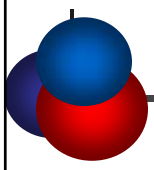
Dealing with Interference on Today's Wireless Hardware



Peter Steenkiste
Departments of Computer Science and Electrical and Computer Engineering
Carnegie Mellon University

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Outline

- Context
  - Self-managing chaotic wireless networks
  - Wireless network emulator testbed
- Interference model (Xi Liu, Srini Seshan)
  - A networking view
- Auto transmit rate selection (Glenn Judd, Xiaohui Wang)
  - Interference a non-issue (really)
- Auto transmit power selection (Xi Liu, Srini Seshan)
  - Interference a big issue

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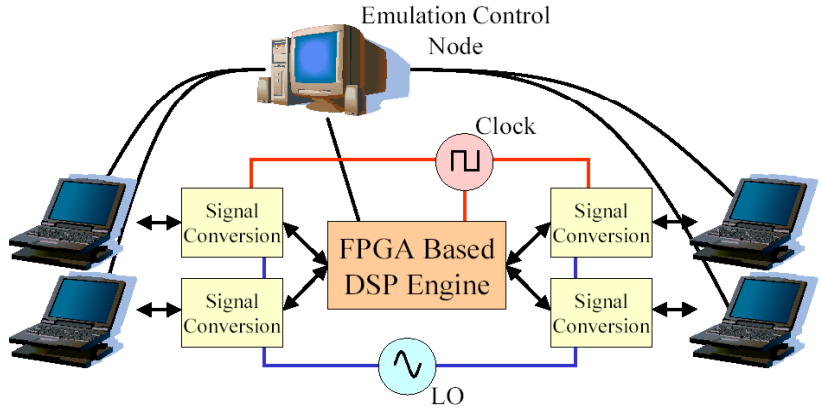
Testbed based on Signal Propagation Emulation



- Real hardware ➔ high degree of realism
- Digital emulation of channels ➔ full control
- Isolated from environment ➔ fully repeatability
- Programmable ➔ very diverse experiments

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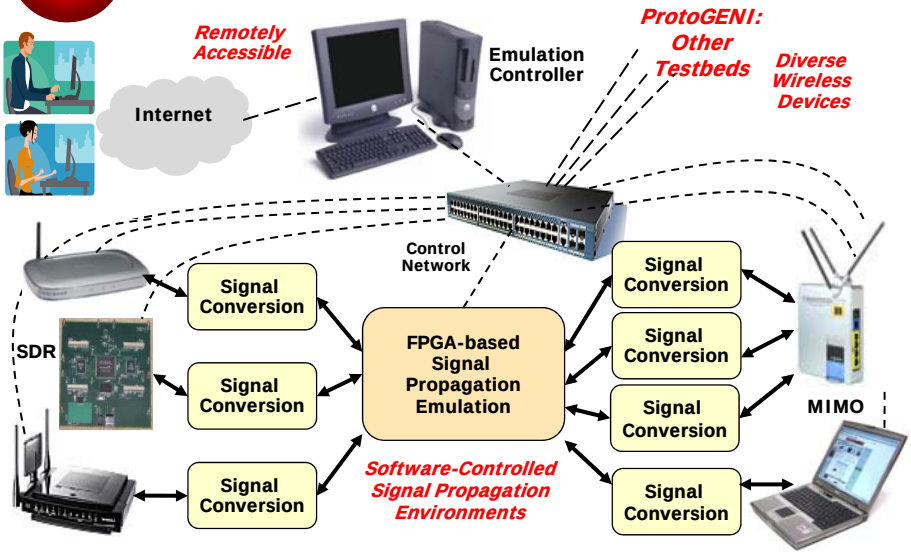
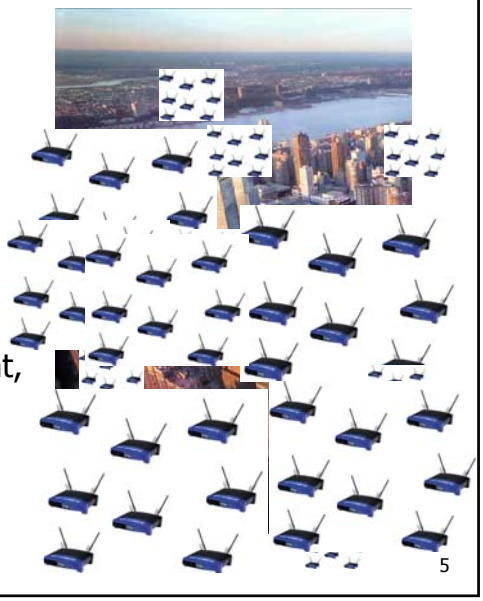
Current System



Chaotic Wireless Networks

- Unplanned:
  - Independent users set up APs
  - Spontaneous
  - Variable densities
  - Other wireless devices
- Unmanaged:
  - Configuring is a pain
  - ESSID, channel, placement, power
  - Use default configuration

→ "Chaotic" Deployments



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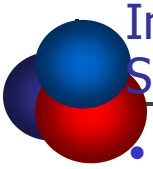
Chaotic Project Roadmap

- Goal: self-configuration and self-optimization
- What can we do with today's commercial hardware?
  - Automatically tune parameters to optimize network performance
  - E.g.: channel, transmit power, transmit rate
- Leverage emerging wireless technologies
  - Tomorrow's commercial hardware
  - Software defined radios, smart antennas
- Optimize use of the scarce wireless spectrum
  - Dynamic spectrum sharing

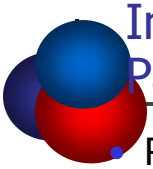


Interference: So Many Models to Choose From!

- Circle model => Use low power levels reduce interference
- SINR model => Use higher power levels provides better performance by reducing effects of noise

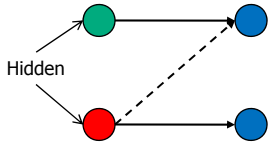
$$SINR = \frac{S}{I + N}$$

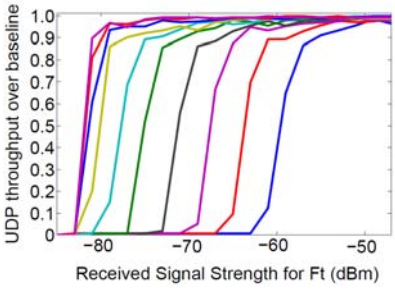
- Capture effect is key: Can higher signal power overcome effect of interference?
  - What does real hardware do?



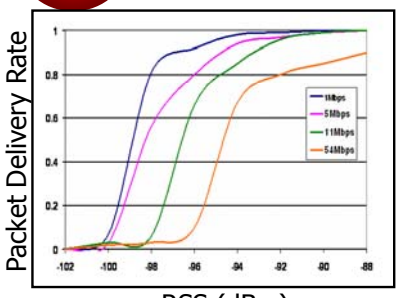
Impact of Interference on Packet Reception Rate

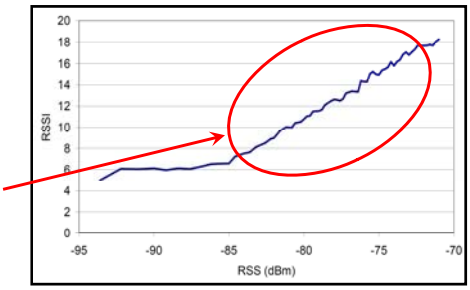
- Ran experiment on wireless emulator
  - Atheros cards + create hidden terminal
- Measure packet success rate as function of transmit power for different levels of interference
  - Interference changed in steps of 4db
- SINR formula holds
  - Increasing interference = reducing power





Automatic Transmit Rate Selection

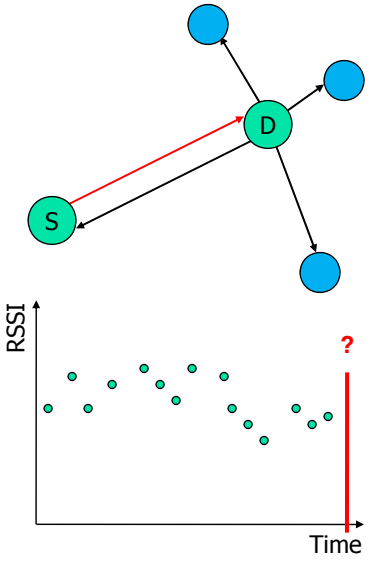




- Best transmit rate depends on the SINR
  - Signal to noise and interference ratio
- Can be estimated on 802.11 cards based on RSSI
  - Can measure received signal strength using RSSI
  - Can exchange information about transmit power, noise, etc.

Charm: Channel-Aware Rate Selection

- Leverage channel reciprocity: overhear packets sent by destination to learn about channel conditions
  - Build history of path loss for each channel
- When transmitting packet, use path loss history to "predict" path loss
- Select best transmit rate from look up table
  - Per destination rate threshold table
  - Thresholds dynamically adjusted based on experience



The Formulas

$= PL_{(Rx\ to\ Tx)}$ (*Reciprocity Theorem*)

$$RSS_{(at\ Rx)} = P_{Tx} + G_{Tx} - PL_{(Tx\ to\ Rx)} + G_{Rx}$$

$$PL_{(Rx\ to\ Tx)} = P_{Rx} + G_{Rx} + G_{Tx} - RSS_{(at\ Tx)}$$

$$RSS_{(at\ Rx)} = RSS_{(at\ Tx)} + P_{Tx} - P_{Rx}$$

Constant

$$SINR_{(at\ Rx)} = RSS_{(at\ Rx)} - N_{Rx}$$

Note: no I_{Rx}
No interference

But hold your guns, please!

P_{Tx}/P_{Rx}	: Transmit Power at transmitter/receiver
G_{Tx}/G_{Rx}	: Transmit Antenna Gain/Receive Antenna Gain
PL	: Path Loss

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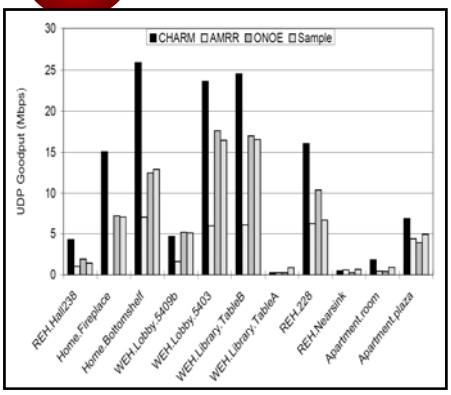
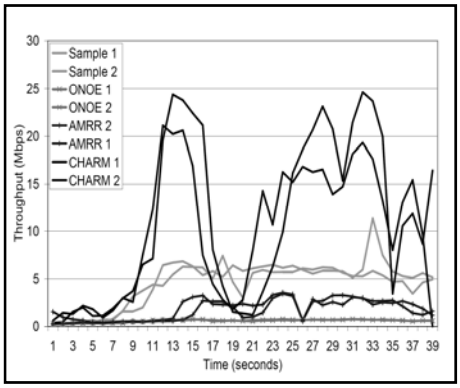
Charm Performance

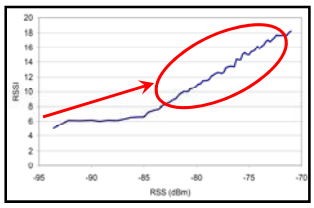


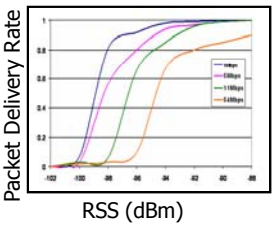


- Charm performs better in both static and dynamic scenarios

Dealing with Real Hardware

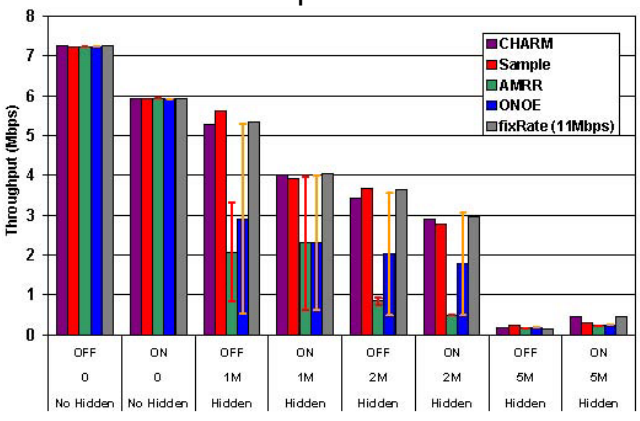
- RSSI versus RSS
  - Fairly linear but there can be an offset
    - Automatically dealt with by auto-tuning
  - Some noise in RSSI measurements
    - Filter out with "time-aware" algorithm
- Interference can affect Tx RSSI reading and SINR at Rx
  - Not really – lots of reasons
- Lack of calibration of transmit power, noise values, RSSI offset, etc.
  - Automatically dealt with by auto-tuning
- Calibration of xmit rate thresholds
  - Adjust automatically based on observed success/failure of transmissions
  - Deals with above calibration issues

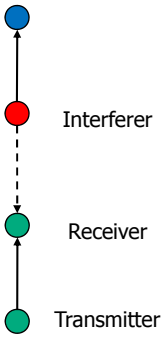




Transmit Rate Selection and Hidden Terminals

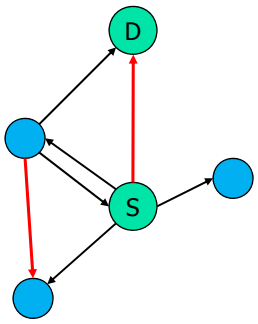
- Some rate selection algorithms perform poorly in hidden terminal situations
  - Collision -> reduce rate -> increased chance of collisions
- Create simple hidden terminal scenario on emulator





Transmit Power Control to Minimize the Effect of Interference

- Simple idea: reduce transmit power to minimum needed to reach destination
  - Based on SINR
- Does not work!
  - Interference is not constant but affected by transmit power used by other nodes
  - Reducing transmit power makes receiver more susceptible to interference



- Simple experiment: if all nodes cut transmit power in half, SINR stays the same
  - Assuming noise is not a concern

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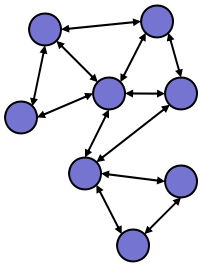
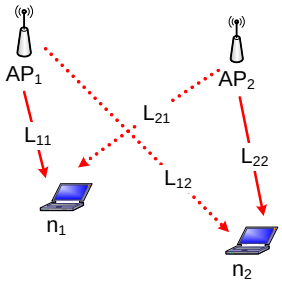
Automatic Power Control: Concepts





- Any transmission creates interference on all links
- Captured in pair-wise interference conflict graph:
  - Nodes are wireless links
  - Edge if simultaneous transmission not possible
- Concurrent transmission is possible if

$$SINR_1 + SINR_2 \geq 2 * SINR_{threshold}$$

Power Control Algorithm

- Greedily remove edges from conflict graph by adjusting transmit power for links
  - Converges when no more edges can be removed
- Must also adjust "Clear Channel Assessment" threshold
  - Done in a separate phase using variant of existing algorithm (altruistic Echos)
- Centralized algorithm is quite simple - distributed algorithm is a bit more involved
  - Nodes exchange information about transmit power and RSS observed from neighbors
  - Each node operates on local conflict graph

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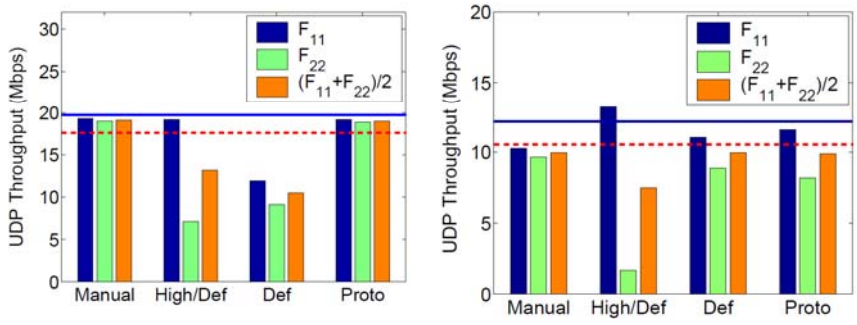
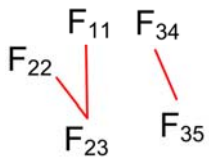
UDP Throughput

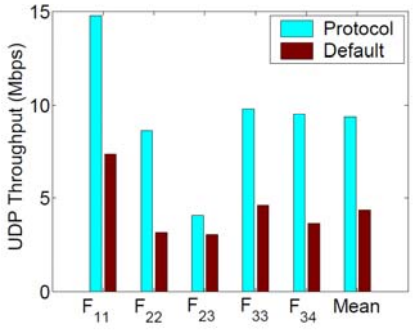
- 36Mbps: F_{11} interferes with F_{22} using default txpower
  - Concurrent transmission possible by reducing F_{11}'s txpower
  - Not fair even with default low CCA
- 48Mbps: no concurrent transmission
  - fairness of the protocol is slightly worse because of relatively high CCA
  - fairness can be achieved by reducing F_{11}'s txpower



Experiment with 8 nodes

- F_{11} interferes with F_{23}, but not with F_{22}
- Pair-wise assumption inaccurate on F_{34}
- Default behavior is better than expected





Hardware We Would Like

- Per-packet transmit power and CCA threshold
  - Only on Intel 2915/2200 with AP driver (kind of)
- Receiver threshold control separate from CCA
  - Tied together on above platform
  - Problem: cannot hear weak signals when CCA is high
- Accurate RSSI measurement and transmit power control
  - Depends on card: linear RSSI readings on Atheros, linear transmit power control on Intel card
  - But have per-card offsets

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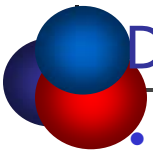

Dealing with Real Hardware

- Smoothing of RSSI readings
  - Both to deal with occasional spurious reading and to get estimates that are stable enough
- Sensitivity of CCA offset and transmit power
  - Need a certain margin to work reliably
- Calibration of transmit power control and RSSI readings
  - Automated protocol to account for card offsets
  - Really messy: 2 cards ➔ N cards
- Need to mix cards to get what you want
  - Really ugly – you don't want to know
  - Cards were optimized for today's WiFi

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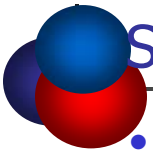

Summary

- Today's cards provide several readings and controls that are useful in fighting interference
  - RSSI, CCA, transmit power
  - Linear on some cards
- But need to deal with different offsets on cards and some noise, imprecision
- Requires on the fly calibration
  - Complexity depends on application
  - Not clear you can avoid this

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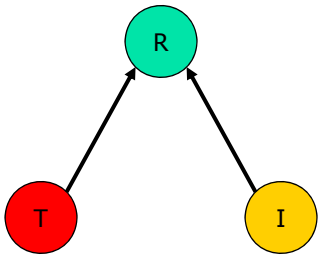
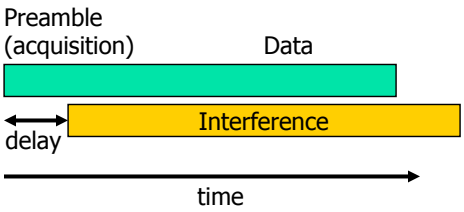
More on Capture

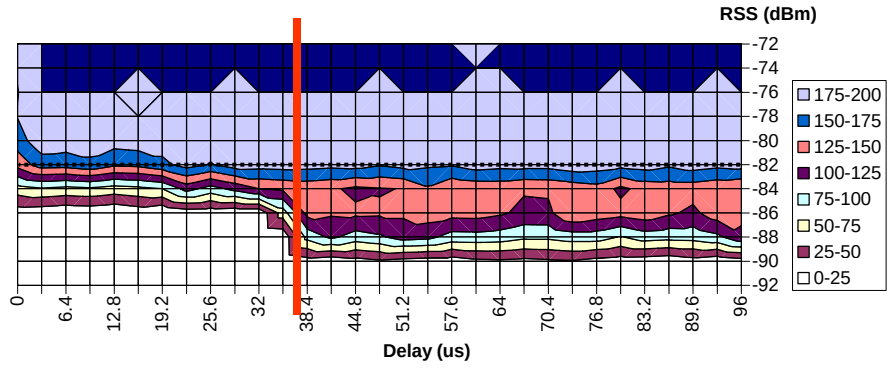
Capture vs. Collision Delay





- Interference fixed at -82 dBm
- Change target signal strength and delay
- 1 & 2 Mbps have strong capture after acquisition
- 5.5 & 11 stick with the stronger signal
- These results for Prism II cards!

1Mbps



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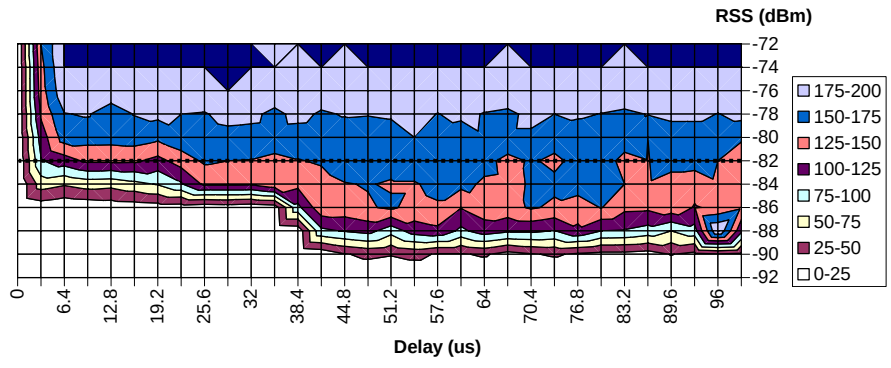
2Mbps



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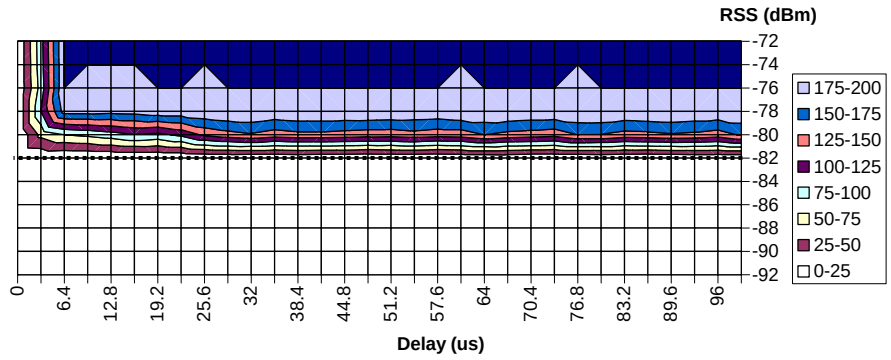
5.5Mbps



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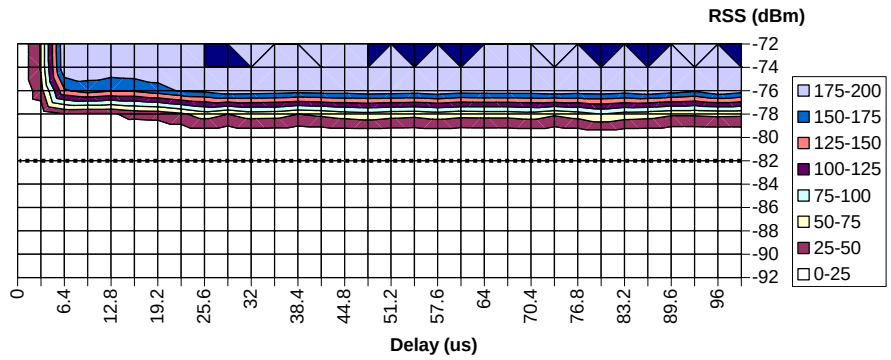
11Mbps



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More on Multi-Path

- Two-path channels
- Keep the primary path constant
- Change channel delay and strength of second path

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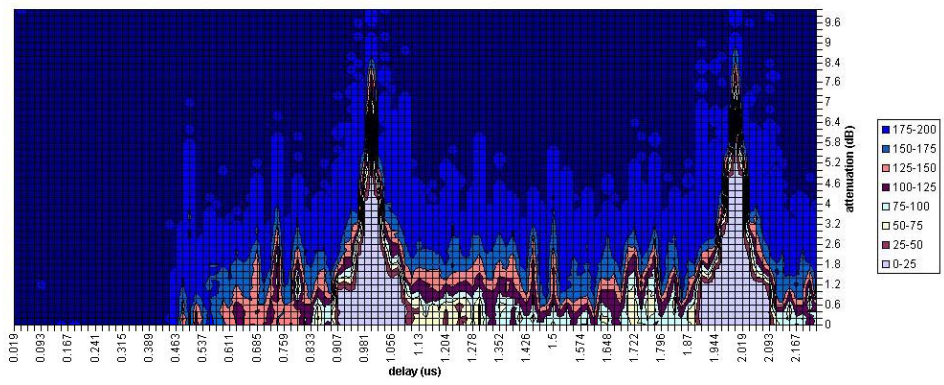

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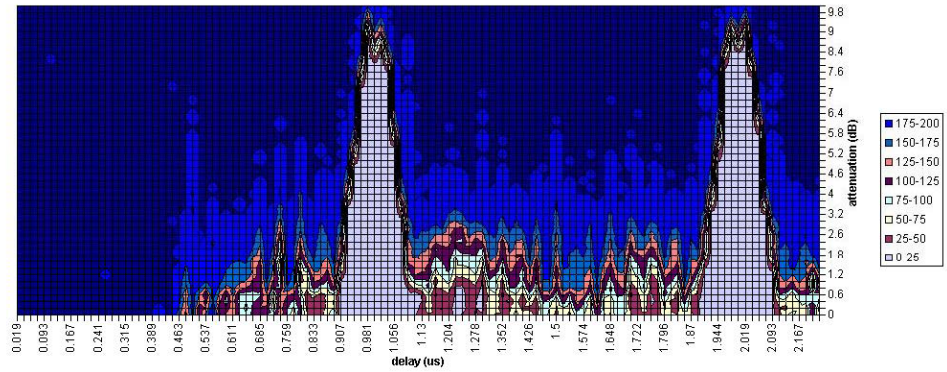
Impact of Delay and Attenuation (2 Mbs)



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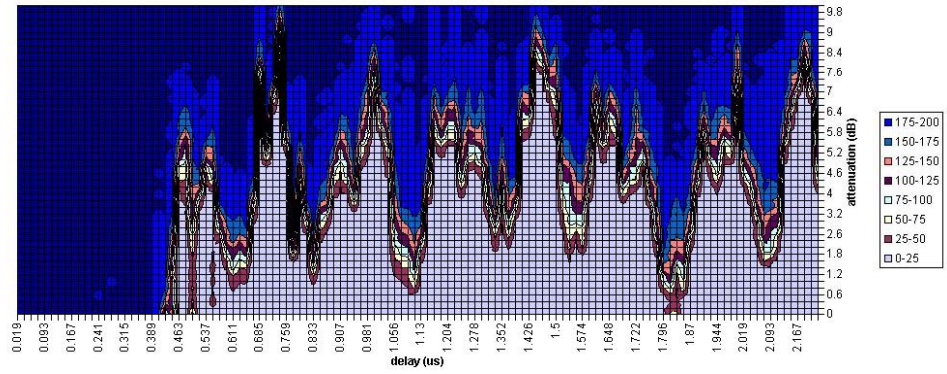

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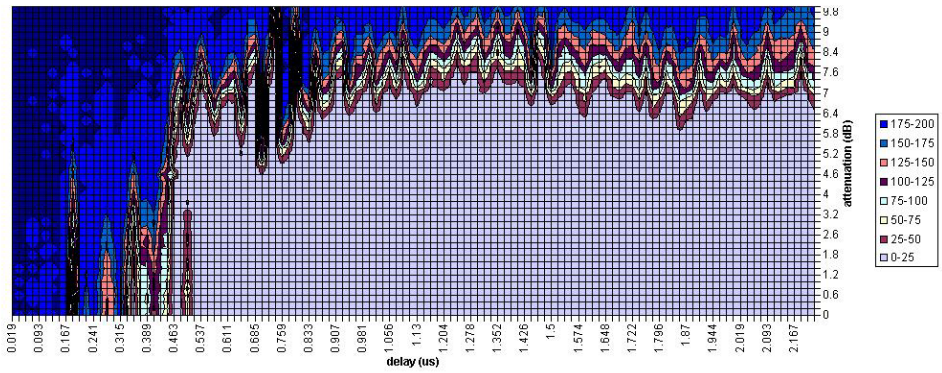
Impact of Delay and Attenuation (11 Mbs)



Card design for indoor environments