Hype, Myths, Fundamental Limits and New Directions in Wireless Systems

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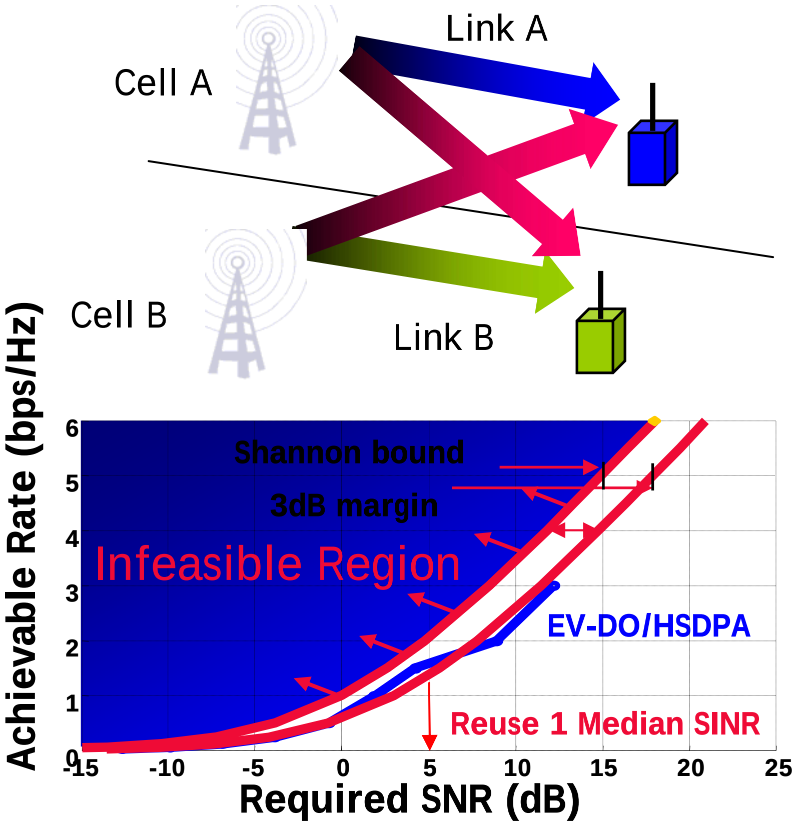
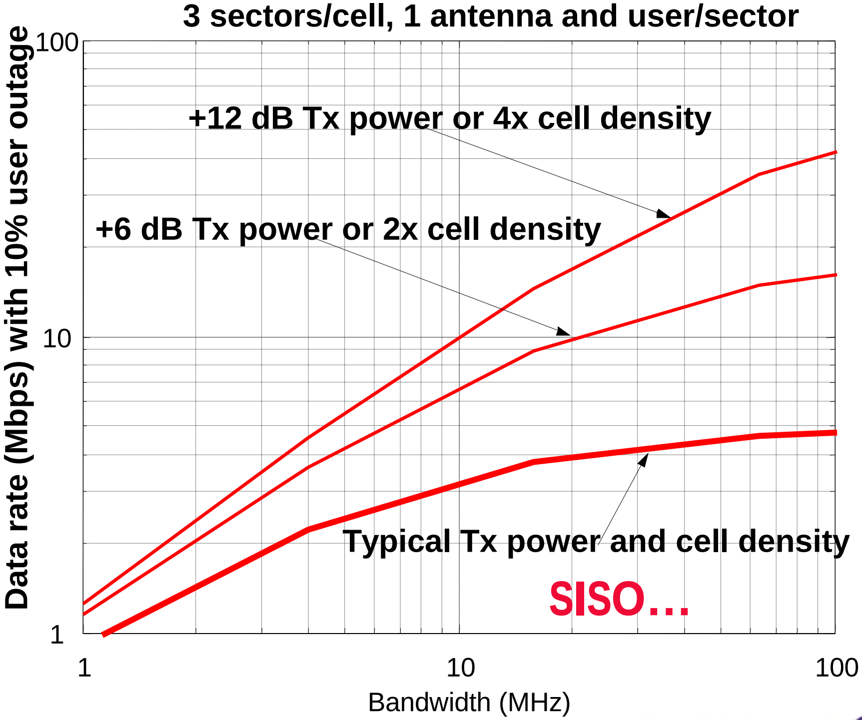
Need to greatly increase rates for new apps and services….

…Not possible to break the laws of physics…

- Cellular revolution from extensive coverage and mobility
- Universal reuse maximizes spectral efficiency
- Classic deployments dominated by interference (Not the case for Hot Spot, Indoor)
- Link performance is approximating fundamental limits
- Gains from smaller cells, increased spectrum and Interference cancellation



Increasing BW or reducing range is expensive or ineffective



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1-D FDM ORTHOGONAL RELAYS WITHOUT REUSE

K relays between source and destination at unit distance

N=K+1 orthogonal channels, each gets 1/N of full system bandwidth

Reuse options also explored

All nodes transmit all the time

Reference SNR (K = 0): ρ

Propagation loss reduction: N^{γ}

Capacity (total power constant): $1/N \cdot \log_2(1 + \rho N^{\gamma})$

1/N the power per node

Similar to TDM with peak power limit

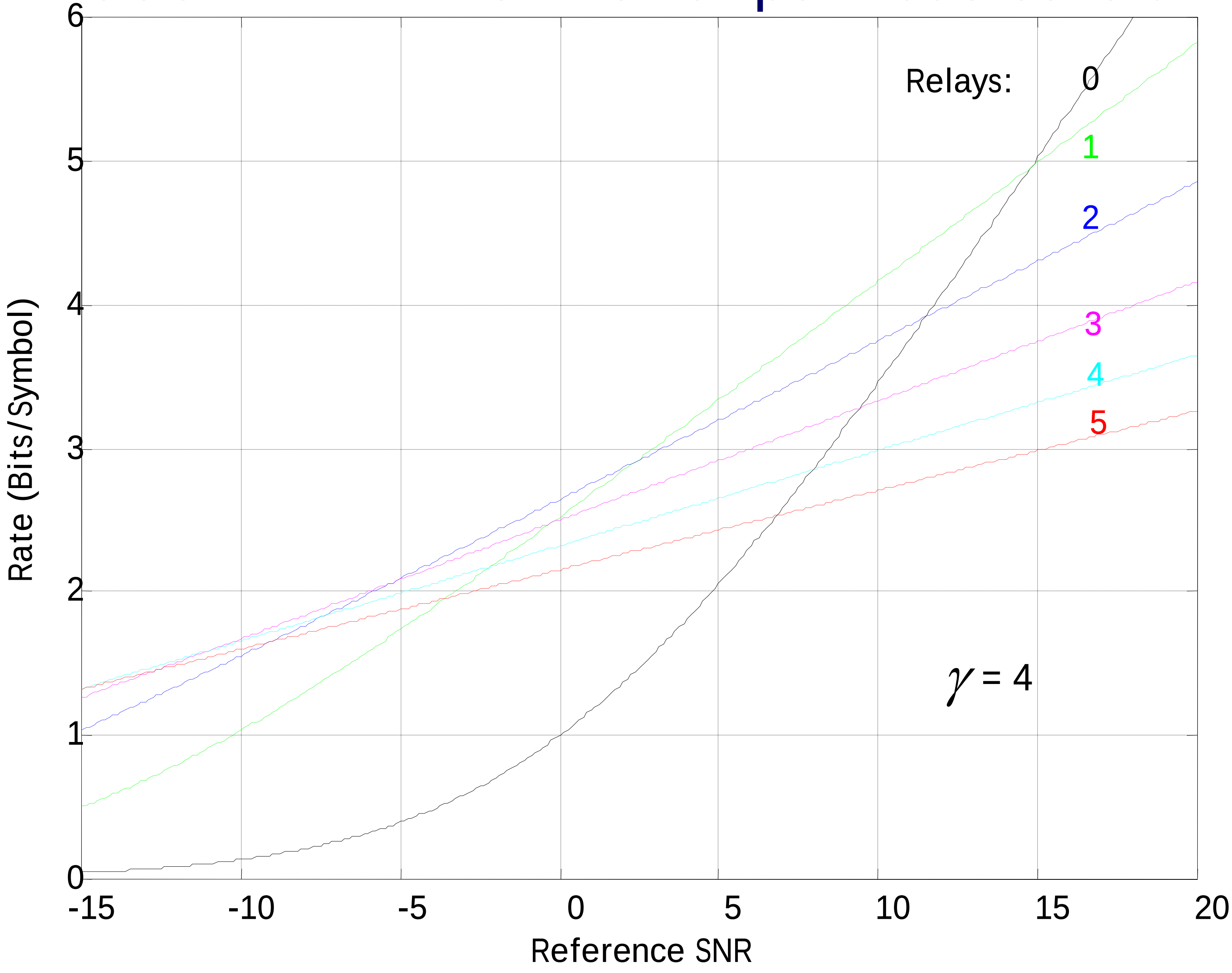
Capacity (power per node constant): $1/N \cdot \log_2(1 + \rho N^{\gamma+1})$

N times total power

Similar to TDM with average power limit

**Bandwidth and Power Efficient Routing in Linear Wireless Networks,* M. Sikora, J. N. Laneman, M. Haenggi, D.J. Costello and J. Fuja, IEEE Trans.on IT,Vol. 52 No. 6, 6/06

ORTHOGONAL RELAYS - Power per node constant



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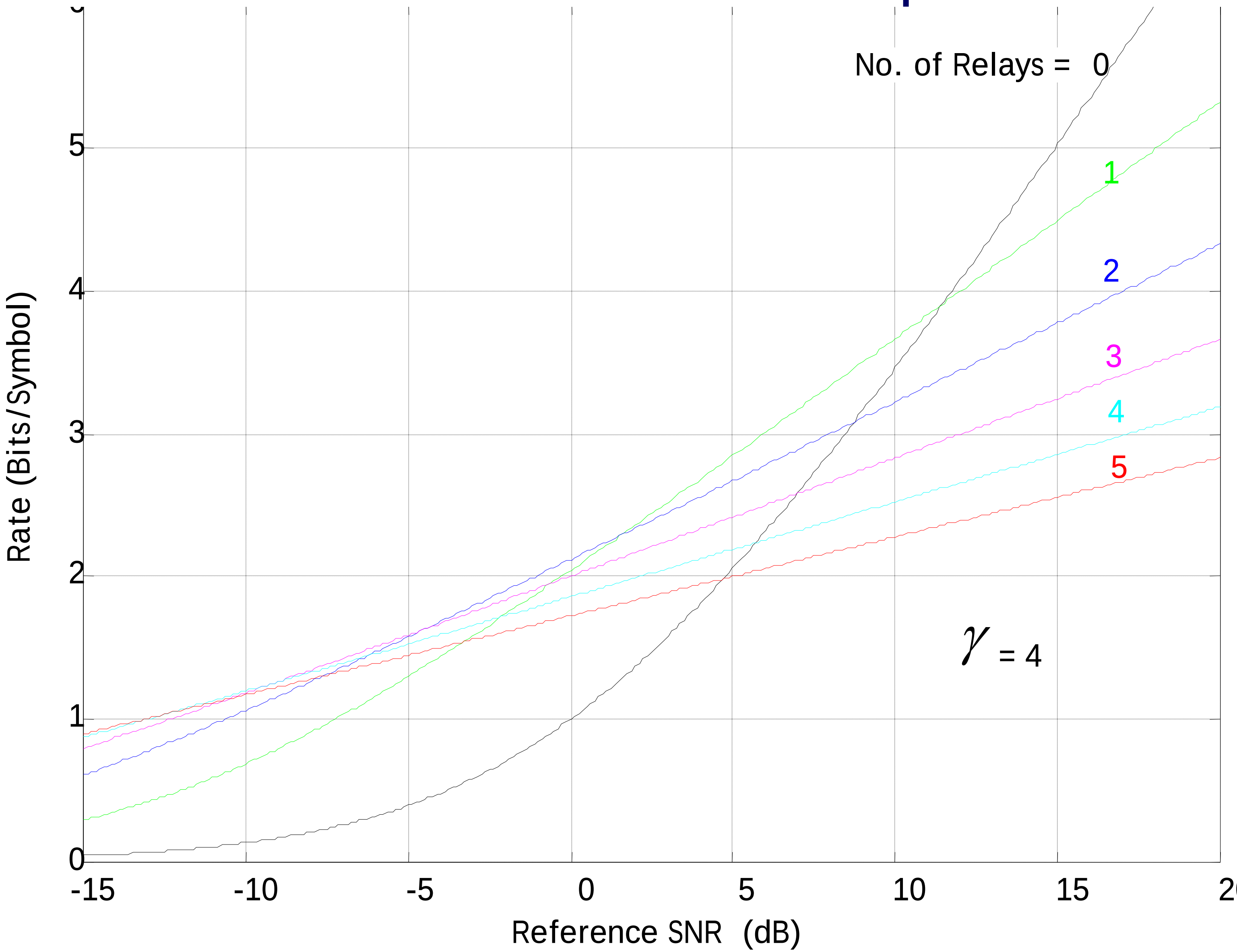
ORTHOGONAL RELAYS - Total power constant



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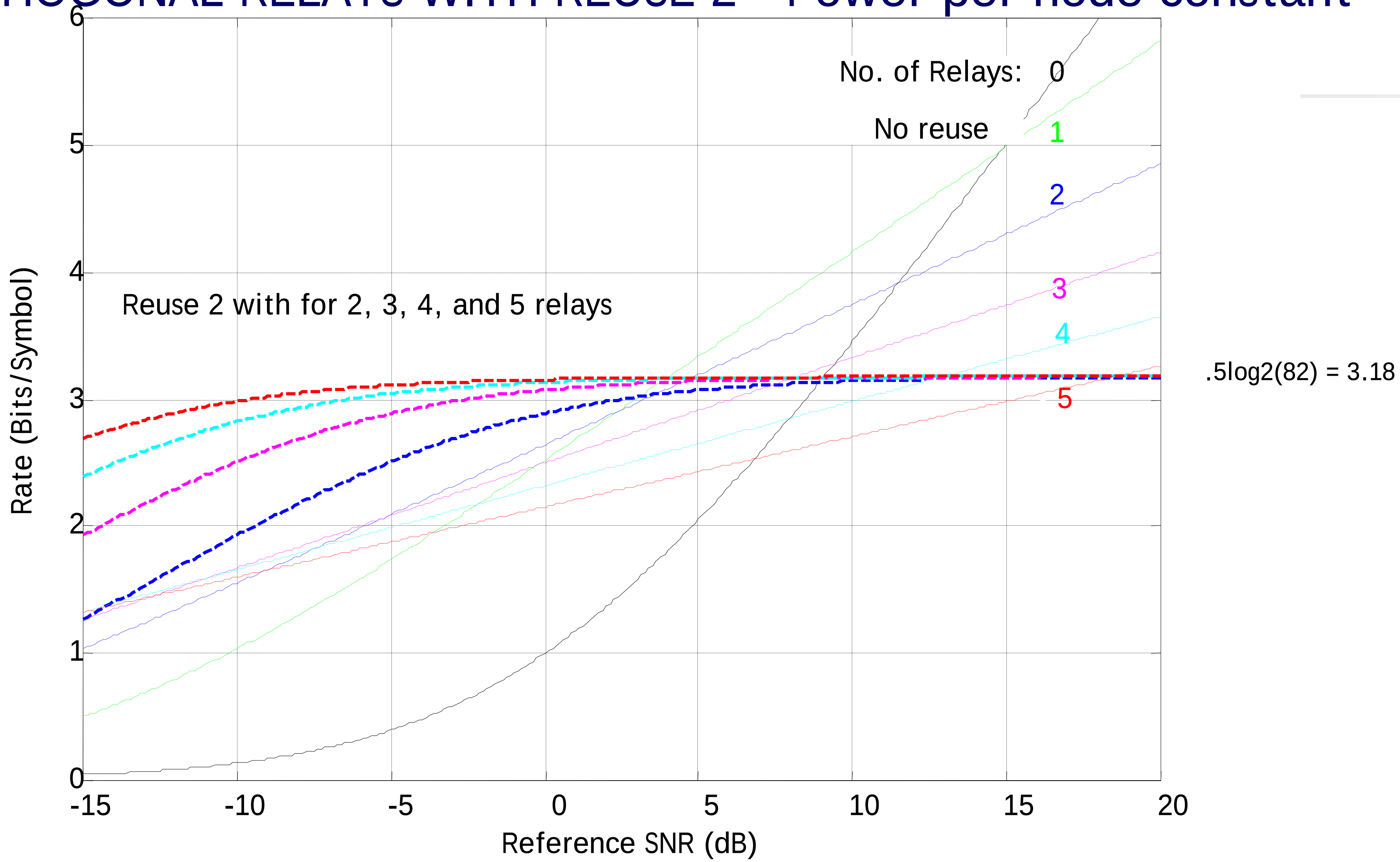
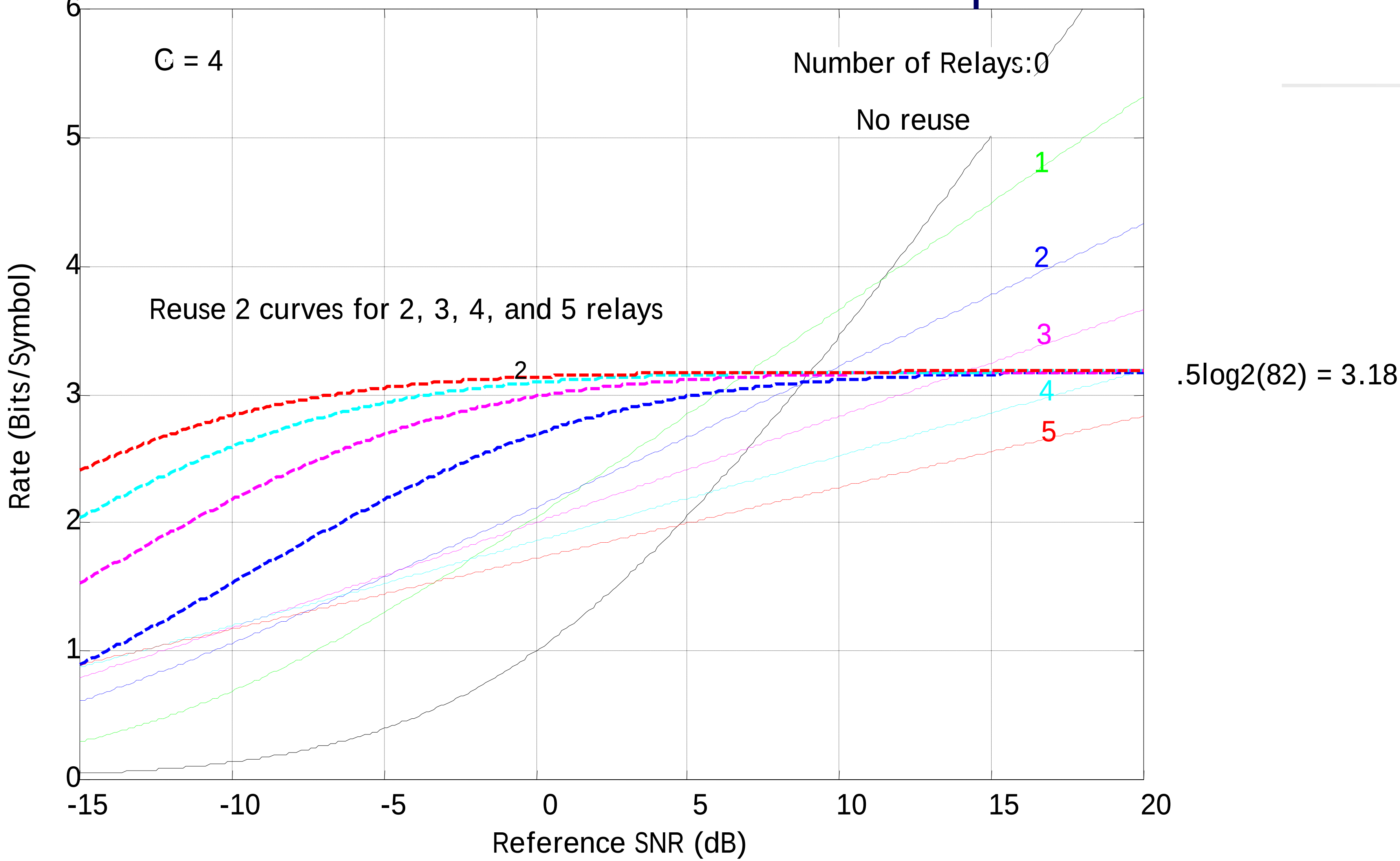
ORTHOGONAL RELAYS WITH REUSE 2 – Power per node constant



Reuse improves performance below 3.18 b/symbol / 4 dB

ORTHOGONAL RELAYS WITH REUSE – Total power constant



Reuse improves performance below 3.18 b/symbol / 7 dB

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Reducing out of cell interference with pico cells

- Increasing base station density for the same users
- Increases capacity per unit area
- At some point most neighboring cells will be idle
- Hardware Versus Software? (NetMIMO) approach

Methodology

Baseline network:

- Same number of users and bases

Denser base deployment

- Number of users and geographical coverage fixed
- Increase base density by N along each dimension

Single base detection

- Idle bases create a de facto guard band reducing ICI
- Infrastructure upgrade, hardware approach

Gerard Foschini, Dmitry Chizhik, Reinaldo Valenzuela – Bell Labs
Yifan Liang, Andrea Goldsmith – Stanford University

Reducing Out of Cell Interference with Net MIMO

Net MIMO methodology

Realistic channel models

- Planar array, downlink
- Empirical propagation models

Criterion

- Portion q of users allowed outage
- Deliver equal rate to remaining users

Tradeoff between rate region and complexity

- Dirty Paper Coding (DPC) optimal, complexity high
- Suboptimal schemes include Zero Forcing (ZF), ZF-DPC

Characterization at system level

- Maintain Infrastructure
- Advance signal processing

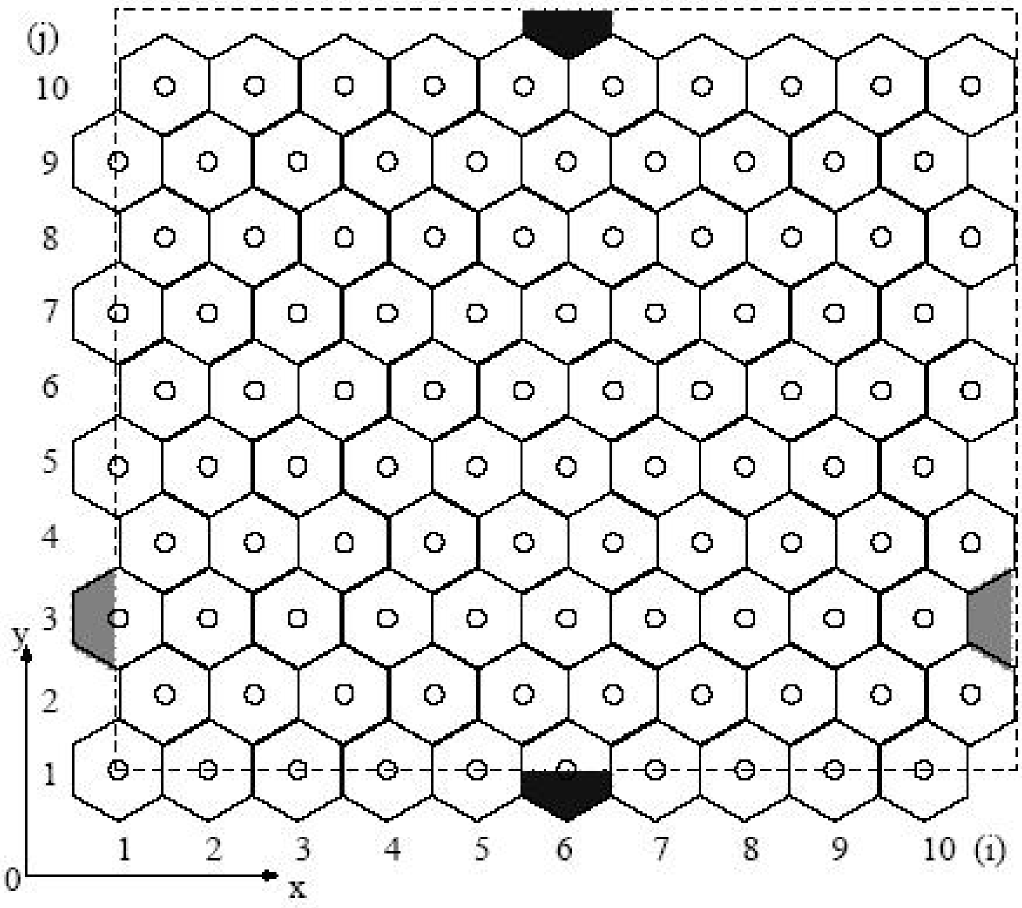
System Topology

Two dimensional planar array

One user per cell (TD/FD)

User location within each cell

i.i.d. uniform distributed



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Propagation Model

Short-range (SR) model

- Mobile user in the neighborhood of the base
- Free-space path loss + Rayleigh

$$P_r = (\lambda / 4\pi d)^2 \cdot G \cdot g \cdot P_t$$

Long-range macro-cell model (Hata)

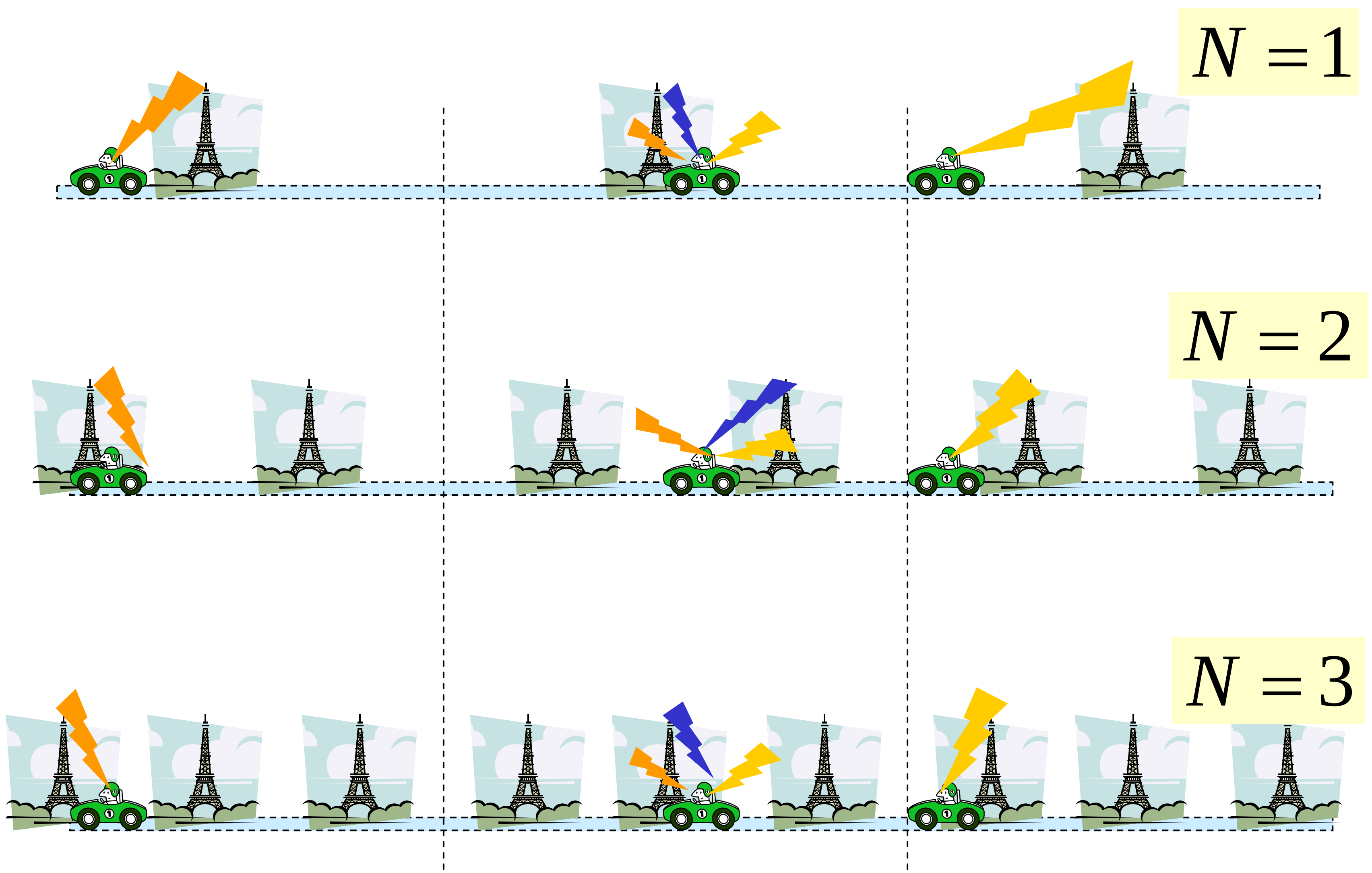
- Path-loss + shadowing + fading

$$10\log_{10}(P_r / P_t) = -L_{dB} + G_{dB} + \psi_{dB} + 10\log_{10}(g)$$

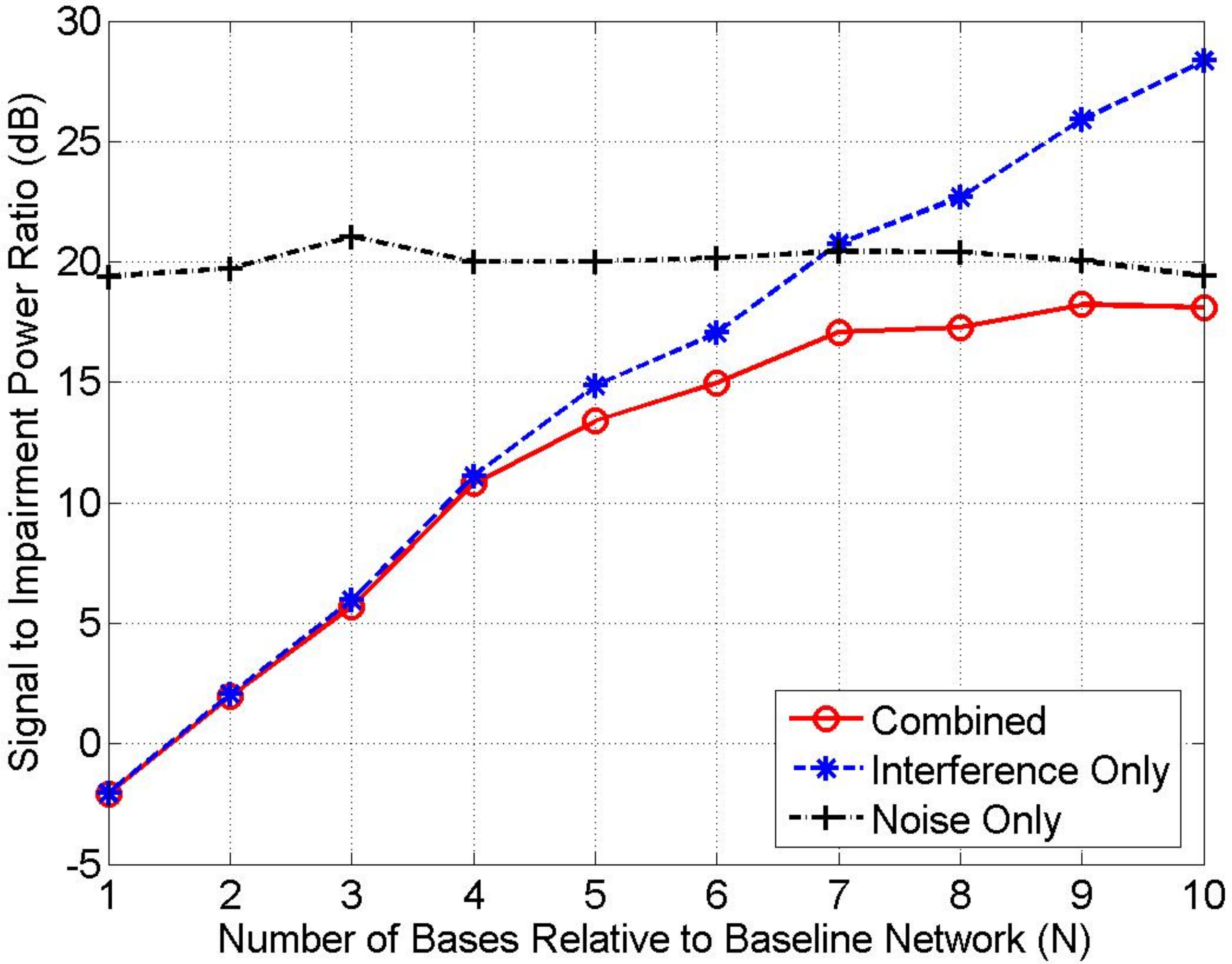
Propagation characteristics change at

- Transition distance dt, i.i.d. 30~70m
- Cutoff distance dc, $2\sqrt{3}R$

Infrastructure Upgrade



Operating Regime Shift



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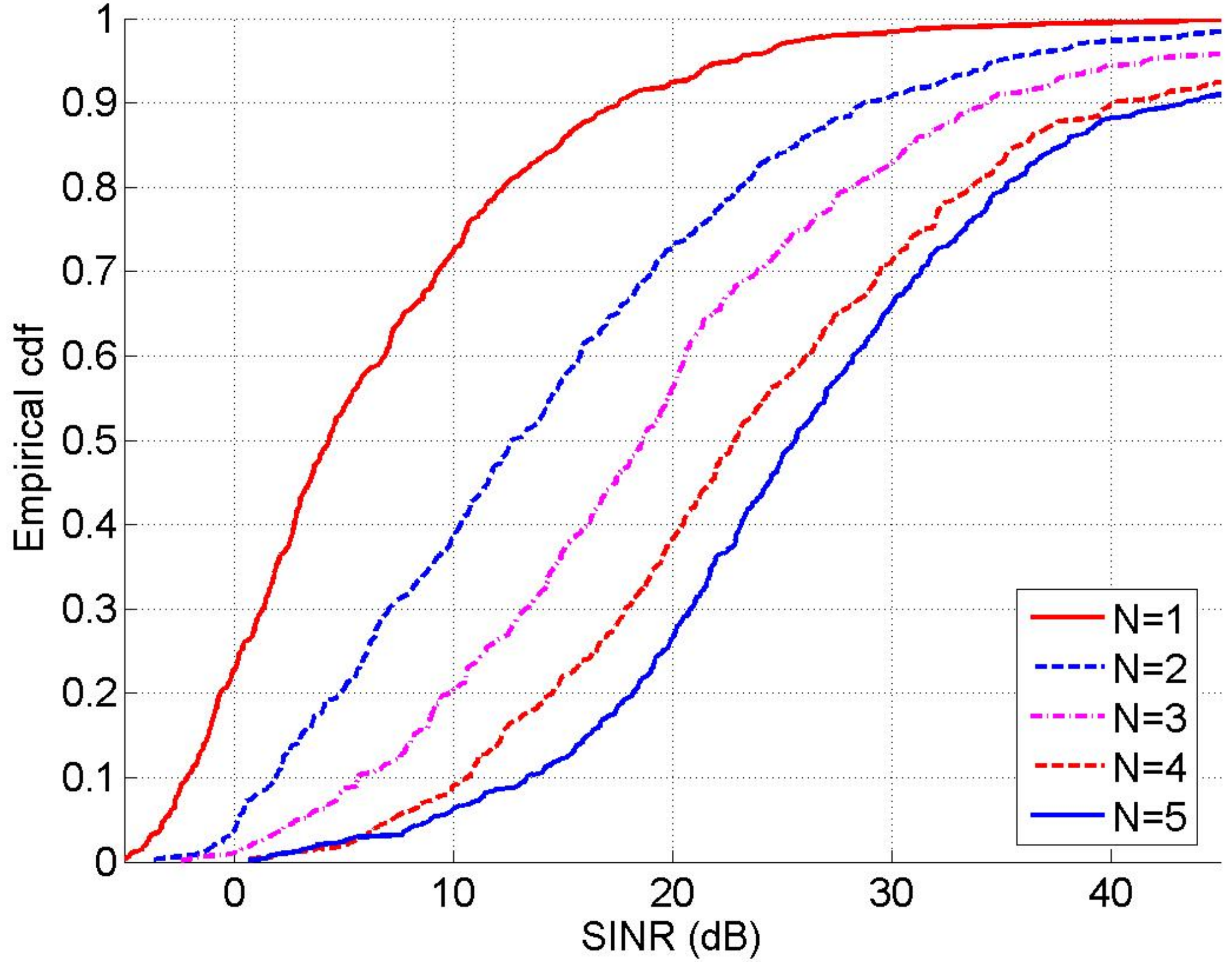
CDF of SINR



Empirical cdf
SINR (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
N=1
N=2
N=3
N=4
N=5

Net MIMO: Zero-Forcing Beamforming

Declare portion q of users in outage

- Users with smallest channel gain norms

Notations

- Input X
- Precoding W
- Channel H
- Output Y
- Noise Z

$$Y_{m_r \times 1} = H_{m_r \times m_t} \cdot W_{m_t \times m_r} X_{m_r \times 1} + Z_{m_r \times 1}$$

$$H_{m_r \times m_t} \cdot W_{m_t \times m_r} = I$$

ZF: NO ICI

Power Optimization for ZF

Criterion: max min received SNR

$$\rho_i = P_i / N_0$$

Subject to per-antenna power constraint

$$\sum_{i=1}^{m_r} \left| W_{ji} \right|^2 P_i \leq P_{\max}, \qquad \text{for} \quad 1 \leq j \leq m_t$$

Solution

$$P_i = P_{ZF} = \frac{P_{\max}}{\max_j \sum_{i=1}^{m_r} \left| W_{ji} \right|^2}$$

Zero-Forcing Dirty Paper Coding

Interference totally eliminated through

- Orthogonal constraint
- Dirty paper coding

Declare portion q of users in outage

- Users with smallest channel gain norms

Specify encoding order

- Heuristic algorithm proposed in view of fairness

Optimization for ZF-DPC

Channel QR decomposition H = LQ

Precoding matrix W = Q′

Receive signal y = HX + z = LQQ′x + z = Lx + z

Criterion: max min received SNR

Subject to per-antenna power constraint

$$\left|L_{ii}\right|^2 P_i \Big/ N_0$$

Solution

$$P_i = \frac{P_{ZFDPC}}{\left|L_{ii}\right|^2} = \frac{P_{\max} \Big/ \left|L_{ii}\right|^2}{\max_j \sum_{i=1}^{m_r} \left|W_{ji} / L_{ii}\right|^2}$$

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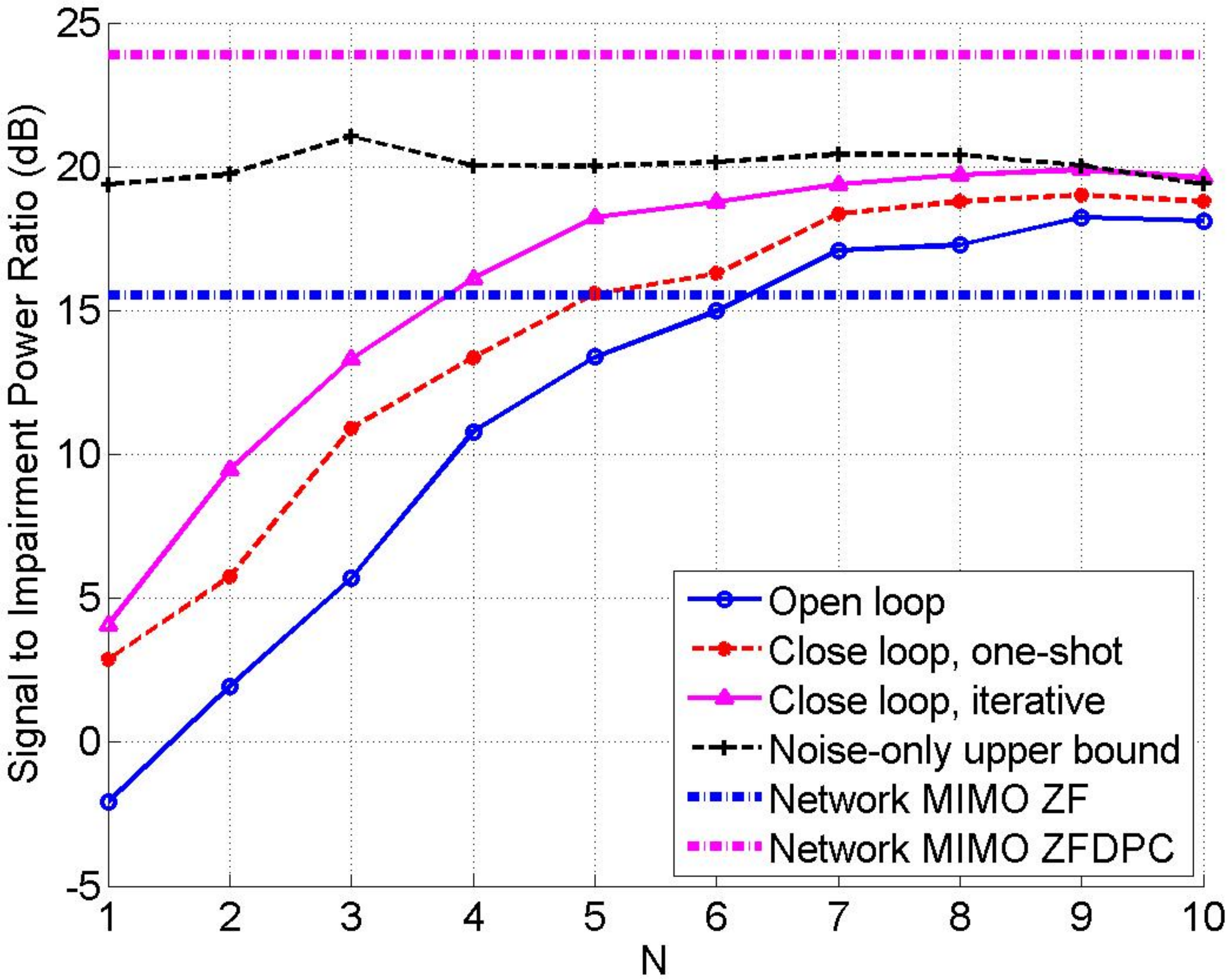
Comparison: Pico Cells Vs. Net MIMO



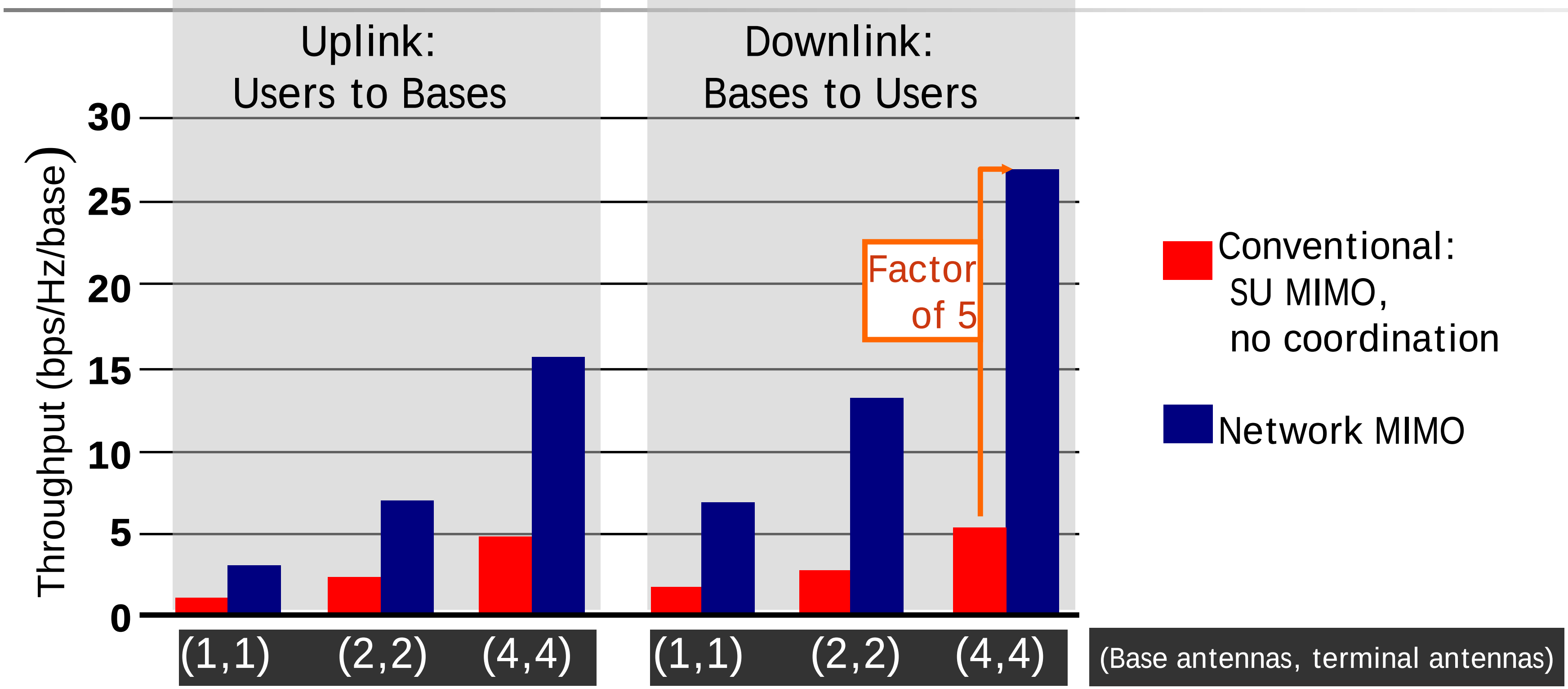
Target: max min SINR at outage level q

Under a realistic channel model

Denser deployment outperforms ZF when N >= 4

Close-to-optimal ZF-DPC outperforms denser deployment

Network MIMO: Potential performance gains



Up to a factor of 5 capacity gain using network MIMO under ideal conditions.

What gains could be achieved in practice?

[R. Valenzuela department]

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Summary: MIMO strategies

Recommended strategy	Cellular network type
SU MIMO techniques	▪ Urban macrocell with reduced frequency reuse and peak rate is more important than throughput (6-sectors + SU-MIMO (SM))
MU MIMO techniques	▪ Urban macrocell with universal frequency reuse (6-sectors + MU-MIMO (ZF-BF)) ▪ Suburban macrocell (adaptive BF for increasing throughput) ▪ Rural macrocell (adaptive BF for increasing range)
Network MIMO	▪ Cluster of cells with high-speed backhaul (indoor femtocell network or future macrocell network)

Concluding remarks

Next generation systems must deliver a significant and cost effective performance improvement

- Increasing Bandwidth hits battery power limits
- Reducing cell size or increasing Tx power may be too expensive
- Relay help with coverage at low spectral efficiency

Network MIMO may deliver substantial performance gains:

- Initial uplink results are promising:
  - Median goodput more than doubled.
  - 5-fold increase in cell edge (90% availability) goodput.

Results show that network MIMO is viable within constraints of WiMAX.

- In particular, channel estimation not a problem indoors (but real test will be outdoors).

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