

# Throughput Improvements in Micro-Cellular Multi-Hop Networks

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*Throughput Improvements in  
Micro-Cellular Multi-Hop Networks*

**Ozgur Oyman and Sumeet Sandhu**

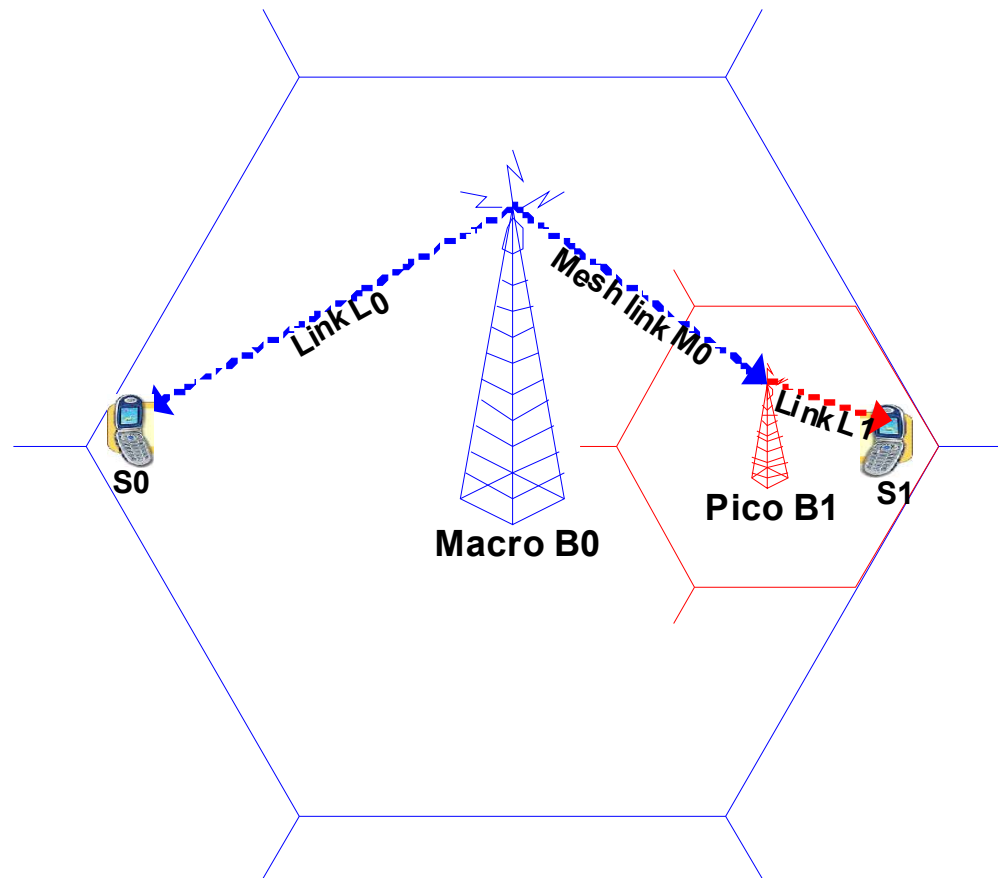
**Intel Corporate Technology Group**

**IEEE 802.16 MMR Study Group Meeting**

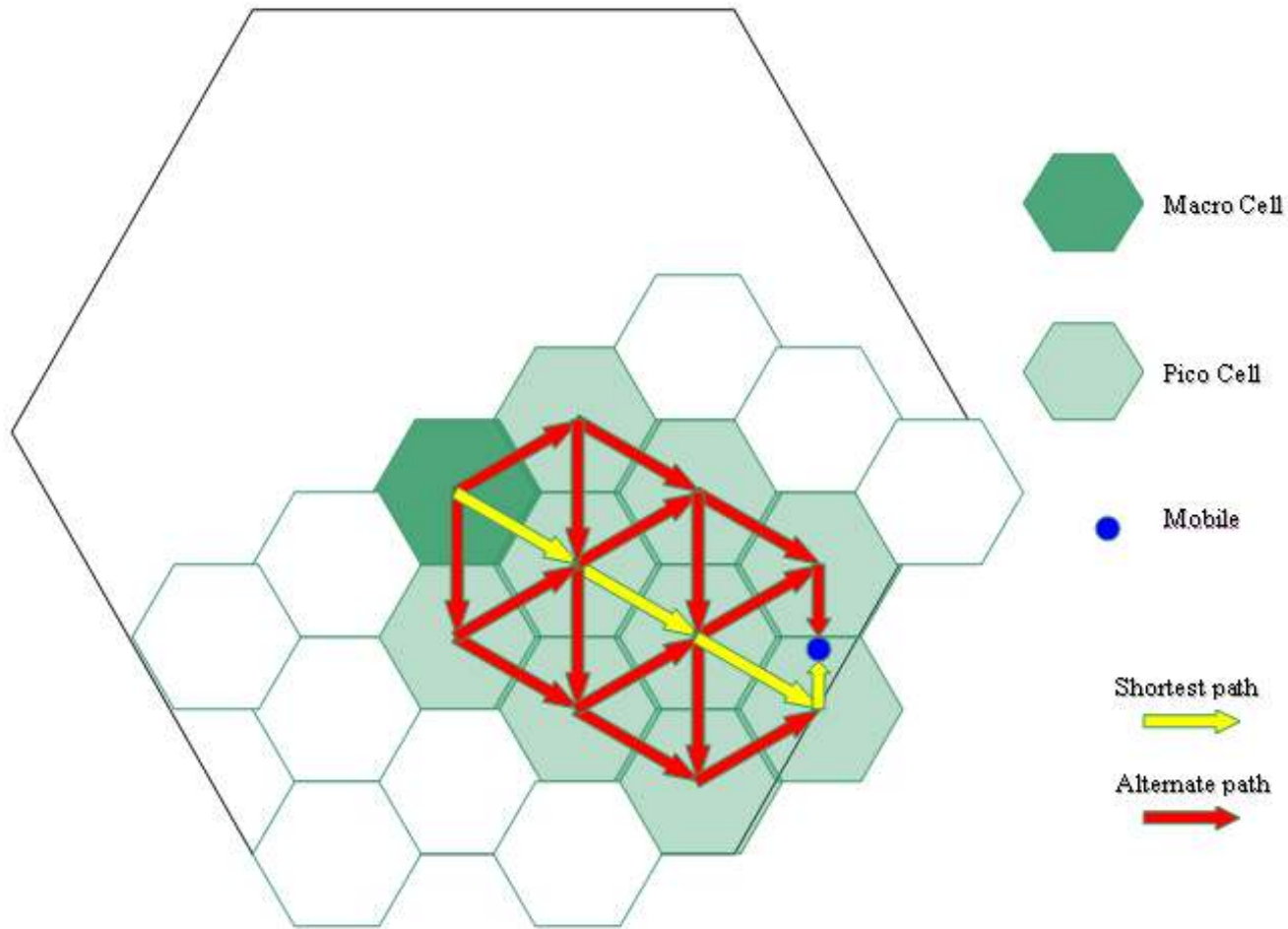
**November 14-18, 2005**

# Problem

- Does breaking up the link L0 into two links M0 and L1 result in a net performance increase?

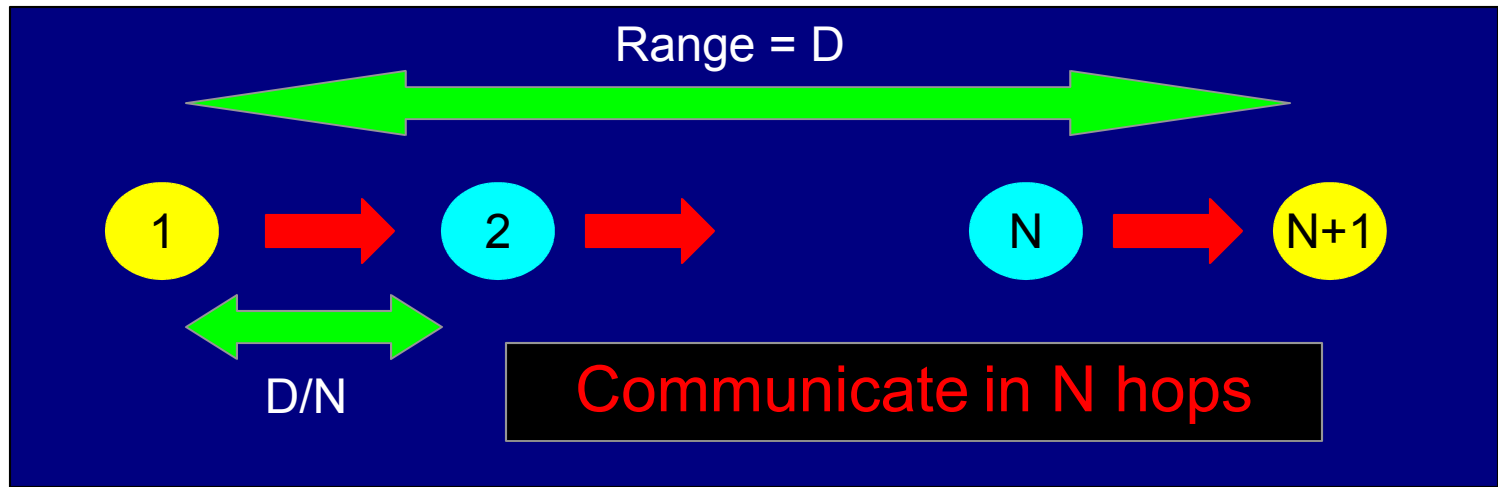


# 802.16 Micro-Cellular Networks



**Objective:** Performance analysis of multi-hop wireless

# Simple 1D Model



## *1D-TD Model Assumptions:*

- Message of Node 1 hops through all intermediate nodes until it reaches Node  $N + 1$ .
- Time-division (TD) based communication model
- Node  $k$  only receives from Node  $k - 1$  and transmits to Node  $k+1$

# Basic Throughput Analysis

- Only assume path loss:

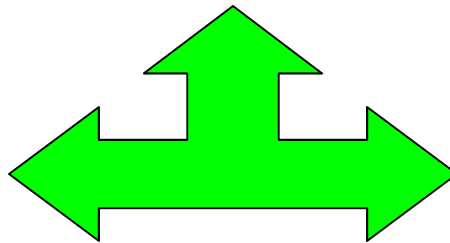
$$\text{Received Power: } P_{rec} (D/N)$$

- Consider the AWGN channel:

$$C = \frac{1}{N} \log_2 \left( 1 + \frac{P_0 D}{N} \right)$$

Low SNR regime

$$C \approx \frac{N^{-1}}{D}$$

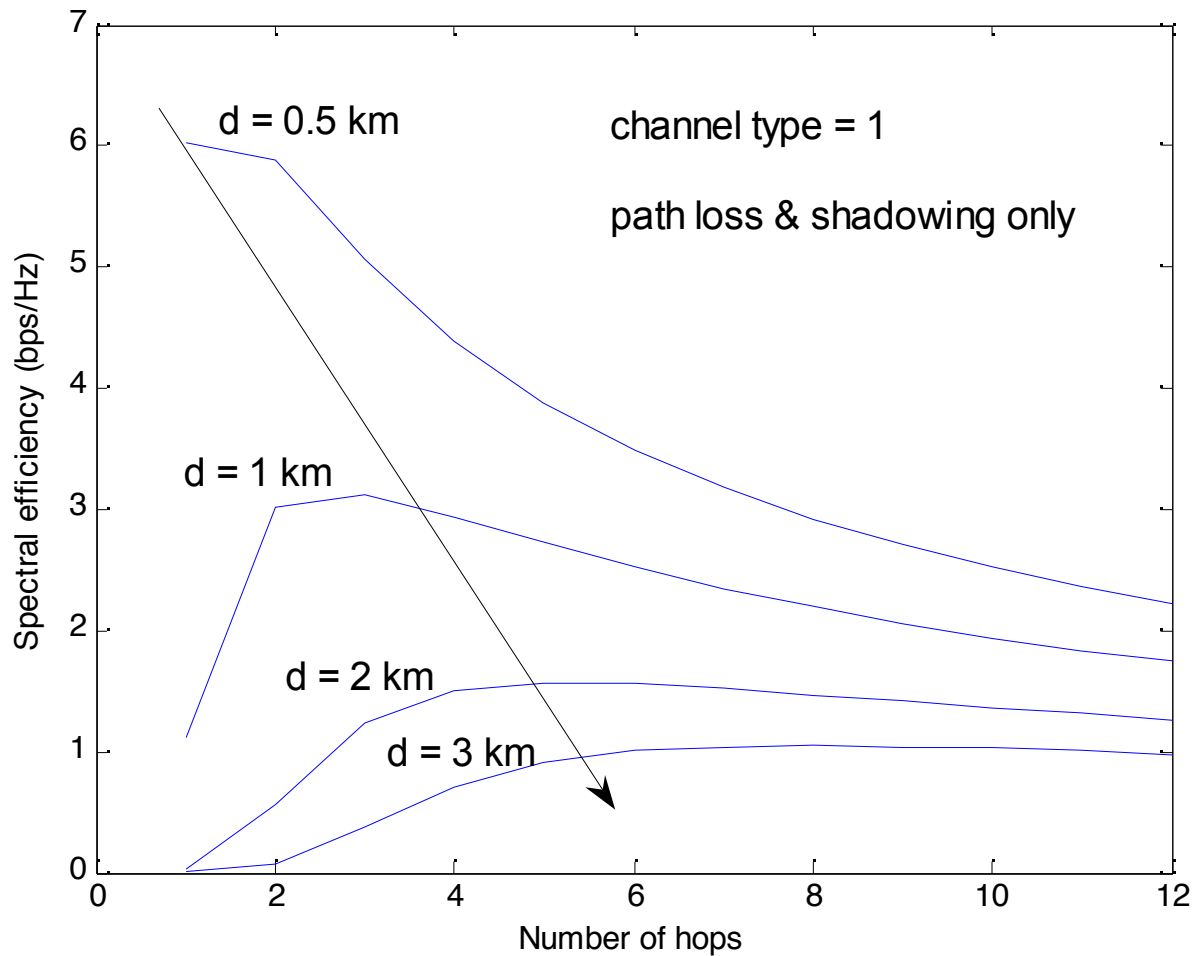


High SNR regime

$$C \approx \frac{1}{N} \log_2 \left( \frac{N}{D} \right)$$

There exists an optimal number of hops to maximize throughput!

# Optimizing Mesh Throughput



# Channel Model

- Path loss (exponent 2-6)

$$PL = A + 10 \gamma \log_{10} (d/d_0) + s \quad \text{for } d > d_0,$$

- Lognormal Shadowing (std = 4-8 dB)
- Rayleigh Fading
- Macro BS Power = 41.76 dBm (15 W)
- Micro BS Power = 34.77 dBm (3 W)
- Macro BS Height = 34 m
- Micro BS Height = 12.5 m

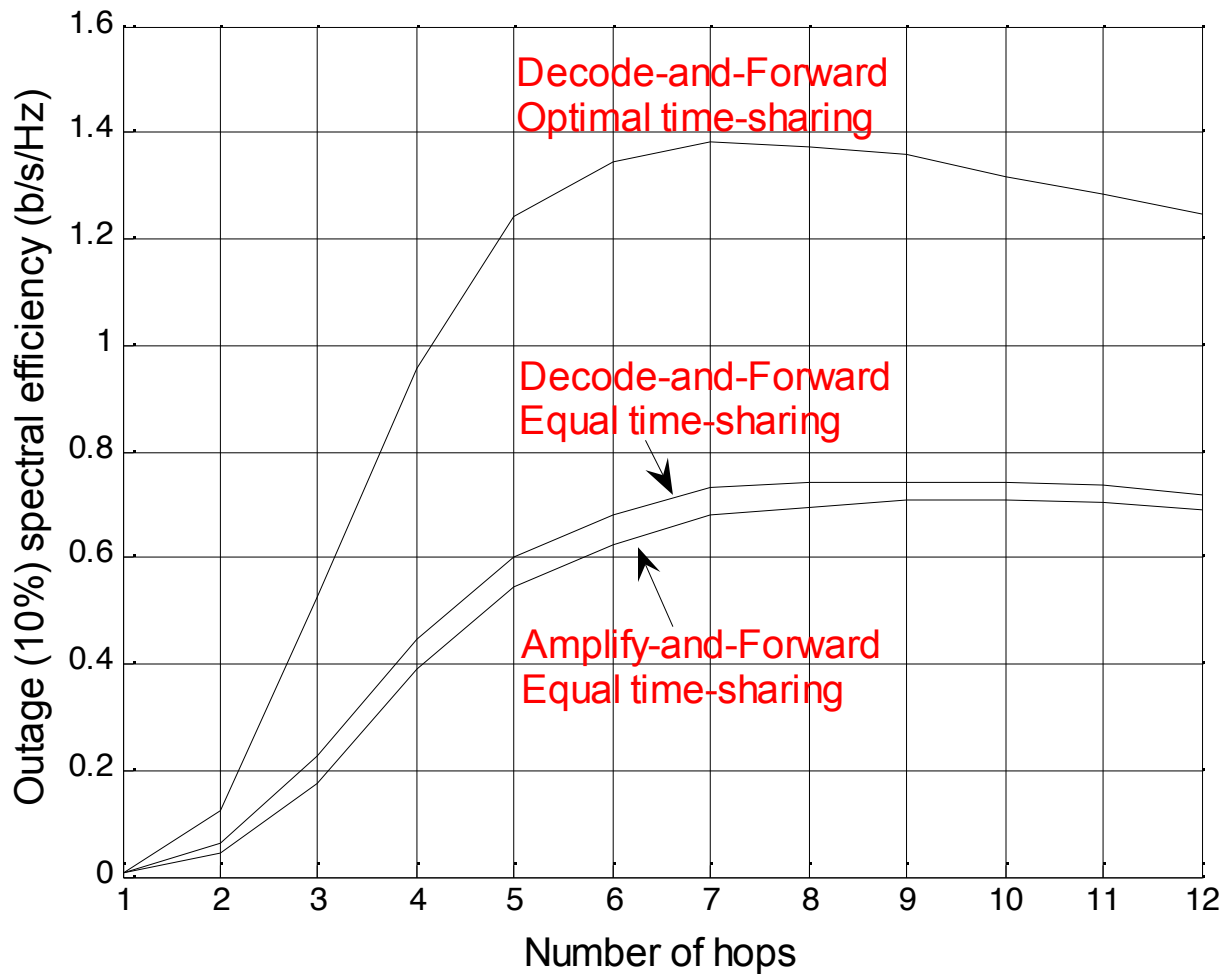


# Network Capacity

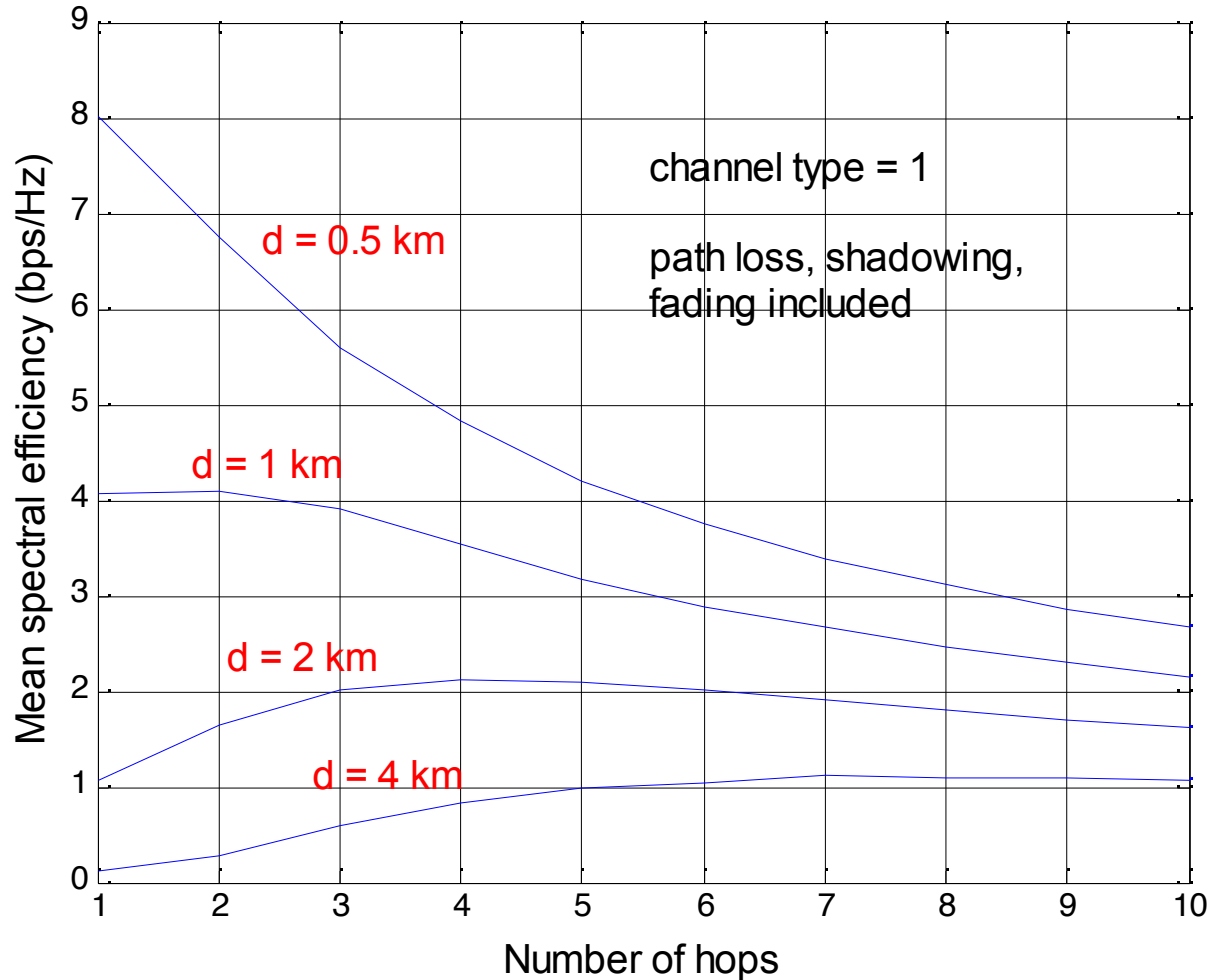
- Let  $C(i)$  denote the maximum achievable rate per unit bandwidth during hop  $i$ .
- Let  $\lambda_i$  be the fractional time channel  $i$  is used.
- Capacity under time-division

$$C = \max_{\lambda_i} \min_{i=1, \dots, N} \lambda_i C_i \quad \longrightarrow \quad C = \frac{1}{\sum_{i=1}^N \frac{1}{C(i)}}$$

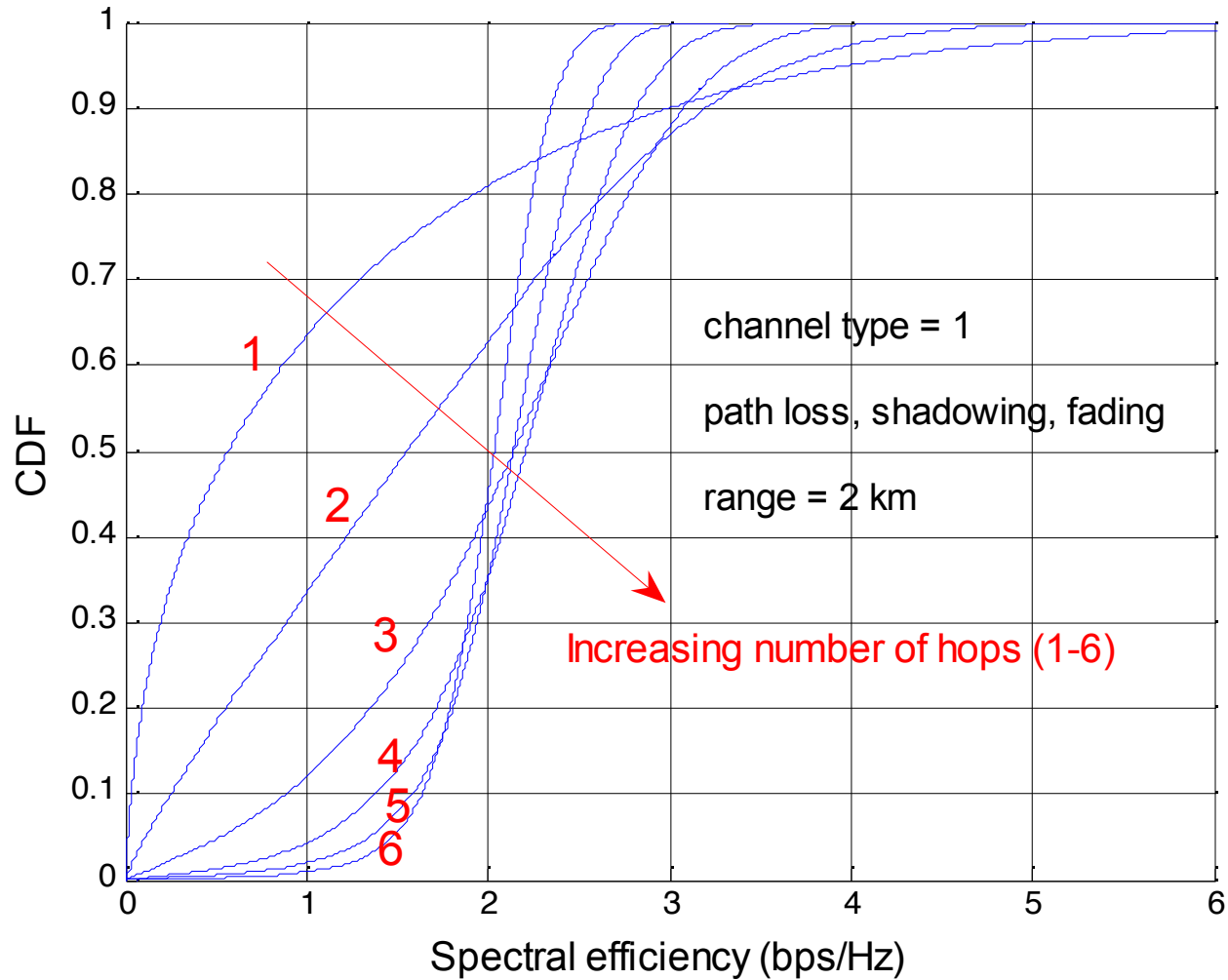
# Per-link adaptation is better than worst link adaptation



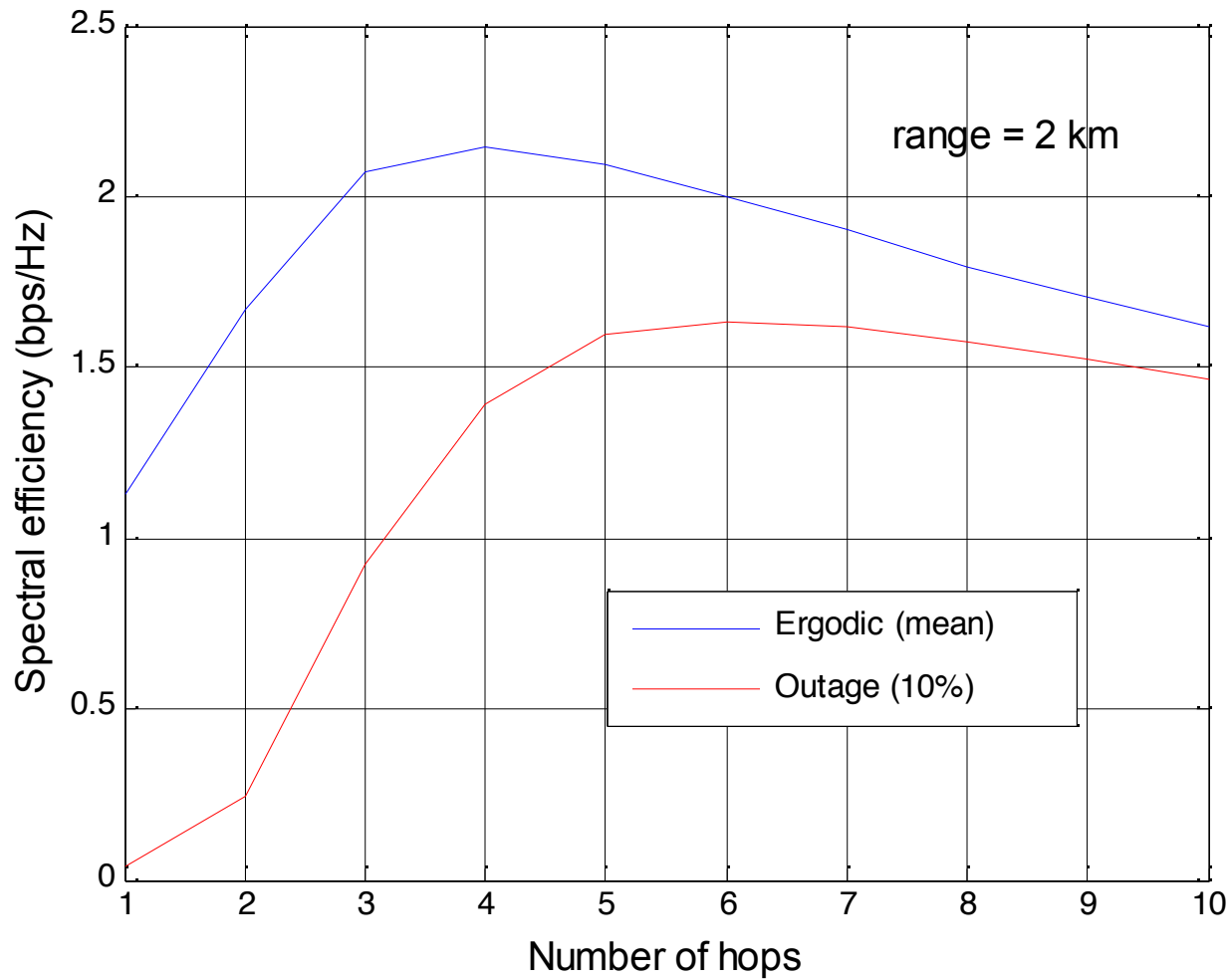
# Throughput at Different Ranges



# Hop More at Outage - I



# Hop More at Outage - II



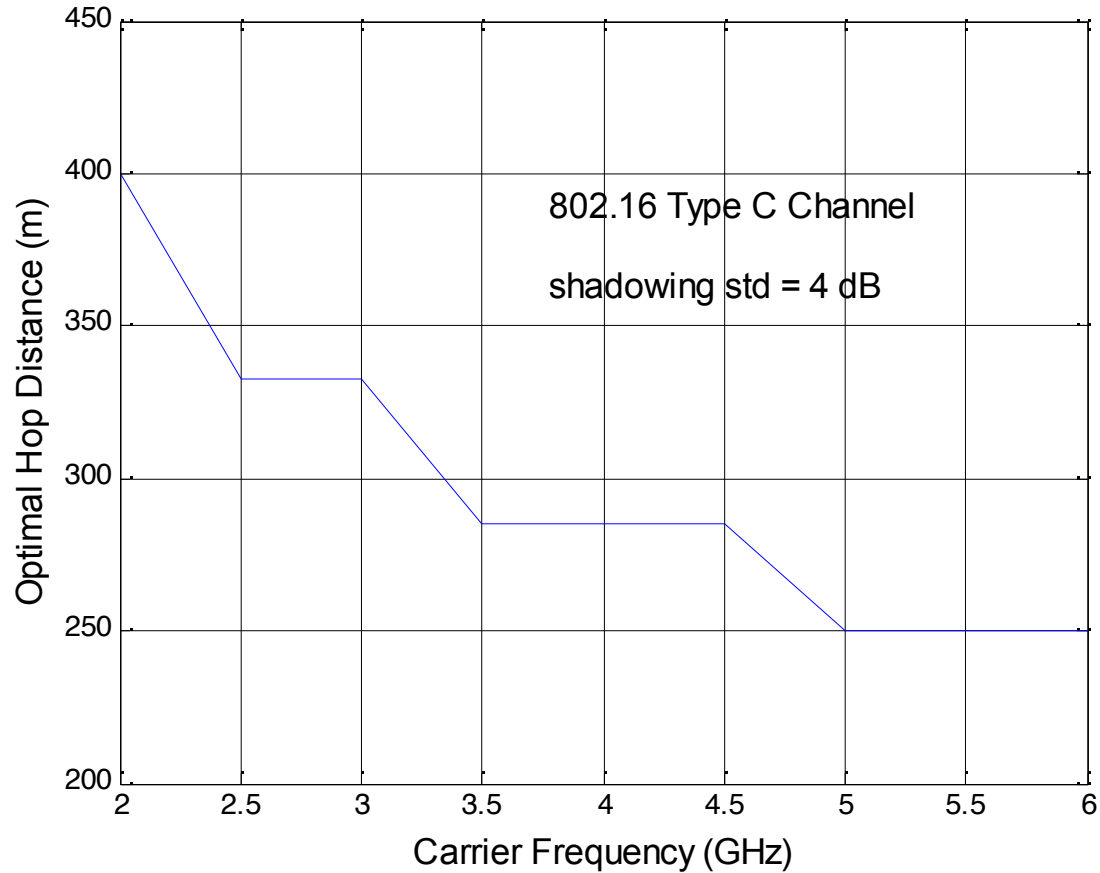
# Throughput Results Summary

- We observed that for any given range there exists an **optimal number of hops** to maximize end-to-end throughput.
- Optimal number of hops increases for longer range
  - ➔ There exists an **optimal hop distance**.
- Under fading, we showed that hopping can be an additional source of diversity over other forms of diversity (space, time or frequency).
- **Multi-hop diversity** is especially useful at low outage levels.

# Channel Sensitivity

- Next step: Verification of channel models
- Current models: COST, ITU, Erceg-Greenstein
- How sensitive are the multihop gains to different propagation environments?
- Key variables: Antenna heights, carrier frequency, hop distance, shadowing std, LOS / NLOS path loss exponent

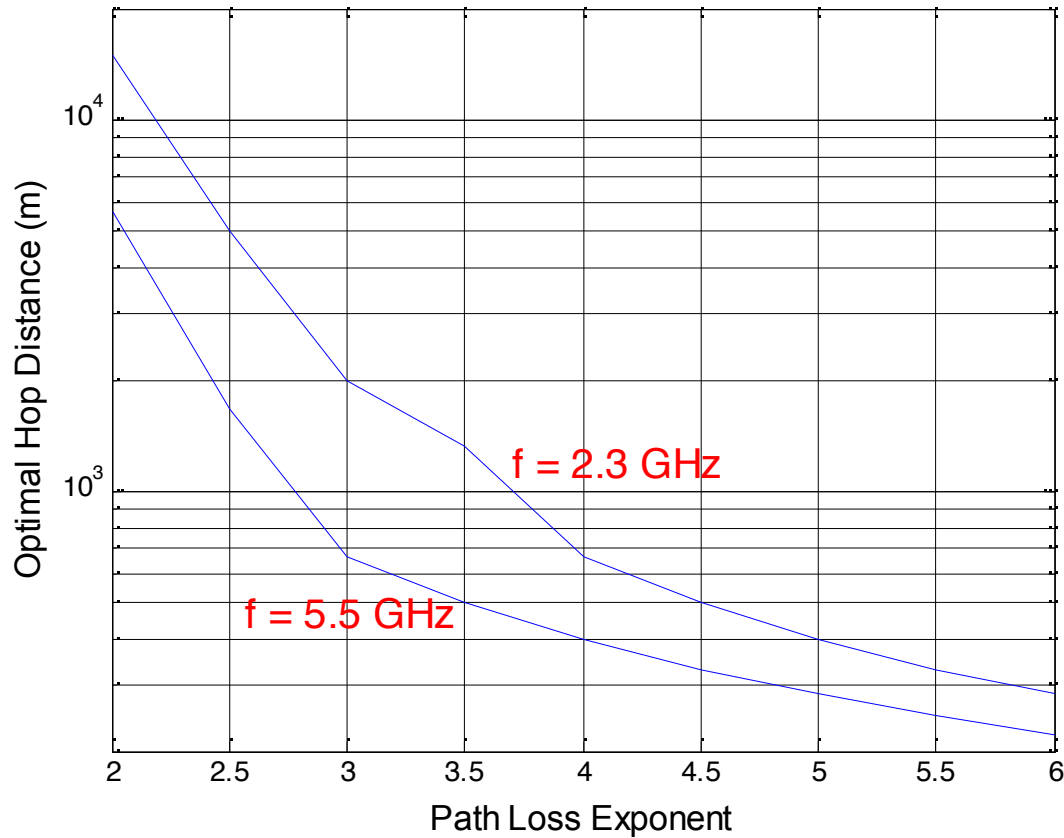
# Sensitivity to Carrier Frequency



**Optimal hop distance varies drastically with carrier frequency!**



# Sensitivity to Path Loss Exponent



Optimal hop distance varies drastically with different path loss exponents!

# Conclusions

- We characterized the **end-to-end throughput performance** of multihop relaying and showed significant gains over direct transmissions.
- Throughput-optimal design of multihop networks is very **sensitive** to the channel behavior.
- One necessary step into MMR design is to decide on appropriate channel models.
- The performance improvements of multihop relaying also allows better **range extension**.