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

MobiCom ‘10

Lei Yang, Ben Y. Zhao, Haitao Zheng
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”
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

\[ I_{i \rightarrow s}^{\text{cross}}(f) \approx \sum_{k \in F_i} P_i \cdot A_{i \rightarrow s}(f) \cdot \Omega(k, f, GB_{i \rightarrow s}) \quad (1) \]

\[ I_{i \rightarrow s}^{\text{cross}}(F_s) = P_i \cdot A_{i \rightarrow s} \cdot \hat{\Omega}(GB_{i \rightarrow s}) \quad (2) \]

\[
S_s(F_s)_{dB} - I_{i \rightarrow s}^{\text{cross}}(F_s)_{dB} \geq \gamma.
\]

\[
GB_{i \rightarrow s} \geq \frac{I_{i \rightarrow s}(F_i)_{dB} - S_s(F_s)_{dB}}{a} + \frac{b + \gamma}{a}
\]

\[
= a' \cdot H_{i \rightarrow s} + b'
\]

(a) An Abstract Representation

(b) Measured Cross-band Interference
Model Verification and Calibration

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

\[ GB_{i \rightarrow s} = g(H_{i \rightarrow s}) = \begin{cases} H_{i \rightarrow s}, & H_{i \rightarrow s} \geq 2 \\ 2, & H_{i \rightarrow s} < 2 \end{cases} \]
Key Observations

• Local Information Is Not Enough

\[ GB_{s,i} = \max(GB_{i \rightarrow s}, GB_{s \rightarrow i}) \]

• A Case for Reducing Power Heterogeneity

![Graphs showing good and bad placement of power frequencies](image)
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

• 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)
  - Experiment Topology

- Topology 2 (Heterogeneous link attenuation)
  - Experiment Topology
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