CE693: Adv. Computer Networking

L-09 Wireless in the Real World

Acknowledgments: Lecture slides are from the graduate level Computer Networks course thought by Srinivasan Seshan at CMU. When slides are obtained from other sources, a a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.

Wireless in the Real World

- Real world deployment patterns
- Mesh networks and deployments
- Assigned reading
  - Architecture and Evaluation of an Unplanned 802.11b Mesh Network
  - White Space Networking with Wi-Fi like Connectivity

Wireless Challenges

- Force us to rethink many assumptions
- Need to share airwaves rather than wire
  - Don’t know what hosts are involved
  - Host may not be using same link technology
- Mobility
- Other characteristics of wireless
  - Noisy → lots of losses
  - Slow
  - Interaction of multiple transmitters at receiver
    - Collisions, capture, interference
  - Multipath interference

Overview

- 802.11
  - Deployment patterns
  - Reaction to interference
  - Interference mitigation

- Mesh networks
  - Architecture
  - Measurements

- White space networks

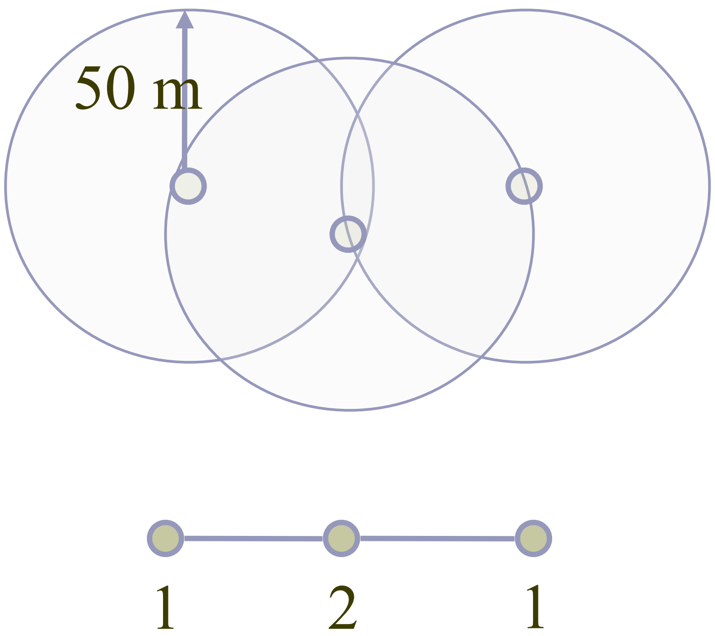
Characterizing Current Deployments

- Datasets
- Place Lab: 28,000 APs
  - MAC, ESSID, GPS
  - Selected US cities
  - www.placelab.org
- Wifimaps: 300,000 APs
  - MAC, ESSID, Channel, GPS (derived)
  - wifimaps.com
- Pittsburgh Wardrive: 667 APs
  - MAC, ESSID, Channel, Supported Rates, GPS

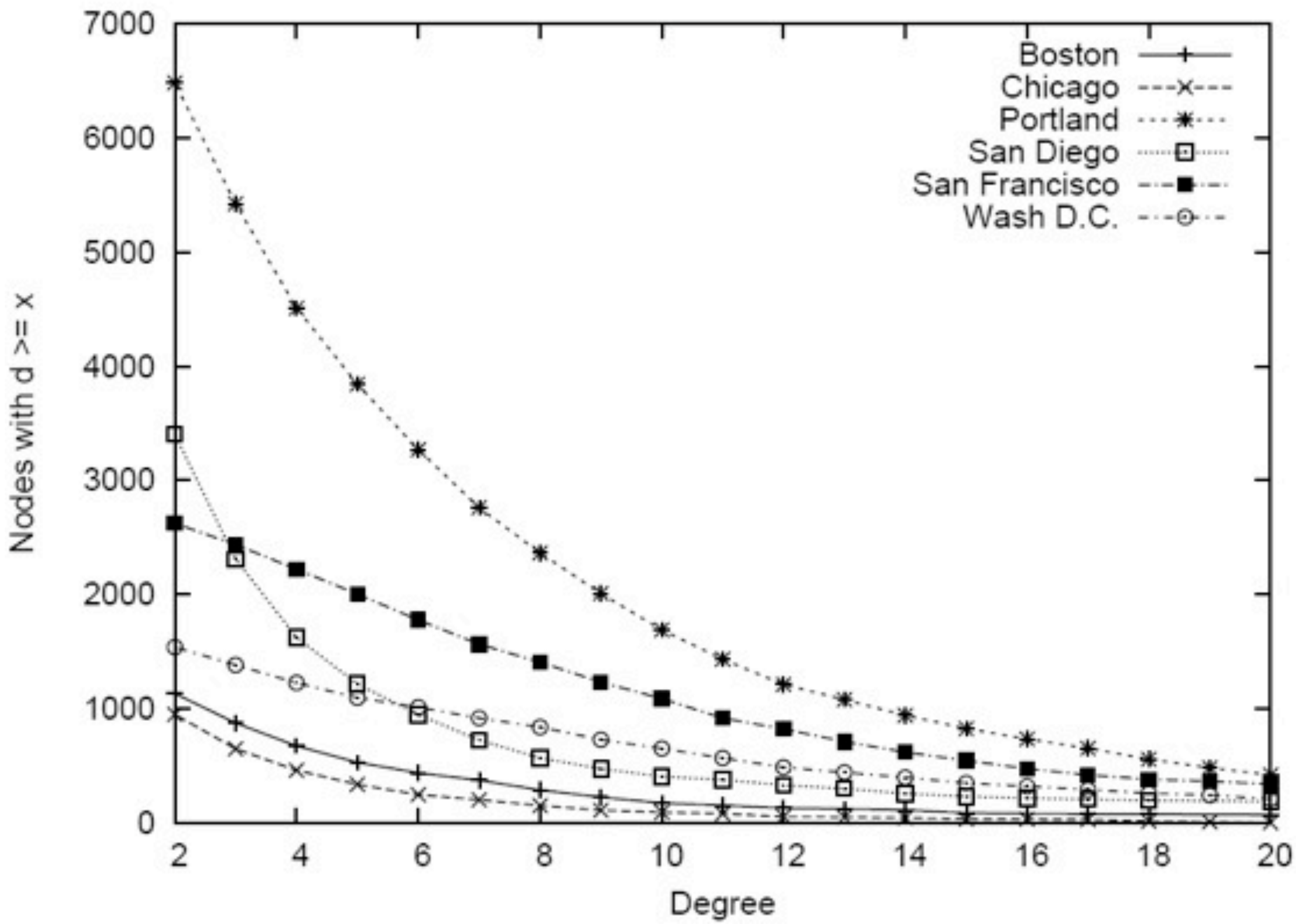
AP Stats, Degrees: Placelab

(Placelab: 28000 APs, MAC, ESSID, GPS)

	#APs	Max. degree
Portland	8683	54
San Diego	7934	76
San Francisco	3037	85
Boston	2551	39



Degree Distribution: Place Lab



Unmanaged Devices

WifiMaps.com
(300,000 APs, MAC, ESSID, Channel)

Channel %age

6	51
11	21
1	14
10	4

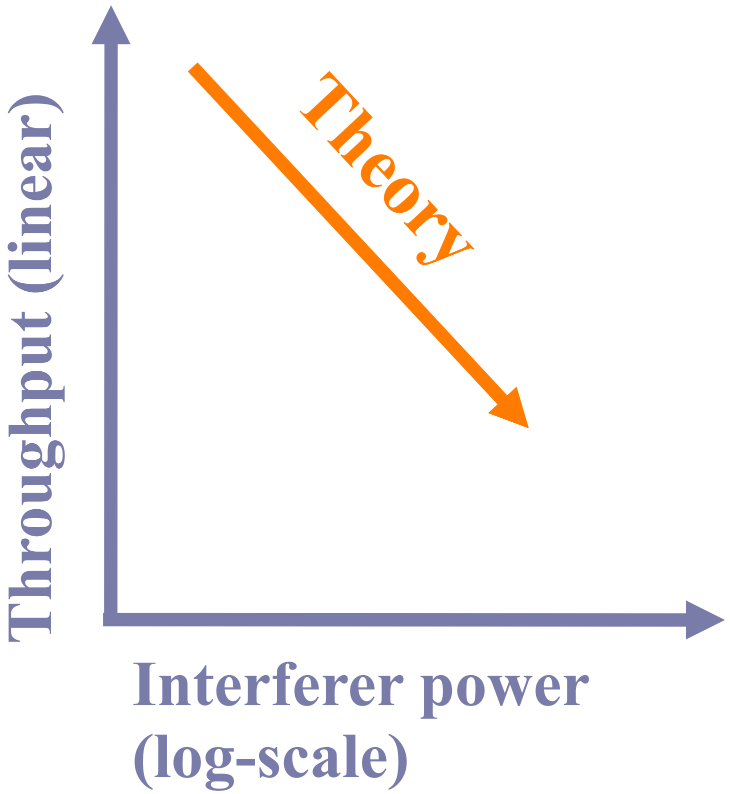
- Most users don’t change default channel
- Channel selection must be automated

Growing Interference in Unlicensed Bands

- Anecdotal evidence of problems, but how severe?
- Characterize how 802.11 operates under interference in practice

What do we expect?

- Throughput to decrease linearly with interference
- There to be lots of options for 802.11 devices to tolerate interference
  - Bit-rate adaptation
  - Power control
  - FEC
  - Packet size variation
  - Spread-spectrum processing
  - Transmission and reception diversity



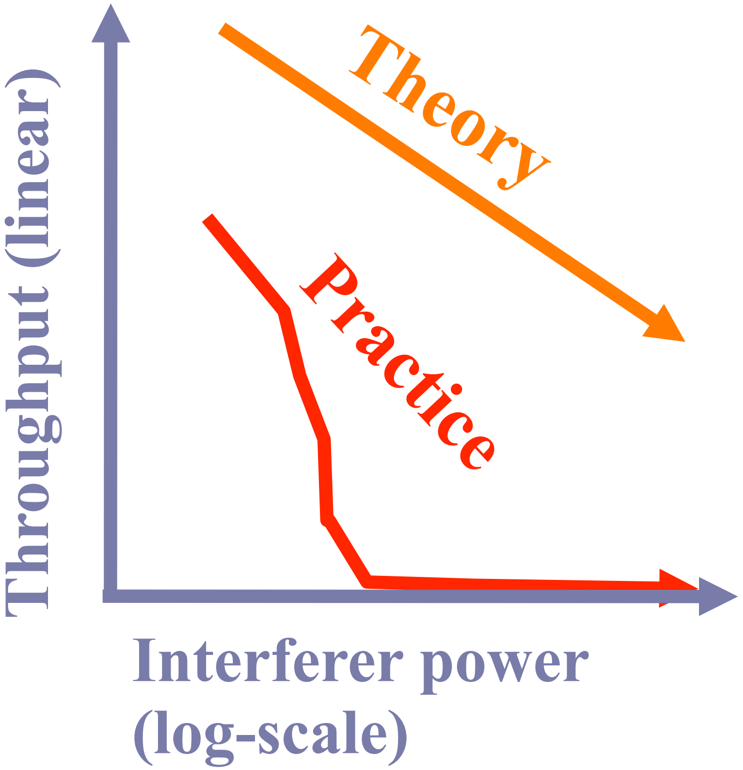
Key Questions

- How damaging can a low-power and/or narrow-band interferer be?
- How can today's hardware tolerate interference well?
  - What 802.11 options work well, and why?

What we see

- Effects of interference more severe in practice

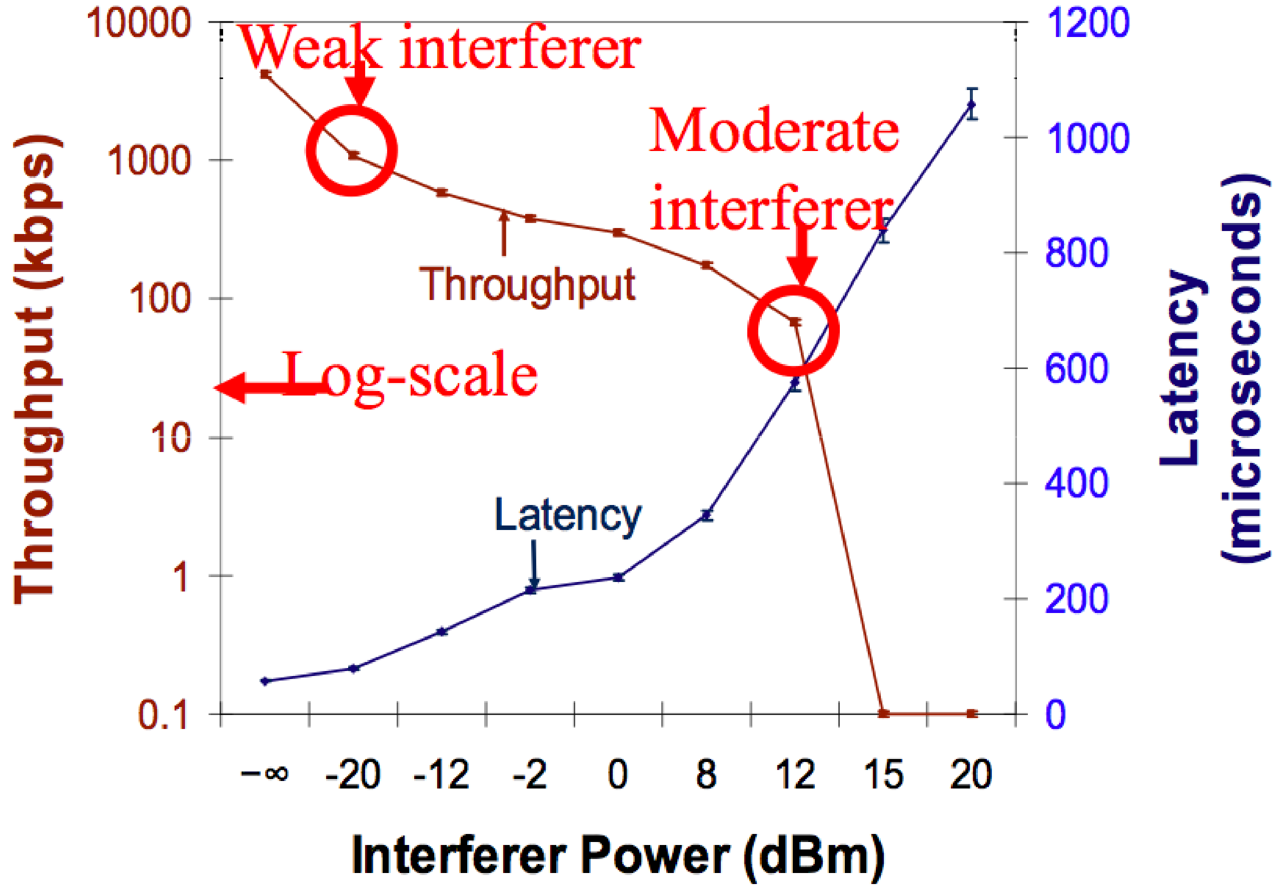
- Caused by hardware limitations of commodity cards, which theory doesn't model



Experimental Setup

Timing Recovery Interference

- Interferer sends continuous SYNC pattern
- Interferes with packet acquisition (PHY reception errors)



Interference Management

- Interference will get worse
  - Density/device diversity is increasing
  - Unlicensed spectrum is not keeping up
- Spectrum management
  - “Channel hopping” 802.11 effective at mitigating some performance problems [Sigcomm07]
  - Coordinated spectrum use – based on RF sensor network
- Transmission power control
  - Enable spatial reuse of spectrum by controlling transmit power
  - Must also adapt carrier sense behavior to take advantage

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  - Interference mitigation
- Mesh networks
  - Architecture
  - Measurements
- White space networks

Roofnet

- Share a few wired Internet connections
- Goals
  - Operate without extensive planning or central management
  - Provide wide coverage and acceptable performance
- Design decisions
  - Unconstrained node placement
  - Omni-directional antennas
  - Multi-hop routing
  - Optimization of routing for throughput in a slowly changing network

Roofnet Design

- Deployment
  - Over an area of about four square kilometers in Cambridge, Massachusetts
  - Most nodes are located in buildings
    - 3~4 story apartment buildings
    - 8 nodes are in taller buildings
  - Each Rooftnet node is hosted by a volunteer user
- Hardware
  - PC, omni-directional antenna, hard drive …
  - 802.11b card
    - RTS/CTS disabled
    - Share the same 802.11b channel
    - Non-standard “pseudo-IBSS” mode
      - Similar to standard 802.11b IBSS (ad hoc)
      - Omit beacon and BSSID (network ID)

Roofnet Node Map

Typical Rooftop View

A Roofnet Self-Installation Kit

Antenna ($65)
8dBi, 20 degree vertical

Computer ($340)
533 MHz PC, hard disk, CDROM

802.11b card ($155)
Engenius Prism 2.5, 200mW

50 ft. Cable ($40)
Low loss (3dB/100ft)

Miscellaneous ($75)
Chimney Mount, Lightning Arrestor, etc.

Software ("free")
Our networking software based on Click

Total: $685

Takes a user about 45 minutes to install on a flat roof

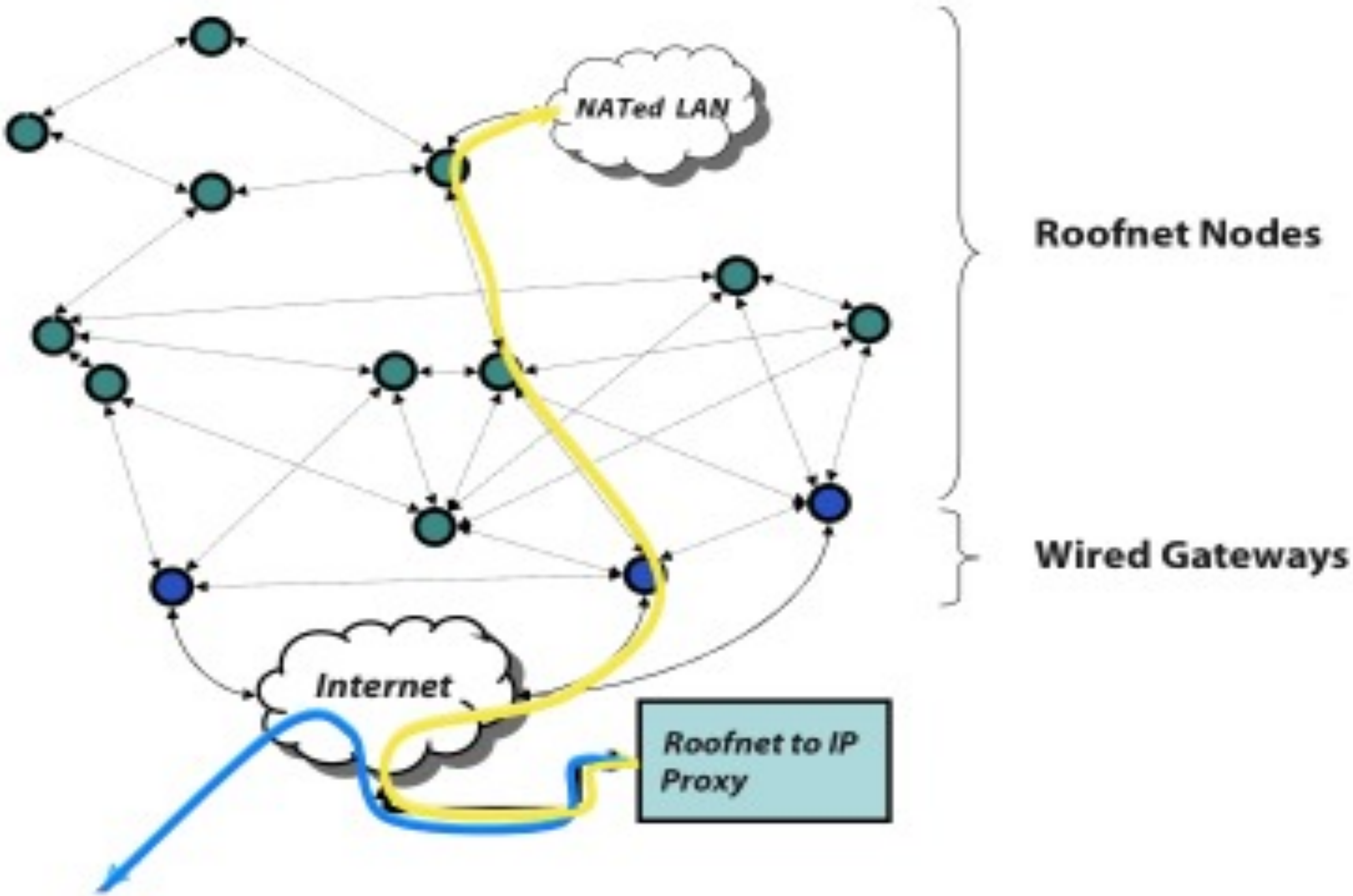
Software and Auto-Configuration

- Linux, routing software, DHCP server, web server …
- Automatically solve a number of problems
  - Allocating addresses
  - Finding a gateway between Roofnet and the Internet
  - Choosing a good multi-hop route to that gateway
- Addressing
  - Roofnet carries IP packets inside its own header format and routing protocol
  - Assign addresses automatically
  - Only meaningful inside Roofnet, not globally routable
  - The address of Roofnet nodes
    - Low 24 bits are the low 24 bits of the node's Ethernet address
    - High 8 bits are an unused class-A IP address block
  - The address of hosts
    - Allocate 192.168.1.x via DHCP and use NAT between the Ethernet and Roofnet

Software and Auto-Configuration

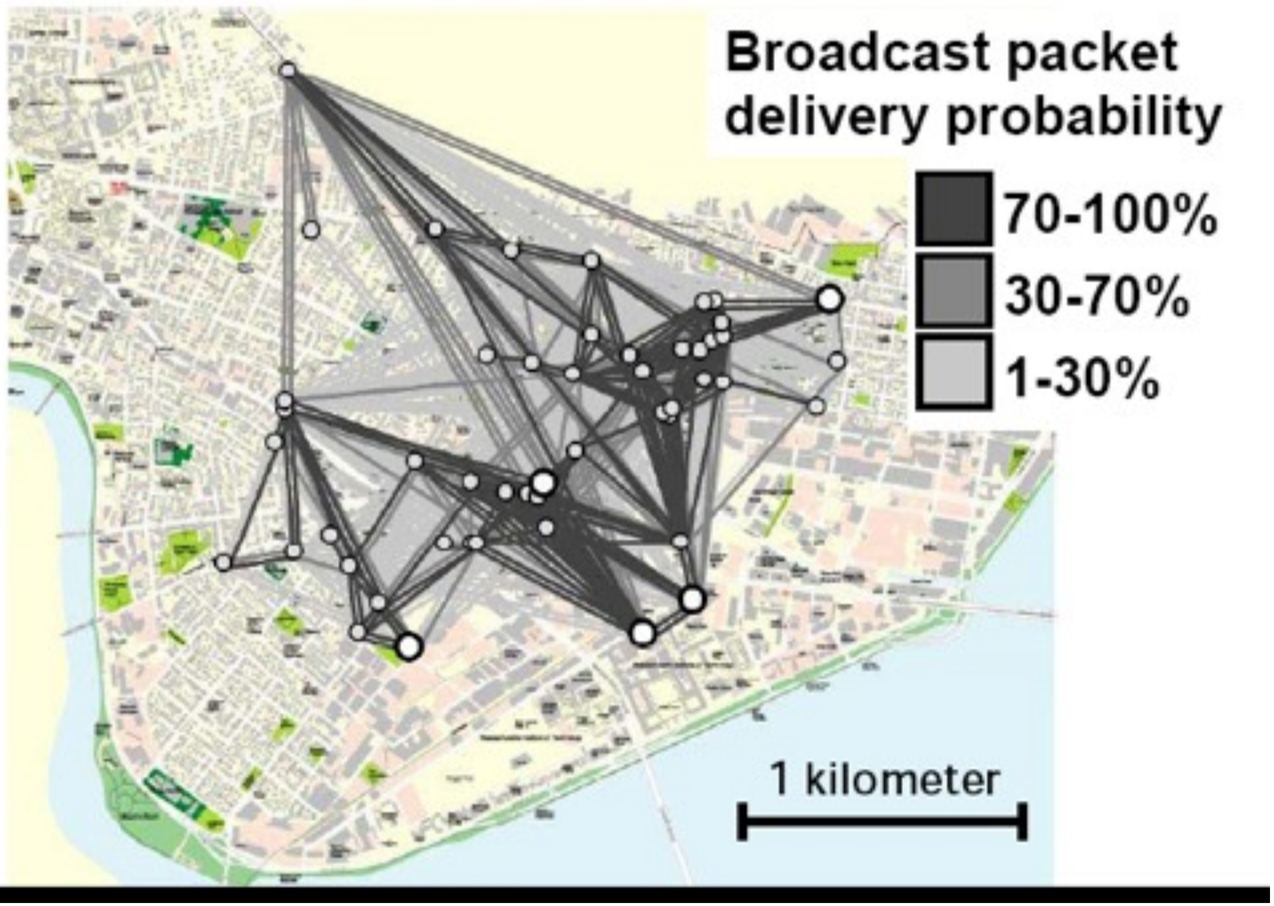
- Gateway and Internet Access
  - A small fraction of Roofnet users will share their wired Internet access links
  - Nodes which can reach the Internet
    - Advertise itself to Roofnet as an Internet gateway
    - Acts as a NAT for connection from Roofnet to the Internet
  - Other nodes
    - Select the gateway which has the best route metric
  - Roofnet currently has four Internet gateways

Roofnet

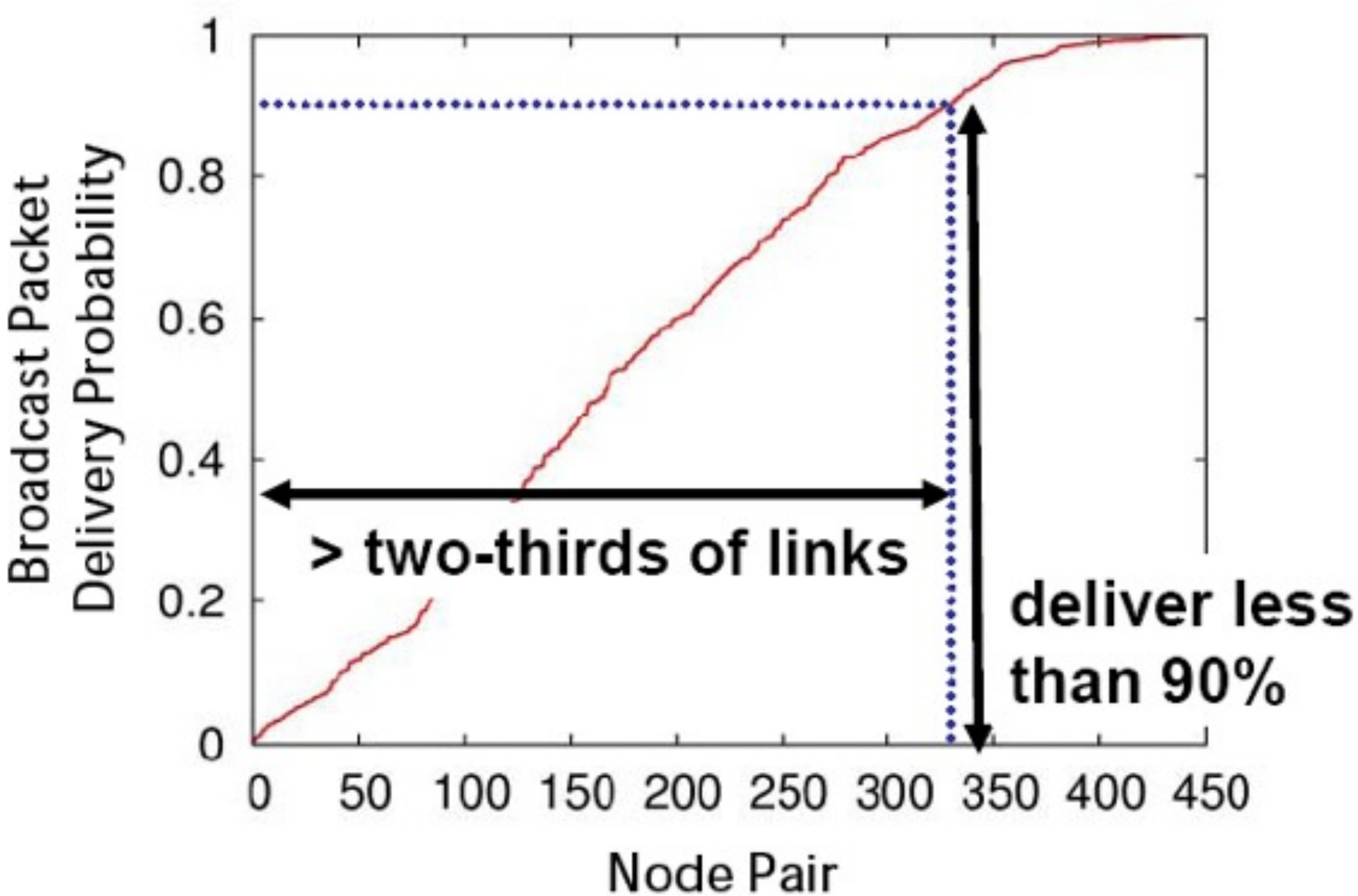


NATed LAN
Roofnet Nodes
Wired Gateways
Internet
Roofnet to IP Proxy

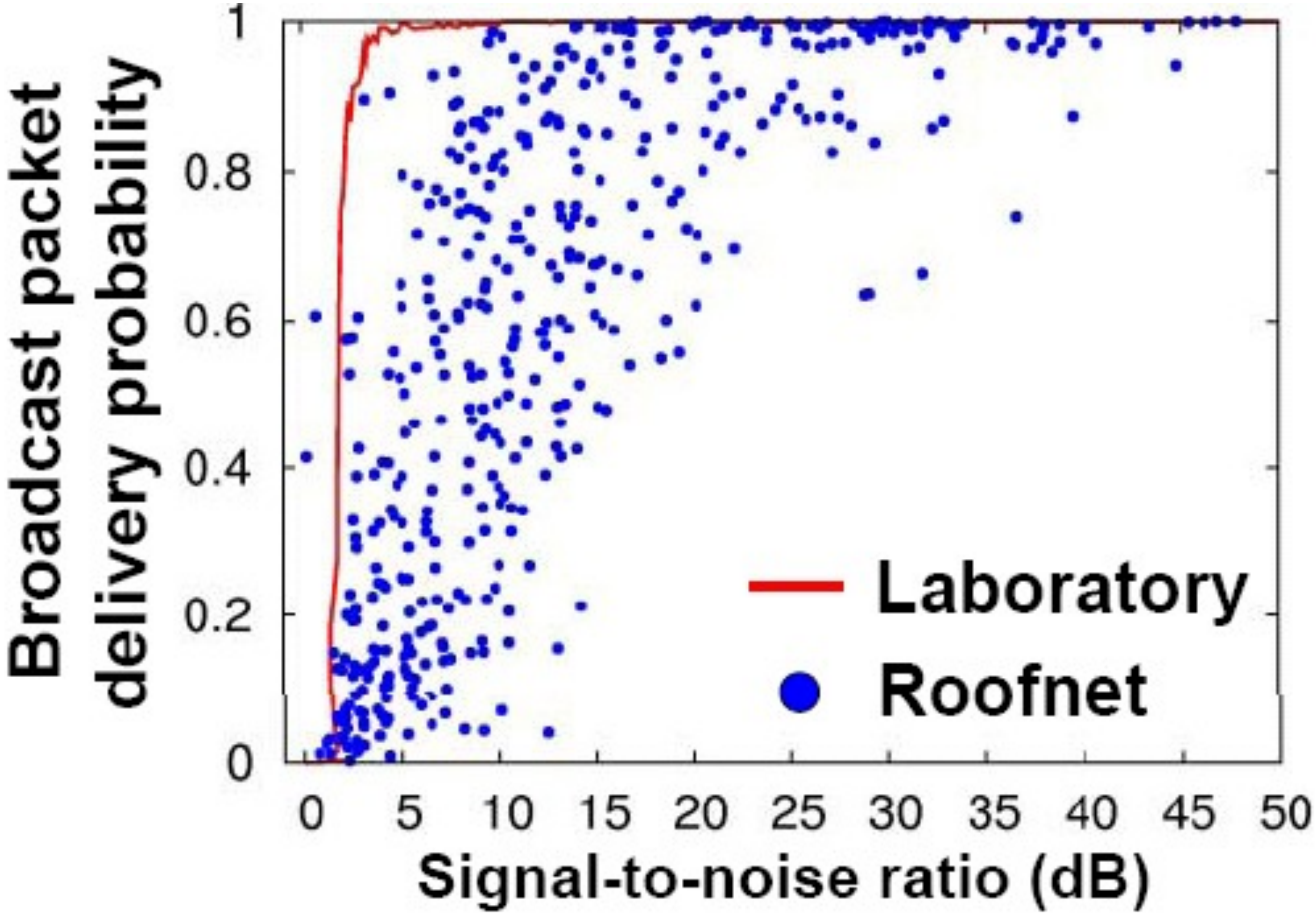
Lossy Links are Common



Delivery Probabilities are Uniformly Distributed



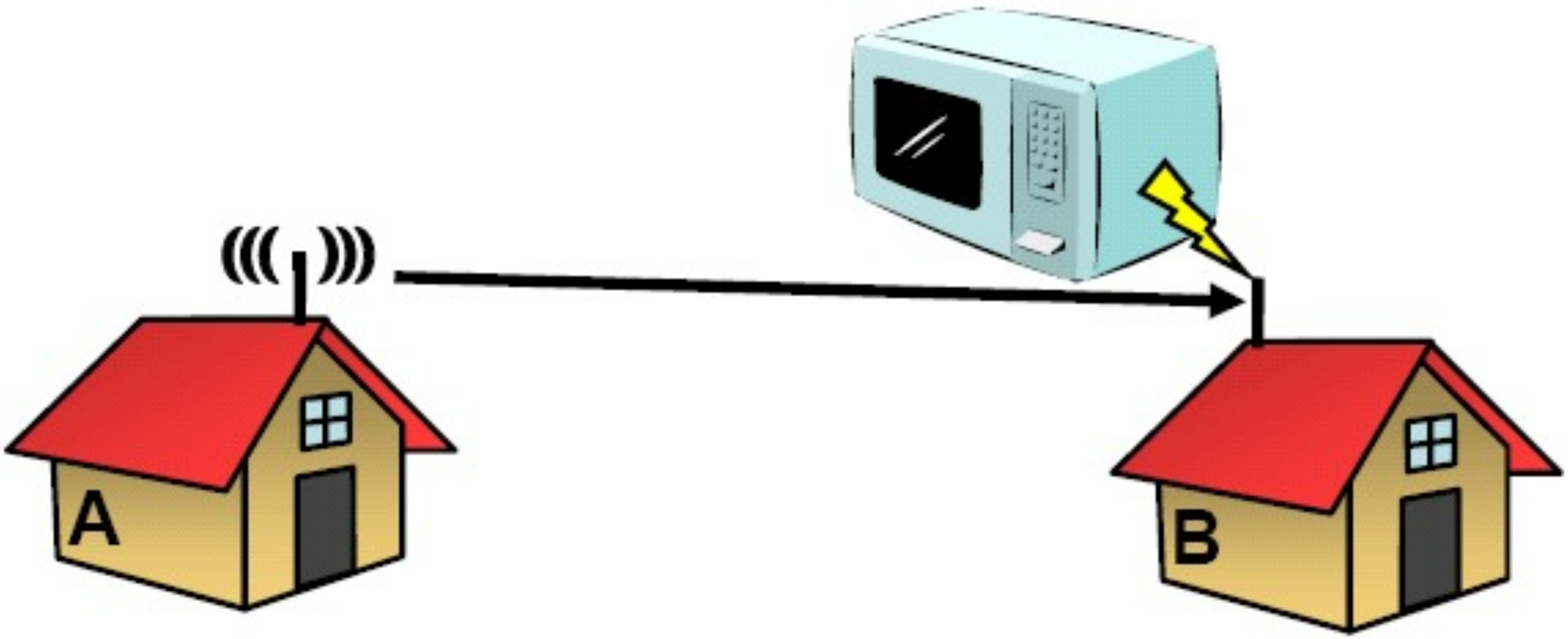
Delivery vs. SNR



- SNR not a good predictor

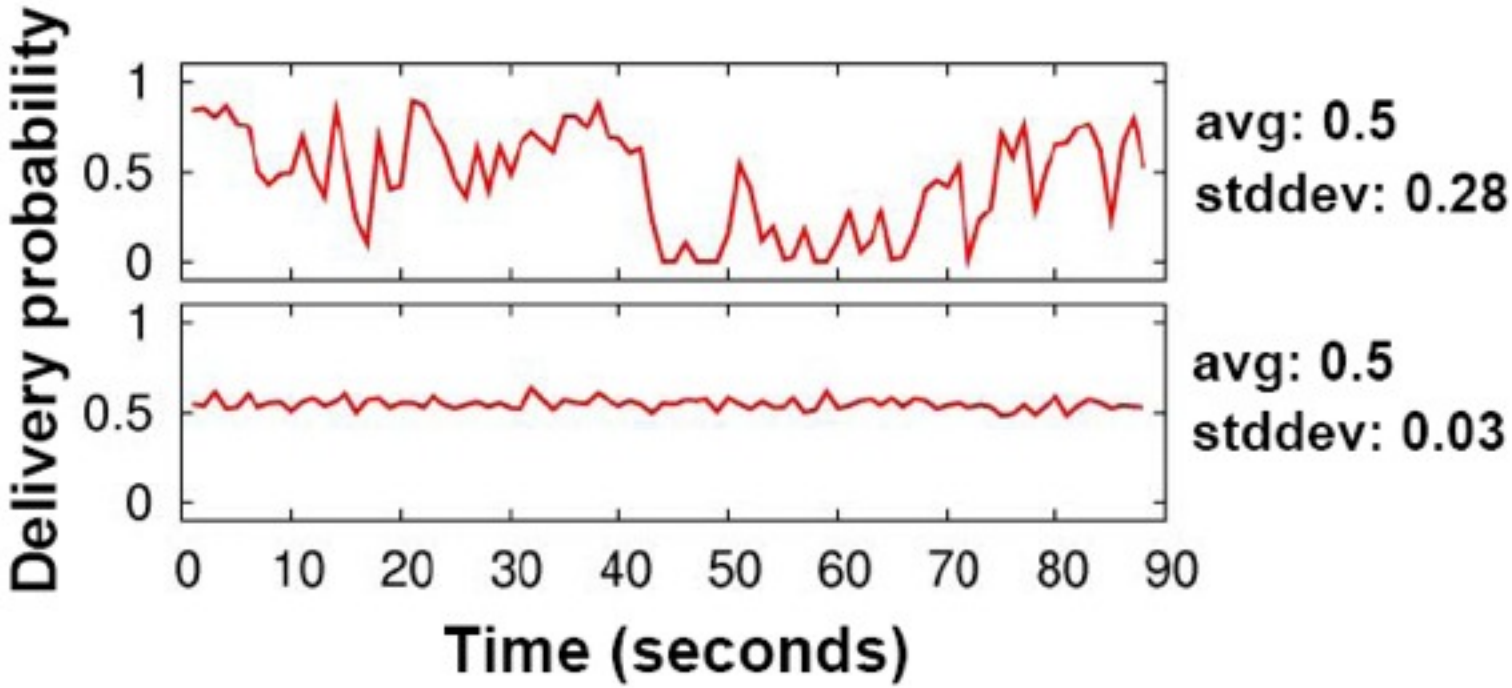
Is it Bursty Interference?

- May interfere but not impact SNR measurement

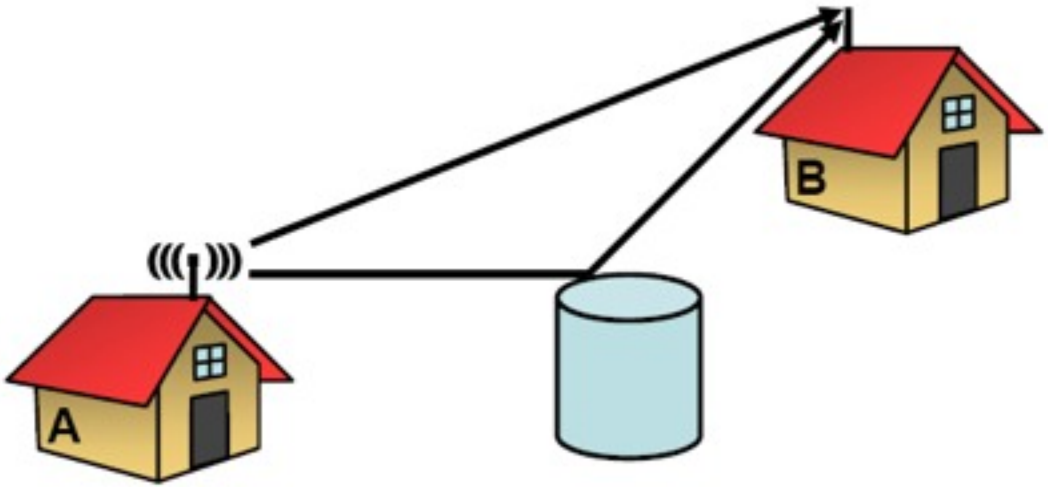


Two Different Roofnet Links

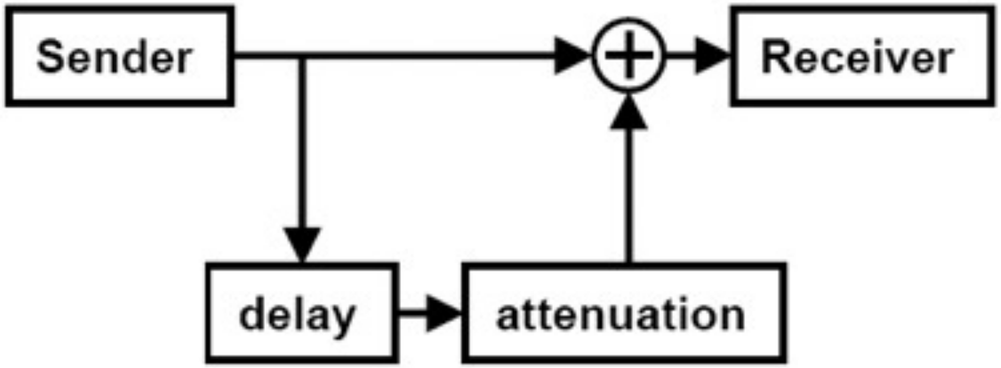
- Top is typical of bursty interference, bottom is not
- Most links are like the bottom



Is it Multipath Interference?

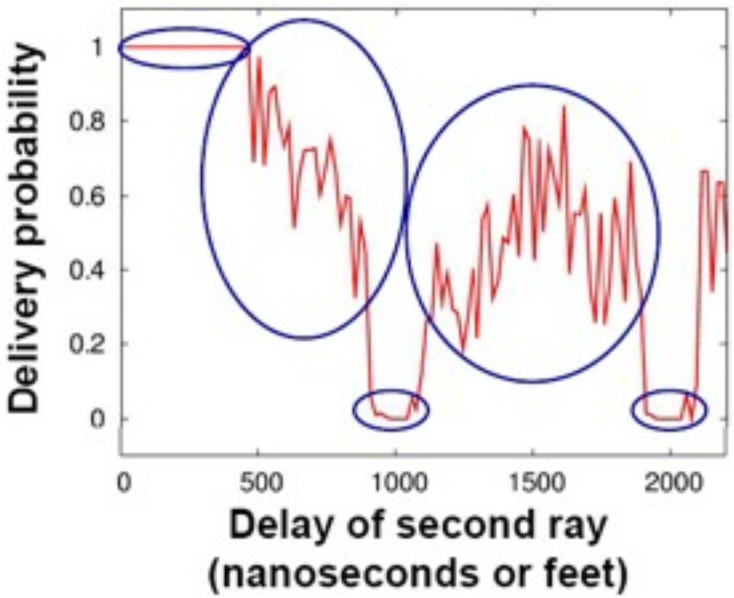


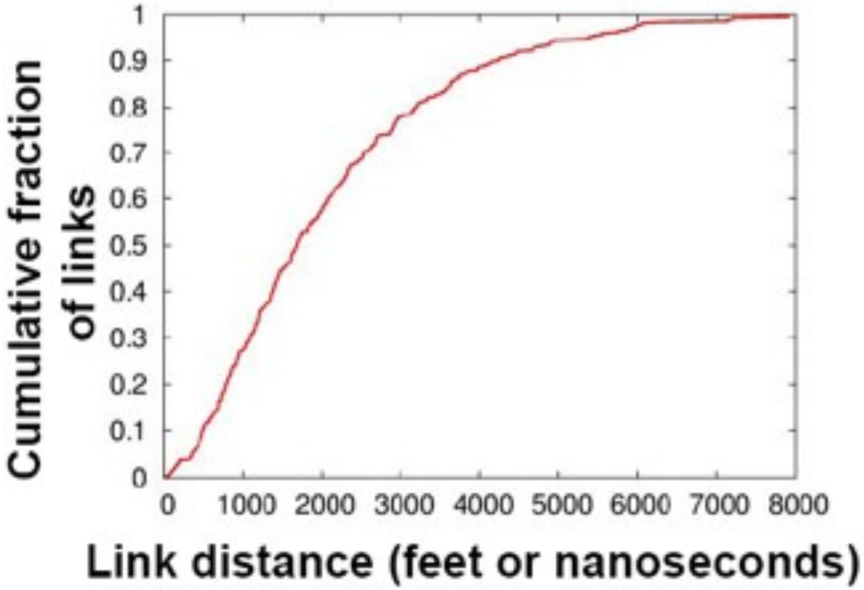
- Simulate with channel emulator



A Plausible Explanation

- Multi-path can produce intermediate loss rates
- Appropriate multi-path delay is possible due to long-links





Key Implications

- Lack of a link abstraction!
  - Links aren’t on or off… sometimes in-between
- Protocols must take advantage of these intermediate quality links to perform well
- How unique is this to Roofnet?
  - Cards designed for indoor environments used outdoors

ETX measurement results

- Delivery *is* probabilistic
  - A 1/r^2 model wouldn't really predict this!
  - Sharp cutoff (by spec) of "good" vs "no" reception. Intermediate loss range band is just a few dB wide!
- Why?
  - Biggest factor: Multi-path interference
    - 802.11 receivers can suppress reflections < 250ns
    - Outdoor reflections delay often > 1 \mu sec
    - Delay offsets == symbol time look like valid symbols (large interferece)
    - Offsets != symbol time look like random noise
    - Small changes in delay == big changes in loss rate

Deciding Between Links

- Most early protocols: Hop Count
  - Link-layer retransmission can mask some loss
  - But: a 50% loss rate means your link is only 50% as fast!
- Threshold?
  - Can sacrifice connectivity. ☹
  - Isn’t a 90% path better than an 80% path?
- Real life goal: Find highest throughput paths

Is there a better metric?

- Cut-off threshold
  - Disconnected network
- Product of link delivery ratio along path
  - Does not account for inter-hop interference
- Bottleneck link (highest-loss-ratio link)
  - Same as above
- End-to-end delay
  - Depends on interface queue lengths

ETX Metric Design Goals

- Find high throughput paths
- Account for lossy links
- Account for asymmetric links
- Account for inter-link interference
- Independent of network load (don’t incorporate congestion)

Forwarding Packets is Expensive

- Throughput of 802.11b =~ 11Mbits/s
  - In reality, you can get about 5.
- What is throughput of a chain?
  - A → B → C ?
  - A → B → C → D ?
  - Assume minimum power for radios.
- Routing metric should take this into account! Affects throughput

ETX

- Measure each link's delivery probability with broadcast probes (& measure reverse)
- P(delivery) = (d_f * d_r)   (ACK must be delivered too…)
- Link ETX = 1 / P(delivery)
- Route ETX = Σ link ETX
  - Assumes all hops interfere - not true, but seems to work okay so far

ETX: Sanity Checks

- ETX of perfect 1-hop path: 1
- ETX of 50% delivery 1-hop path: 2
- ETX of perfect 3-hop path: 3

- (So, e.g., a 50% loss path is better than a perfect 3-hop path! A threshold would probably fail here…)

Rate Adaptation

- What if links @ different rates?
- ETT – expected *transmission time*
  - ETX / Link rate = 1 / (P(delivery) * Rate)
- What is best rate for link?
  - The one that minimizes ETT for the link!
  - SampleRate is a technique to adaptively figure this out.

Discussion

- Value of implementation & measurement
  - Simulators did not “do” multipath
    - Routing protocols dealt with the simulation environment just fine
    - Real world behaved differently and really broke a lot of the proposed protocols that worked so well in simulation!
- Rehash: Wireless differs from wired…
- Metrics: Optimize what matters; hop count often a very bad proxy in wireless
- What we didn’t look at: routing protocol overhead
  - One cool area: Geographic routing

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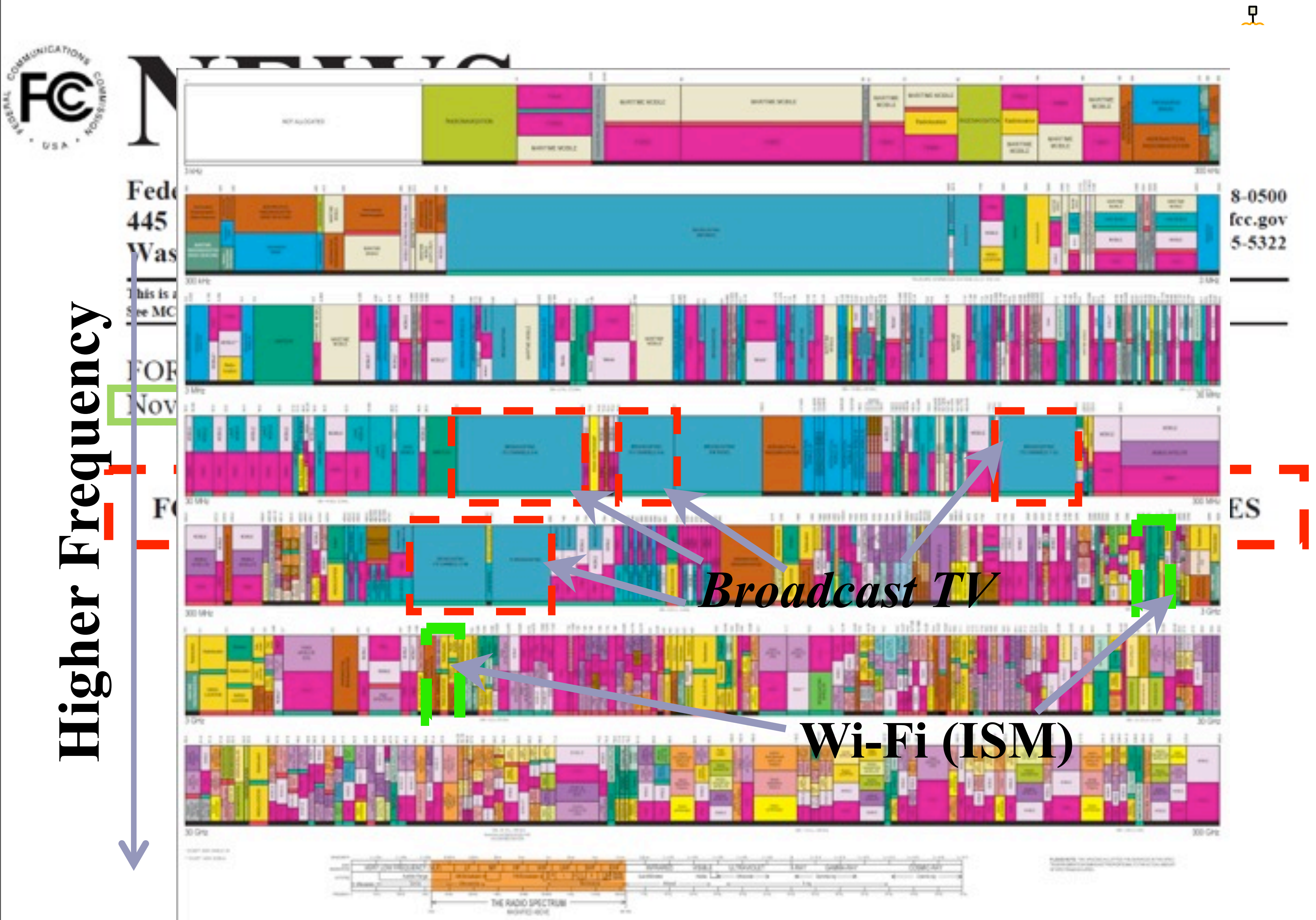
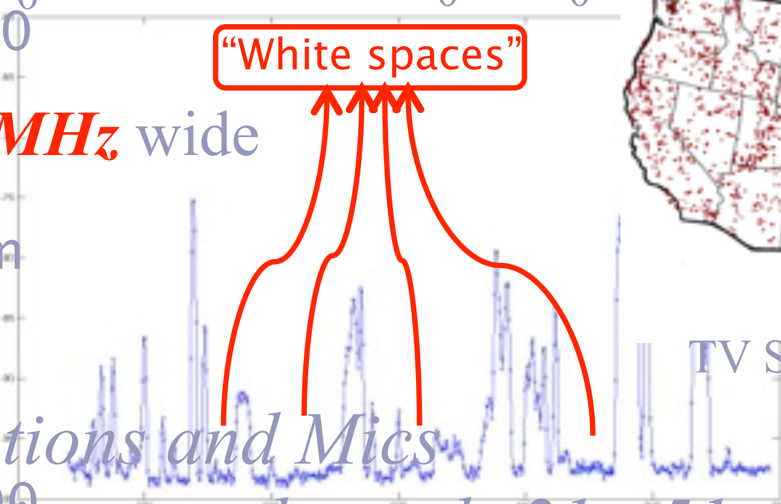

Higher Frequency
Broadcast TV
Wi-Fi (ISM)

What are White Spaces?

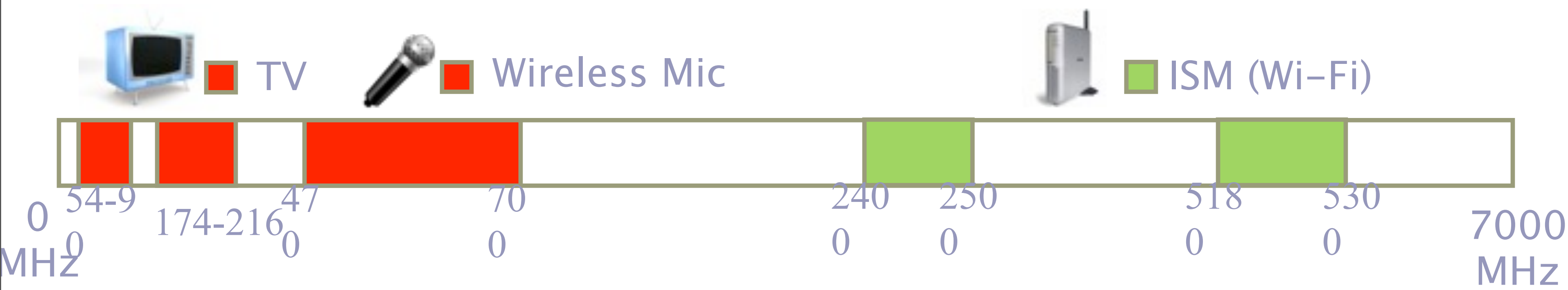
- **50** TV Channels
- Each channel is ***6 MHz*** wide
- FCC Regulations*
  - *Sense TV stations and Mics*
  - *Portable devices on channels 21 - 51*



TV Stations in America

White Spaces are *Unoccupied* TV Channels

The Promise of White Spaces



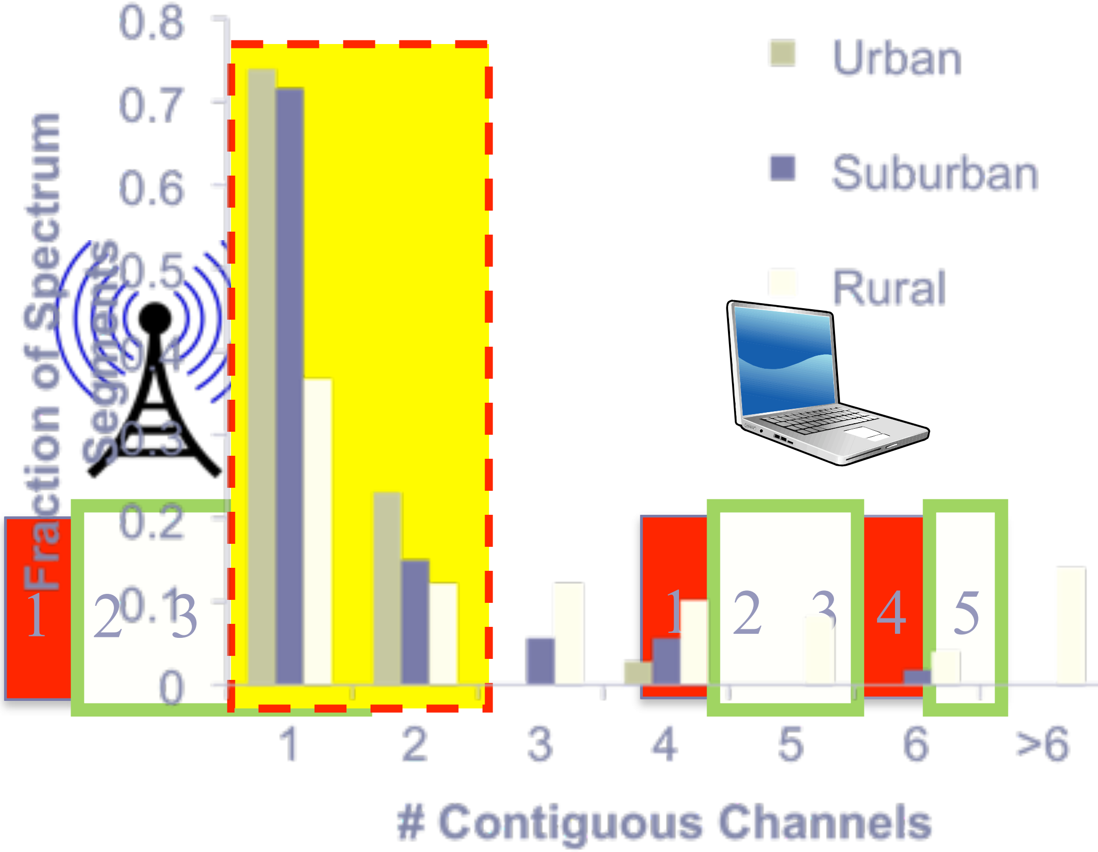
Up to 3x of 802.11g

More Spectrum

Longer Range

at least 3 - 4x of Wi-Fi

White Spaces Spectrum Availability



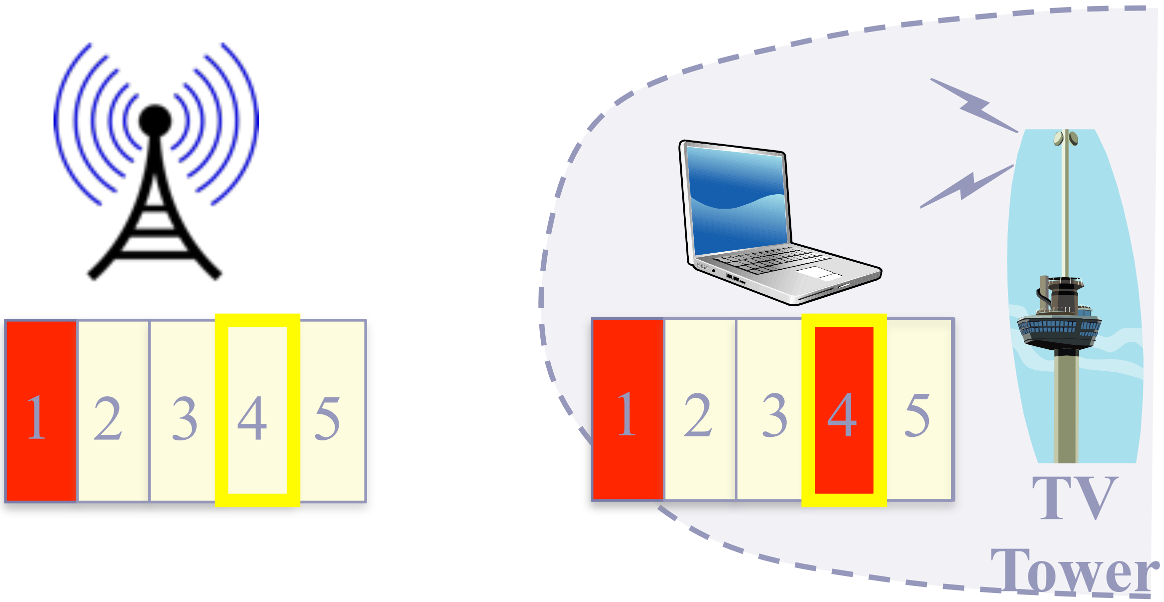
Differences from ISM(Wi-Fi)

Fragmentation

Variable channel widths

Each TV Channel is 6 MH **Spectrum is Fragmented** **nnels for more bandwidth**

White Spaces Spectrum Availability



Differences from ISM(Wi-Fi)

Fragmentation

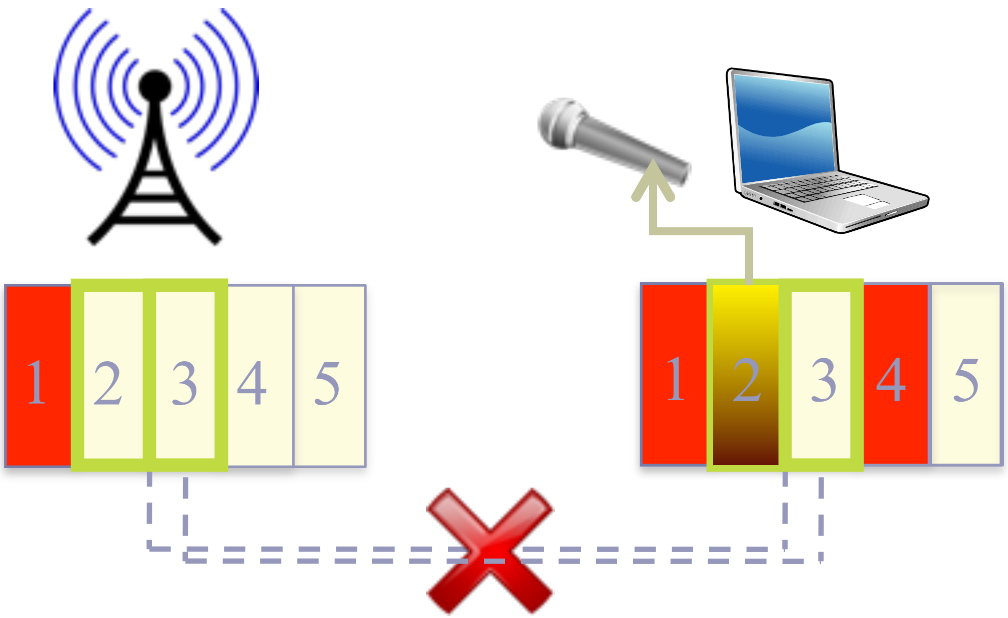
→ **Variable channel widths**

Spatial Variation

→ **Cannot assume same channel free everywhere**

Location impacts spectrum availability ⇒ Spectrum exhibits spatial variation

White Spaces Spectrum Availability



Differences from ISM(Wi-Fi)

Fragmentation

→ Variable channel widths

Spatial Variation

→ Cannot assume same channel free everywhere

Temporal Variation

→ Same Channel will not always be free

→ *Any* connection can be disrupted *any* time

Incumbents appear/disappear over time ⇒ Must reconfigure after disconnection

Channel Assignment in Wi-Fi

Fixed Width Channels $\Rightarrow$ Optimize *which* channel to use

Spectrum Assignment in WhiteFi

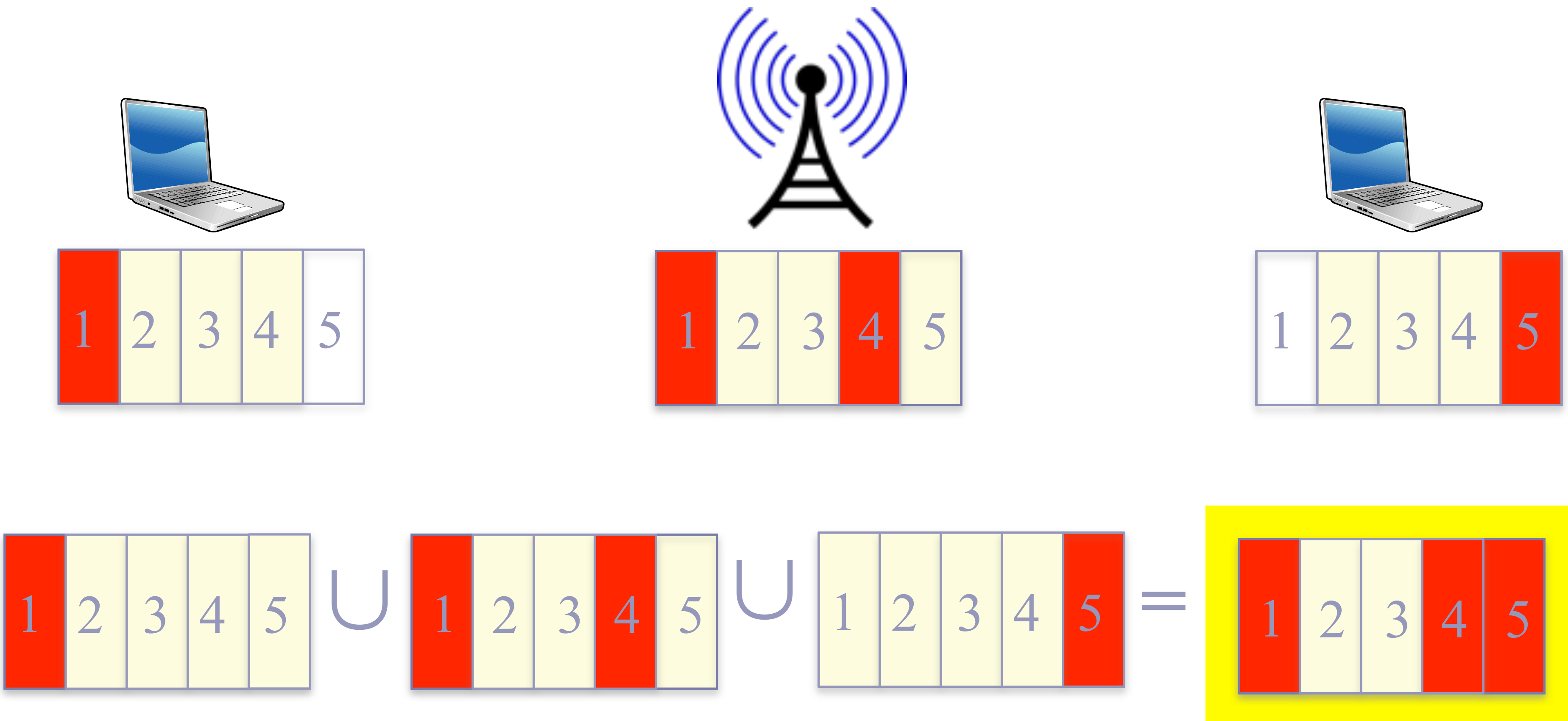
Spectrum Assignment Problem

Goal	**Maximize Throughput**
Include	**Spectrum at clients**
Assign	**Center Channel & Width**

Fragmentation ⇒ Optimize for *both*, **center channel** and **width**

Spatial Variation ⇒ BS must use channel *iff* free at client

Accounting for Spatial Variation



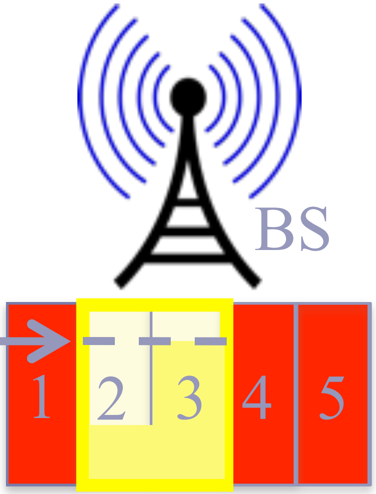
Intuition

Intuition

Use widest possible channel

But

Limited by *most* busy channel

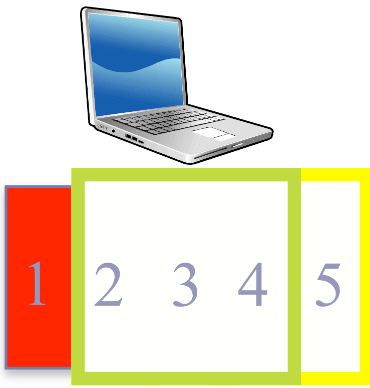


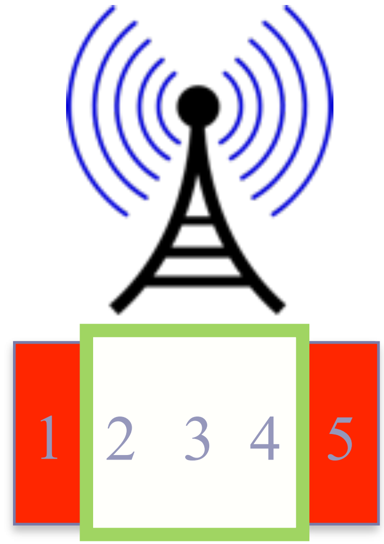
- Carrier Sense Across **All** Channels

- **All** channels must be free
  - ρ_{BS}*(2 and 3 are free)* = ρ_{BS}*(2 is free) x* ρ_{BS}*(3 is free)*

Tradeoff between wider channel widths and opportunity to transmit on each channel

Discovering a Base Station





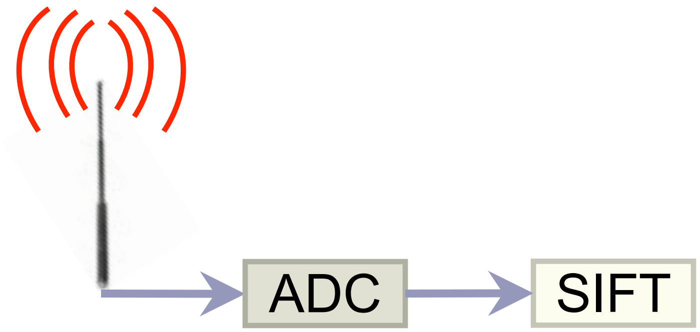
Discovery Time = O(*B x W*)

Fragmentation ⇒ Try different center channel and widths

channels used by the BS?

SIFT, by example

5 MHz



SIFT

Does not decode packets

Pattern match in time domain