The Spaces Between Us: Setting and Maintaining Boundaries in Wireless Spectrum Access

MobiCom '10

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Outline

- Background
- Motivation
- Proposed Solution- Ganache
- Model Estimation, Verification and Calibration
- Interference Detection
- Evaluation
- Conclusion

Trends in 802.11a

- OFDM scheme:

  -Orthogonal wireless channels

  -Crossband Interference

- Fixed Size Guardband:

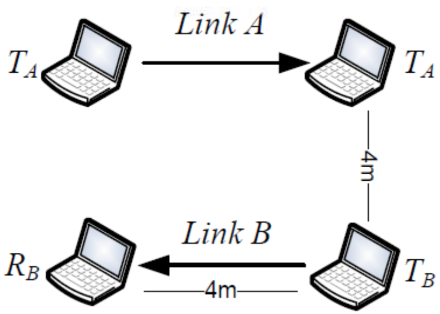
  -20 MHz channel bandwidth

  -3.4 MHz guardband between channels

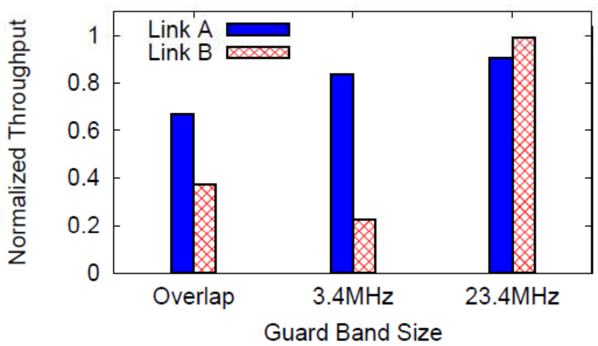
  -17% Overhead

Crossband Interference in 802.11a

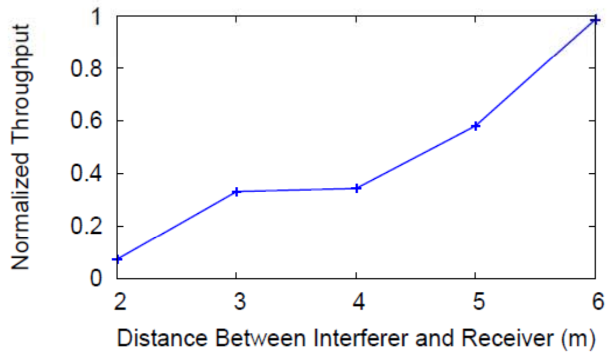
- 3.4 MHz: 20% for link A; 75% for link B
- Carrier Sensing Off: from 80% to 65%
- Significant Impact from “Guardband Size”



(a) Topology



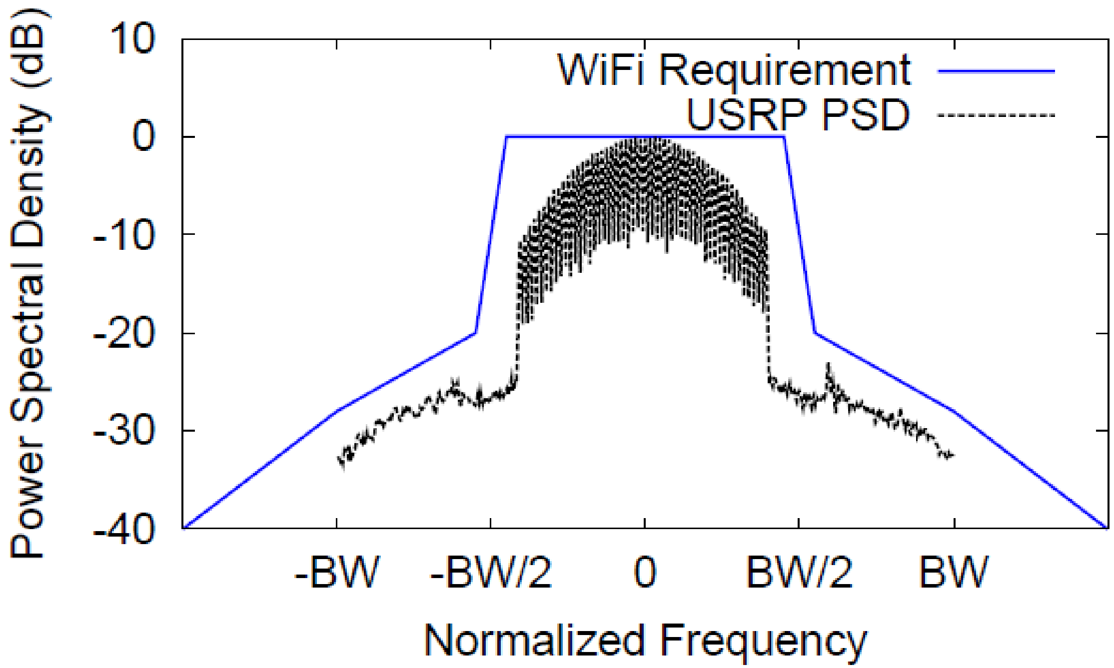
(b) Carrier Sensing On



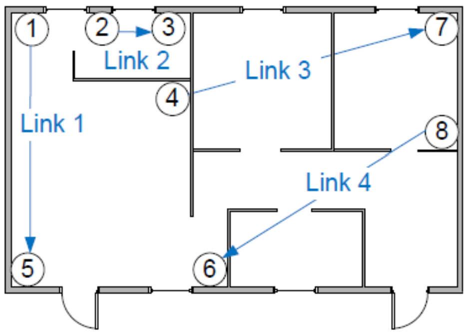
(c) Carrier Sensing Off

USRP GNU Radio

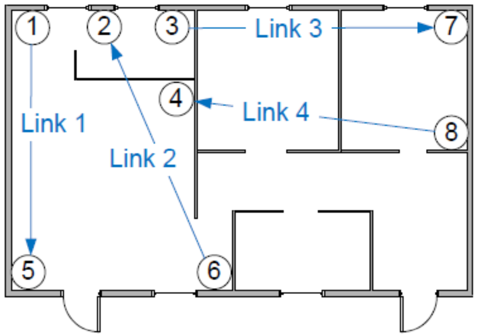
- Software-define radio
- Flexible to design desired frequency usage with OFDM scheme



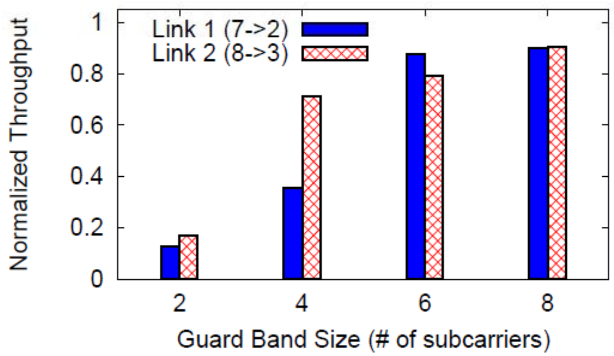
Crossband Interference in Different Topology



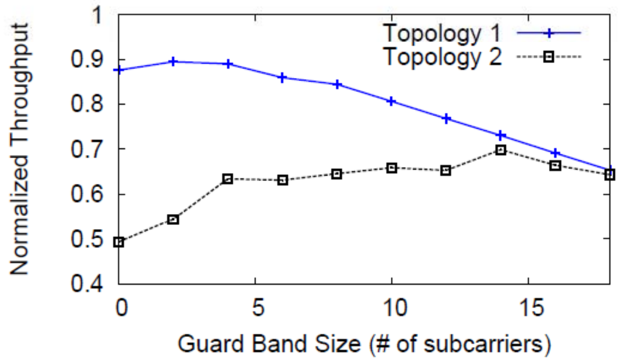
(a) Experiment Topology 1



(a) Experiment Topology 2



(b) Link Level Results (2 links)



(c) Network Level Results (4 links)

Brief Summary

- Cross-band Interference is Harmful
- Fixed-sized Guardband Placement is Ineffective
- What is the best way to configure guardband for today's high density networks?

Most Common Solutions

- Link Adaptation
  -significant reduction in power efficiency
- Carrier Sensing
  -delay transmissions waste spectrum
- Power Control
  -lower power link becomes vulnerable
- Interference Cancellation
  -complexity, tight synchronization

Ganache

- Centralized Frequency Planning
- Local Guardband Adaptation

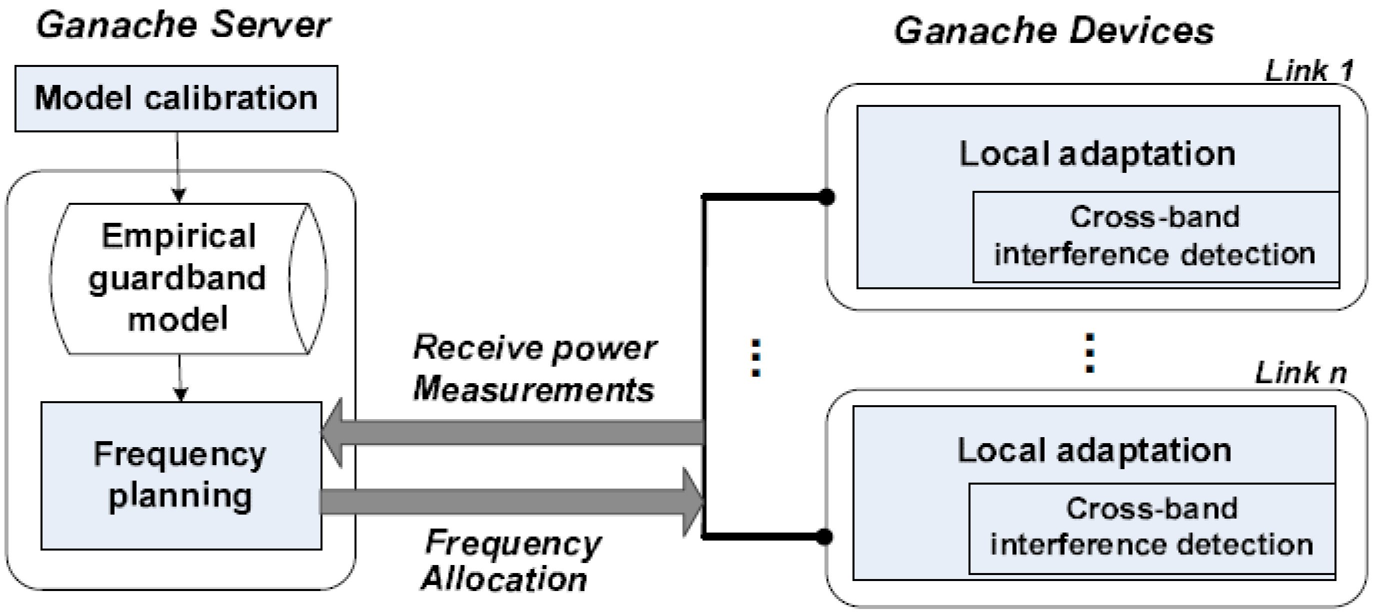


Figure 4: Ganache system architecture.

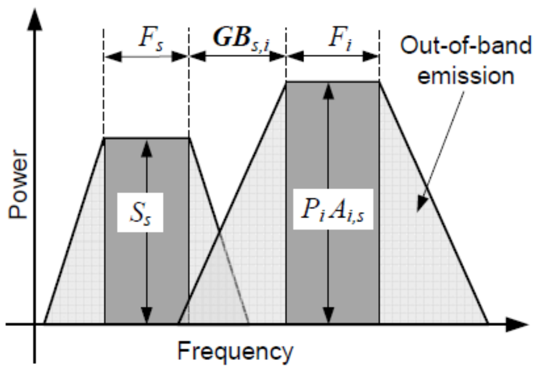
The Relationship Between Network Condition and Guardband Size

$$\mathbf{I}_{i\to s}^{cross}(f) \approx \sum_{k \in F_i} P_i \cdot A_{i\to s}(f) \cdot \Omega(k, f, \mathbf{GB}_{i\to s}) \qquad (1)$$

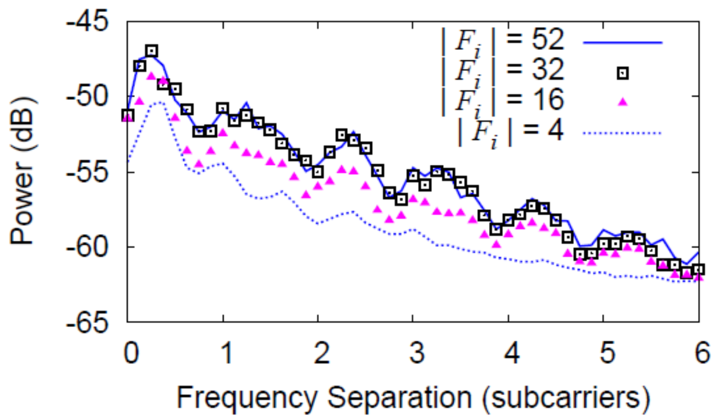
$$I_{i\to s}^{cross}(F_s) = P_i \cdot A_{i\to s} \cdot \hat{\Omega}(\mathbf{GB}_{i\to s}) \qquad (2)$$

$$S_s(F_s)_{dB} - I_{i\to s}^{cross}(F_s)_{dB} \geq \gamma.$$

$$\begin{aligned}\mathbf{GB}_{i\to s} &\geq \frac{I_{i\to s}(F_i)_{dB} - S_s(F_s)_{dB}}{a} + \frac{b+\gamma}{a} \\ &= a' \cdot \mathbf{H}_{i\to s} + b'\end{aligned}$$



(a) An Abstract Representation

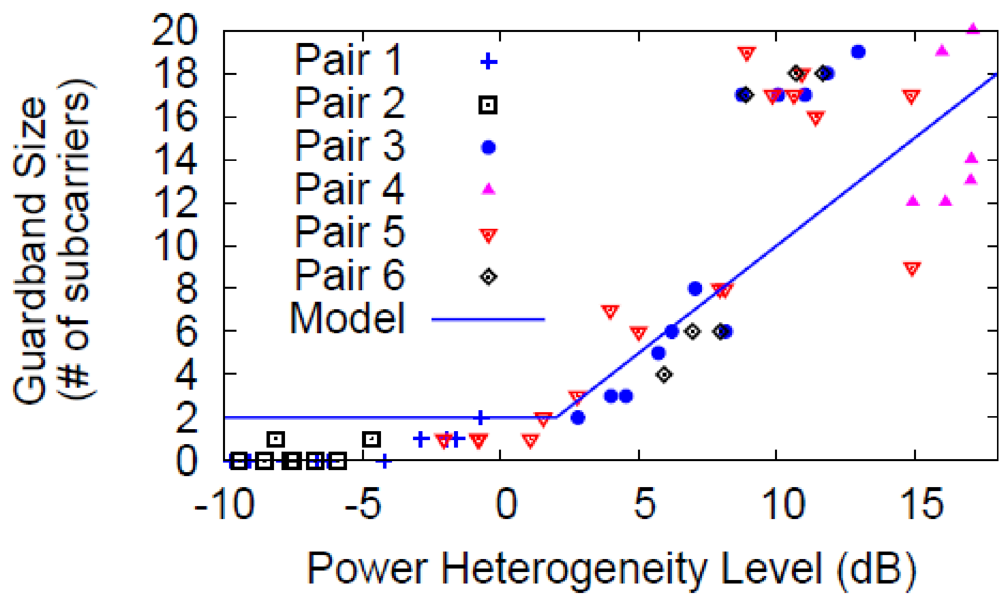


(b) Measured Cross-band Interference

Model Verification and Calibration

- Find the minimum guardband size to suppress the impact of interference

$$\mathbf{GB}_{i\rightarrow s} = g(\mathbf{H}_{i\rightarrow s}) = \begin{cases} \mathbf{H}_{i\rightarrow s}, & \mathbf{H}_{i\rightarrow s} \geq 2 \\ 2, & \mathbf{H}_{i\rightarrow s} < 2 \end{cases}$$

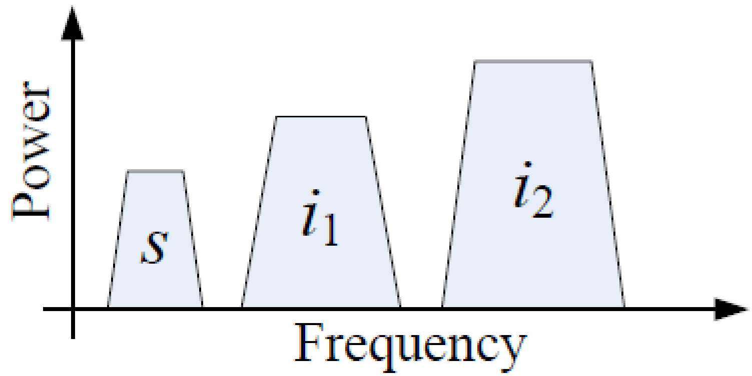


Key Observations

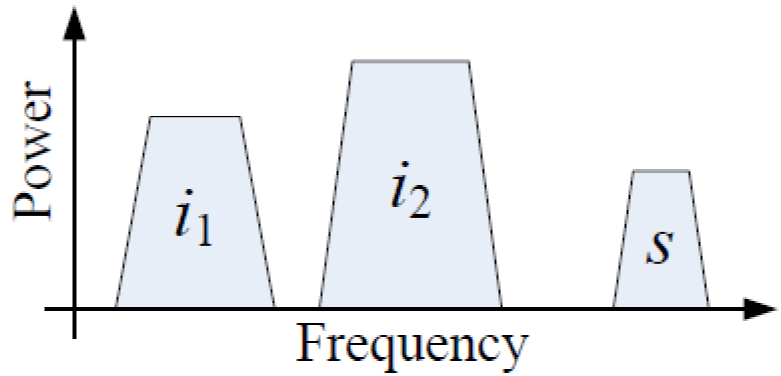
- Local Information Is Not Enough

$$\mathbf{GB}_{s,i} = \max(\mathbf{GB}_{i \to s}, \mathbf{GB}_{s \to i})$$

- A Case for Reducing Power Heterogeneity



(a) Good Placement



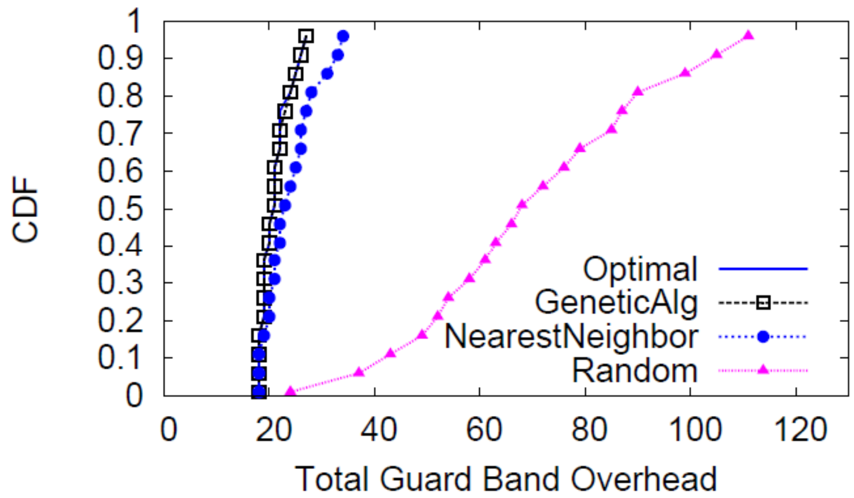
(b) Bad Placement

Centralized Frequency Planning

- Phase 1. Signal Measurements

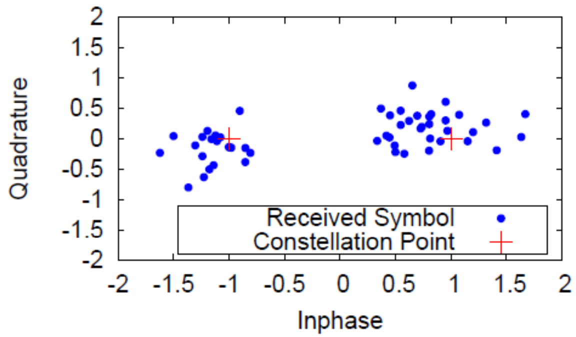
  -compute directly from physical layer symbols
- Phase 2. Frequency Planning

  -NP-complete: Traveling Salesman Problem

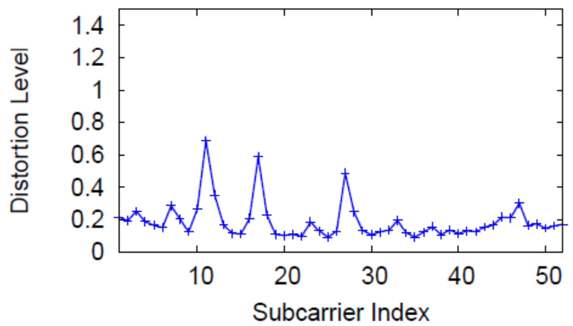


Adapting Guardband Usage

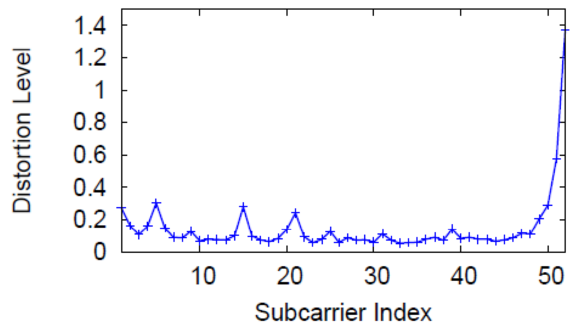
- Detecting Cross-band Interference



(a) Constellation Map



(b) No cross-band interference



(c) A cross-band interferer at the right side

- Local Adjustments

  -increase one additional subcarrier if crossband interference detected

A Ganache Prototype

- Physical Layer

  -decentralized OFDM

  -500KHz is divided into 64 subcarriers with at most 52 subcarriers for data transmission
- Access Layer

  -server to GNU radios: Ethernet

  -sender/receiver handshaking for sync

  -crossband assertion:

  edge distortion > 3 * average distortion

Evaluation

- Performance Metrics: Normalized Impact

  - 1 – (the ratio of per-link throughput to ideal throughput)
- Five Schemes

  -Uni-Cons: 22 subcarriers for each guardband

  -Uni-Aggr: 2 subcarriers for each guardband

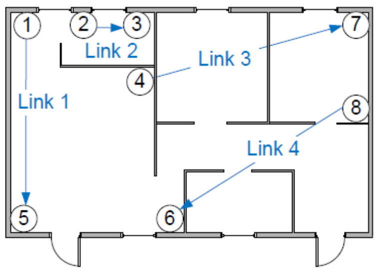
  -Model: compute guardband value

  -C-Planning: centralized planning

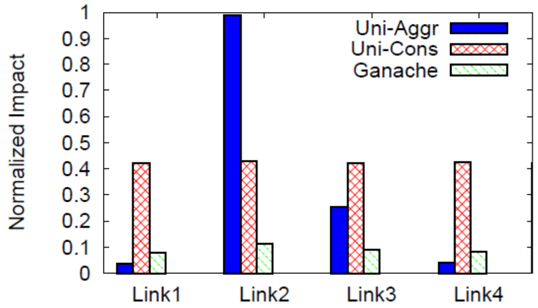
  -Ganache

Ganache vs. Fixed-size Configuration

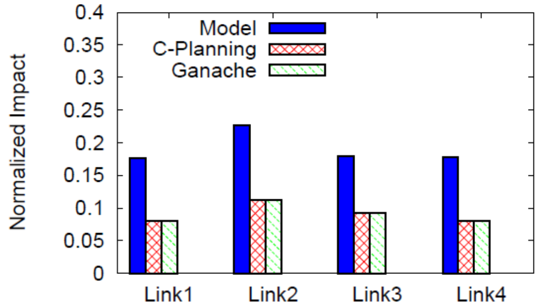
- Topology 1 (Heterogeneous trans. power)



(a) Experiment Topology

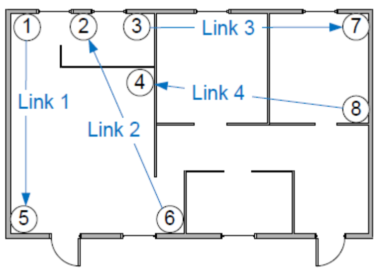


(b) Ganache vs. Fixed-size Approach

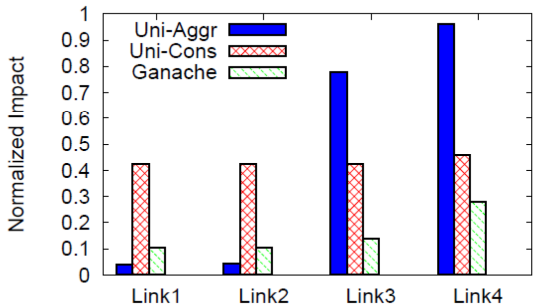


(c) Ganache Performance Breakdown

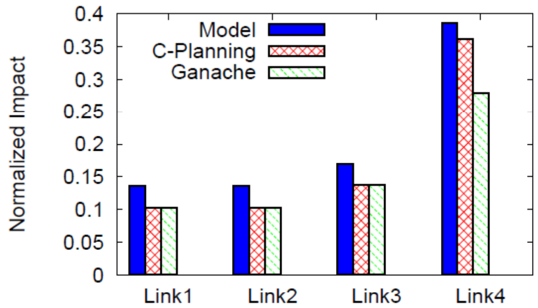
- Topology 2 (Heterogeneous link attenuation)



(a) Experiment Topology



(b) Ganache vs. Fixed-size Approach

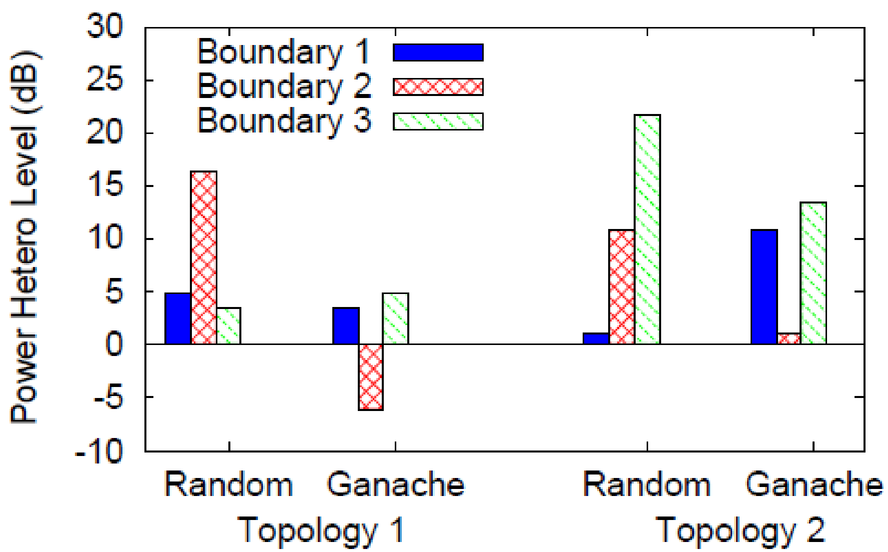


(c) Ganache Performance Breakdown

Impact of Individual Components

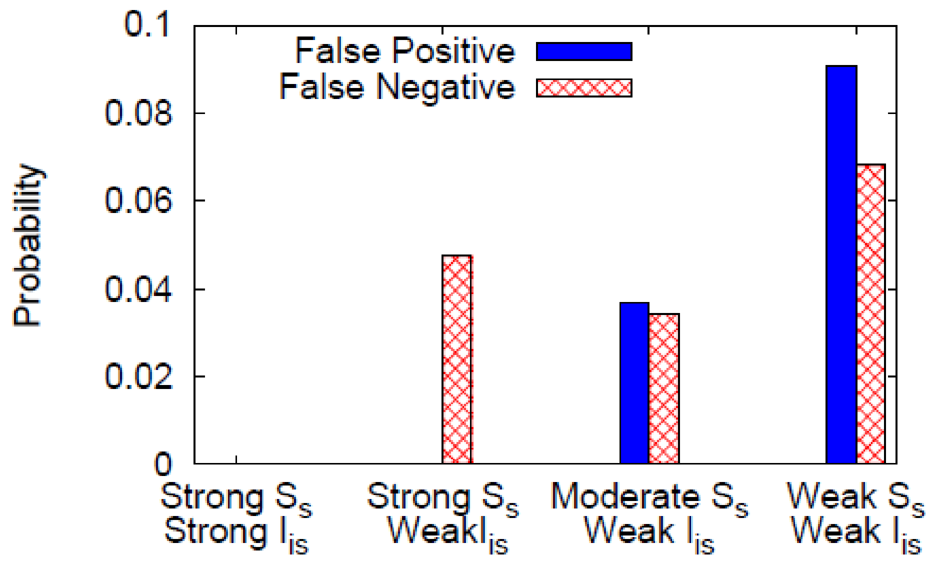
- Model-based Guardband Estimations

  -50+% improvement for both topologies
- Frequency Planning
- Local Adaption



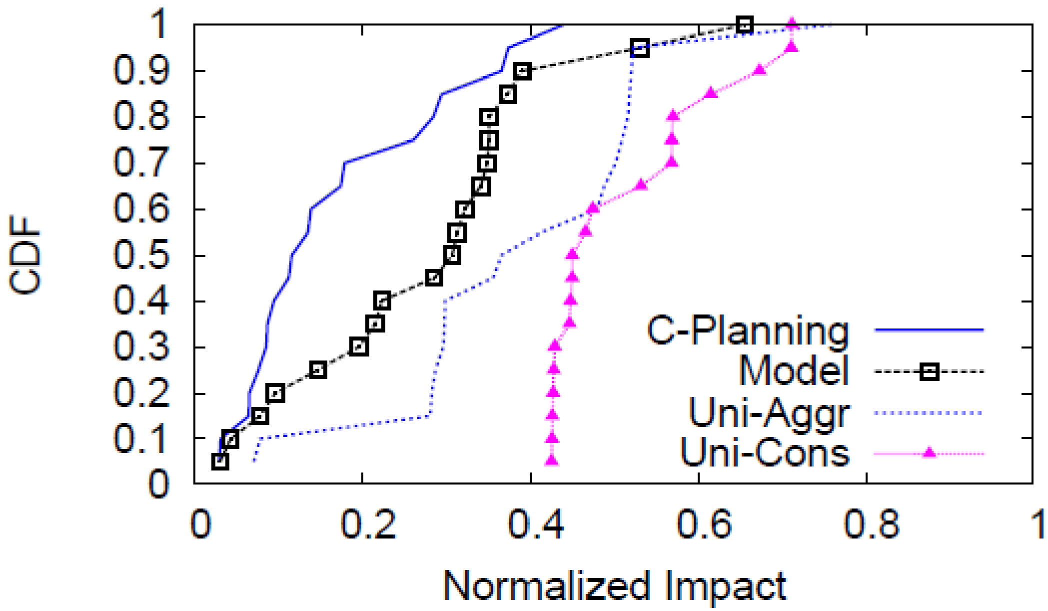
Cross-band Interference Detection

- False Positives: detecting normal impairments as cross-band interference
- False Negative: failing to detect cross-band interference



Overall Efficiency

- Heterogeneity in transmit power settings
- 20 randomly generated 4-link topologies



Related Work

- Spectrum Sharing Systems
- Cross-band Interference in WiFi
- Adaptive Guard Interval
- Using Physical Layer Hints

Conclusion

- The impact of cross-band interference on high density networks
- Ineffective using fixed-size guardbands
- Prototype Ganache
- 150% throughput improvement
- Limitation- mobility