n) = O\left(n^{1-\frac{\alpha}{2}+\varepsilon}\right)$$

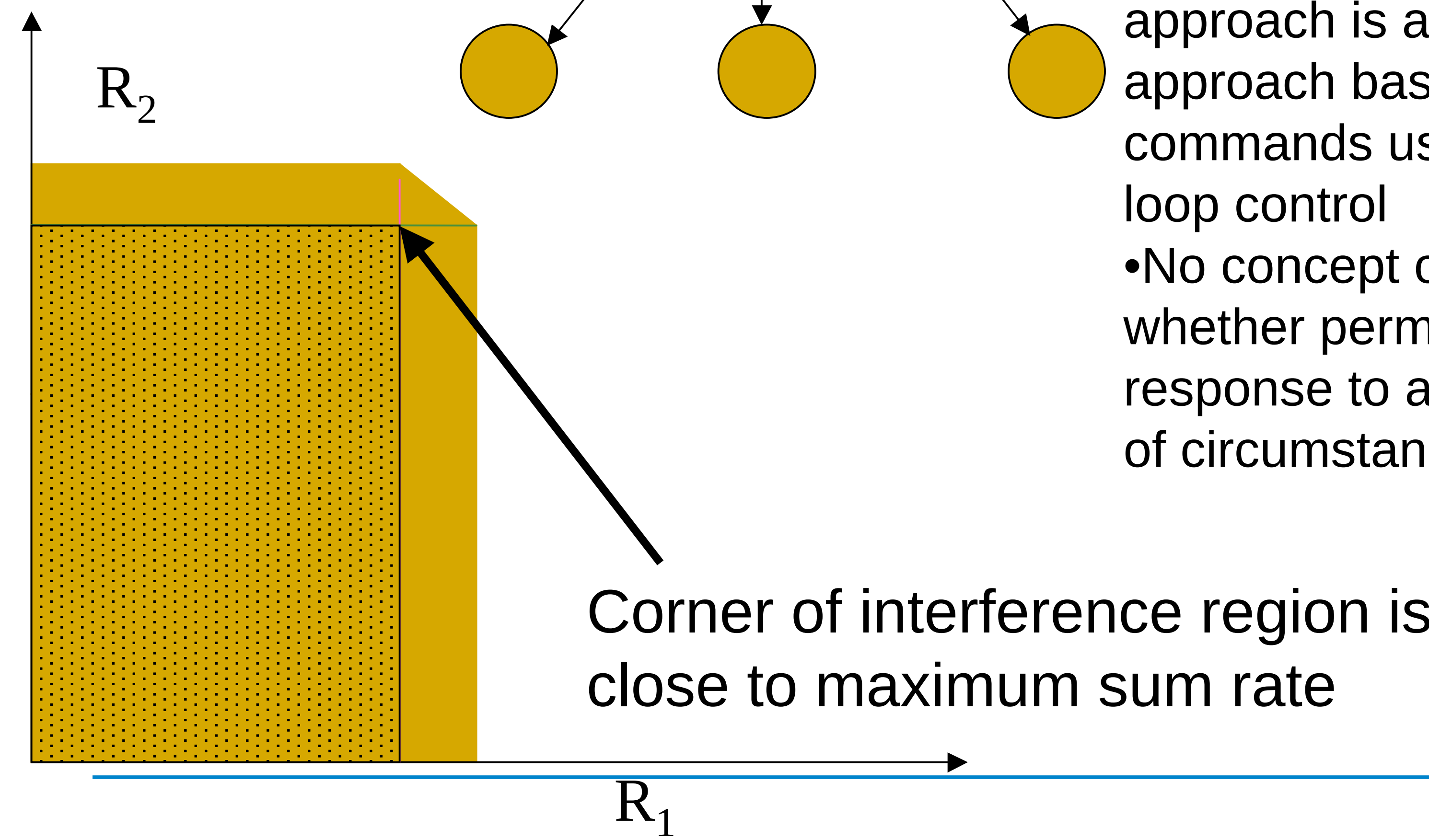
for ε > 0 arbitrarily small and for any2 < α 3

- Thus scheme is order optimal for 2 < α < 3, so that decomposition is not detrimental in an order sense

Low SNR case - Interference



- The users compete for SIR at receiver
- The traditional cellular approach is a max-min approach based on explicit commands using closed-loop control
- No concept of priority, whether permanent or in response to a rapid change of circumstances



Going further

- Use of uncertain channel multiple access schemes in network settings
- Placing soft constraints of multiple access in place of hard conflicts
- Use of multiple access as an enabler for network coordination in moderate size networks
- Low SNR networks – multiple access are locally obviated