The Myth of Spatial Reuse with directional antennas in Indoor Wireless Networks

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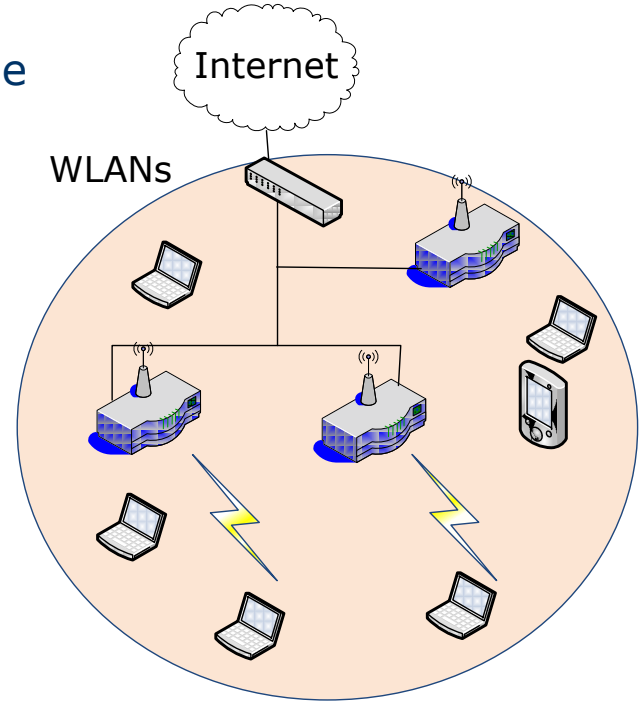
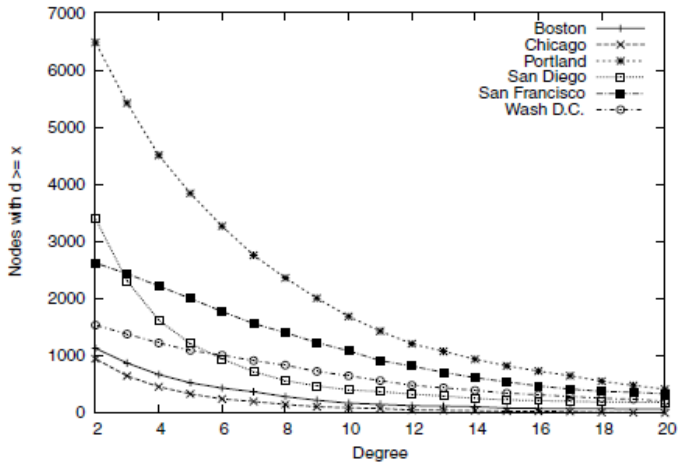
Introduction

- Popularity of indoor wireless networks
  - Over 100 Million Wifi deployments worldwide
  - With limited spectrum, increasing density increases interference
  - Motivates techniques for concurrent transmissions (spatial reuse)





Akella et al., "Self-management in chaotic wireless deployments", ACM Mobicom 2005

Introduction

- Directional antennas
  - control signal power spatially and reduce interference
  - popular in outdoor settings such as cellular networks

- This work: Do directional antennas really improve spatial reuse in indoor wireless networks? If so, how well?

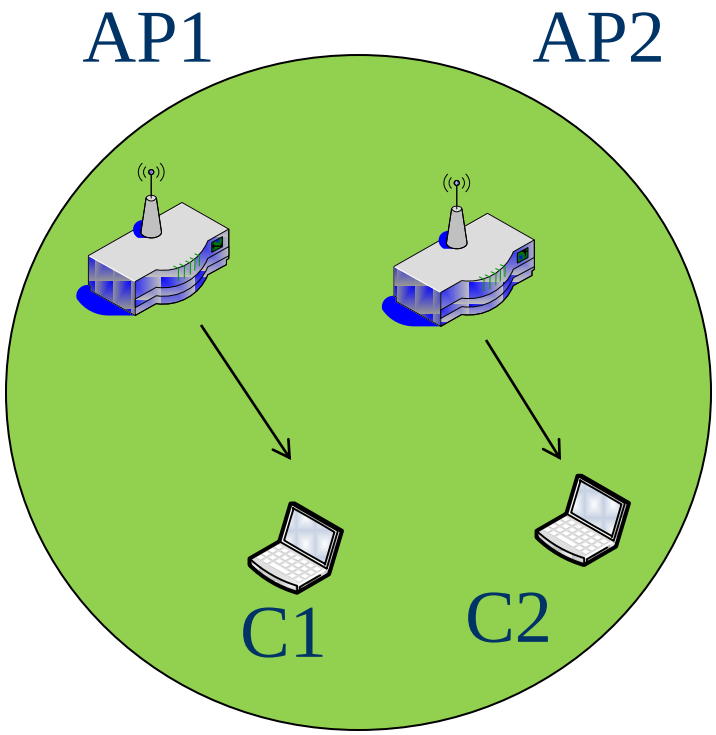
Outline

- Background and Motivation
- Experimental Methodology, Metrics and Strategies
- Experimental Results and Alternative Strategies
- Conclusions and Future Work

Background (1/2)

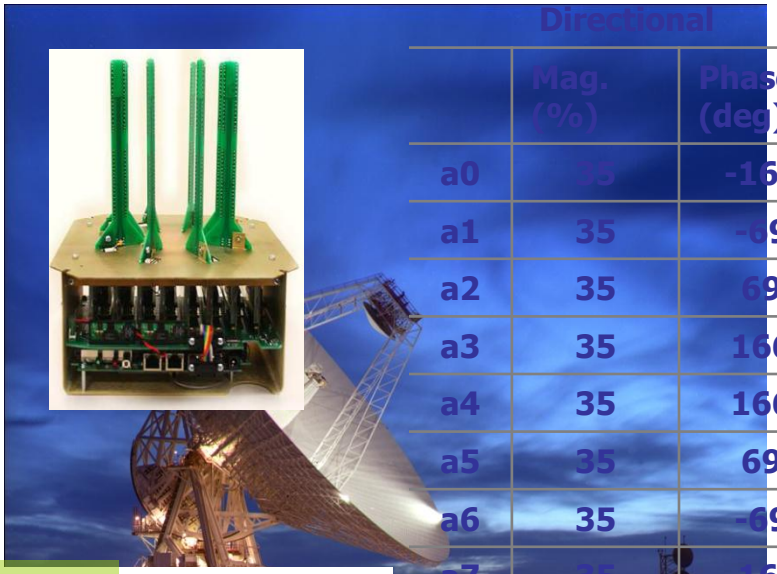
- Current WLANs
  - Collisions: Concurrent co-channel transmissions cause interference leading to losses
  - Collision avoidance: Nearby transmissions separated in time and frequency (channel)
  - Omni-directional communication

- Spatial Reuse: Measure of concurrency of transmissions that can be successfully accomplished in a given network area



Background (2/2)

- Directional antenna - principle
  - Form spatially focused beams
  - Gains
    1. Improve link quality
    2. Reduce interference to other receivers
- Directional antenna - practice
  - Mechanical/Structural
  - Electronic/antenna array
  - Beam can be steered different directions

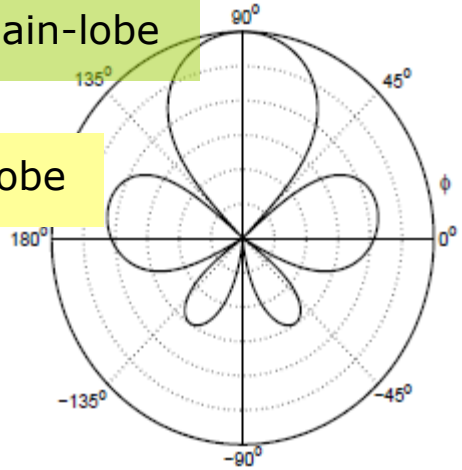


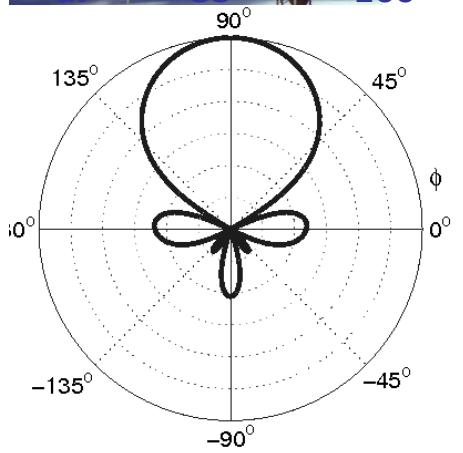
Directional

	Mag. (%)	Phase (deg)
a0	35	-166
a1	35	-69
a2	35	69
a3	35	166
a4	35	166
a5	35	69
a6	35	-69
a7	35	-166

Main-lobe

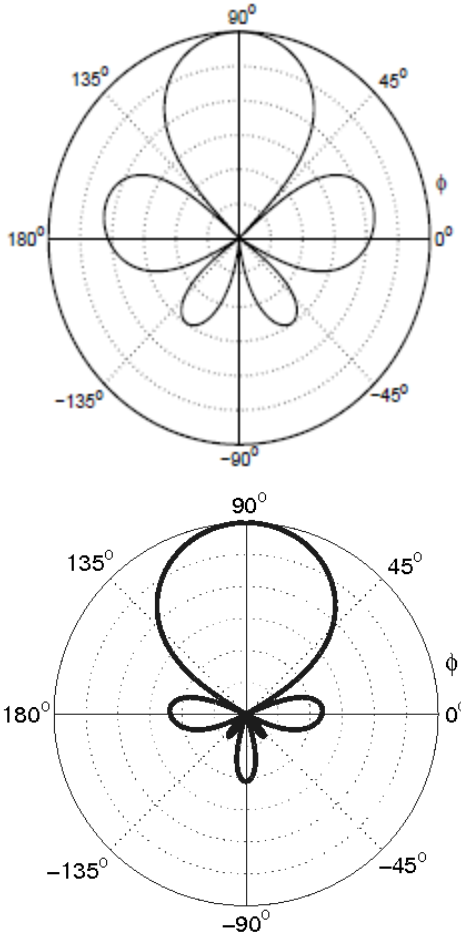
Side-lobe





Background and Related work

- Current wisdom
  - Sidelobes even under ideal environmental conditions [Paulraj03]
  - Smaller mainlobes lead to larger side lobes
  - Sidelobes cannot be eliminated
  - Link directionality affected by indoor multipath [Paulraj03, Marc08]
- Related Work
  - Theory[Paulraj03, Choudary06, Das06] and outdoor environments[Raman05, Navda07, Subramanian08]
  - Limited indoor experimental work focusing on link quality [Marc08] and assuming reuse [Liu09, Subramanian09]
  - None of these works quantify 'spatial reuse' in practice

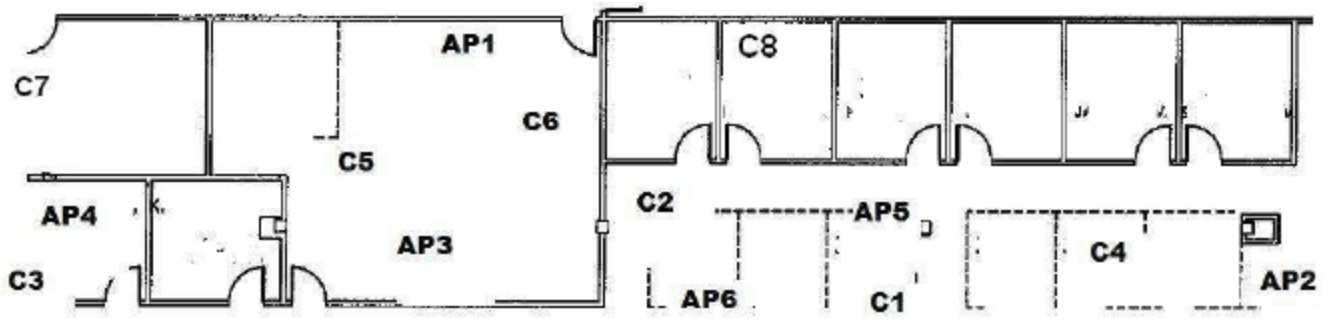


Experimental objective

- Do directional antennas improve spatial reuse in indoor wireless networks? If so, by what magnitude?

- Are there simple yet effective strategies that provide improved spatial reuse in indoor wireless networks?

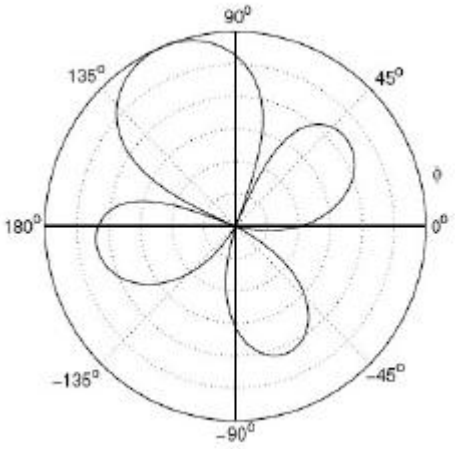
Experimental Setup

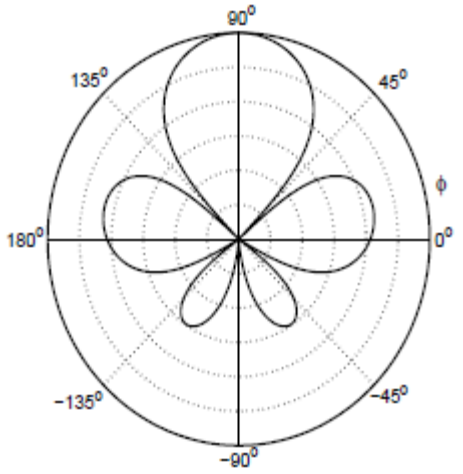


- Six 802.11g Access Points from Fidelity-Comtech
  - each with eight element circular array
- Eight 802.11g clients
  - D-Link cards with AR5212 chipset and Madwifi driver
  - Omni-directional antenna with 5dBi gain
- Static APs and clients

Methodology

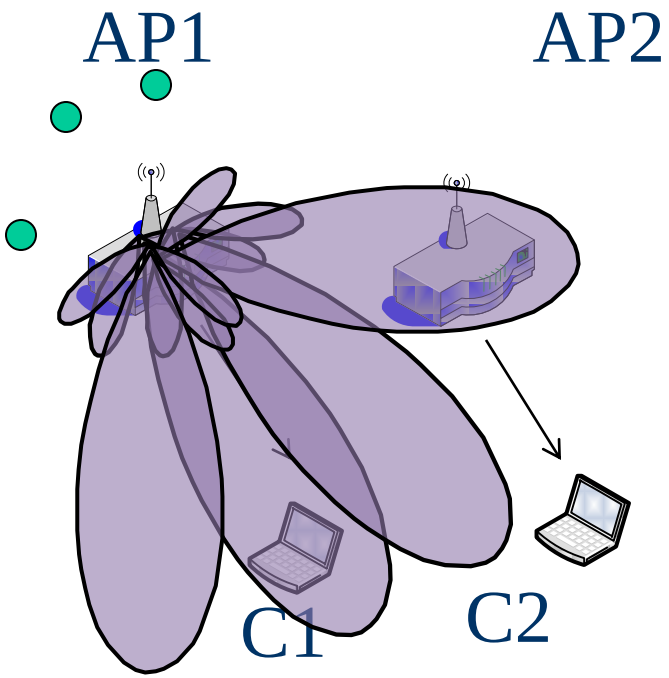
- Each AP equipped with 16 patterns each with 45° Beamwidth and span 360°
- Each client associates with AP that yields highest signal strength
  - Some APs have more than one associated client
- Total of sixty link pairs





Methodology

- Strategies
  - Omni-TDMA and Omni-Joint
  - Dir-TDMA and Dir-Joint
- Each of the two APs cycles through its sixteen beams to yield 256 combinations
- 128 Byte UDP packets transmitted on channel 6 downlink with no other interference
- Received Signal strength (RSSI) measured



Metrics

1. Aggregate rate:

$$R(l_1, l_2) = \log(1 + SINR_1) + \log(1 + SINR_2)$$

2. Interference power ratio :

$$IF = \frac{\text{Interference power from a directional beam}}{\text{Interference power from omni beam}}$$

3. Spatial Reuse Factor :

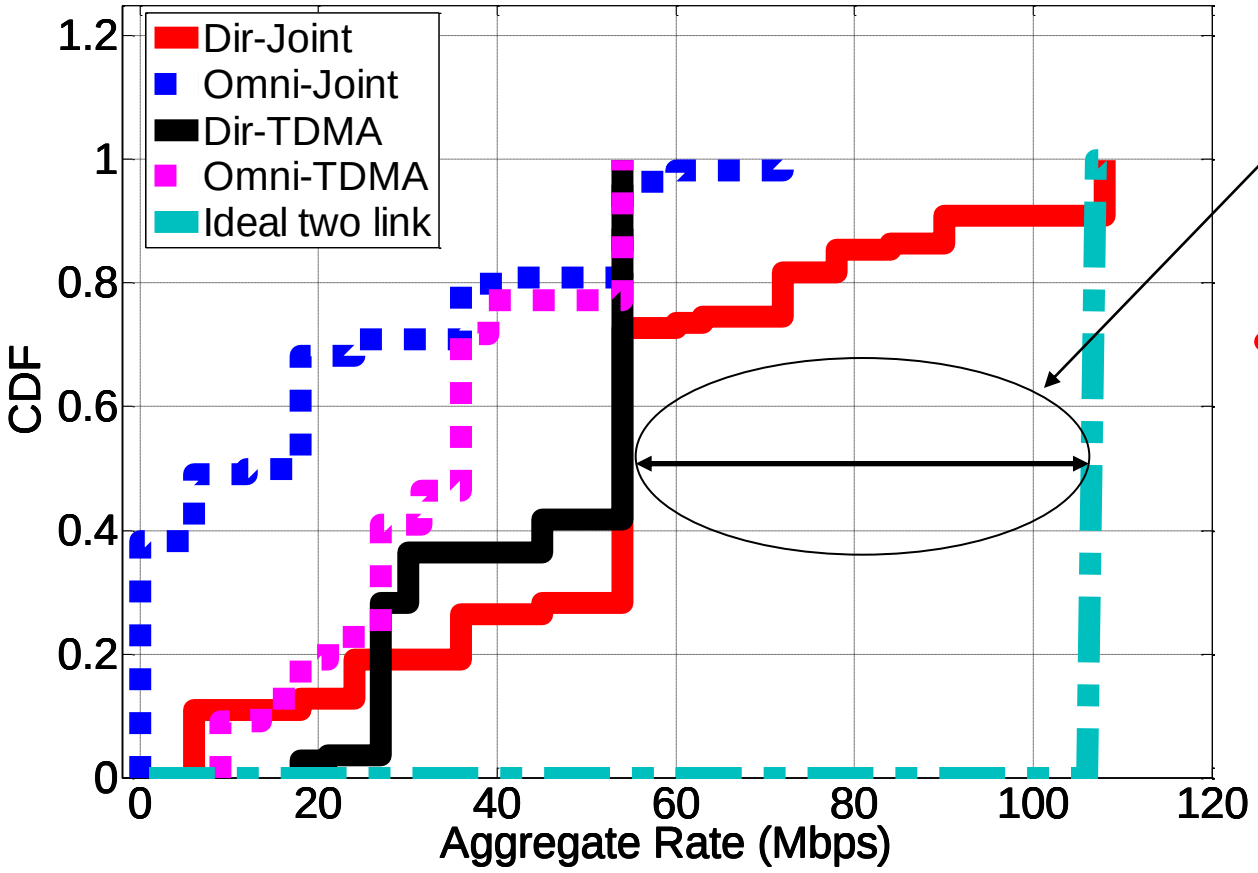
$$\beta = \frac{\text{Sum rate of concurrent directional links}}{\text{Average rate of isolated directional links}}$$

Higher rate, lower IF and 1 < ß <= 2 → High spatial reuse
Low rate, high IF and 0 < ß <= 1 → Low spatial reuse

Results

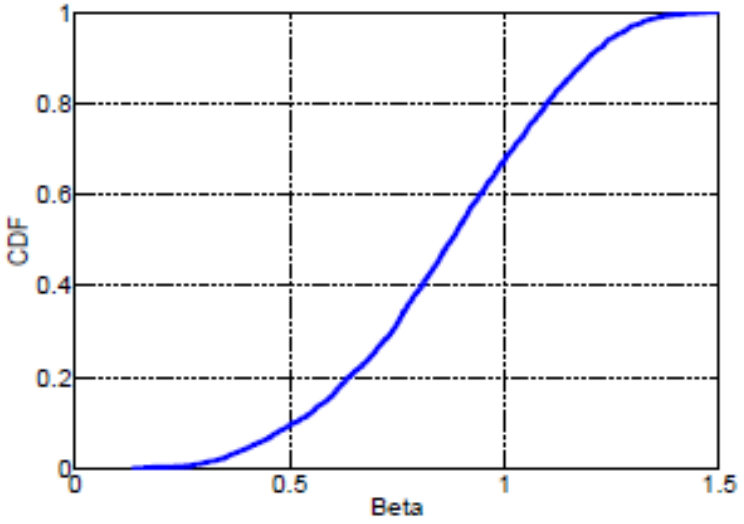
- What aggregate rates achieved?
- Why reduced aggregate rate?
- Why reduced spatial reuse?
- What are more intelligent strategies?

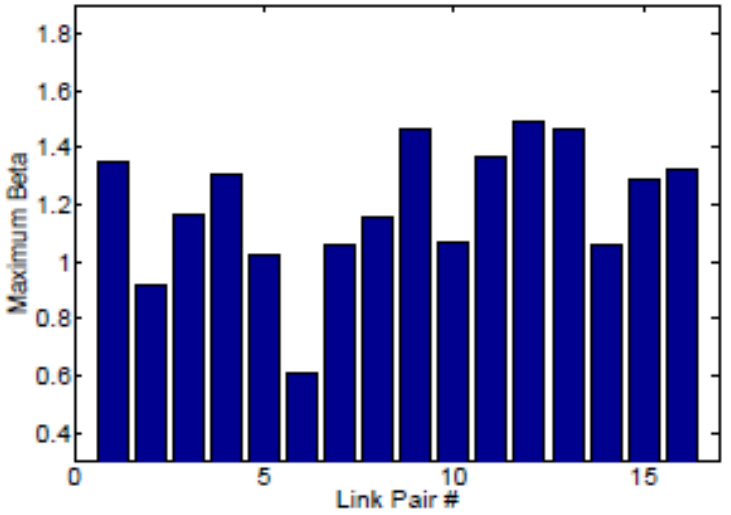
Results: Aggregate Rate



- Median Aggregate rate is not improved
- Directional antennas do not yield expected spatial reuse improvements for many (> 90%) indoor scenarios

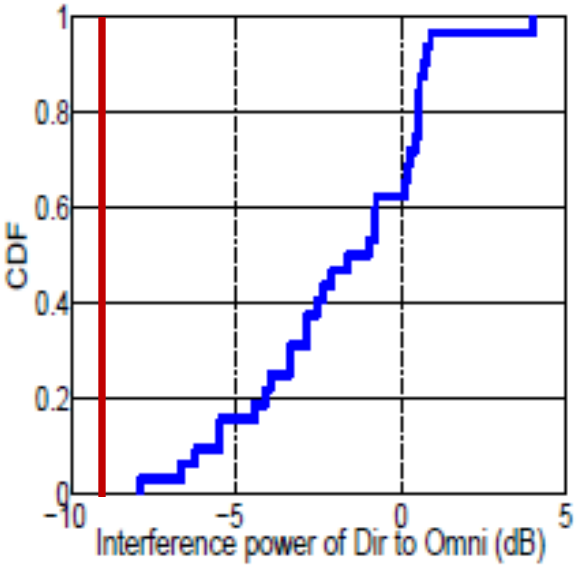
Why reduced throughput?

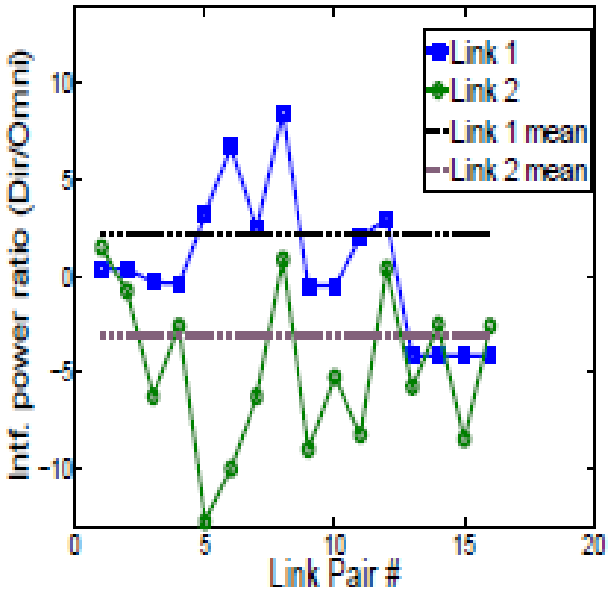




- Spatial reuse factor between 0.4 and 1.5 with median of 0.8
- ß less than 1 even with ideal beam selection!
- The degradation in performance is primarily due to lack of spatial reuse as opposed to link quality

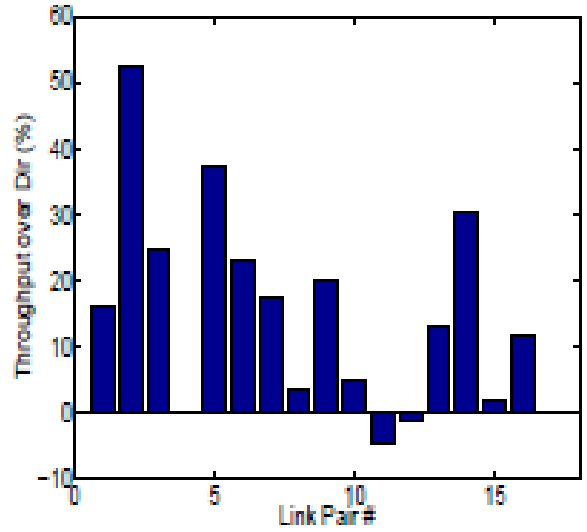
Why limited spatial reuse?

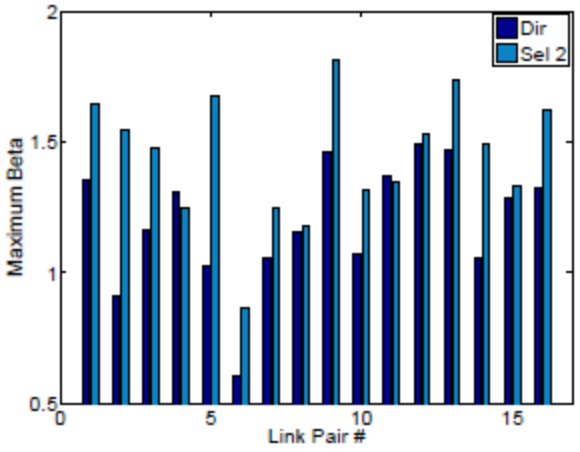




- Insights
  - Maximum interference reduction is just 7 dB
  - More than 39% of directional beams cause more interference in contrast to expectation!
  - Even best choice of directional beams does not help
- Interference reduction affected by multipath effects

Alternate strategy: Selection





- Strategy: Selecting pairs, quadruples of antennas as opposed to using all antennas and outdoor beams
- Improves throughput compared to Dir even with few antennas
- Gains mainly from enhanced spatial reuse

Conclusions and Future Work

- Directional antennas provide limited spatial reuse improvements indoors
  - Median aggregate rate stays the same as Omni
  - Less than 10% of cases achieve full spatial reuse
  - Multipath impairs directionality and increases interference powers
- Antenna selection holds promise for better spatial reuse
  - Affected less by multipath and provides flexibility in choosing low-interference subset of antennas
- Future work
  - Development of intelligent antenna selection algorithm
  - Integration with MIMO systems such as 802.11n

GNAN Research Group

Thank you !

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