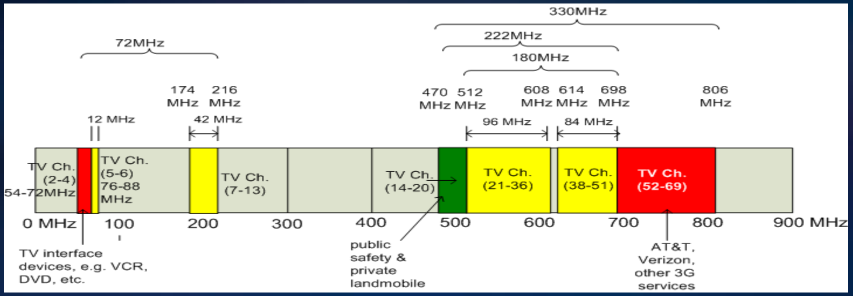
White Space Networking

"Past, Present and Future"



Victor Bahl
Microsoft Research

People Involved

Cognitive Wireless Networking Research Program

MSR Redmond

- Victor Bahl
- Ranveer Chandra
- Thomas Moscibroda

MSR Cambridge

- Alexandre Proutiere
- Bozidar Radunovic

MSR Asia

- Kun Tan
- Haitao Wu
- Yongguang Zhang

Interns

- Rohan Murty (Harvard)
- Hariharan Rahul (MIT)
- Eeyore Wang (CMU)
- George P. Nychis (CMU)

Advanced Strategy & Policy

- Anoop Gupta

EMIC

- Alain Gefflaut
- Andreas Steinmetzler
- Zhou Wang

Core Networking

- Amer Hassan

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We care about…

- Ubiquitous Services
- Pervasive Internet Access
- Ease-of-Use & end-user experience

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The Potential of Connected Services

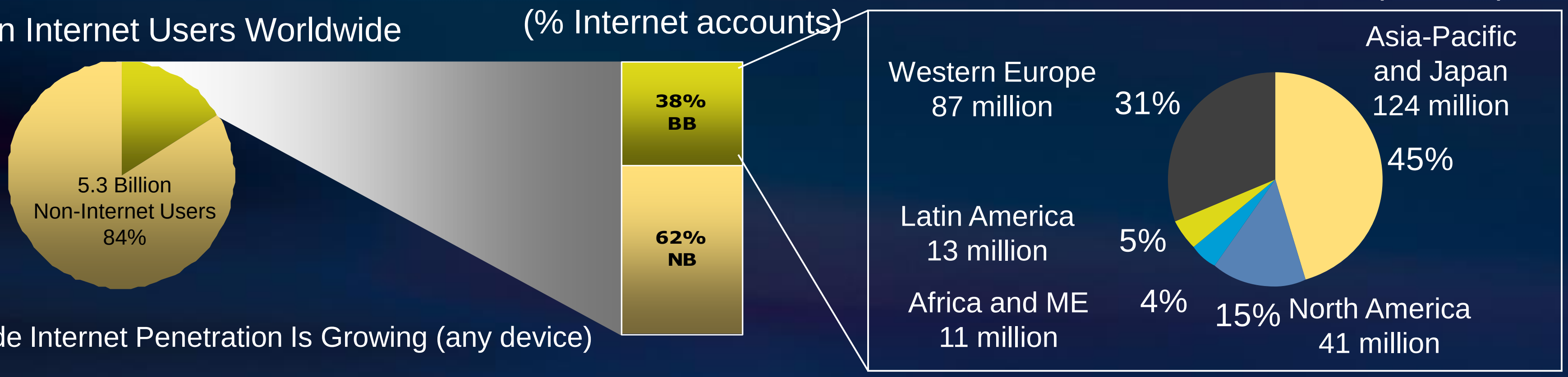
Worldwide Internet Penetration < 20%

Worldwide, Internet and broadband use are concentrated in Asia-Pacific, Europe, and North America

1 Billion Internet Users Worldwide

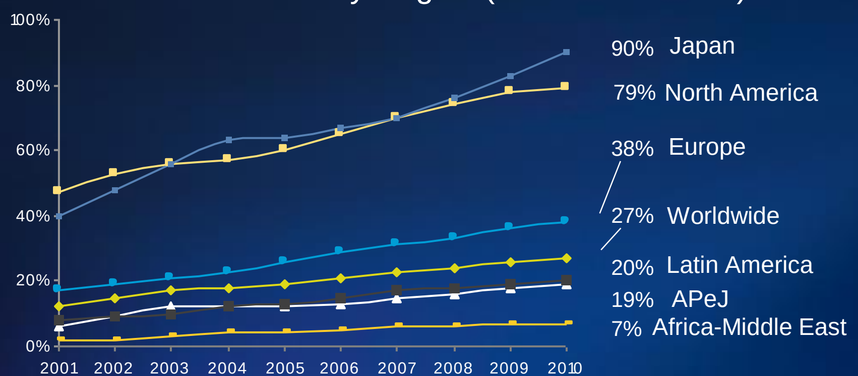
Worldwide Broadband versus Narrowband Penetration (% Internet accounts)

Broadband Users Worldwide (Millions)



Worldwide Internet Penetration Is Growing (any device)

Internet Penetration by Region (% of Households)



Broadband penetration is the prime lever of Internet activity growth

Source: Pyramid Research, April 2006. Internet use may include access via devices other than PCs.

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We care about reach

Source: EECS, UC Berkeley

The power of ideas and opportunities, fueled by local entrepreneurial energy, is the most important resource available in the resource-scarce part of our world.

\- Richard Newton, Former Dean UC Berkeley

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We care about quality

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Connecting the Remaining Billions

Expanding our reach

How?

Find new radio spectrum

and

Use better technology

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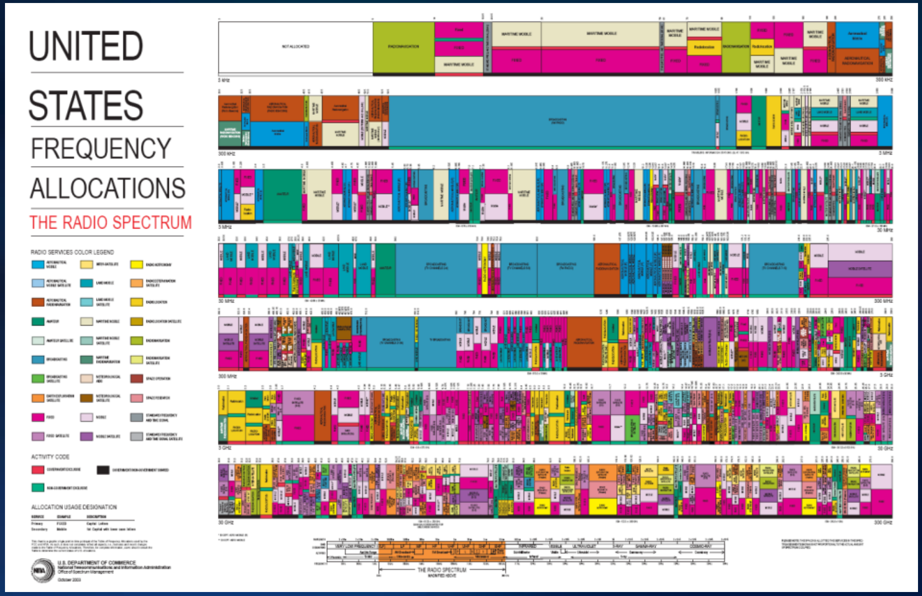
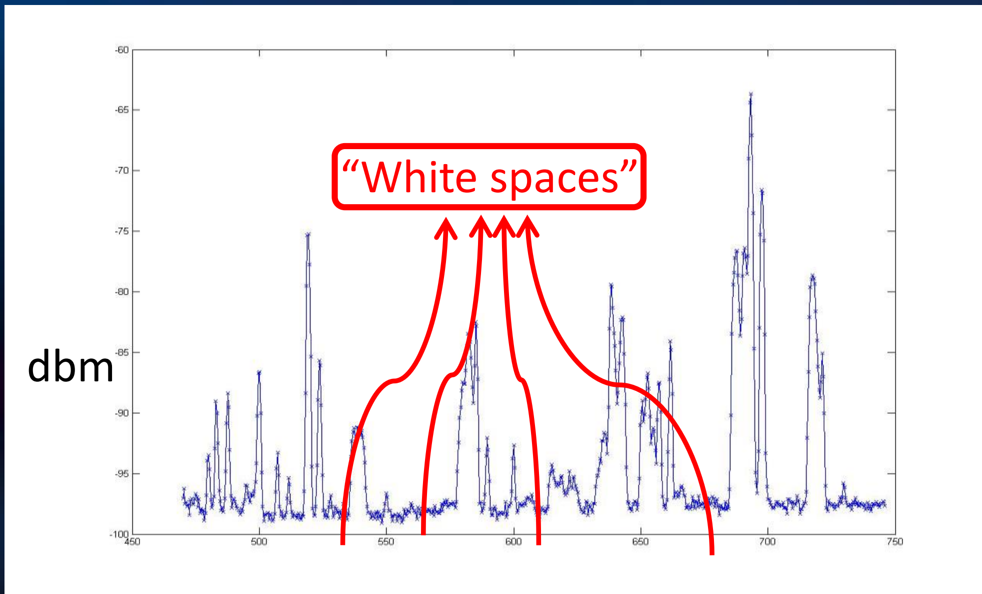
The Key Question …

Is there any spectrum out there that we can use to build inexpensive networking?

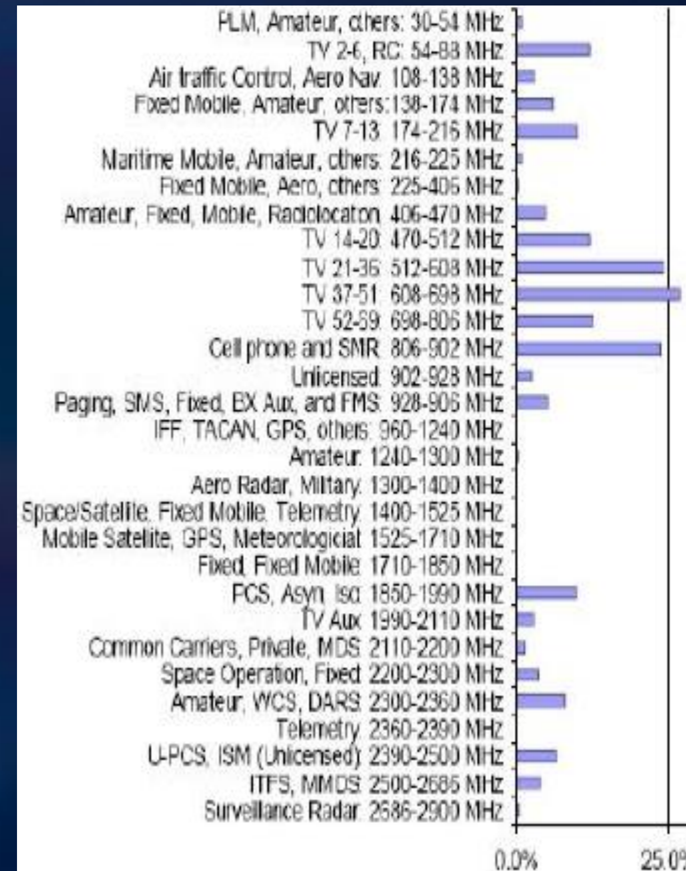


A: ……

Spectrum Reform is Needed!



470 MHz Frequency 750 MHz



Source:
Shared Spectrum Company

- Only 5% of licensed spectrum is being used (Source Shared Spectrum Company)

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Hitting gold!

The DTV Transition

- In 1996, the U.S. Congress authorized the distribution of an additional broadcast channel to each broadcast TV station so that they could start a digital broadcast channel while simultaneously continuing their analog broadcast channel.
- From June 12, 2009 full-power television stations can broadcast in digital only.

….and new spectrum opens up

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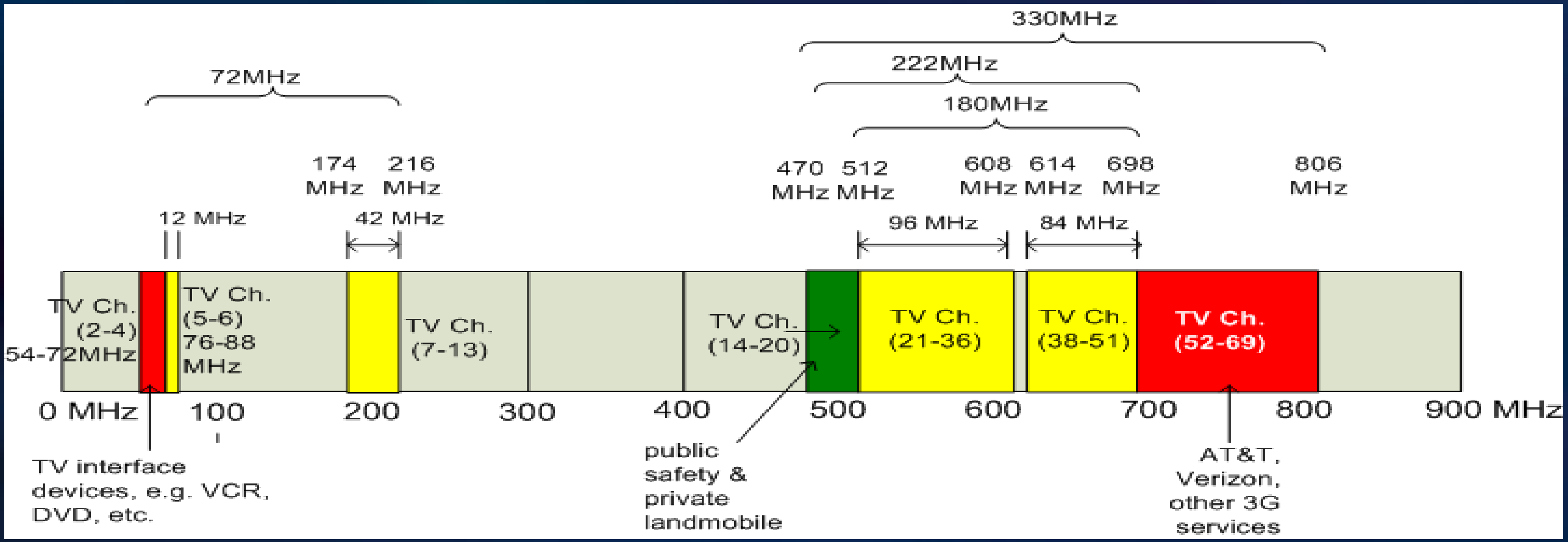
White Spaces Defined

Unused UHF Television Frequencies



In the US, primarily the upper UHF "700-megahertz" band, covering television frequencies between 698 to 806 MHz (TV channels 52 to 69)

The White Spaces Coalition

- 8 large IT companies that want to enable high speed broadband internet access in the '**white space**'
  - Microsoft, Google, Dell, HP, Intel, Philips, Eathlink, and Samsung

UHF Analog TV Bands
Highly Desirable for Networking

"Analog TV spectrum is prime real estate, the wireless equivalent of Hawaiian beachfront property and a Park Avenue brownstone in New York all rolled into a single package. The reason is simple: signals in the analog TV spectrum travel very well and can easily be received indoors."

Eric Bangeman , April 17, 2007

ars

ars technica

Proponents believe it's good for

- Broadband wireless for rural areas
- Within enterprise
- Public safety, first responders
- In-home multimedia
- Backhaul operations
- Open neighborhood access

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The Potential of WSN
"Wi-Fi on Steroids"

From the Economist.com (Nov. 7, 2008)

Economist.com

- Longer range
- Minimal impact of weather
- Can carry lots of data
- Penetrate deep into the nooks and crannies
- Possible “third pipe”
  - Teleco and Cable being the other two
- Opens up waves of Innovation

Think about what Wi-Fi did to 2.4 GHz band
- in 2008 387 million Wi-Fi enabled devices (Wi-Fi Alliance)
- 1 billion in 2012

What do you predict will happen in the unlicensed WSDs?

The Impact of Frequency

Range Calculations

Link budget calculations for line of sight communication with free space loss

$$P_R = P_T - L_{fs} - L_T - L_R$$

where P_R & P_T are received & transmitted powers in dBm; L_{fs} is path loss; L_T & L_R are signal loss at the transmitter & receiver in dB

Friis Transmission Equation

Free-space path loss

$$L_{fs} = 32.44 + 20\log d + 20\log_{10} f - G_T - G_R$$

Where, L_{fs} is the loss in dB; f is the frequency in MHz; G_T & G_R are the transmitter & receiver antenna gain in dBi; and d is the distance in Km at which the loss is calculated

Range Calculations

- When receiver sensitivity is known, link budget calculations provide an estimate of the range.
- The formula captures the fact that range is effected by *frequency*, *distance*, *transmission power*, *antenna gains*, and losses at the transmitter and receiver.

4 times better range in WS than Wi-Fi with the same power budget

At higher frequency

- signals are absorbed more rapidly by water in the air
  - attenuate faster
- signals are blocked by objects
  - do not refract; leave a complete shadow behind obstacles
  - lower frequency signals refract (bend) around obstacles

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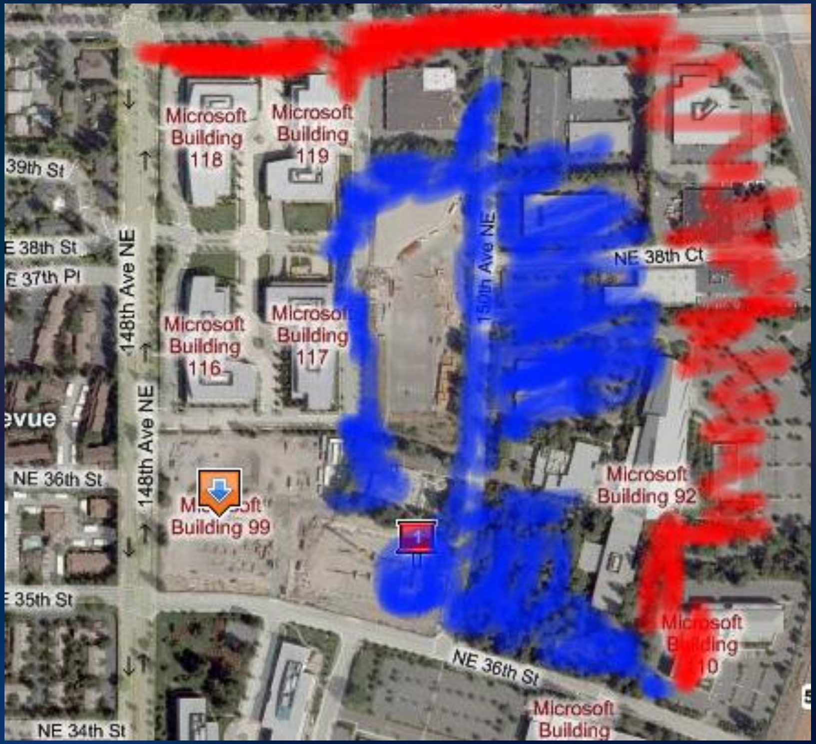
Does Reality match up?



Real life: Range is > 5 times Wi-Fi range

(using the same transmit power and receiver sensitivity)

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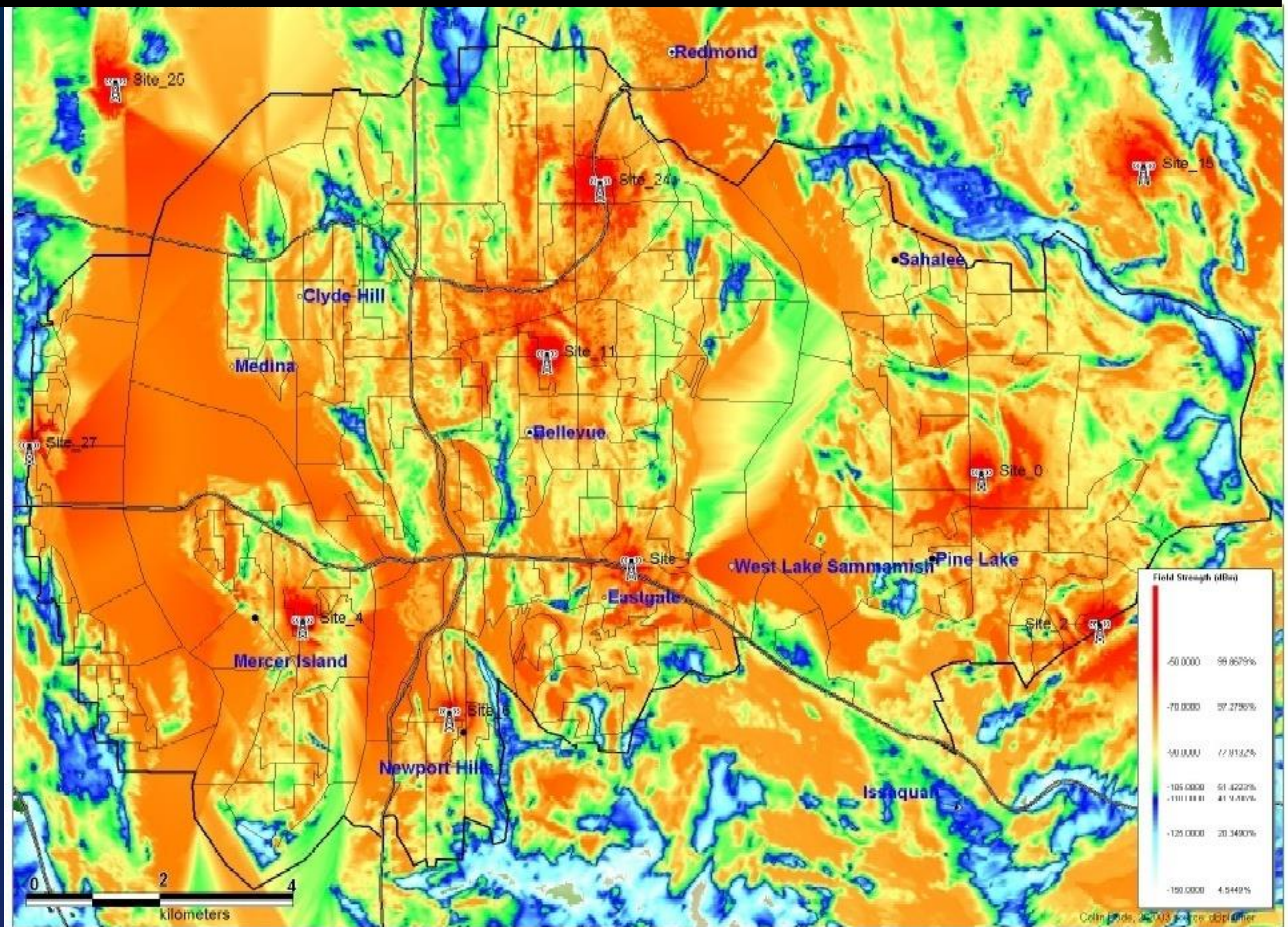
Propagation at 2600 MHz: 10 Sites

Seattle Eastside: Bellevue and Sammamish



~ 250 km^2

Good Coverage

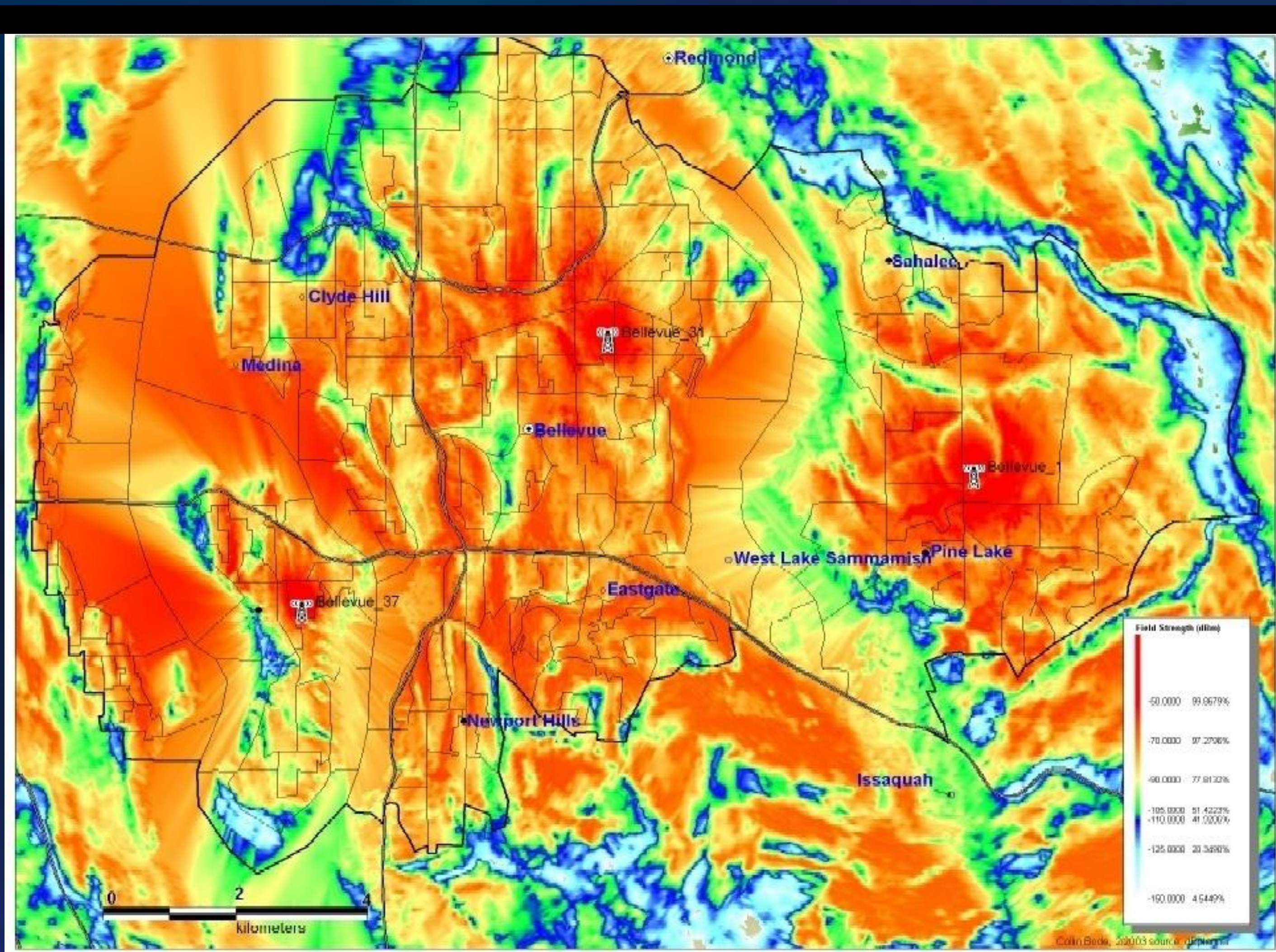
Bad Coverage

Limits of Indoor

Map courtesy Chris Knudsen, Vulcan Capital

Propagation at 700 MHz: 3 Sites

Seattle Eastside: Bellevue and Sammamish



~ 250 km²

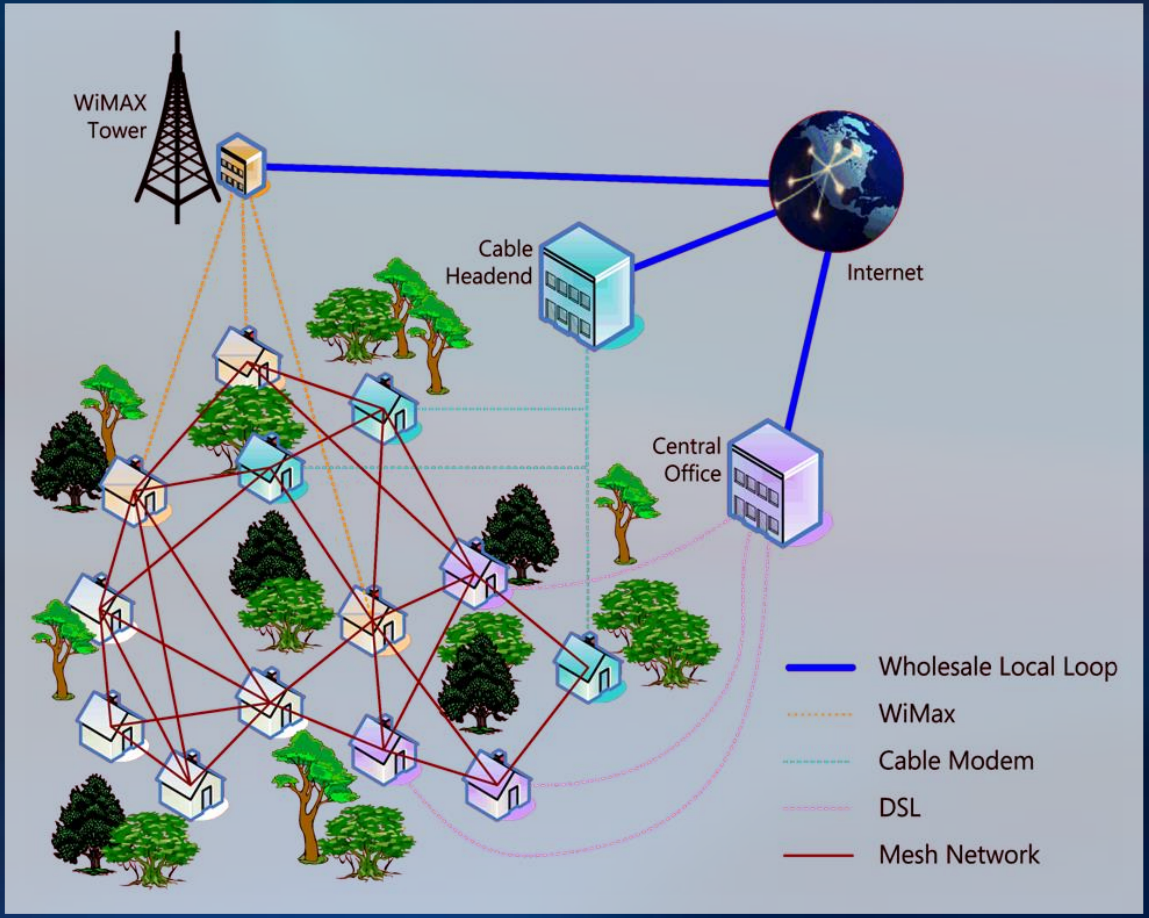
Good Coverage

Bad Coverage

Limits of Indoor

Map courtesy Chris Knudsen, Vulcan Capital

Revisting Mesh Networking



Wireless mesh networks have the potential to bridge the Broadband divide

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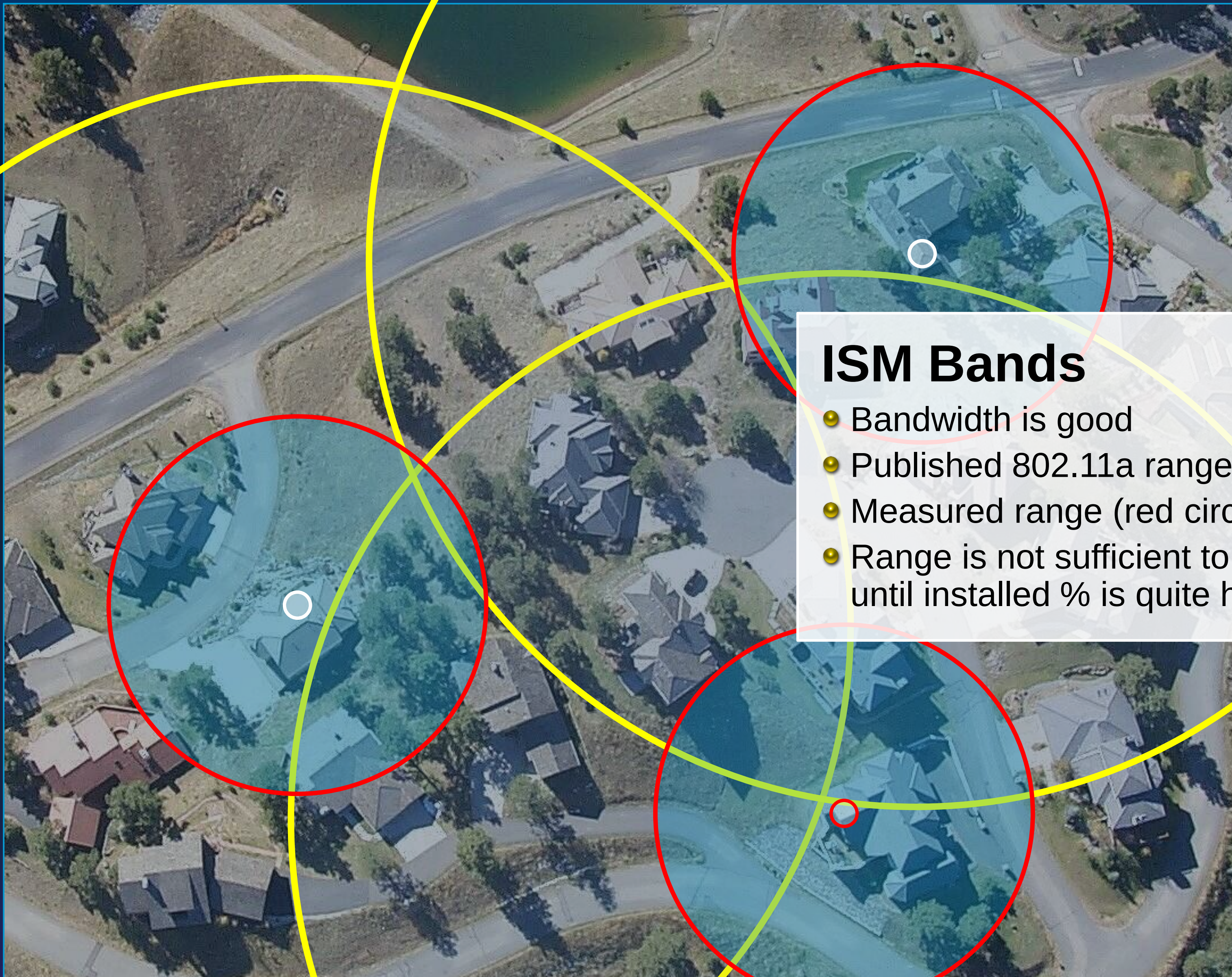
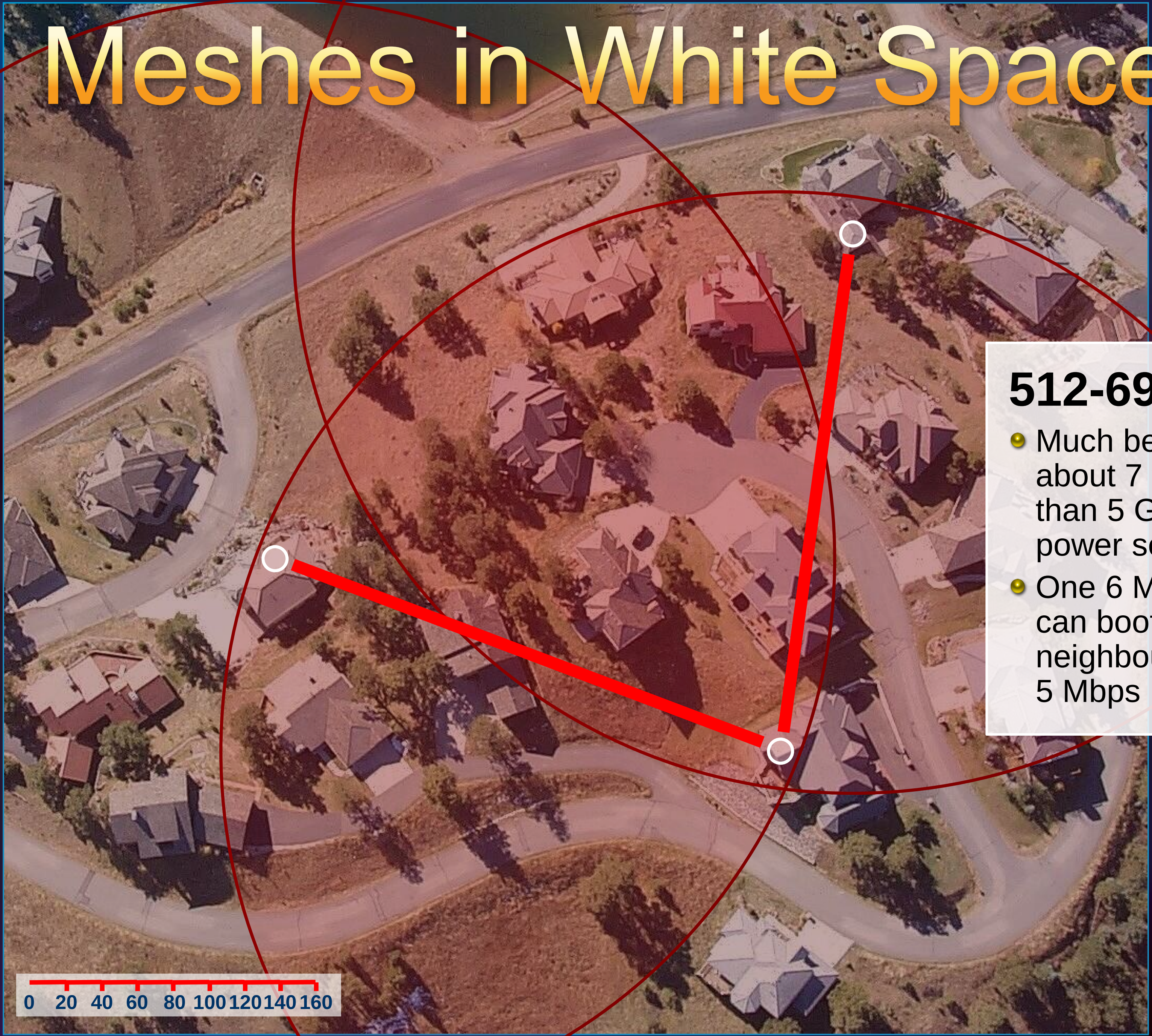
Meshes in ISM Bands



ISM Bands

- Bandwidth is good
- Published 802.11a ranges (Yellow circles)
- Measured range (red circle) poor
- Range is not sufficient to bootstrap mesh until installed % is quite high

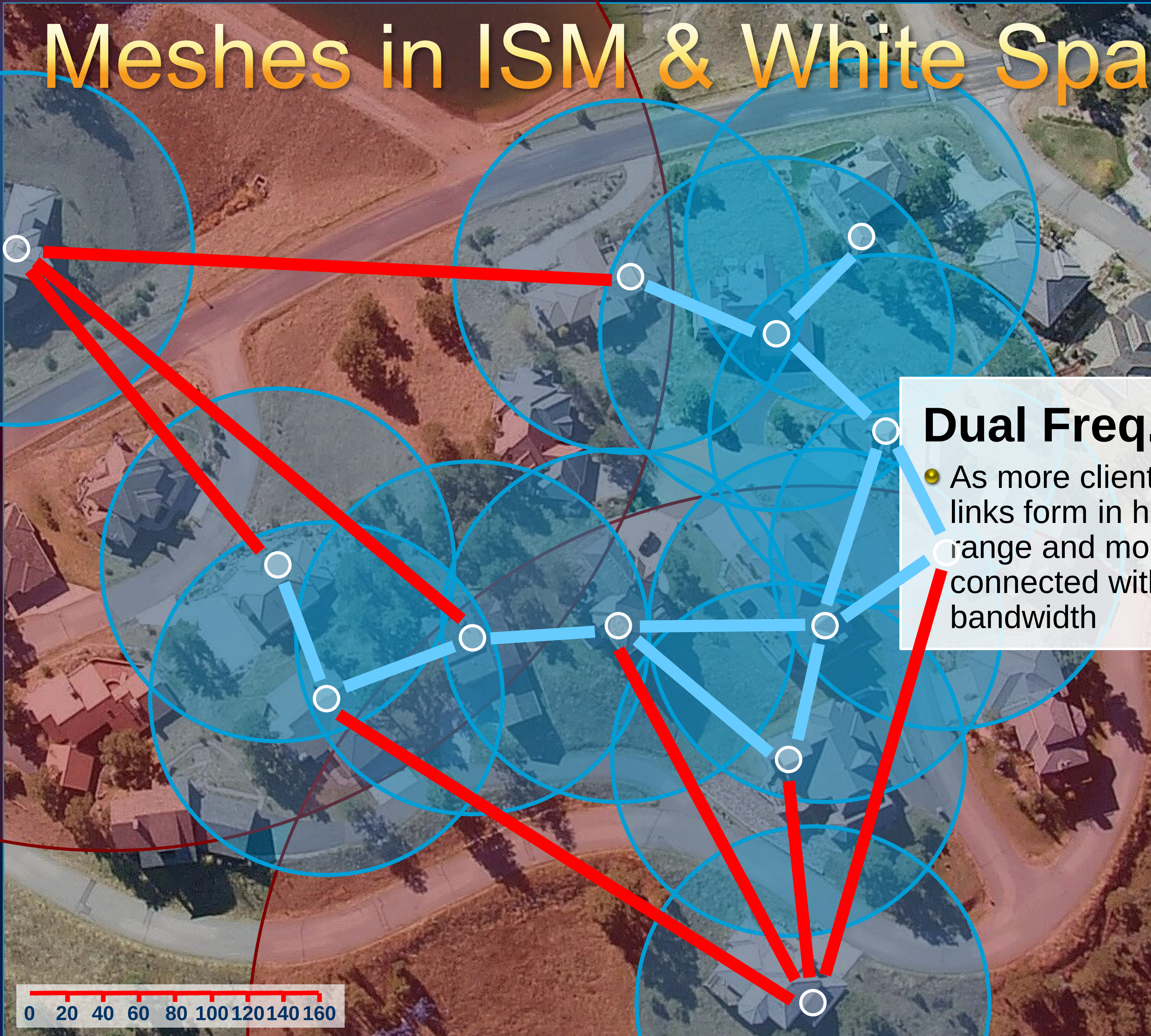
Meshes in White Spaces



512-698 MHz:

- Much better range: about 7 times further than 5 GHz at equal power settings
- One 6 MHz channel can bootstrap a neighbourhood with ~3-5 Mbps

Meshes in ISM & White Spaces



Dual Freq. Network

- As more clients come online, links form in high-frequency range and more of the mesh is connected with high-bandwidth

FCC's Reaction…

- FCC Chairman Michael Powell (May 13, 2004)

Use of unlicensed devices "promises to dramatically increase the availability and quality of wireless Internet connections -- the equivalent of doubling the number of lanes on a congested highway. Such technologies could create the same explosion in new business and growth that we have seen in the case of Wi-Fi and Bluetooth. For instance, it could help bring high-speed Internet services to rural communities without the cables or wires."

- Will consider request to use “White Spaces” but devices must not interfere with the incumbents (TV transmissions, wireless microphone) if they exist

i.e. will consider “Opportunistic use the spectrum" but first prove that your devices can sense presence of incumbents

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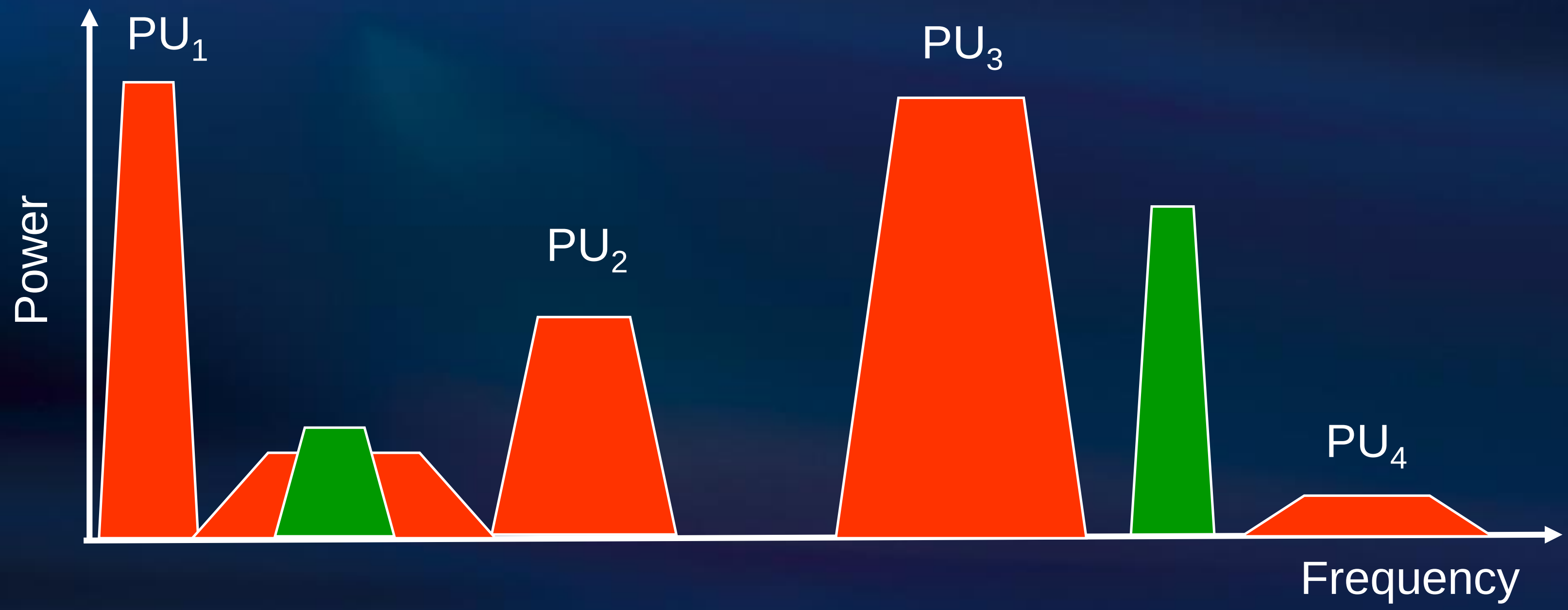
Opportunistic Use



- **Sense** the spectral environment over a wide bandwidth
- **Transmit** in “White Space”
- **Detect** if primary user appears
- **Move** to new white space
- **Adapt** bandwidth and power levels to meet requirements

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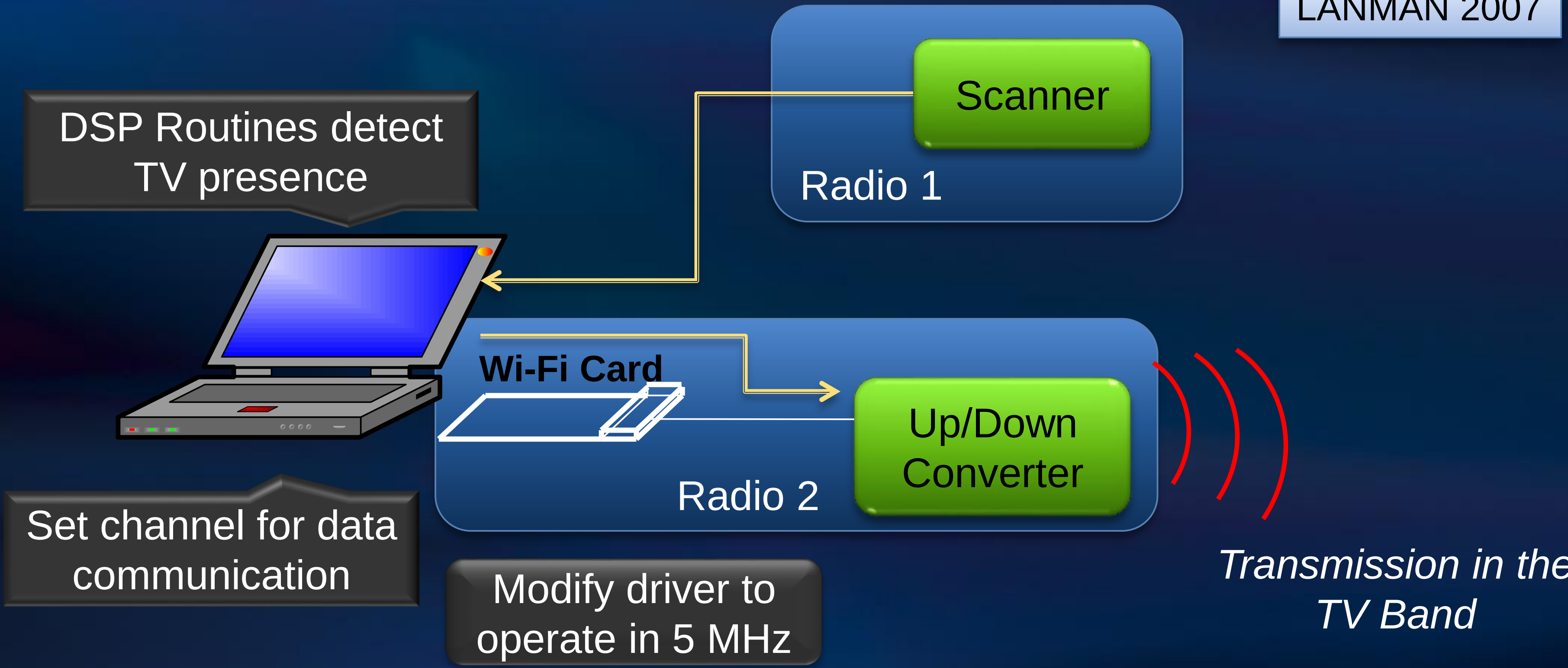
MS Hardware submitted to FCC

LANMAN 2007



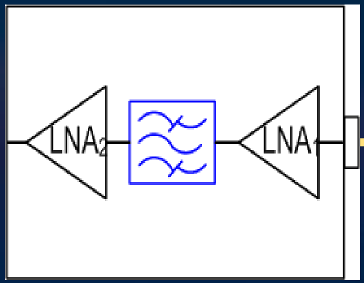
Primary Components

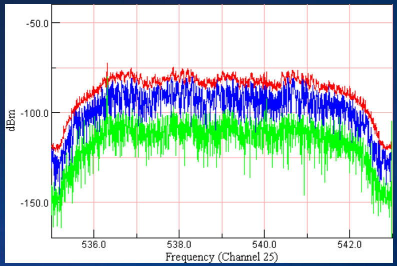
- Wideband spectrum scanner
- Tunable UHF half-duplex transceiver
- Network processor

Wideband Spectrum Scanner

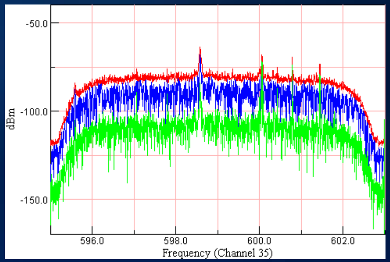
- Discover vacant TV channels in 512-698 MHz
- Scan Frame Bandwidth: 8 MHz
- Scan Frame FFT size: 2048 MHz
- Minimum DTV pilot tone sensitivity: -114dBm<< -85dBm

DSP Functions (Embedded Processor) | Digital Down Converter | A/D Converter | UHF Tuner 512-700 MHz





DTV



NTSC

Performance: TV Signal Detection

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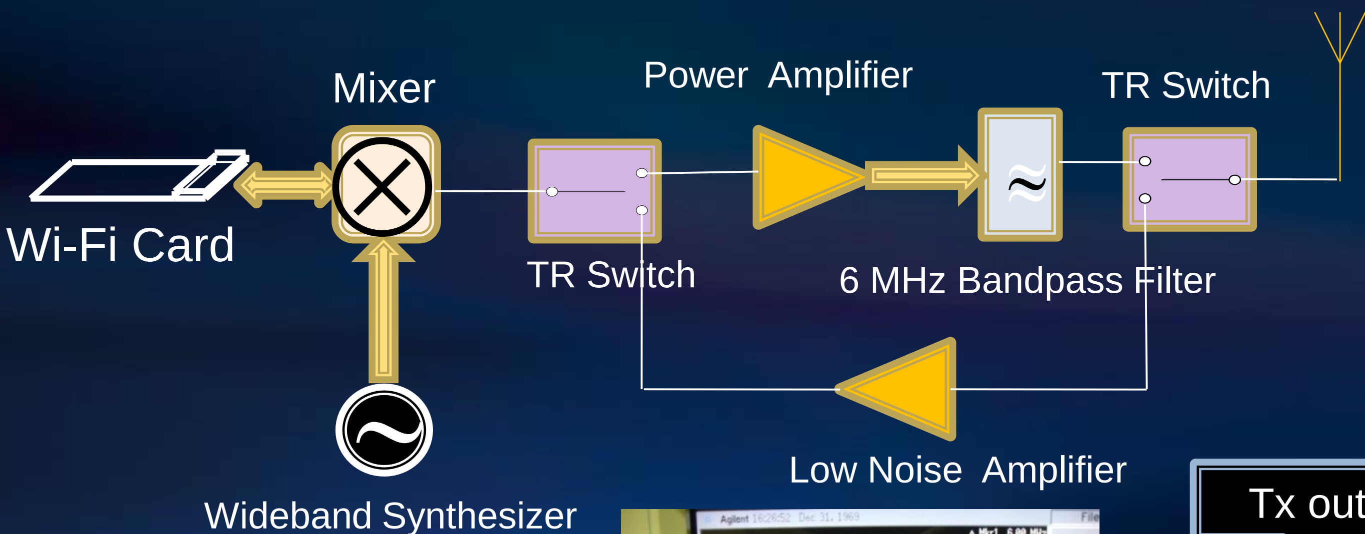
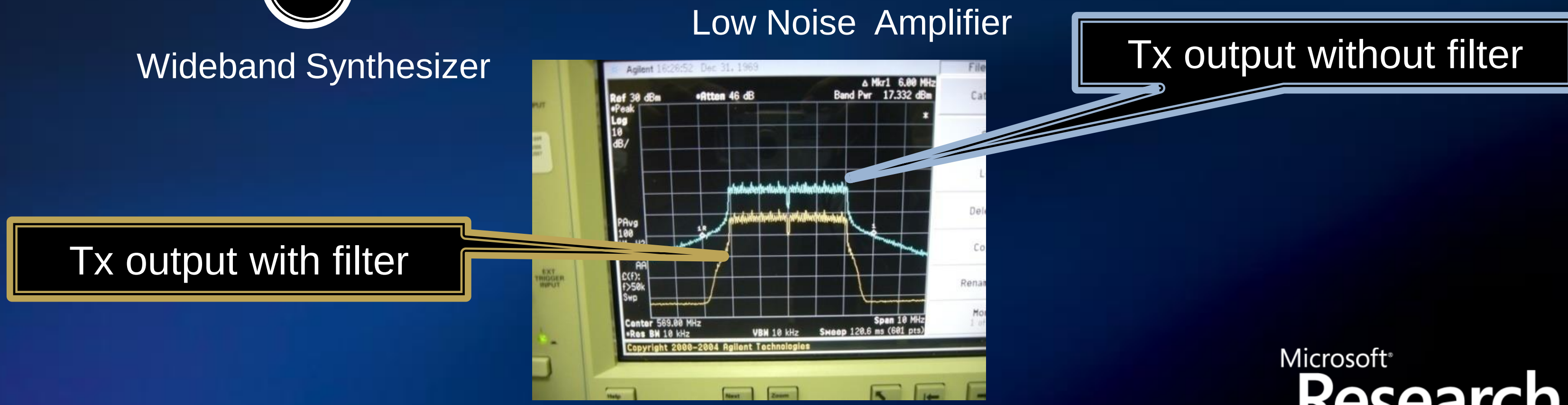
UHF Translator

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





Performance: UHF Translator Output

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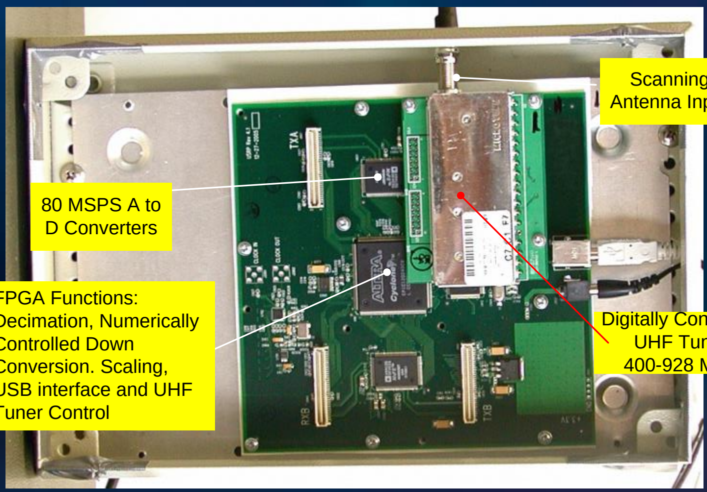
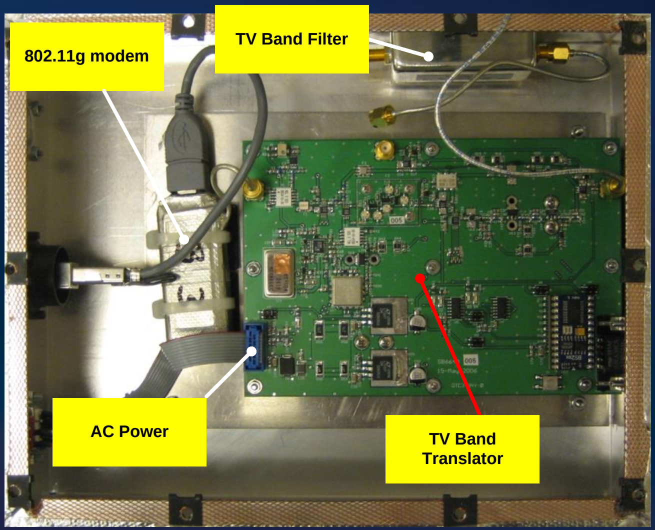
Network Processor

- Integrates scanner with UHF translator
  - Determines white spaces by processing scanner output
  - Sets appropriate parameters at the UHF translator
- Processes samples from scanner
  - Applies 2048 FFT on scanner samples
  - Matches feature templates for digital TV, analog NTSC signals, etc.
- Controls parameters of the UHF translator
  - Channel frequency, Tx power

Note: When not scanning, receive on the 900 ISM band. Tunable transceiver for 400—928MHz

Prototype Submitted to FCC
March 2007



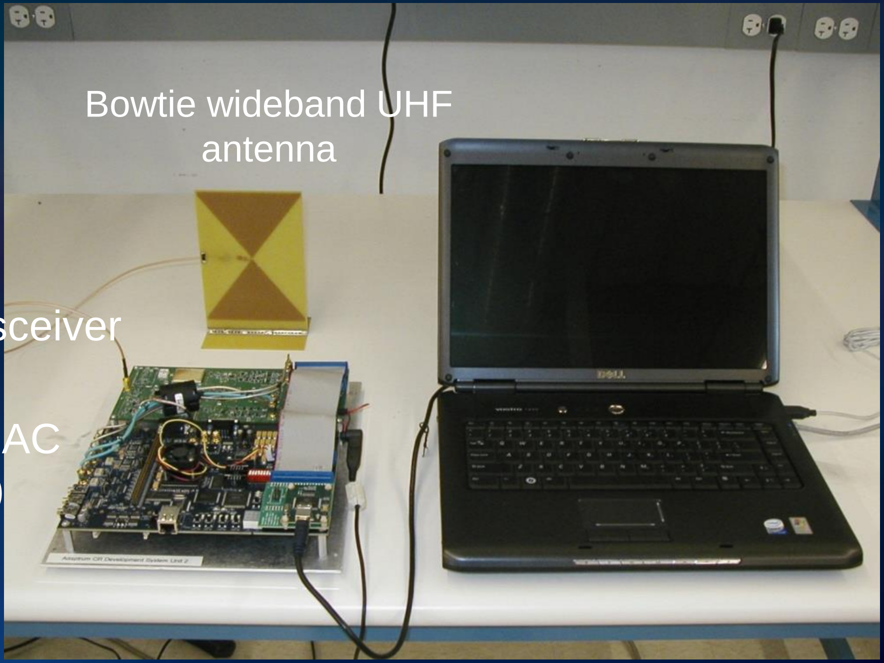


Microsoft's White Space Device

Microsoft Research

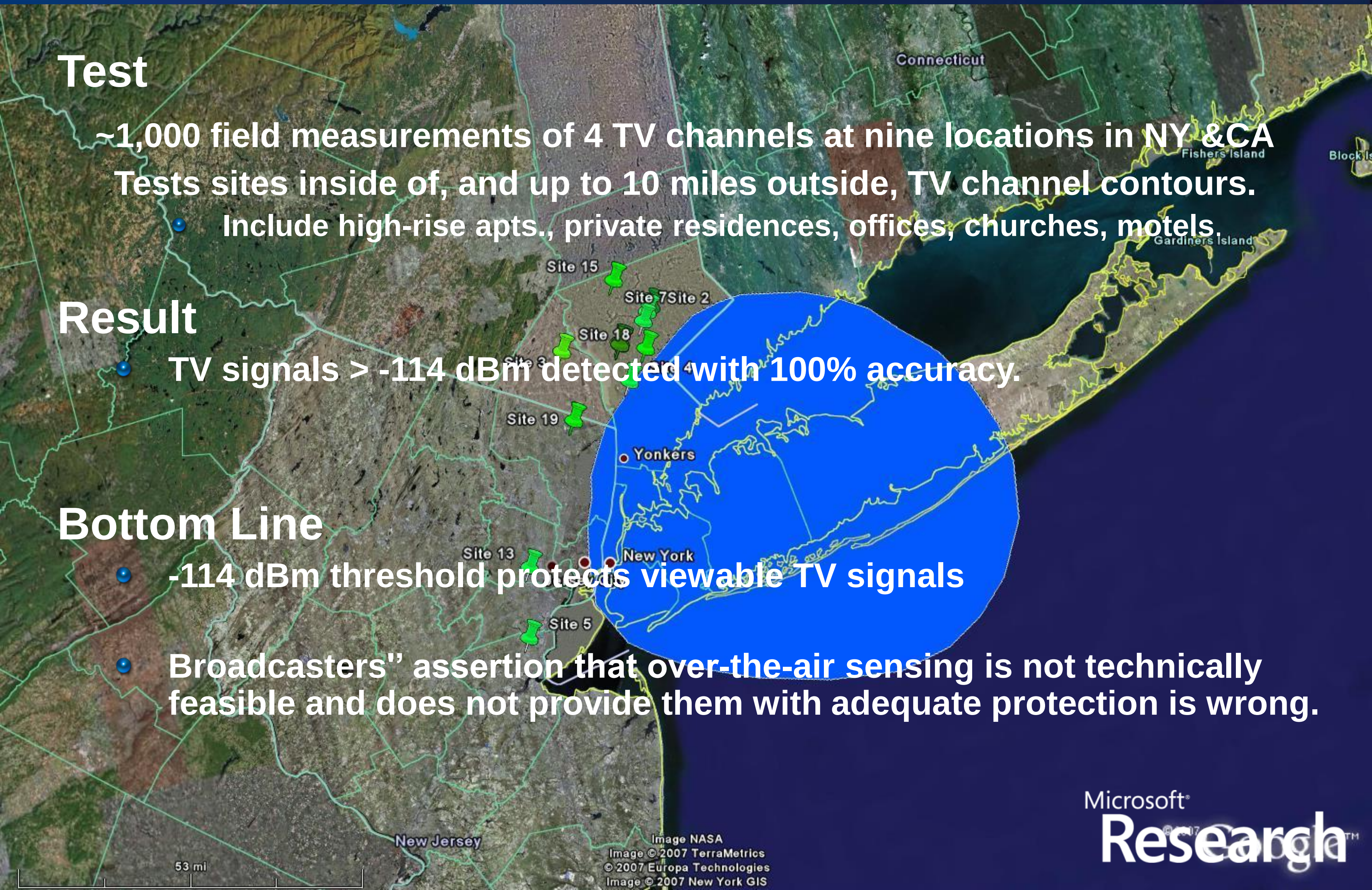
Additional Prototypes Submitted to FCC

Adaptrum' WS Device (Submitted: Dec. 2007)



Courtesy: Haiyun Tang, Co-Founder, CTO Adaptrum

Field Study Summary



Test

~1,000 field measurements of 4 TV channels at nine locations in NY &CA

Tests sites inside of, and up to 10 miles outside, TV channel contours.

- Include high-rise apts., private residences, offices, churches, motels.

Result

- TV signals > -114 dBm detected with 100% accuracy.

Bottom Line

- -114 dBm threshold protects viewable TV signals
- Broadcasters'' assertion that over-the-air sensing is not technically feasible and does not provide them with adequate protection is wrong.

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FCC Adopts Rules For Unlicensed Use Of Television White Spaces

November 4, 2008

msnbc

featuring Today Show Nightly News Dateline Meet the Press MSNBC TV NBC Sports

Business Local business

Categories

- U.S. news
- World news
- Politics

FCC 'white space' decision will open up unused bandwidth; could bring high Internet to rural areas

Science & Technology

Tech.view

Wireless at warp speed

Nov 7th 2008

From Economist.com

White space promises to put WiFi on steroids

THE WALL STREET JOURNAL. Digital Network | WSJ.com | MarketWatch | BARRON'S

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MarketWatch Holiday Gift Guide - Read It now

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LATEST NEWS Nikkei 225 Average ends 0.7% higher at 8,720.55

Tech firms win victory with FCC 'white spaces' vote

Google, Microsoft pressed for approval to use TV bands for Interne

By John Letzing, MarketWatch

Last update: 6:47 p.m. EST Nov. 4, 2008 | Comments: 16

TV Technology

THE DIGITAL TELEVISION AUTHORITY

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RF TechnologyProduction Manager

A Landslide for White Spaces

by Sanjay Talwani, 12.03.2008

Wednesday, December 3, 2008

Will 'White Space' ruling stimulate our sagging economy?

FCC Nov. 4, 2008 Ruling

The rules allow for both fixed & personal/portable unlicensed devices.

- Devices must include geolocation and spectrum-sensing technology. The geolocation data base will tell the white space device what spectrum may be used at that location.
- The rules require that devices also include the ability to listen to the airwaves to sense wireless microphones.
- The Commission will permit certification of devices that do not include the geolocation and database access capabilities, and instead rely solely on spectrum sensing subject to a much more rigorous "proof of performance" approval process.

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A few Details…

	Fixed Devices w. Sensing & Geolocation	Personal / Portable Device w. Sensing & Geolocation	Personal / Portable Device w. Sensing Only
Channels (6 MHz each)	21-51 (except 37) ; fixed-2-fixed: 2 & 5-20 with exceptions	21-51 (except 37)	21-51 (except 37)
Transmit Power	1 W (up to 4W with antenna gain)	100 mW (no antenna gain allowed)	50 mW (no antenna gain allowed)
		40 mW (when licensed user is in adjacent channel)	
Detection thresholds for ATSC, NTSC, & Wireless Microphones	-114 dBm	-114 dBm	-114 dBm
Database Registration	Yes	No	No
Beaconing for identification	Yes	No	No
In-service monitoring / Channel move times	Every 60 seconds / 2 seconds	Every 60 seconds / 2 seconds	Every 60 seconds / 2 seconds
Channel availability time	30 seconds	30 seconds	30 seconds
Location Accuracy	50 meters	50 meters	50 meters

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White Spaces Database Group

CNBC — REAL-TIME QUOTES | All CNBC | News | Video

HOME | NEWS | MARKETS | EARNINGS | INVESTING | VIDEO | CNBC TV | CNBC PLU

U.S. | ASIA-PACIFIC | EUROPE | ENERGY | GREEN | POLITICS | TECHNOLOGY | BLOGS

Tech Industry Leaders Join to Develop Guidelines for White Spaces Database Google, Microsoft, Motorola, Others Launch the White Spaces Database Group

By: Business Wire | 04 Feb 2009 | 10:00 AM ET

新春大吉

sina 科技时代 — 科技时代 > 通讯与电讯 > 正文

谷歌等公司将帮助FCC设立空白频谱数据库

http://www.sina.com.cn 2009年02月07日 02:46 新浪科技

China, Feb. 7, 2009

SmartBrief — SmartBrief > Technology > CABA SmartBrief > Related Stories

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CABA SmartBrief — News — Press Releases

Tech giants will create white space database

CABA SMARTBRIEF | 02/06/2009

ITmedia News — Believe in Technology

ニュース

Google、Microsoftら7社、ホワイトスペース活用のためのデータ ース開発で協力

使用テレビ周波数帯使用を本格化するため、IT業界の7社が団体を設立した。

9年02月05日 08時00分 更新

Japan, Feb. 4, 2009

COMPUTERWORLD Mobile & Wireless — IDG

Tech firms to work on 'white spaces' database for TV spectrum

Goal is to avoid interference from wireless devices in unused TV spectrum

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Around the World

- Digital Switchover (DSO) in the UK will complete in 2012
  - 128 MHz in UHF band (470-862MHz)   [verus 282 MHz in the US]
  - 8 MHz / channel; channels 21-30 , 63-68
  - Referred to as "interleaved spectrum"

- Sweden, Finland, Norway, France and Switzerland have announced their digital dividends

- Other countries likely to follow: Germany, Denmark, Netherlands, Czech Republic, Hungary, Ireland

Networking Challenges

MobiHoc 2007

The KNOWS Program (Cogntive Radio Networking)

How should nodes connect?

How should they discover one another?

Which spectrum-band should two cognitive radios use for transmission?

- Center Frequency, Channel Width, Duration…?

Which mathematical tools should we use to reason about capacity & spectrum utilization?

How should the networked nodes react upon arrival of a primary user?

Which protocols should they use?

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Definitions

Cognitive Radio

a radio that is aware of and can sense its environment, learn from its environment, and adjust its operation according to some objective function

Cognitive Network

a network that has a cognitive process that perceives current network conditions, and then plans, decides, and acts on those conditions. The network can learn from these adaptations and use them to make future decisions, all while taking into account end-to-end goals.

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MSR KNOWS Program
Prototype Development

Version 1: Ad hoc networking in white spaces

- Capable of sensing TV signals, limited hardware functionality, analysis of design through simulations

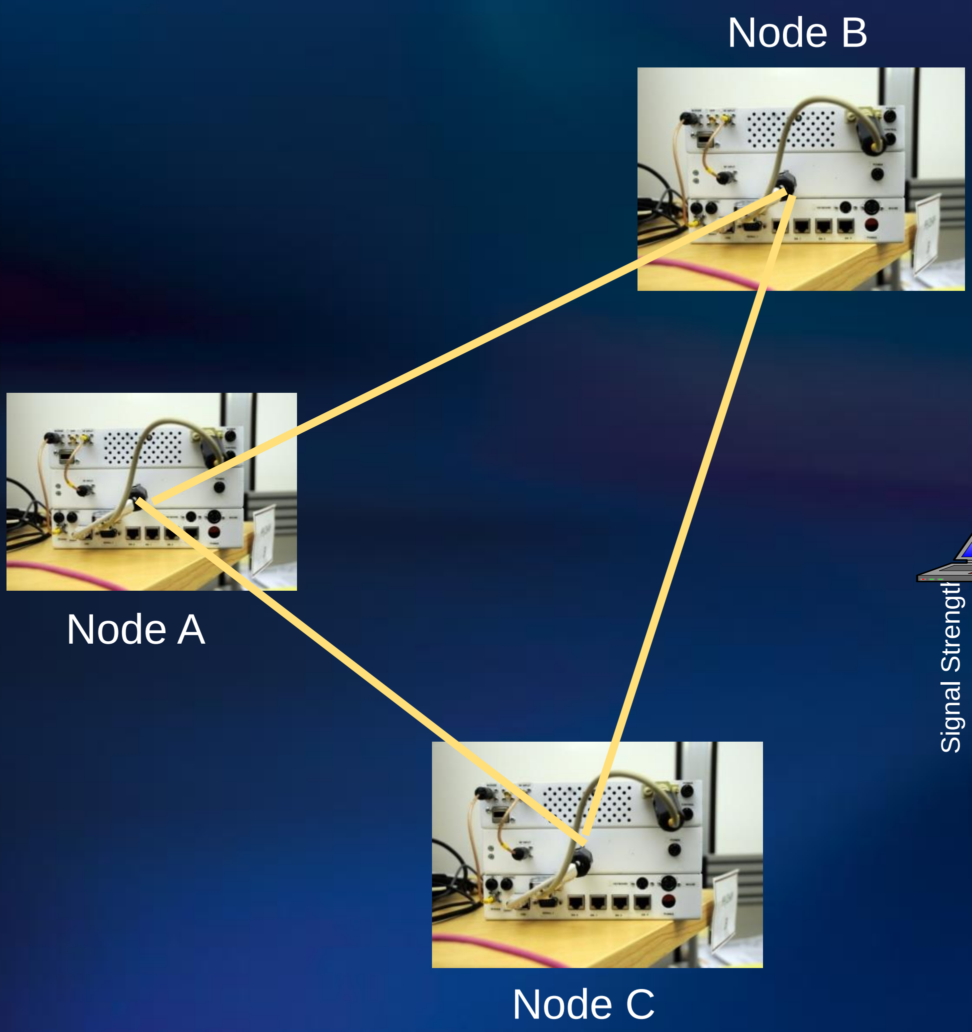
Version 2: Infrastructure based networking (WhiteFi)

- Capable of sensing TV signals & microphones, deployed in lab / demo at TechFest 2009

Version 3: Campus-wide backbone network (WhiteFi + Geolocation) -> Ongoing

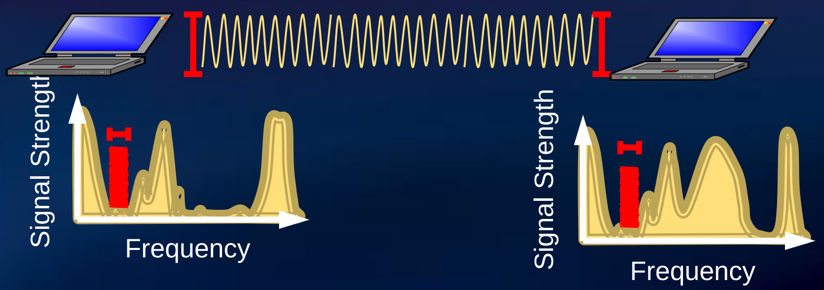
- Intend to deploy on campus, and provide coverage in MS Shuttles

Version 1: Ad Hoc Networking in White Spaces



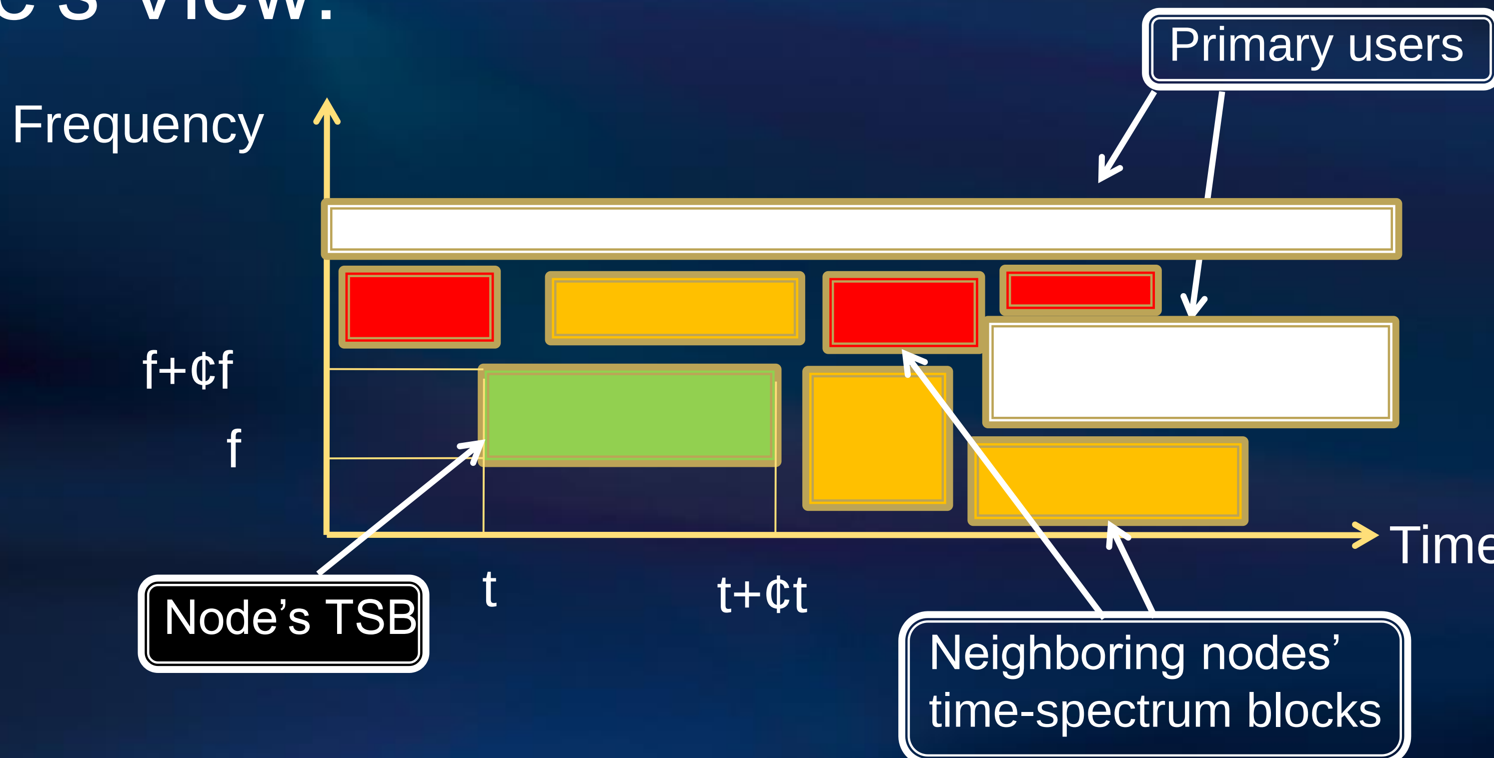
Demonstrated

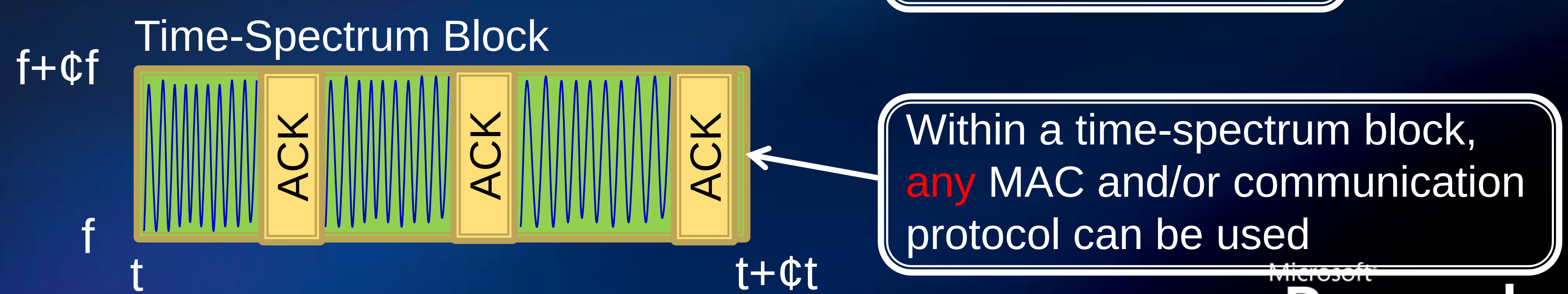
- 700 MHz operation
- TV sensing technology
- One-to-one Opportunistic Networking



Time Spectrum Block (TSB)

Node's View:





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b-SMART

MobiHoc 2007

Distributed SpectruM Allocation overR 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

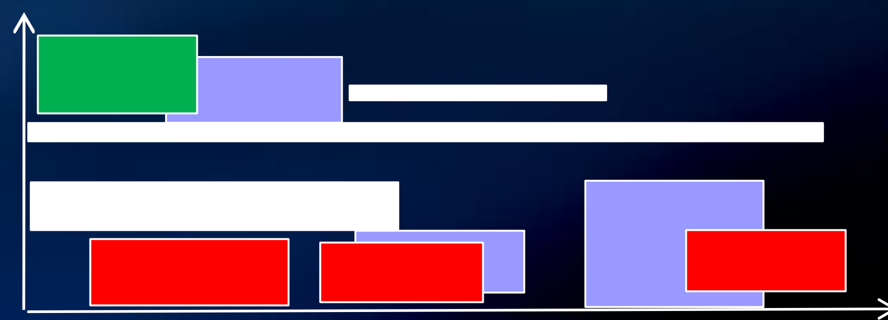
Long blocks: Higher delay

Short blocks: More congestion on control channel

b-SMART

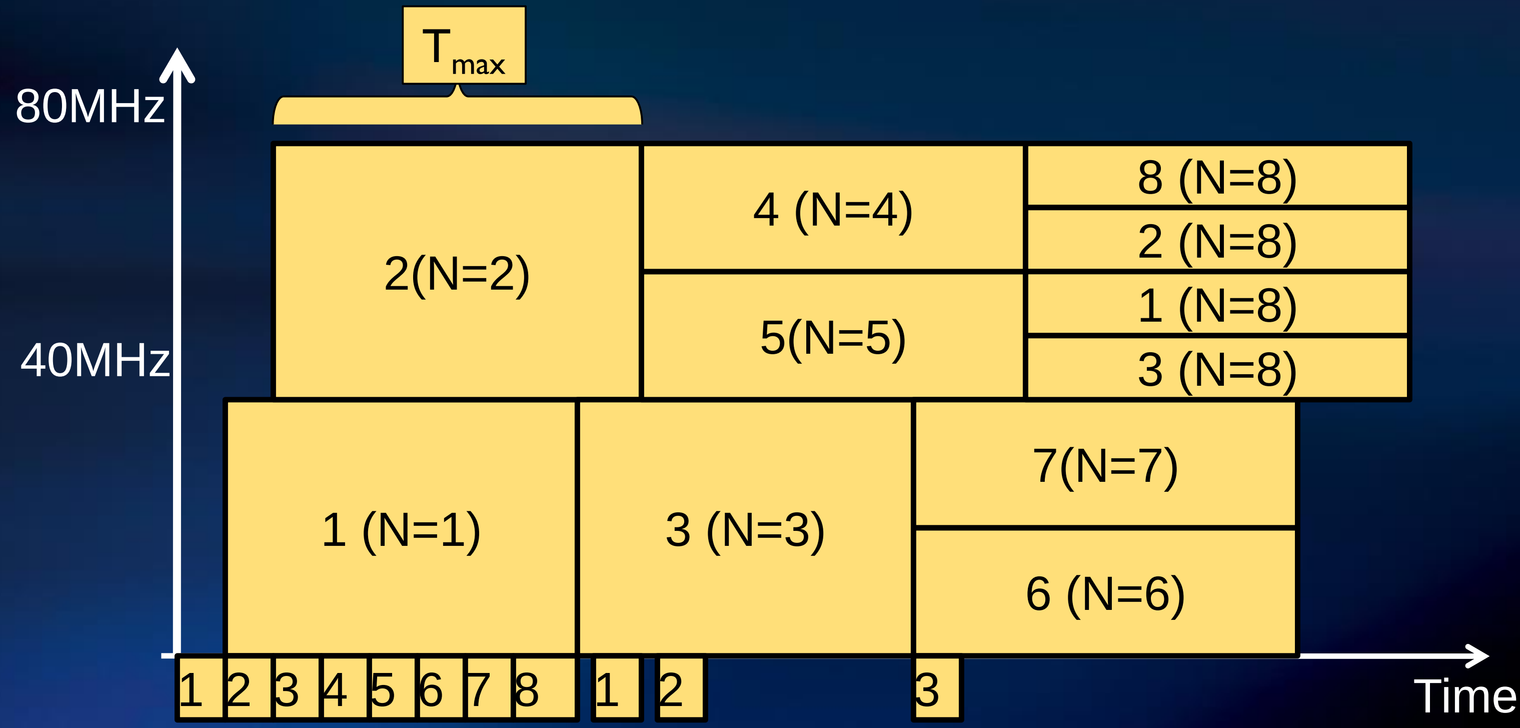
- Upper bound T_{max}~10ms on maximum block duration
- Nodes always try to send for T_{max}

1. Find smallest bandwidth Δb for which current queue-length is sufficient to fill block $\Delta b\ \Delta T_{max}$
2. **If** $\Delta b \geq \lceil B/N \rceil$ **then** $\Delta b := \lceil B/N \rceil$
3. Find placement of $\Delta b \times \Delta t$ block that minimizes finishing time and does not overlap with any other block
4. **If** no such block can be placed due prohibited bands **then** $\Delta b := \Delta b/2$



Example

- Number of valid reservations in NAM → estimate for N
  Case study: 8 backlogged single-hop flows

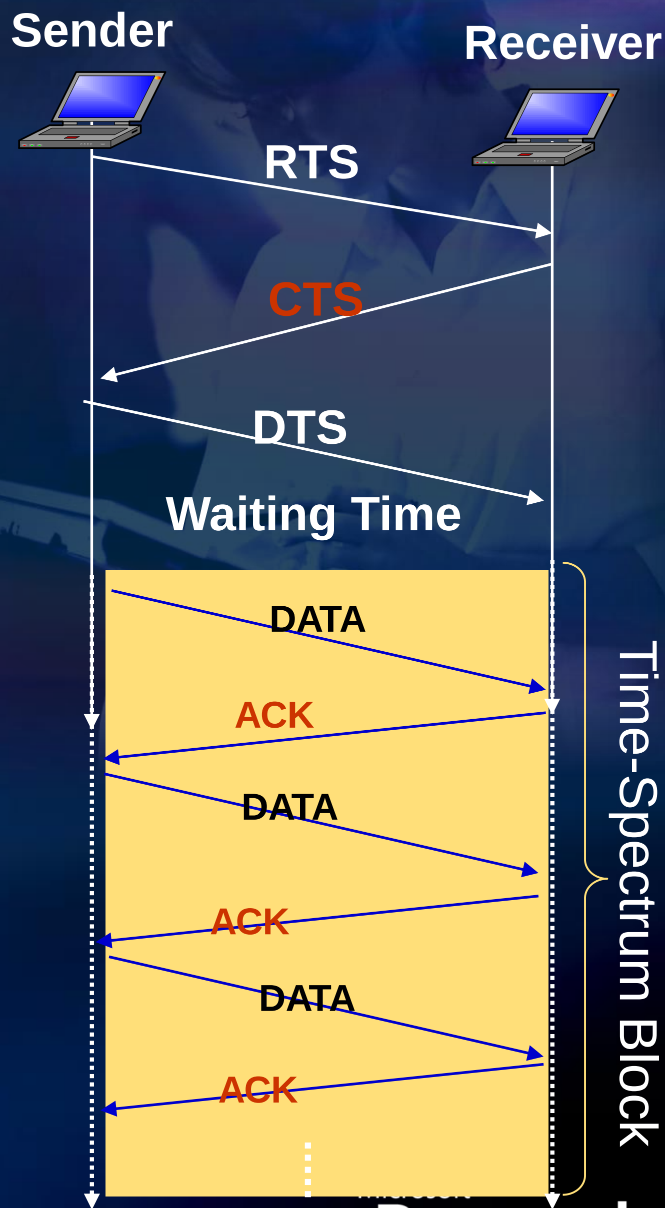


Collaborative Sensing & Access

DySpan 2007

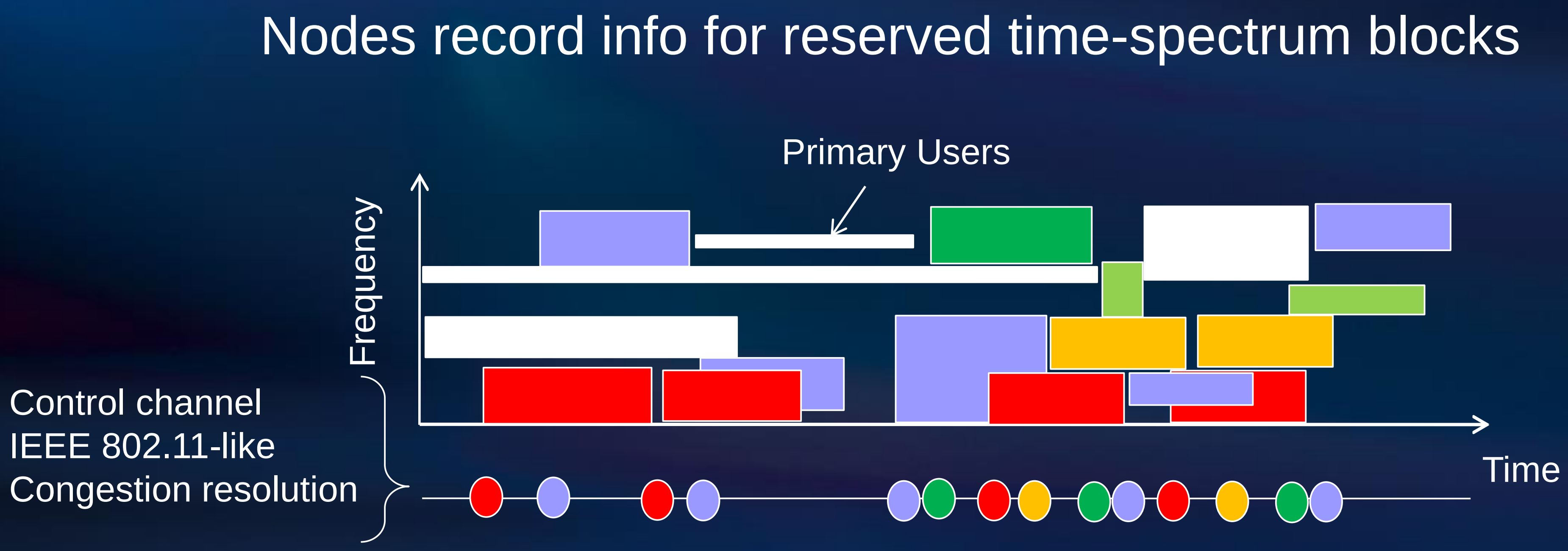
- Common Control Channel (CCC) for rendezvous
  - Contend for frequency band & band time
  - Exchange spectrum availability information
  - Reserve a TSB
  - Scanner listens to CCC while node is transmitting
  - CC operates on 900 MHz channel

- Distributed, adaptive, localized reconfiguration



Research

Resource Allocation Matrix



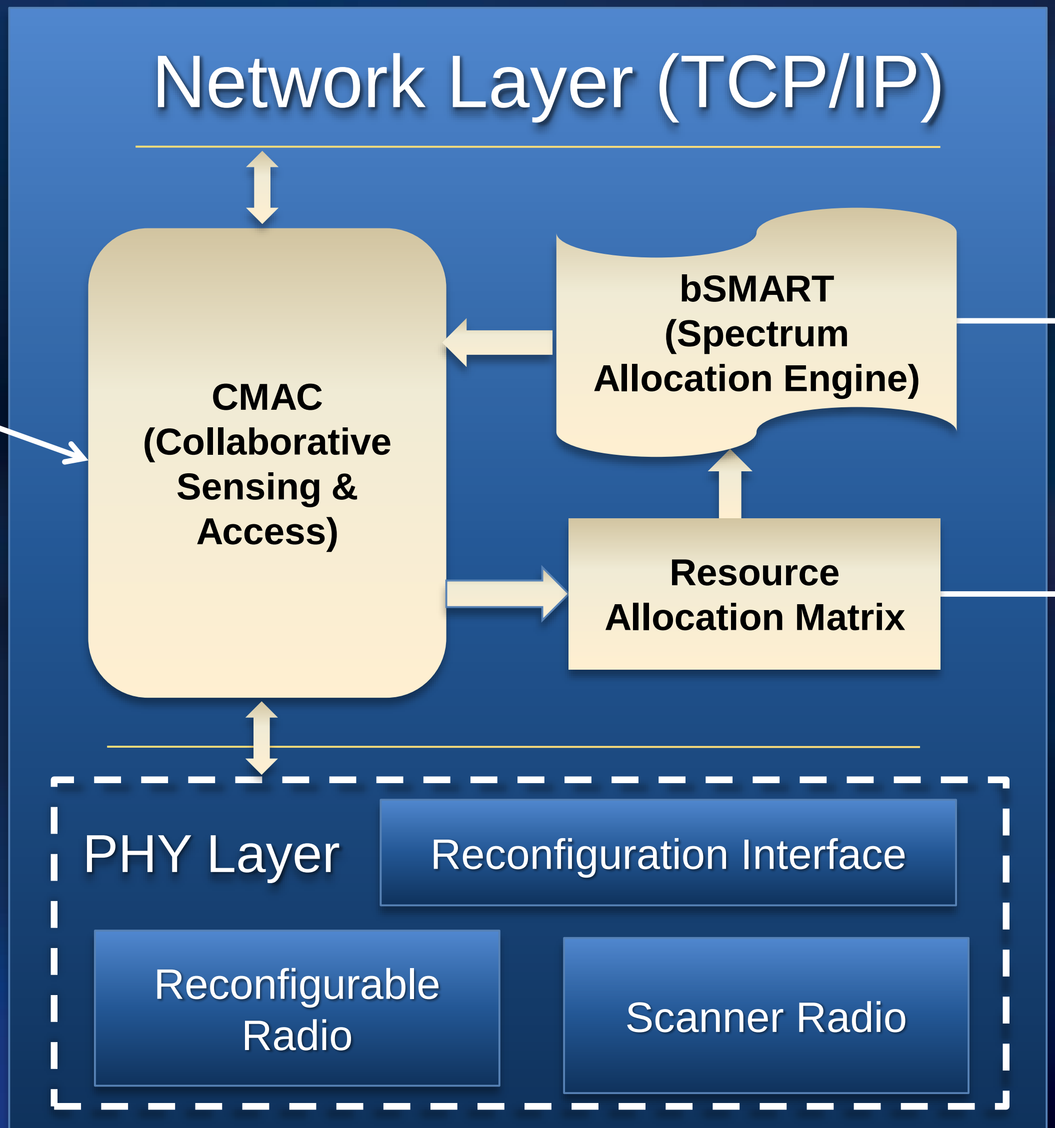
Nodes record info for reserved time-spectrum blocks

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

The Network Stack

DySpan 2007

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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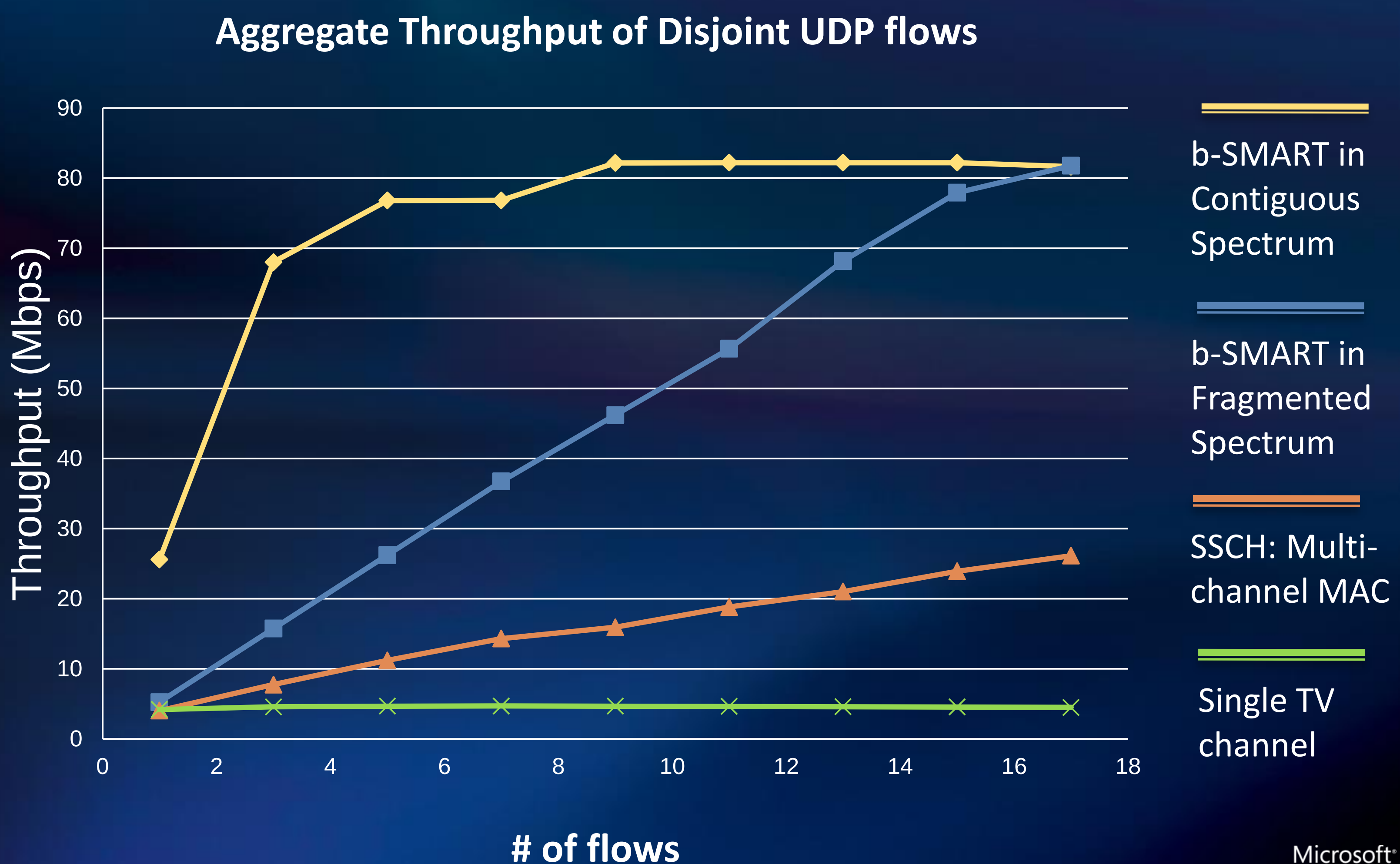
Does it Help?
KNOWS V1 Performance



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Lingering Questions

- KNOWS v1 was a multi-radio system
  - Can we build a single-radio WS network?
- KNOWS v1 was a ad hoc network for portable devices
  - Is the design optimum for fixed WS networks?
- KNOWS v1 required a control channel that can be compromized easily
  - Can we do without a control channel?
- KNOWS v1 introduced DTS & modifed semantics of RTS/CTS
  - Can we reuse the Wi-Fi MAC?

...can we do better?

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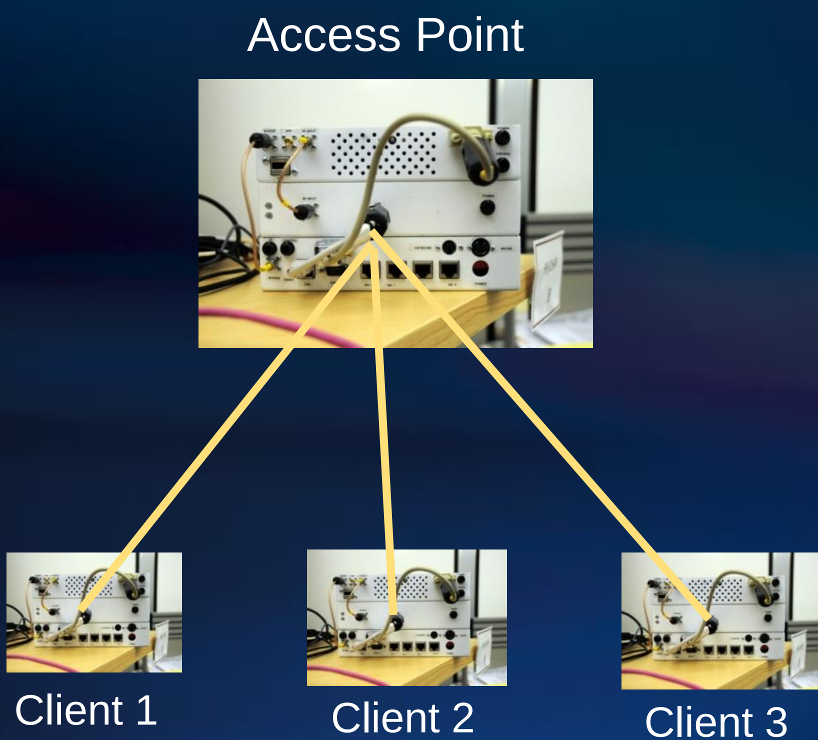
Version 2: Infrastucture Based Networking in White Spaces (WhiteFi)



Demonstrates

- 700 MHz operation
- TV sensing technology
- Limited wireless microphone sensing technology
- One-to-many opportunistic networking

Design Improvements

- No control channel
- No changes to Wi-Fi MAC

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Can we Reuse Wi-Fi?

WS different from Wi-Fi

SIGCOMM 2009

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

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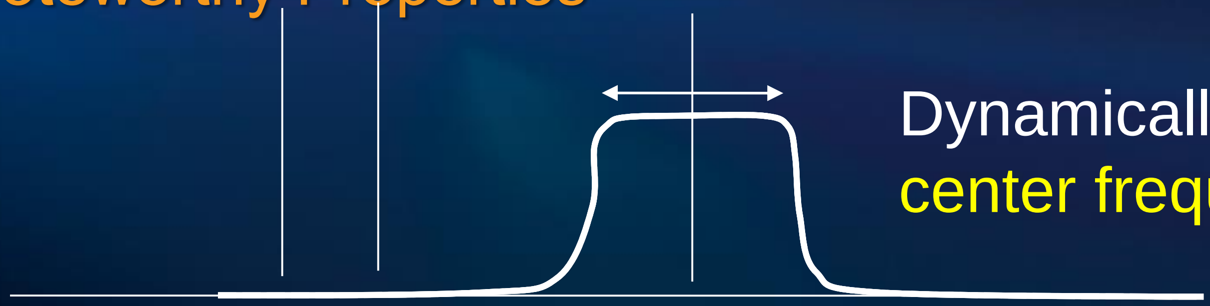
Dynamic Channel Width

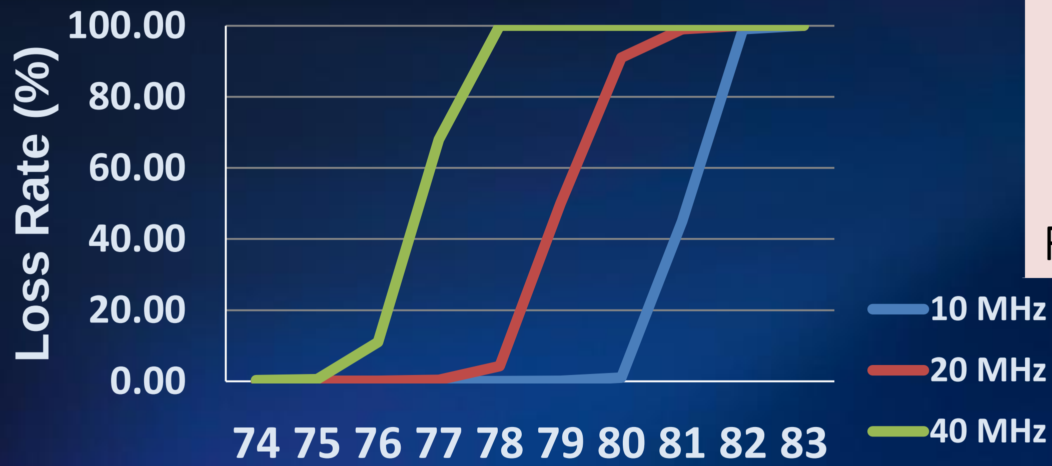
SIGCOMM 2008

Noteworthy Properties



Dynamically adjust
center frequency & width.

Lower widths increase range while consuming less power!



	5MHz	10MHz	20MHz	40MHz
Send	1.92	1.98	2.05	2.17
Idle	1.00	1.11	1.25	1.41
Receive	1.01	1.13	1.27	1.49

Power Drain

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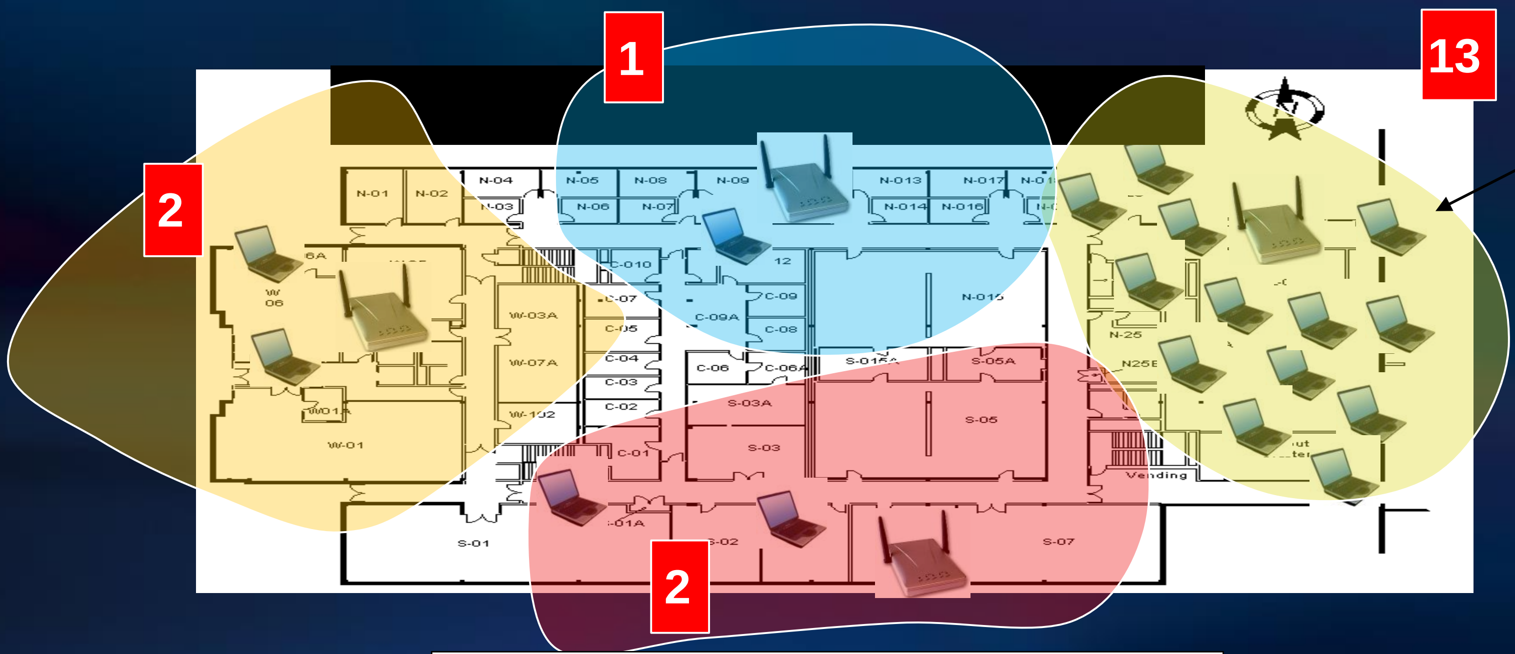
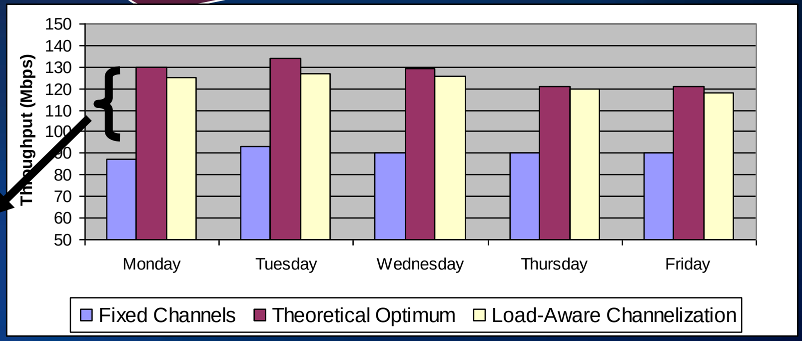
We showed (previous review)

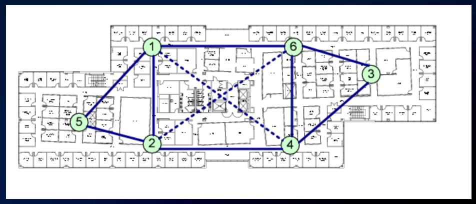
ICNP 2008

- Varying channel widths improve performance (from last review)



Significant increase in overall throughput





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Version 2: Three Major Innovations

- Spectrum Assignment Algorithm
  - Enables AP to pick a channel that is free for all clients AND pick the best possbile 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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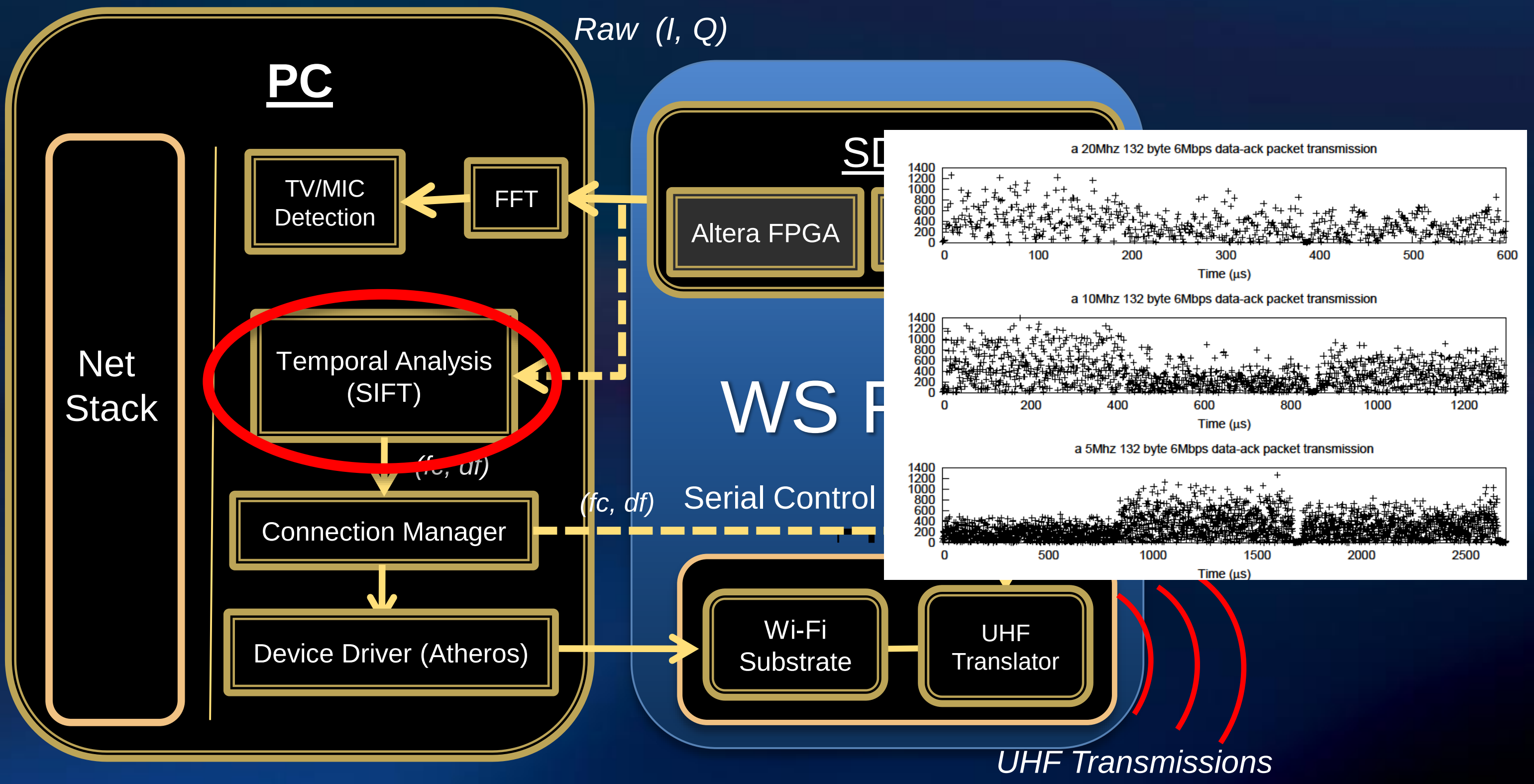
Handling Variable Channels

Determining the frequency and channel width of APs

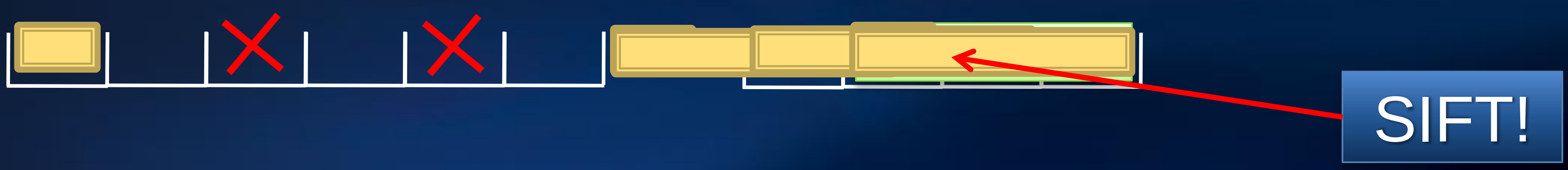


SIFT: Signal Interpretation before Fourier Transform

AP Discovery

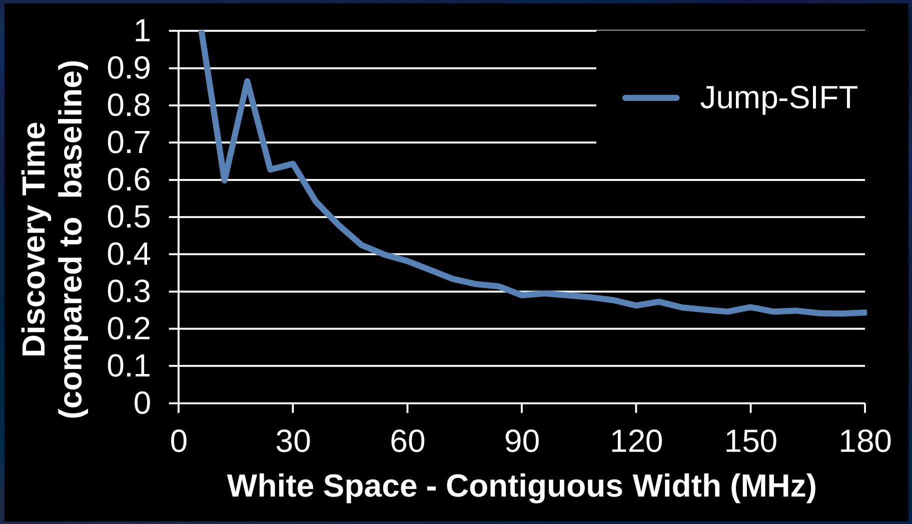
How can Clients quickly find the AP…?
Tradition solution in Wi-Fi → check all possible channels.

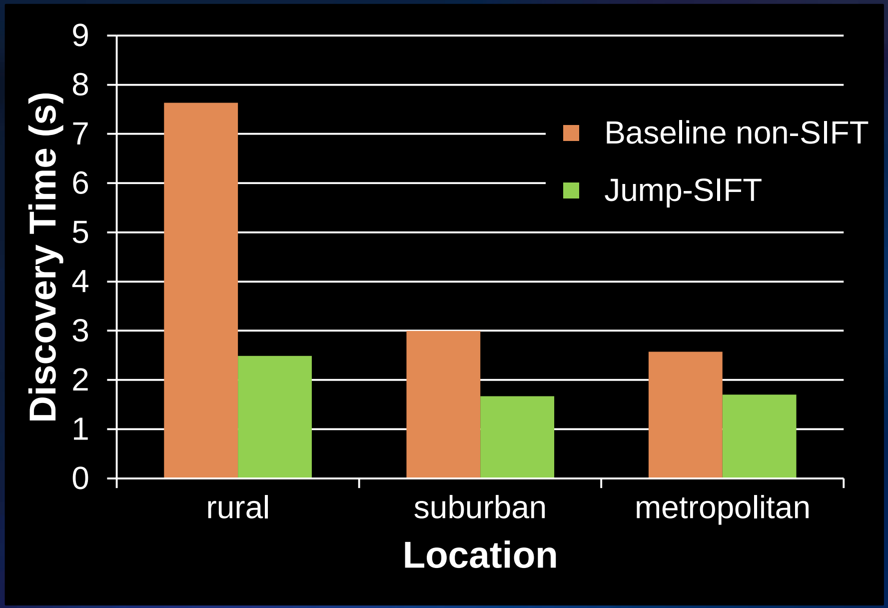
With SIFT, much faster algorithms become possible!
→Jump cleverly across the spectrum, until you hit the AP



AP Discovery

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





Most benefit in rural areas

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The Microphone Detection Challenge

freepress
reform media. transform democracy.

MEDIA ISSUES | POLICY UPDATES | NEWSROOM | RESOURCES

› News Headlines › Media Minutes Audio › Must See Videos › Media Reform Daily

White Space Group Cites Amnesty for Illegal Wireless Mic Use

ars technica, June 18, 2008
By Nate Anderson

In a letter to the FCC, lawyers for the White Spaces Coalition pointed out that "most wireless microphone use is unlawful," and they went after mic maker Shure for its "scare tactic" approach to the white spaces issue.

- 0.5 million microphones in the US
- Mobile, low-power, sporadic usage
- Specifications for microphones *vary* across and ***within*** vendors
  - Typically between 500 – 600MHz, 500-700MHz, 600–800Mhz, 500-800MHz
  - Often operate on different channels
  - Some microphones scan to find “best” channels

- Fragment the spectrum
- Temporal variation and spatial (on a wider scale)

One possible detection solution: Beacons

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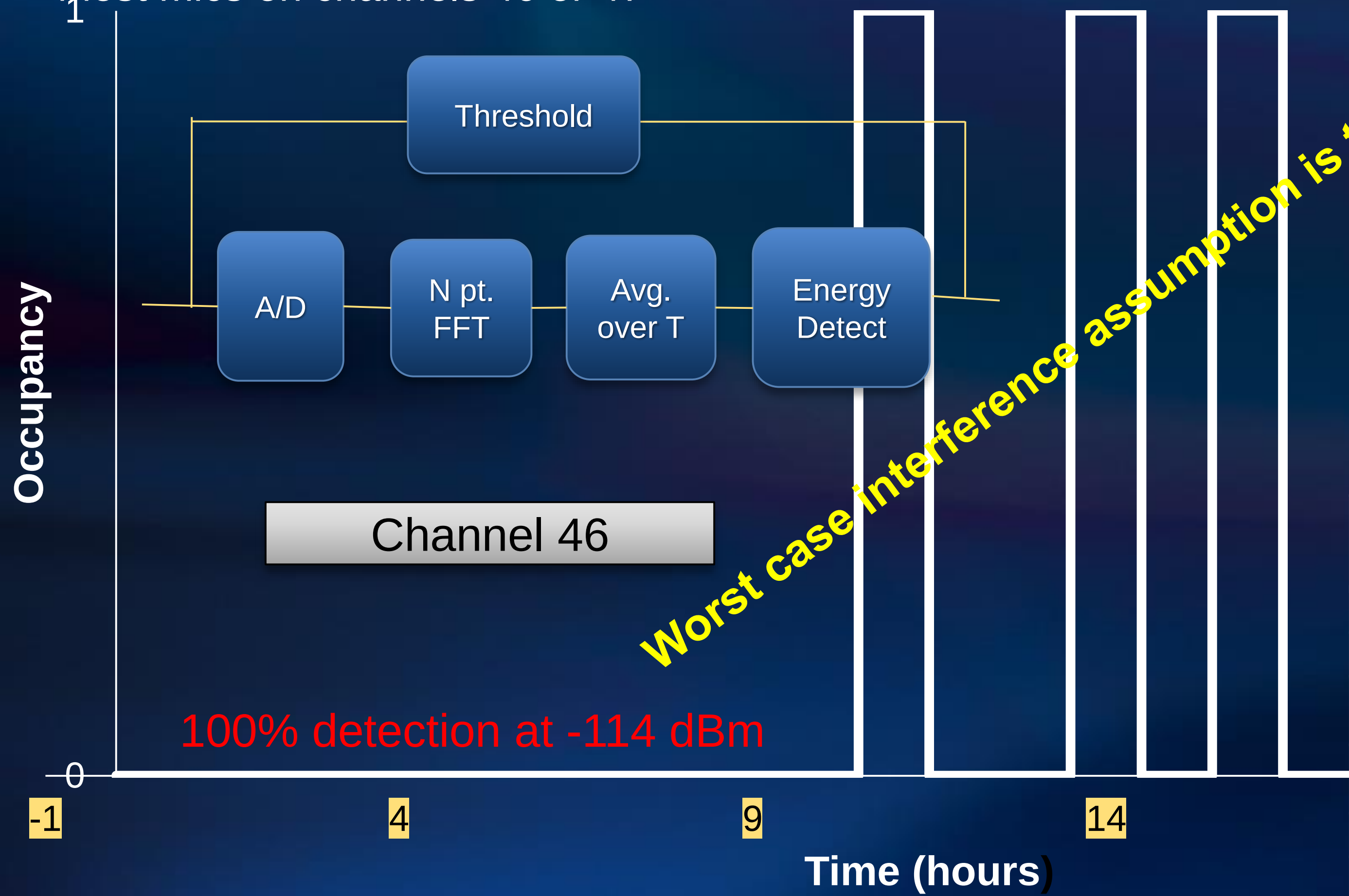
Microphone Detection

MSR lecture rooms have 20 microphones.
Most mics on channels 46 or 47



Worst case interference assumption is too conservative

Regulated by Part 74 FCC rules, use 50 mW for 100 m coverage and 200 KHz channel bandwidth

Parameter	Value for Wireless Microphone
Channel Detection Time	<= 2 sec
Channel Move Time	<= 2 sec
Channel Closing Xmission Time	100 msec
Incumbent Detection Threshold	-114 dBM (over 200 KHz)
Probability of Detection	90%
Probability of False Alarm	10%

Spectrum occupancy changes during the day and is location specific

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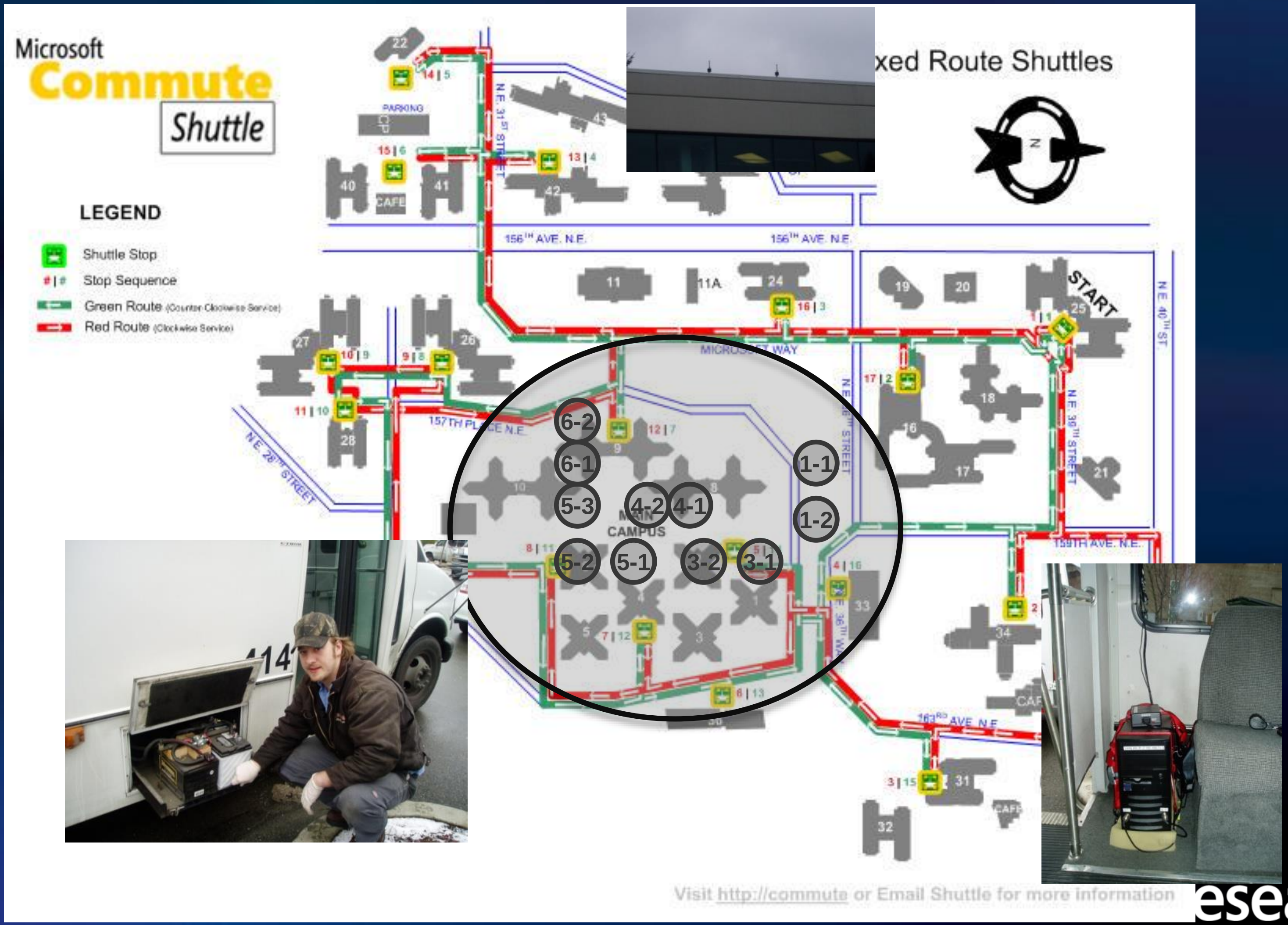
Moving forward….

Build the first fully operational white space network in the world

Version 3: Campus Wide White Space Networking (w. Geolocation)

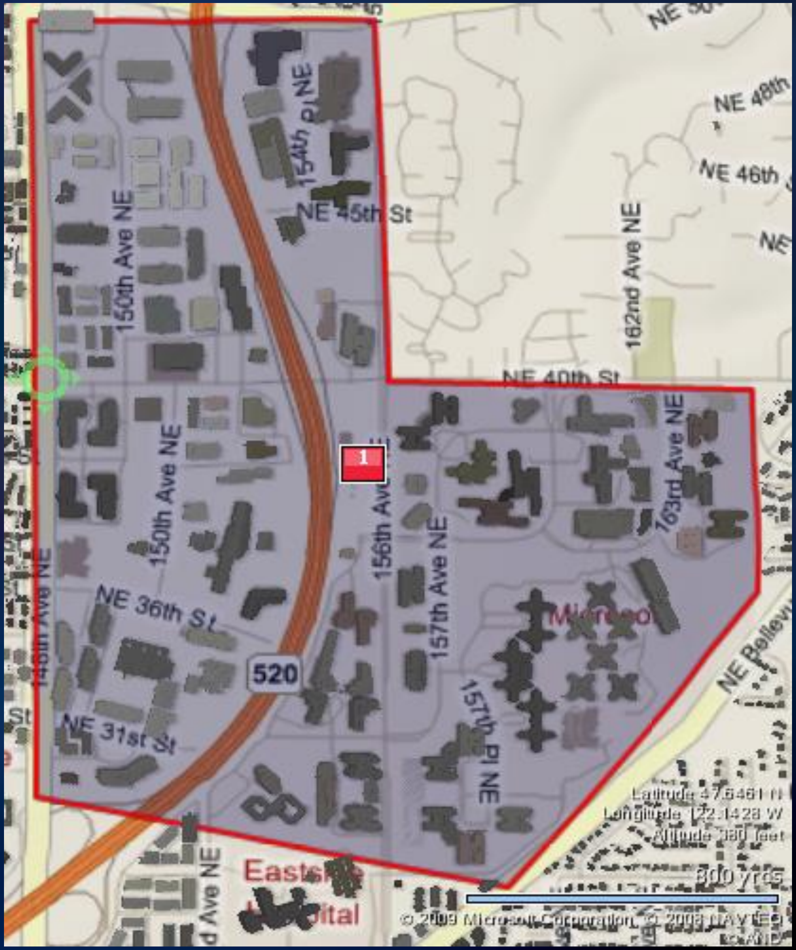


MSR's FCC Experimental License Petition Approved

Experiments

- Centered at (47.6442N, 122.1330W)
- Area of 1 square mile
- Perimeter of 4.37 miles
- WSD on 5-10 campus buildings
- Fixed BS operate at 4 W EIRP
- WSD inside shuttles at 100 mW

Outdoor omni-directional VHF/UHF antenna
(flat 2 dBi gain over 150 – 1000 MHz



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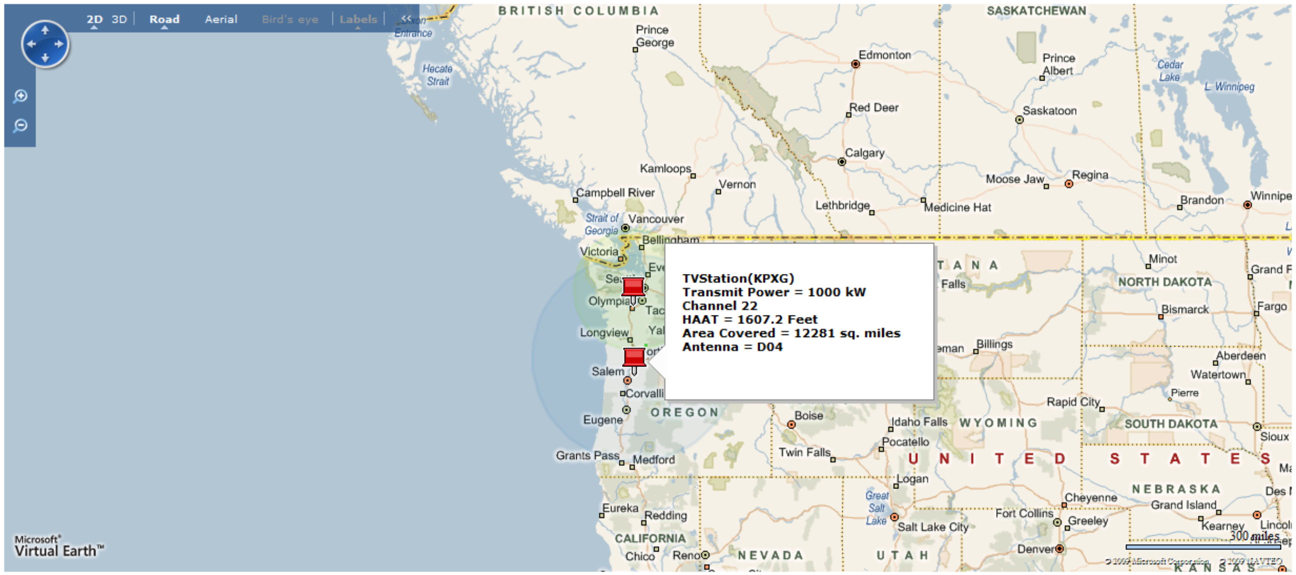
Channel Occupancy Database

http://bilispaces/WSWeb/whitespaces.aspx - Windows Internet Explorer



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26

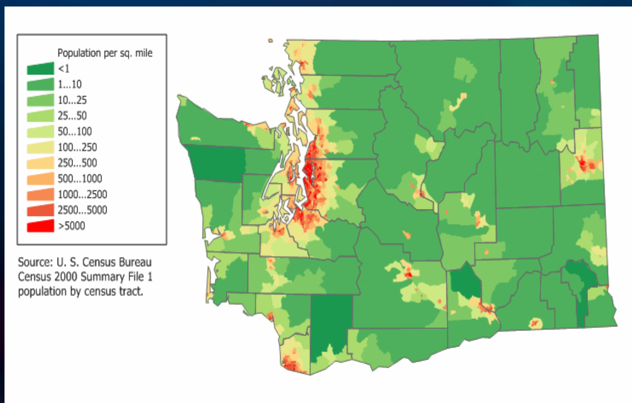
27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51

1113 108th avenue NE Bellevue, WA — Find Address — Show nearby incumbents

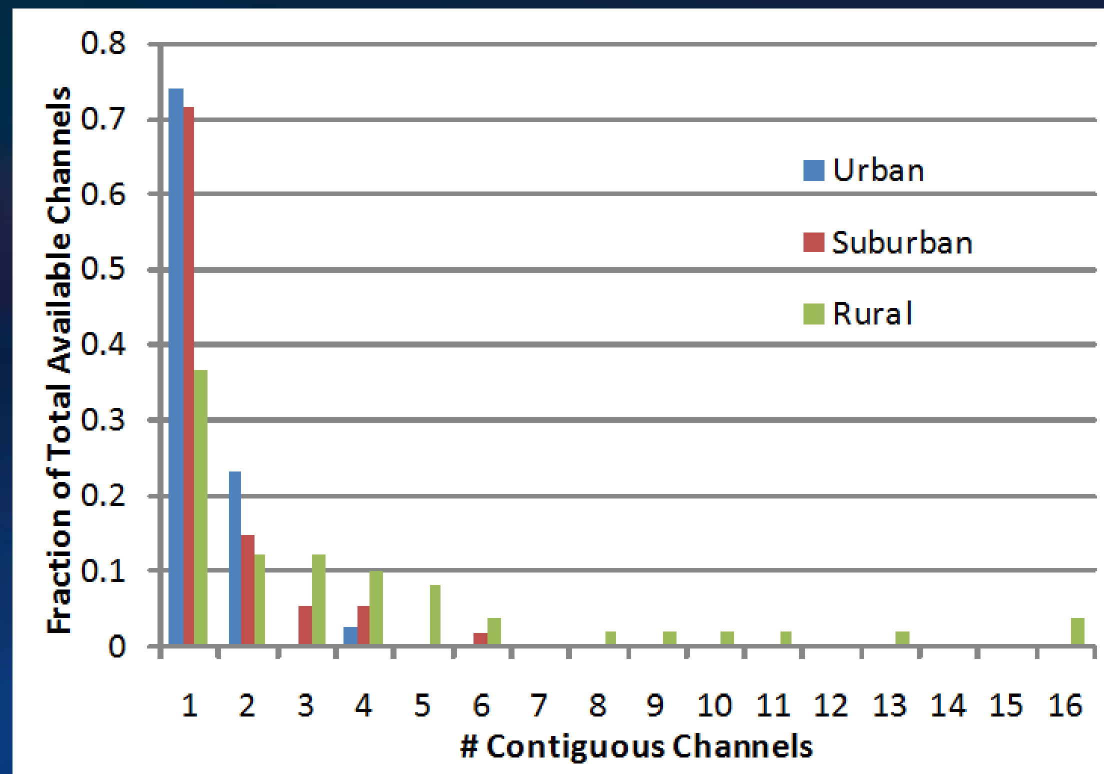
	Type	CallSign	Channel	Signal Strength	TX Power (kW)	HAAT (Ft)	Distance (miles)
Select	TVStation	KCTS-TV	9	-64.1007474959961 dB	7.488	826.56	5.20614711832987
Select	TVStation	KSTW	11	-61.1134486462909 dB	14.742	888.88	5.22154297158824
Select	TVStation	KCPQ	13	-82.3430401049163 dB	23.065	2000.8	28.8885939758145
Select	**TVStation**	**KTBW-TV**	**14**	**-85.2503204402321 dB**	**90**	**1551.44**	**28.3632217390623**
Select	TVStation	KBCB	19	-96.8761390639 dB	165	2482.96	79.0633718101955
Select	**TVStation**	**KPXG**	**22**	**-103.961651758942 dB**	**1000**	**1607.2**	**147.454283841686**
Select	TVStation	KMYQ	25	-50.6445579023998 dB	1000	951.2	5.1814998005338
Select	TVStation	KBTC-TV	27	-95.5920069466484 dB	47.2	734.72	27.910704896901
Select	TVStation	KPDX	30	-105.386869164038 dB	741	1731.84	147.510872238681

Geolocation

UHF TV Band Availability



(512MHz – 698MHz)



Spectrum availability mirrors population density

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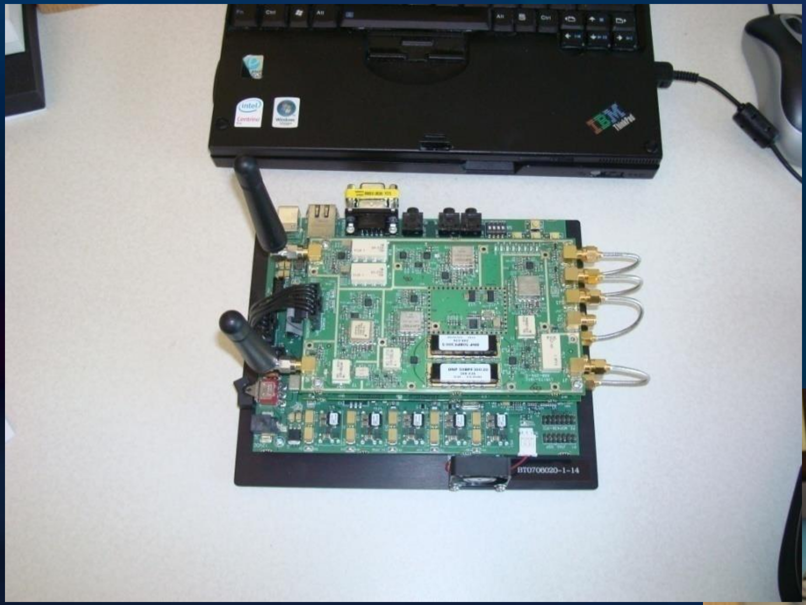
Hardware: Lyrtech SFF SDR



Lyrtech SFF SDR Development Platform

- Virtex-4 SX35 FPGA from Xilinx
- 0.2 – 1 GHz tunable , low-band RF
- Selectable bandwidth: 5 or 20 MHz
- Model based design

Allows us to carry out PHY level innovations

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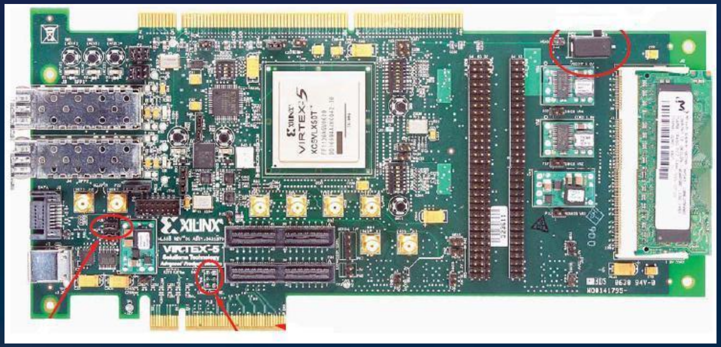
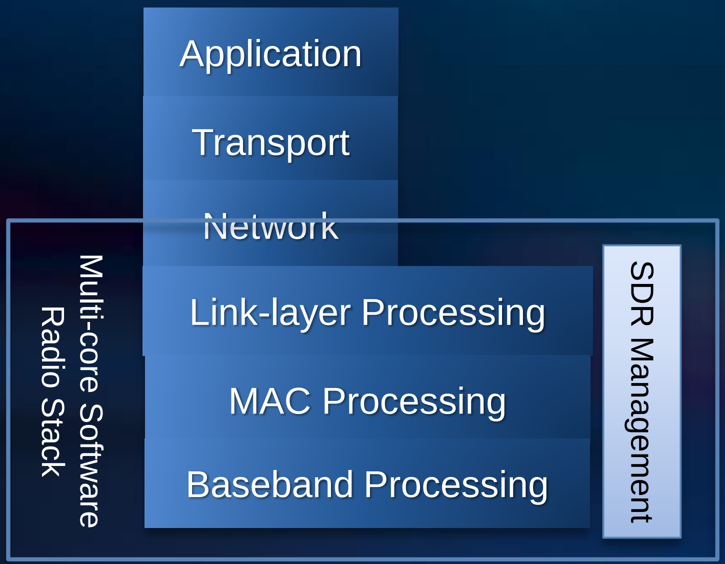
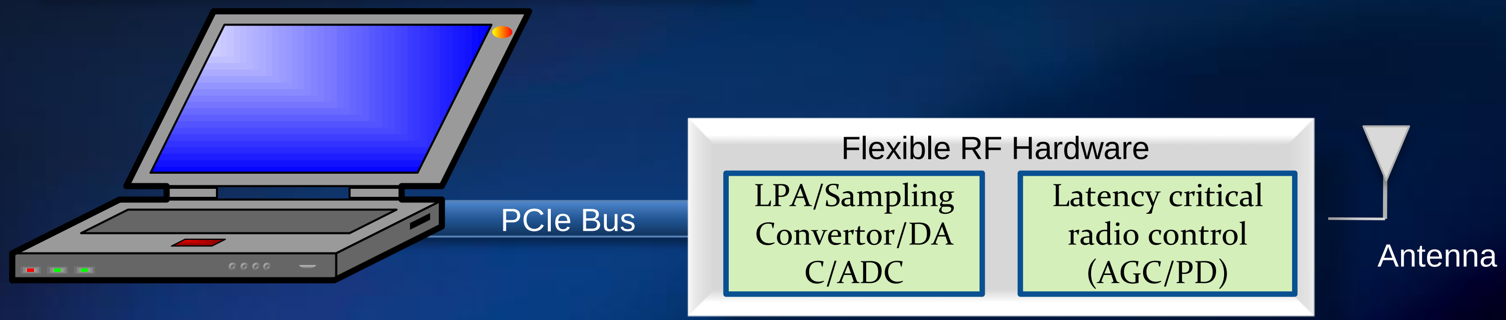
Future Hardware: SDR on Multicore with 700 MHz front-end





Multi-core Processors

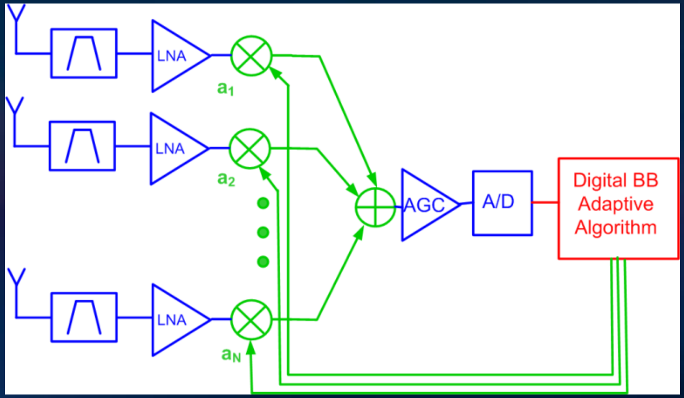
- Parallelization to accelerate PHY layer processing
- Exploit GPP architecture for BB processing
- Reduced heating



Ongoing work in MSR Asia

Hardware Challenges

- Wide band receiving
  - 200 MHz wide antennas for mobile units
  - Small signals need to be sensed in the presence of strong interference & then processed digitally
  - Places difficult requirements on RF front end and A/D



- Fast Sensing
  - Multi-antenna spatial processing
- Multiple radios per device
  - Interferance mitigation, power management

"Multiuser detection can completely remove interference"
– Prof. Andrea Goldsmith (Stanford University)

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Challenges

RF Related

- Asymmetry & fragmentation
  - Subcarrier suppression (SS) over a wide band
  - Subcarrier allocation
  - Channel bonding (CB)

Software Related

- Microphone sensing
- Cross-layer cognition
- Inter-node cooperation
- Protocols must
  - Allow opportunistic use
  - Be self regulating (Fair)
  - Be Load-aware

Theory & Modeling

- New tools, algorithms
- In single/multi-channel systems,
  → graph coloring problem.
- With contiguous channels of variable channel-width, coloring is not an appropriate model!
  → Need new models!

Build on knowledge acquired in V1 & V2

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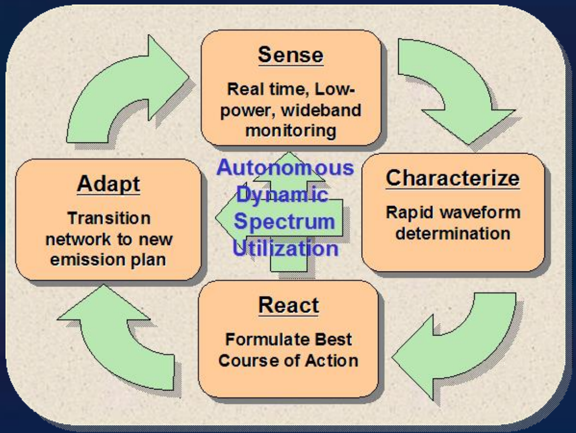
Related Effort & Resources

Government | Universities | Conferences | ….

Government

DARPA's XG program

- Tech. to dynamically access all available spectrum
- Goal : Demonstrate 10X increase in spectrum access



Universities

Carnegie Mellon University, Virginia Tech., Berkeley Wireless Research Center, University of Kansas, Aachen, Rutgers, …

Conferences & Workshops

IEEE DySPAN, CrownCom, CogNet, CogWiNets, CWNets, …

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Resources & Related Effort (Cont.)

…. Standards Companies

Standards

- IEEE 802.11k-2008 Radio Measurement
  - provides geo-location query/response and radio measurement operations

- IEEE 802.11h-2003 Spectrum and Transmission Power Management
  - Dynamic Frequency Selection (DFS) and Transmit Power Control (TPC)

- IEEE 802.22: Wireless Regional Area Network (WRAN) utilizing white spaces
  - Point to Multi[point (P2MP) operation (star topology)
  - BS deployed in neighborhood; Clints (CPE) are homes equipped with antennas (not mobile)
  - EIRP @ BS 4W - Range about 30 km
  - Distributed Sensing - CPEs will share sesing information with BS

Companies

Microsoft, Adaptrum, Motorola, Google, Phillips, HP, Dell, ….

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Key to Success:
Take a Comprehensive Approach

- Business models
- Strategic alliances
- Applications & Services
- Deployment economics

- Greater access
- Bridging the Digital Divide

Standards

- Lobbying the Regulators for open spectrum
- Etiquettes & policies

- DSA
- Harmonious existence
- Interoperability

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On March 3, 2009

ars technica

Law & Disorder : Ars covers the world of tech policy

Broadcasters sue FCC over white space broadband decision

The National Association of Broadcasters has asked a Federal court to shut down the FCC's authorization of white space devices. No details yet on *why* exactly NAB thinks the decision was illegal.

By Matthew Lasar | Last updated March 3, 2009 11:56 AM CT

Thanks

Q/A

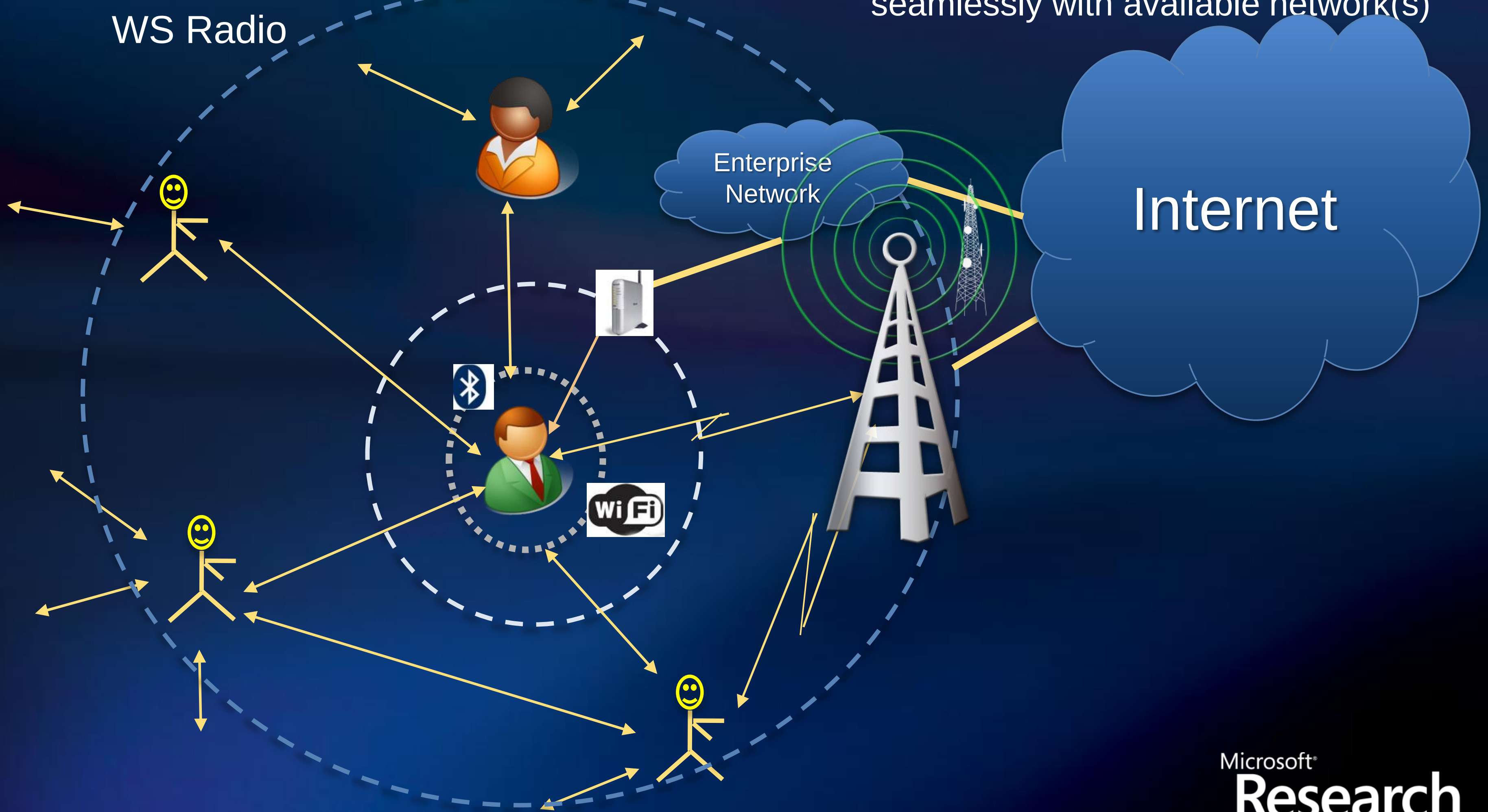
http://whitespaces
http://research.microsoft.com/nrg/

Appendix

Ubiquitous Personal Network

New WSD Scenario

- Personal private network
- **Free** high-bandwidth connectivity to devices & people
- No infrastructure required but interacts seamlessly with available network(s)



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Cognitive Wireless Networking

Location & Context Awareness

+

Spectrum Aware Networking

+

Intention Aware Networking

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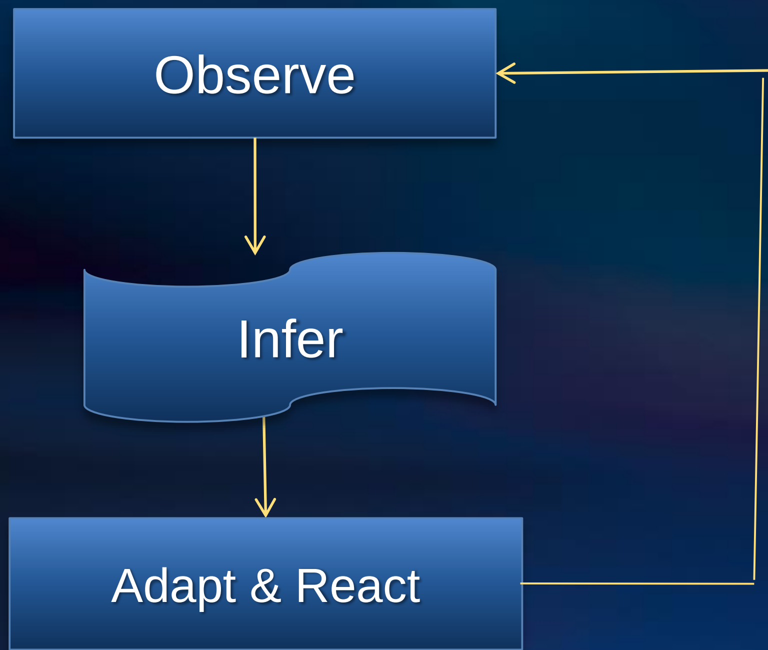
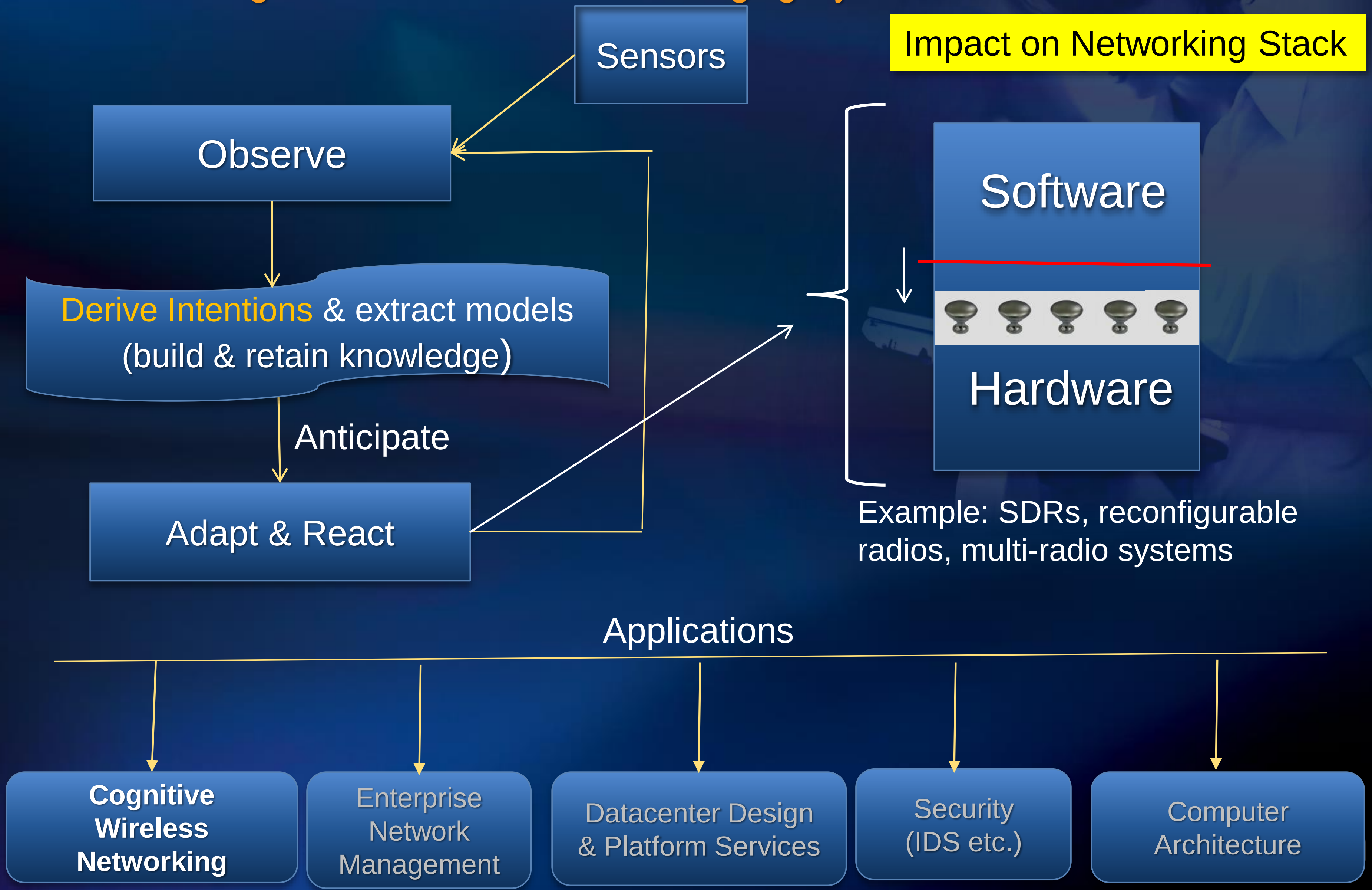
Networking



Examples: TCP, CSMA/CA, Autorate, AD, ….

Intention Aware Networking

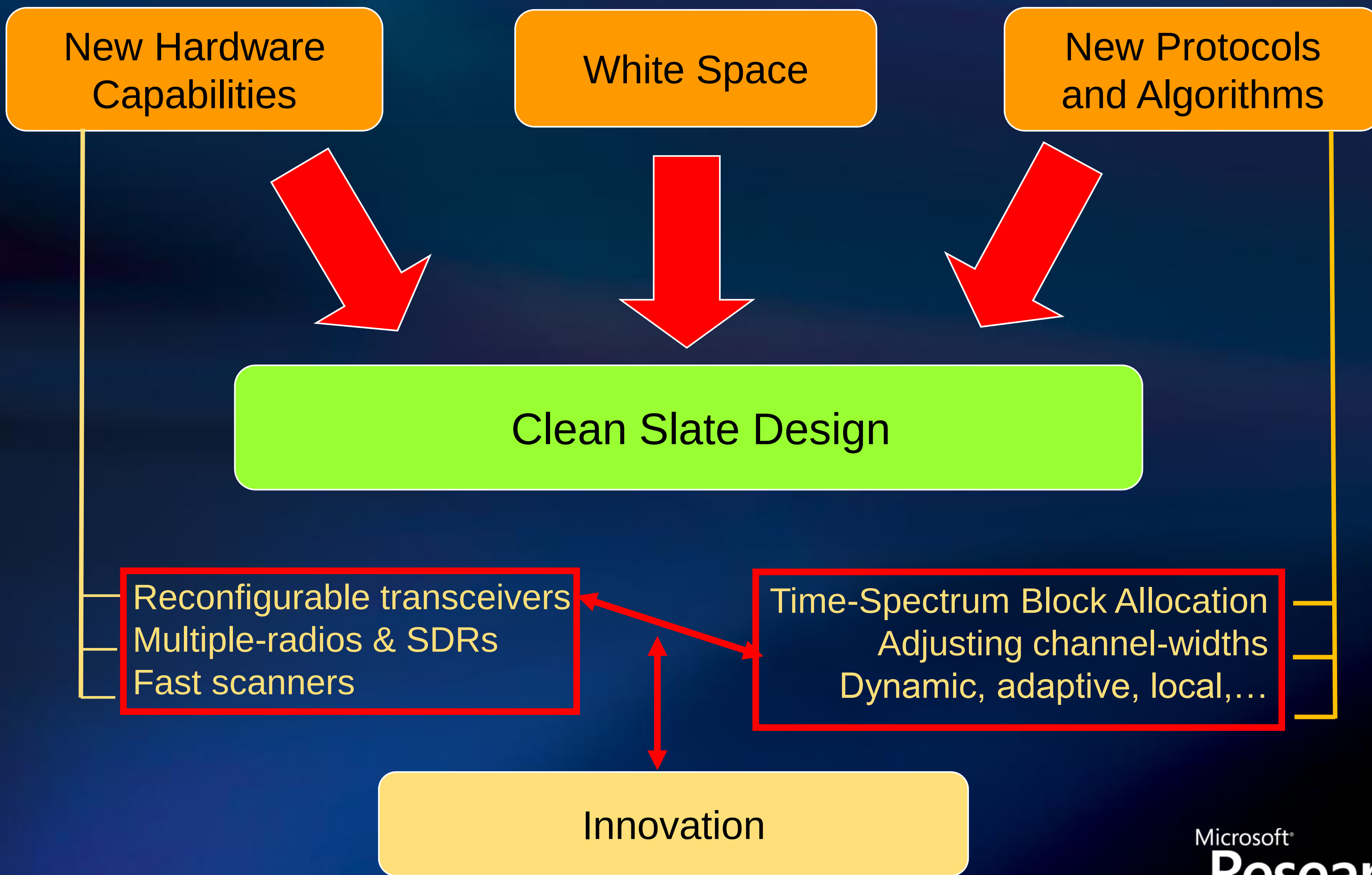
Understanding End-to-End Goals and Managing Dynamism



Spectrum Management

DySpan 2007

Opportunity for Clean-Slate Design



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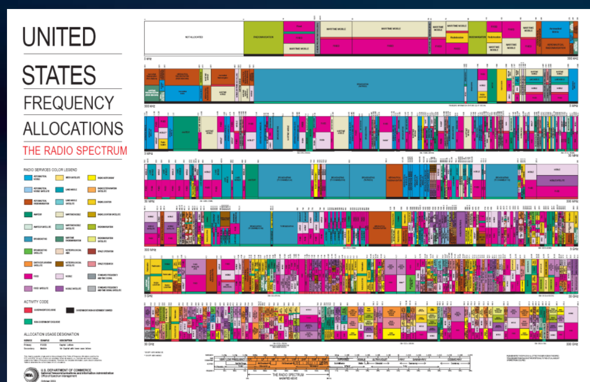
Brodersen's assertion….

MSR Cognitive Summit 2008

- The concept of fixed frequency spectrum allocation has become fundamentally flawed



Shared Spectrum
Shared Spectrum
Shared Spectrum
Shared Spectrum
Shared Spectrum
Shared Spectrum
Shared Spectrum

- We must exploit wireless communication strategies that exploit the time, space and frequency degrees of freedom

- Exploiting these new approaches could allow essentially "unlimited capacity"

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Where are we headed?

- Revisiting high impact scenarios:
  Community mesh networking, Rural networking, Zune social, home LANs, …
- Developing new scenarios with intention aware networking
  UPN, All-Wireless Office, Guardian Phone (with UCLA),..
- Pushing hard on the intention-aware networking & software-hardware boundary
  Adding Cognition
- Driving towards consensus development
  Evangalism, papers, talks, summits…

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