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White Space Networking

Part II: Technical Issues

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PCAST report [July 2012]

"Traditional practice of clearing and reallocating portions of the spectrum used by Federal agencies is not a sustainable model for spectrum policy"

"The norm for spectrum use should be sharing, not exclusivity".

If we get this done then "[we] could multiply the effective capacity of the spectrum by a factor of 1,000."

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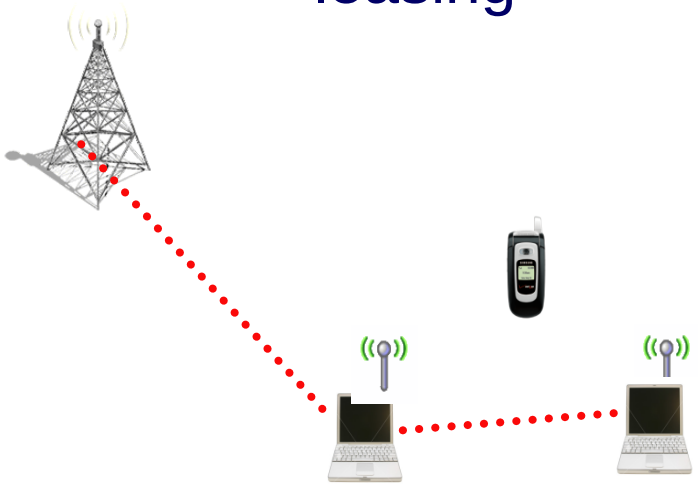
improving spectrum utilization

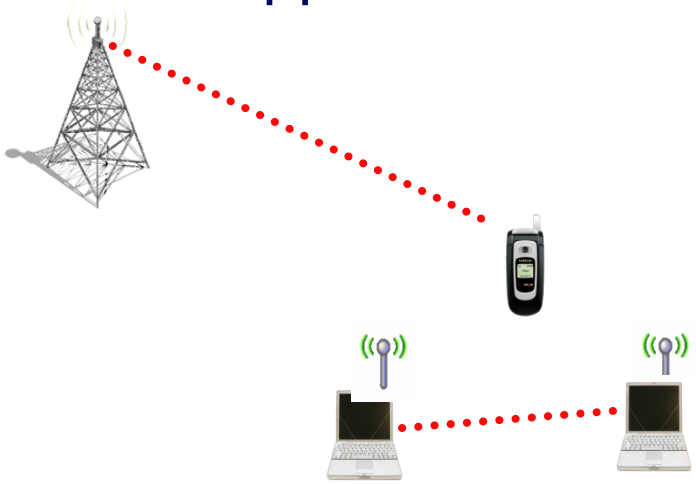
leasing



secondary users may use spectrum by leasing it from primary user

DySPAN 2005

opportunistic



secondary users may use spectrum only when the primary user is not using it

DySPAN 2007

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spectrum leasing

spectrum slice

start time, end time, center frequency, bandwidth, max. power

protocol for coordinated spectrum allocations

DSAP: DHCP-equivalent for spectrum

spectrum fragmentation

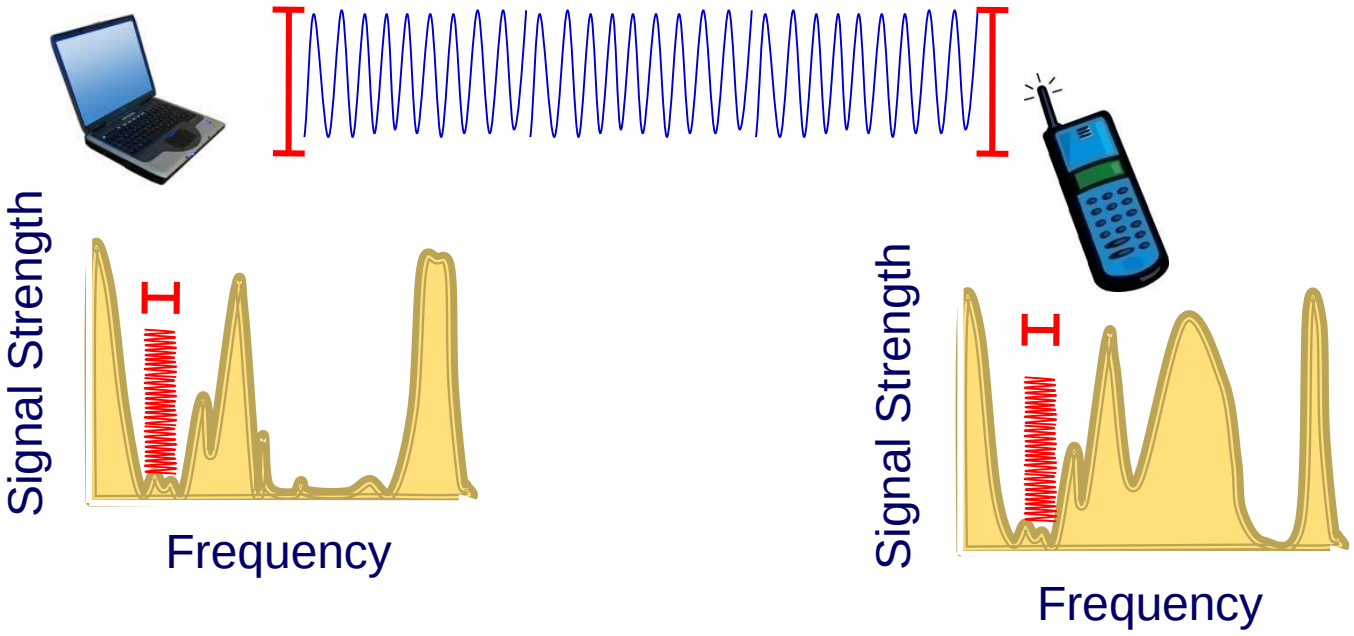
lease enforcement

opportunistic networking
basics - connecting

must identify unused portions of the spectrum

configure radio to operate in “available” frequency band

→ take smart (cognitive?) decisions on how to share the spectrum



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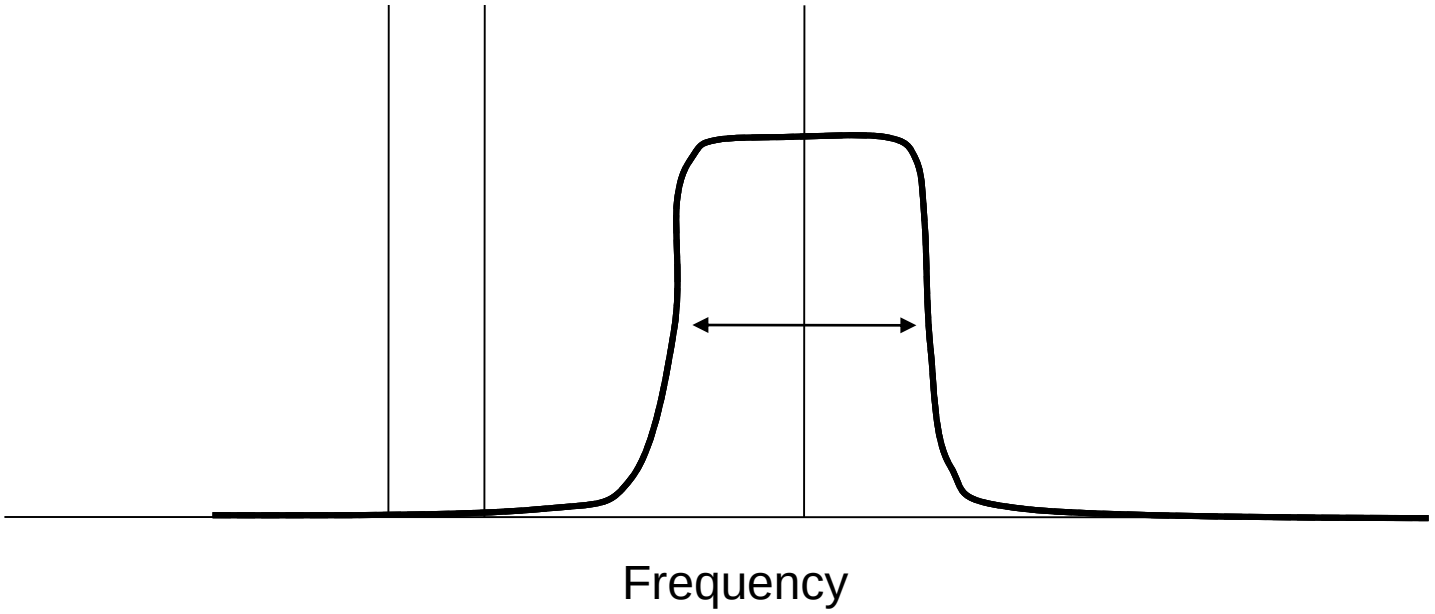
required hardware capabilities

basics – managing channel variability

- should be able to dynamically adjust channel-width and center-frequency
- overhead for switching channels should be low (~0.1ms)
  → should change at very fine-grained time-scale



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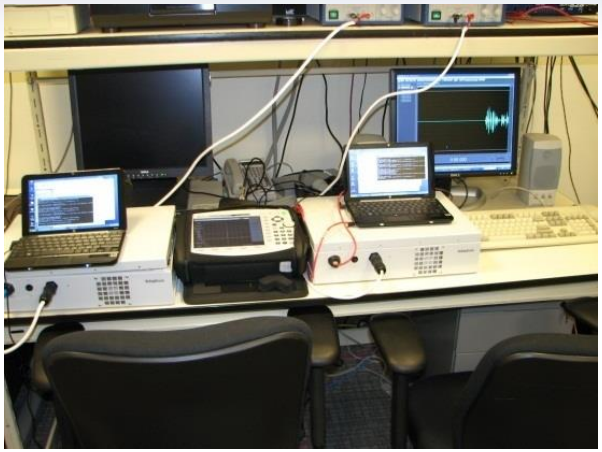
required hardware capabilities

basics – sensing (co-existing with microphones)

subcarrier suppression setup



microphone recording in anechoic chamber

subcarrier suppression

original

recording with on-going white space transmission

recording with on-going white space transmission with subcarrier suppression

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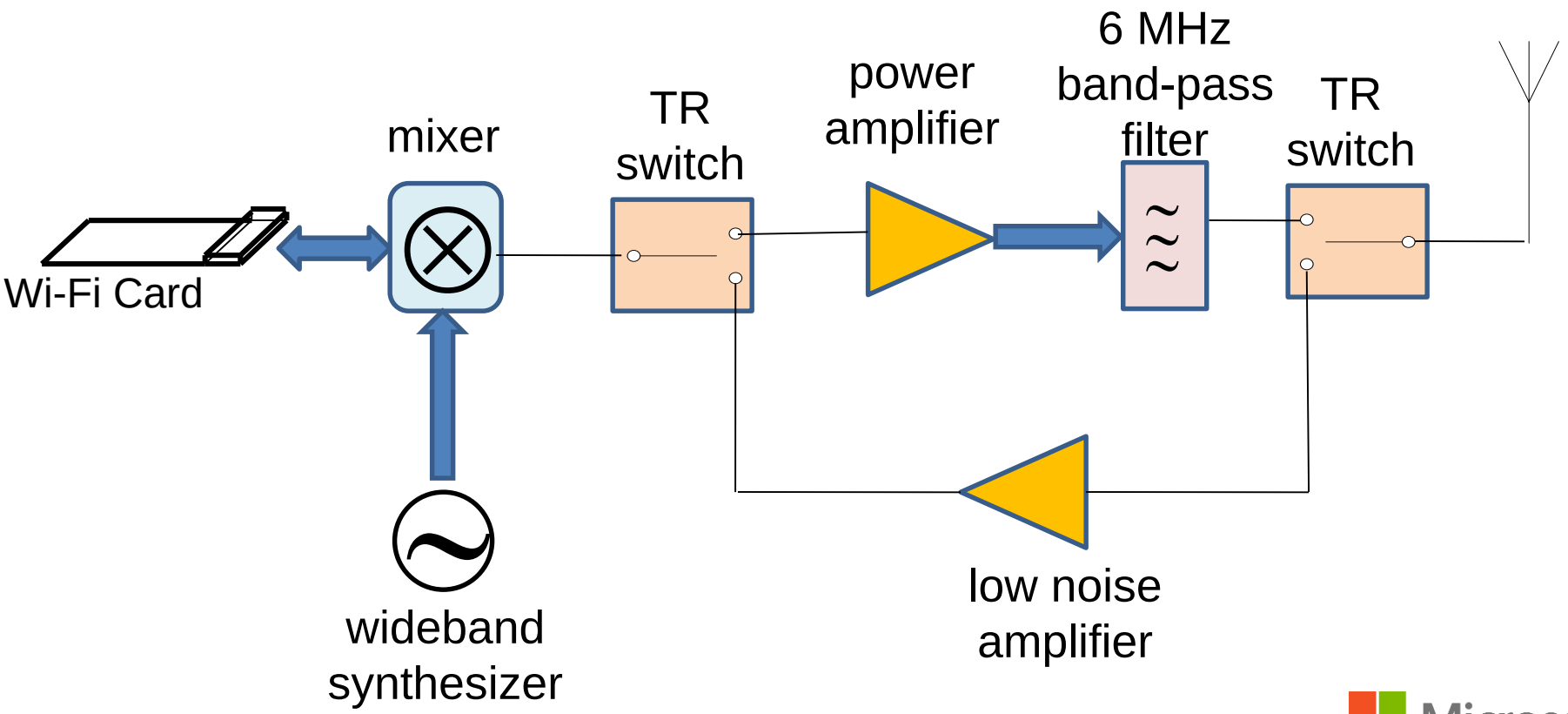
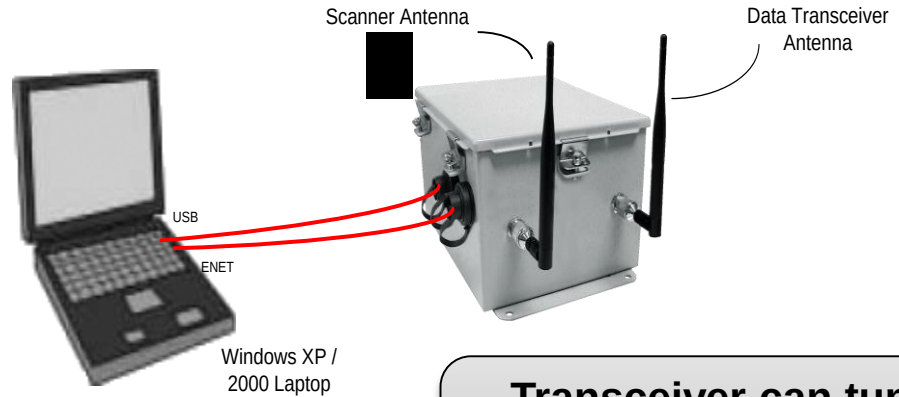
simple UHF translator design

- Uses 2.4 GHz 802.11g modem for primary signal generation
- Shapes OFDM signal to fit in 6 MHz TV band
- 100 mWatts of Tx power with 30 dB TPC



hardware prototype (v1.0)

Phase One System Configuration



Transceiver can tune to contiguous spectrum bands only!

Scanner/Receiver

- Scan: 400MHz ~ 928MHz
- Recv: 900 ISM band, 5 MHz

Reconfigurable transceiver

- Can dynamically adjust channel-width and center-frequency from 400MHz to 928 MHz
- Contiguous 5, 10, 20, 40 MHz
- Power control

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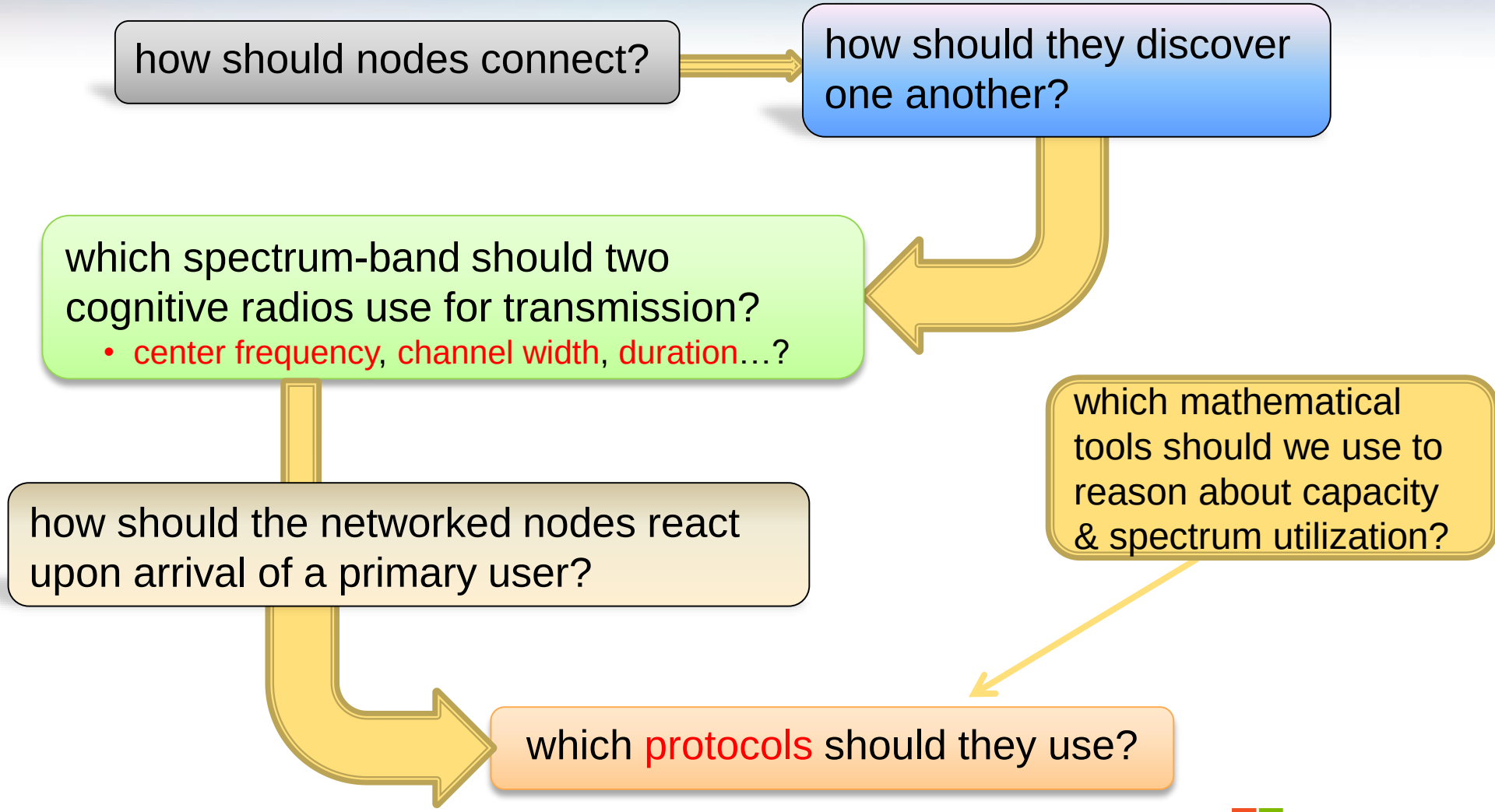
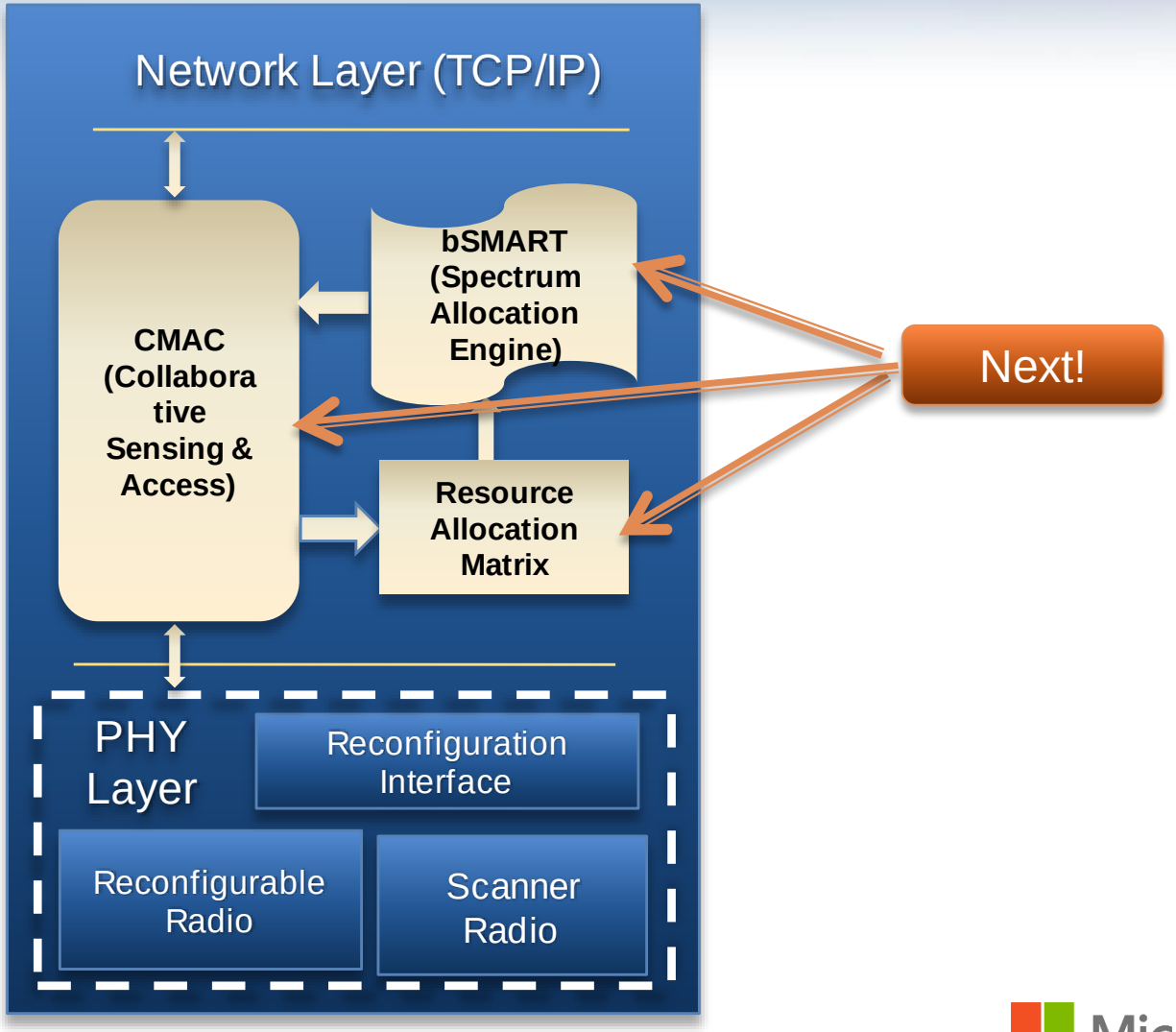
opportunistic access
networking challenges



software architecture

Mutli-radio architecture



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CMAC overview

control channel

- used to contend for spectrum access
- exchange spectrum availability information and reserve a time-spectrum block (TSB)
  - use scanner to listen to control channel while transmitting

spectrum allocation/reservation engine (details coming up)

- overhear neighboring node's control / reservation TSB packets
- generate 2D view of spectrum reservations

distributed, adaptive, localized reconfiguration

CMAC Operation

RTS

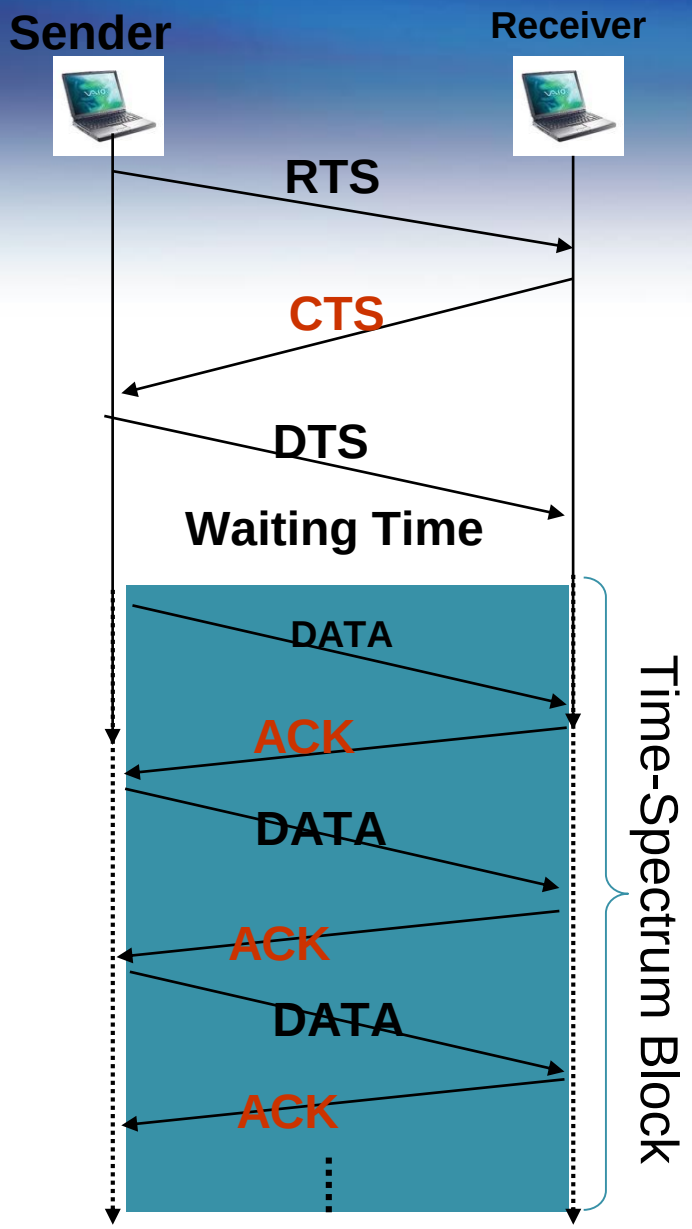
- Indicates intention for transmitting
- contains suggestions for available time-spectrum block (b-SMART)

CTS

- spectrum selection (received-based)
- (f,¢f, t, ¢t) of selected TSB

DTS

- Data Transmission reServation
- announces reserved TSB to neighbors of sender



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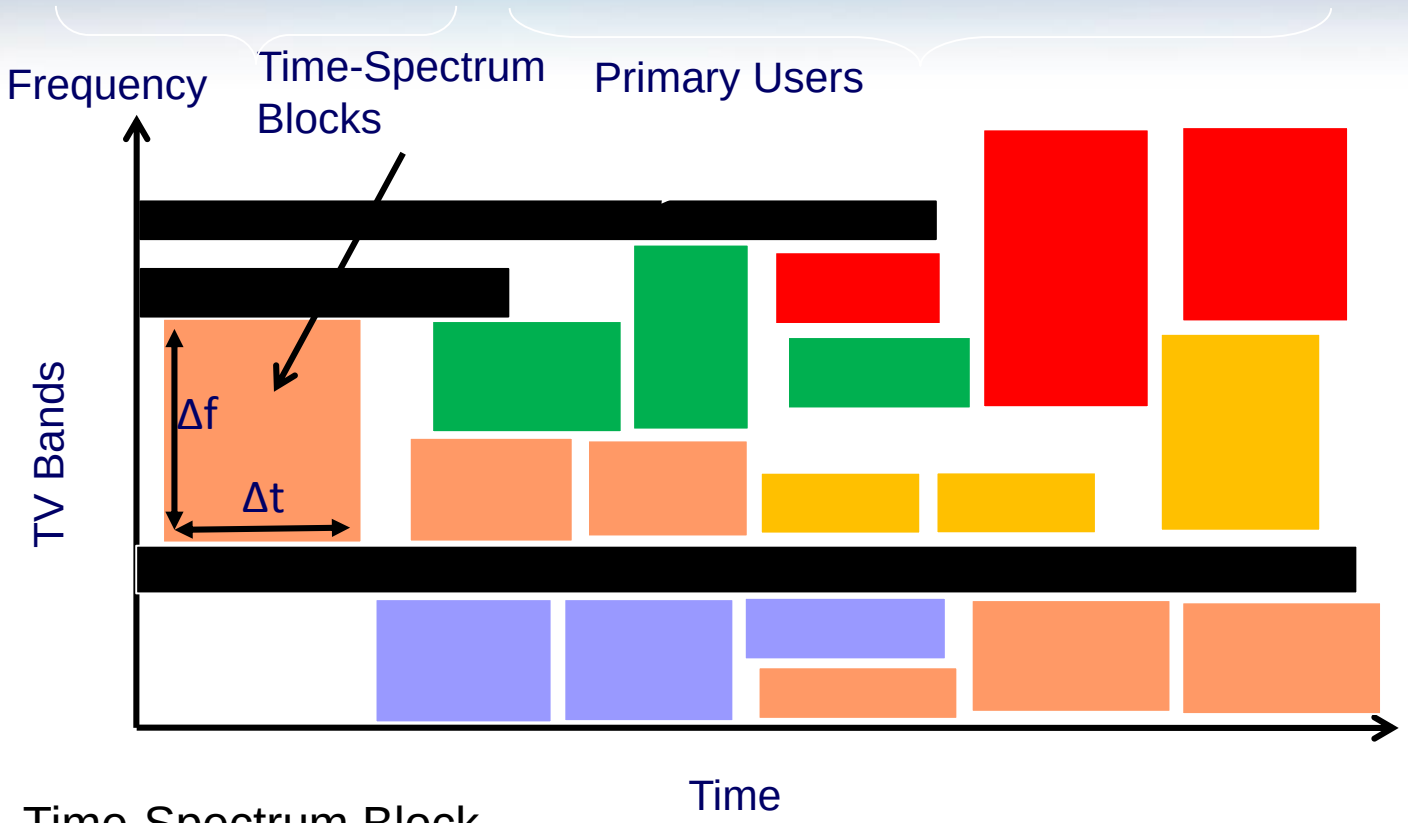
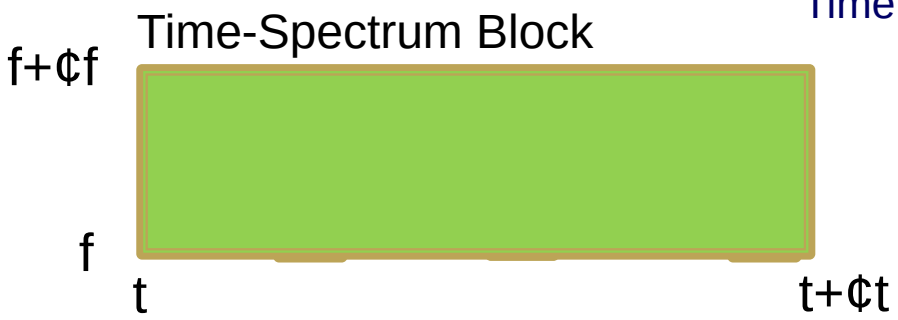
channel management

nodes collaborate to detect and efficiently use white spaces in TV bands





Within a time-spectrum block, any MAC and/or communication protocol can be used

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b-SMART

MobiHoc 2007

Distributed SpectruM Allocation oveR whiTe spaces

- Which TSB should be reserved…?
  - How long…? How wide…?
- Design Principles

1. Try to assign each flow blocks of bandwidth B/N

B: Total available spectrum
N: Number of disjoint flows

2. Choose optimal transmission duration ¢t

Long blocks: Higher delay

Short blocks: More congestion on control channel

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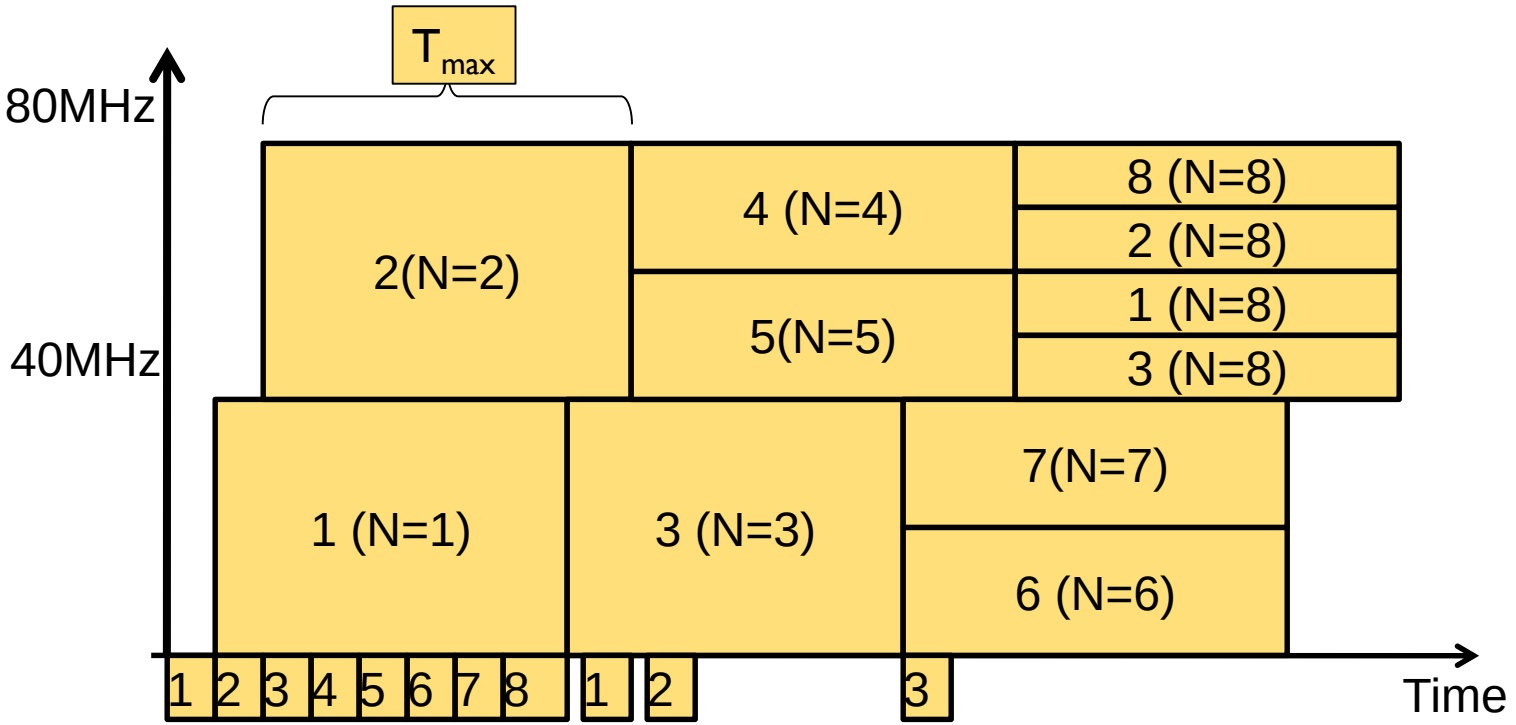
Example

- Number of valid reservations in NAM → estimate for N

  Case study: 8 backlogged single-hop flows



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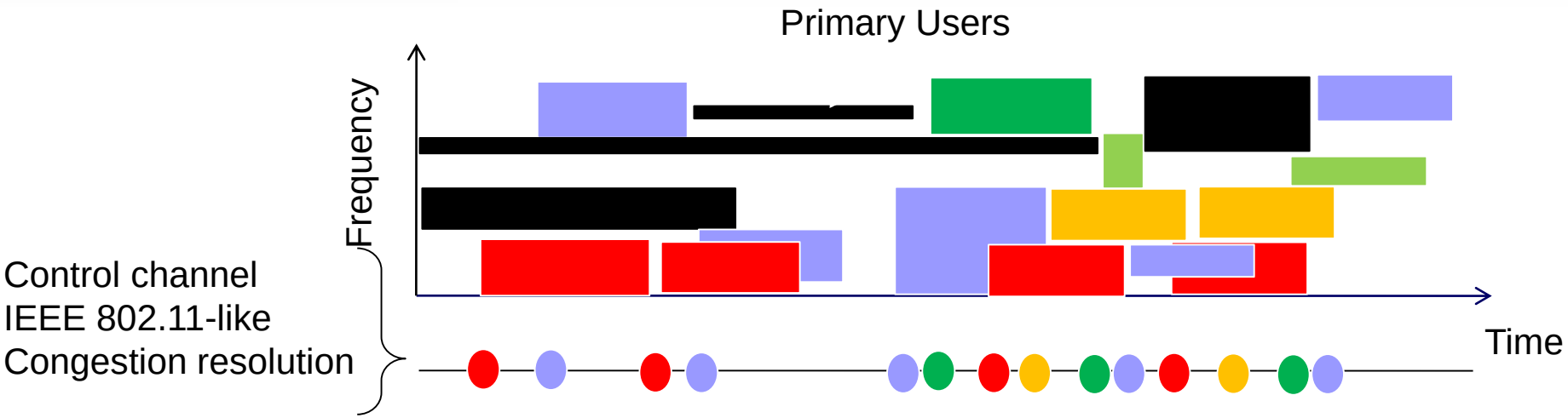
Resource Allocation Matrix

Nodes record info for reserved time-spectrum blocks



Nodes record info for reserved time-spectrum blocks

- Overhear neighboring node's control packets
- Generate 2D view of TSB reservations

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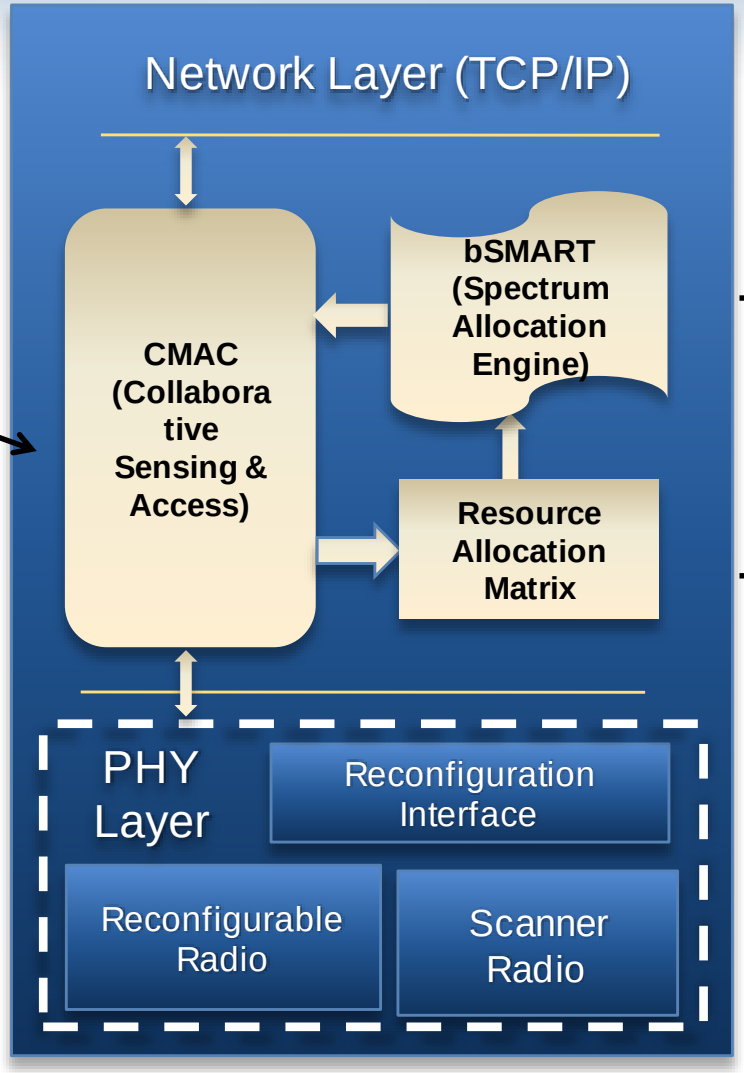
recap - software architecture



Negotiates location of TSB using RTS-CTS-DTS mechanism

Determines size of TSB to map app. req. to available spectrum

Keeps track of neighbors TSB

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business question: can we reuse a single radio system, can we use Wi-Fi?

spatial variation

- secondary cannot interfere with wireless transmission of primary

temporal variation

- primary can become active at any time, secondary must disconnect and move out immediately
  - Need fast AP Discovery across 180 MHz, APs operating on variable channel width

spectrum fragmentation

- incumbents can operate in any portion of the spectrum AND secondary cannot interfere with the primary
  - Channel width can vary

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version 2 innovations

Best Paper
SIGCOMM 09

- eliminate control channel & reuse Wi-Fi
- spectrum assignment algorithm
  - enables AP to pick a channel that is free for all clients AND pick the best possible channel width
- discovery mechanism
  - enable clients to quickly discover an AP over all <*channel, width*> pairs
- fast recovery after disconnection
  - re-connects quickly on a new available channel upon sensing a primary user on existing channel

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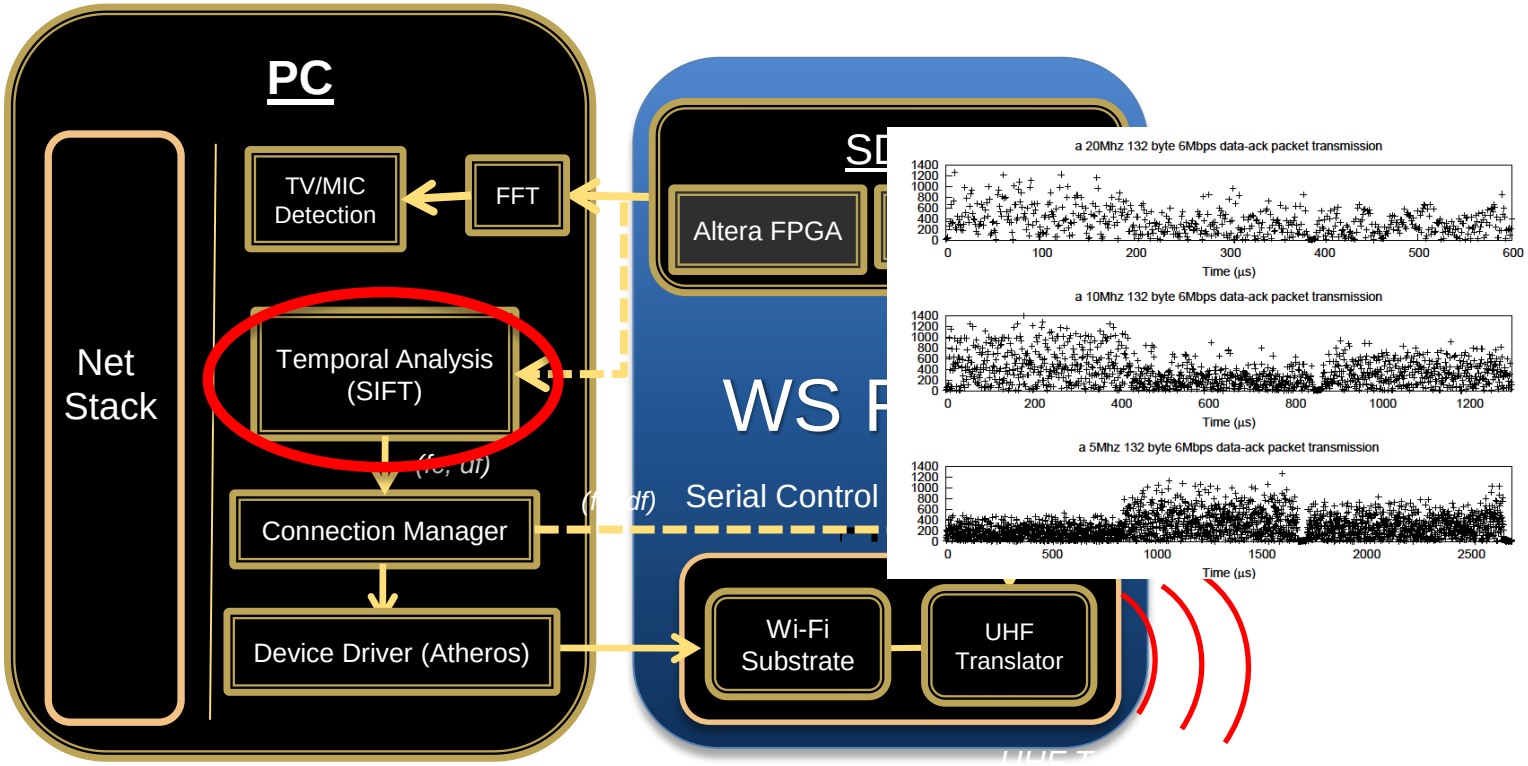
handling variable channels

determining the frequency and channel width of APs



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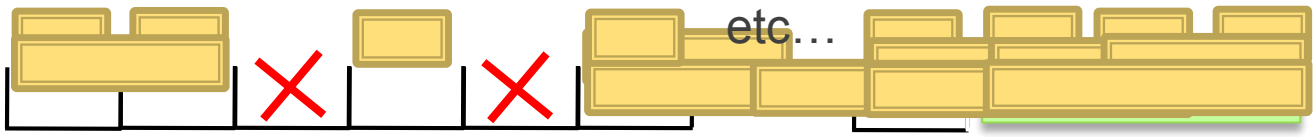
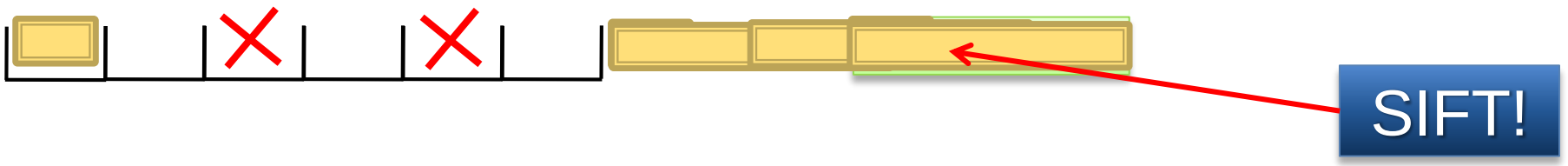
AP discovery

how can clients quickly find the AP…?
tradition solution in Wi-Fi → check all possible channels.



with SIFT, much faster algorithms become possible!
→jump cleverly across the spectrum, until you hit the AP



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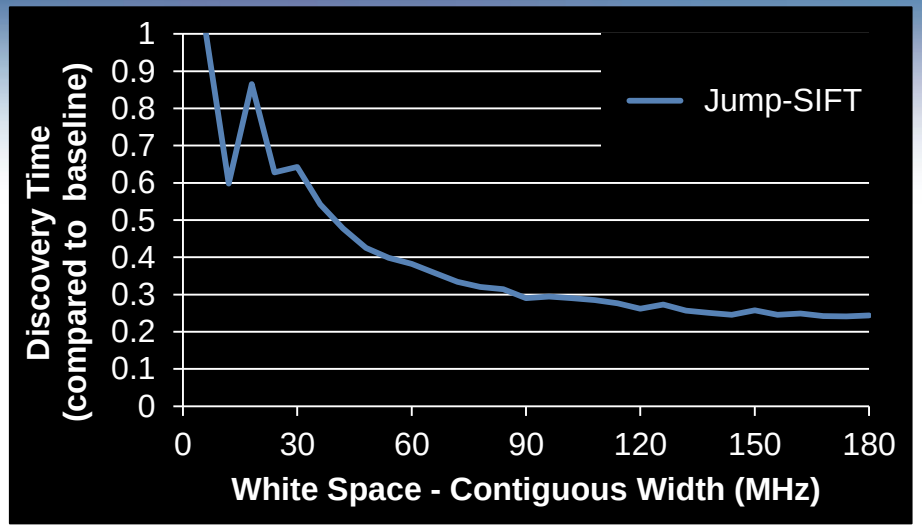
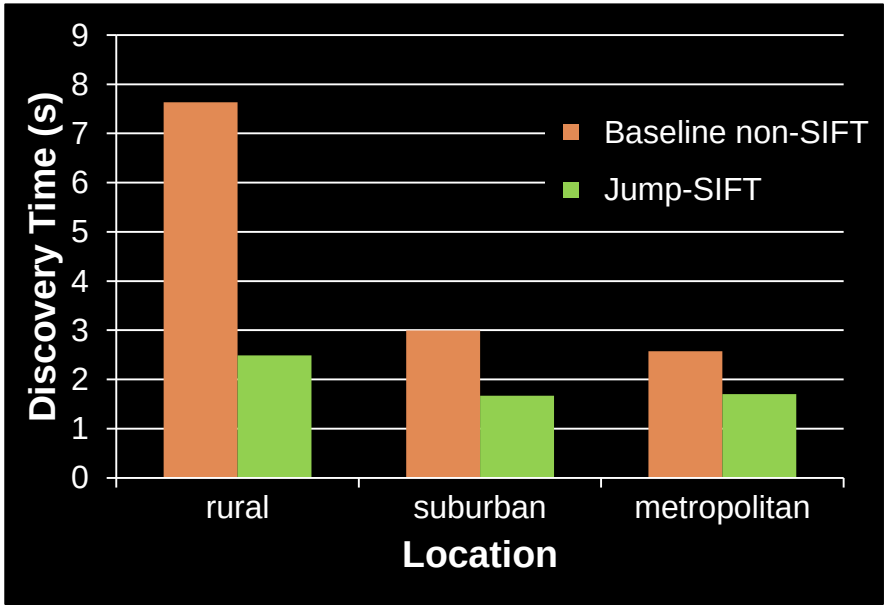
AP Discovery

In most cases, SIFT takes 70% less time in discovery





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spectrum assignment

- clients send <*channel, utilization*> tuple to AP
- AP maintains a spectrum map/table
- AP selects channel(s) that reduces system backlog
  - Channel Set (***C***): Intersection of free channels as seen by the clients & the AP
  - Initialization: AP selects widest width in ***C***
  - Algorithm:
    - Every X seconds, clients reports backlog, throughput to AP
    - AP switches to new channel in ***C*** if it is expected to reduce backlog
    - If no improvement in Y seconds, AP switches to previous channel
- channel switching may be involuntary (upon arrival of PU) or voluntary for better service

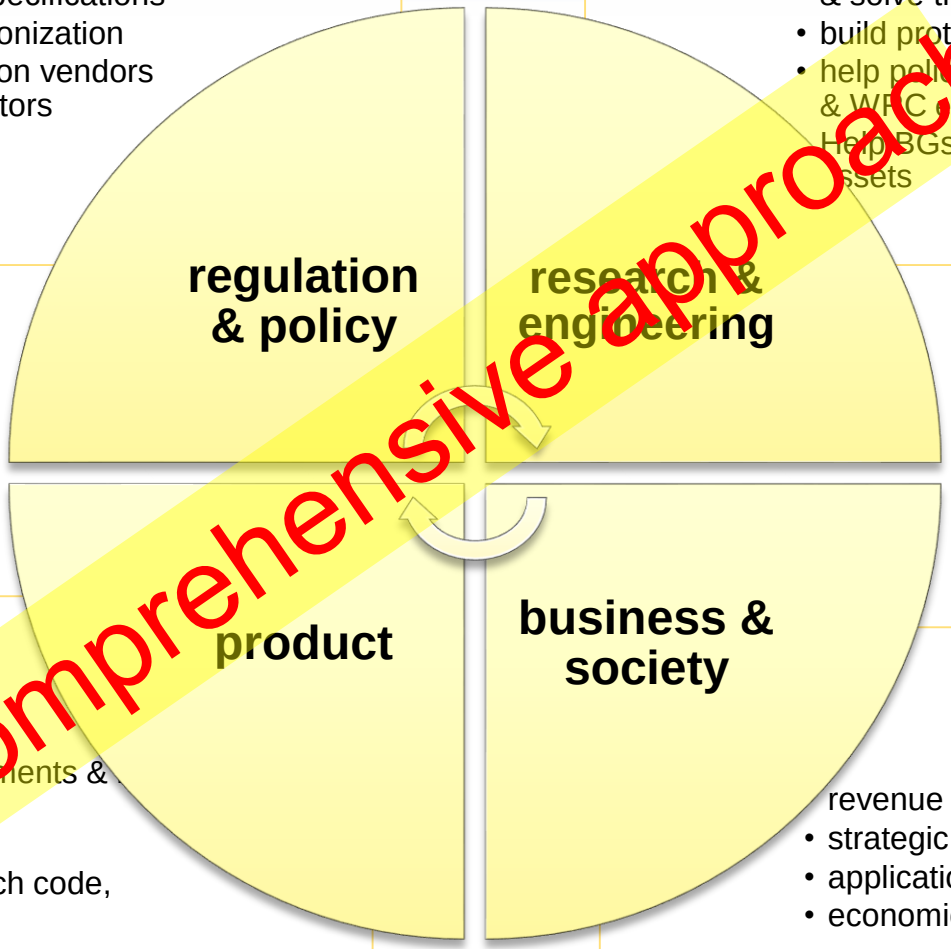
since then…

- Many white space networking papers
  - MobiSys, MobiCom, DySPAN, INFOCOM etc
- Many testbeds
  - Wisconsin, Houston, Cambridge (U.K), Singapore, Brazil, …
- Standards body activates
- Certified hardwared and DBs availale

a journey that began in 2003. . ..

- work with regulators to nail down sensible specifications
- world-wide harmonization
- engage with silicon vendors & system integrators

- Identify technical problems & solve them
- build prototypes
- help policy teams with FCC & WRC engagements
- Help BGs with technology assets



a comprehensive approach

- scenarios
- gather requirements & write down specs
- standards
- harden research code, develop & test

- revenue models
- strategic alliances
- applications & Services
- economics

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Summary

WSN is the first main-stream manifestation of an opportunistic DSA network. It has captured the imagination of the world

- WSN technology is real and it works
- multiple “Super Wi-Fi” scenarios possible
- optimistic about world-wide harmonization
- the ecosystem is ramping up quickly
- active area of research (but viable products are possible)

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thanks!