Microsoft Research

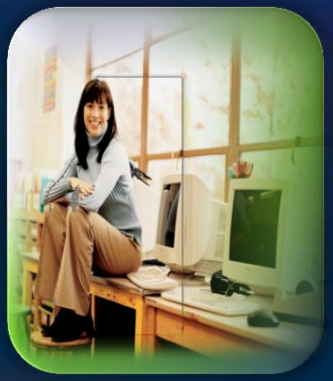
# *Owing the Problem: Opportunistic Dynamic Spectrum Access*

Victor Bahl
Microsoft Research

# Starting with the Big Picture

Healthcare

Education



Rural Connectivity

Science & Eng. Innovation

Energy & Environment

Broadband Foundation

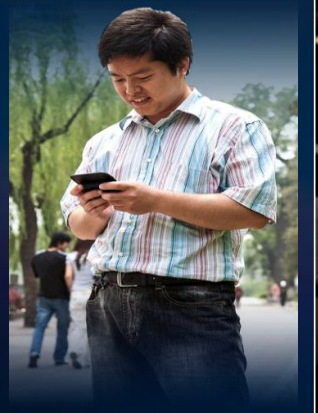
# Thinking of Compelling Scenarios

Smart Homes

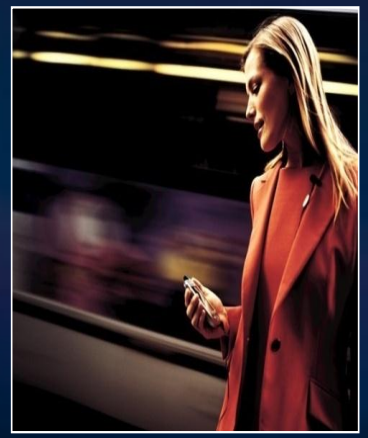
Smart & Safe Transportation

Global Resources, Local Care

Clients + Cloud



Ubiquitous Coverage



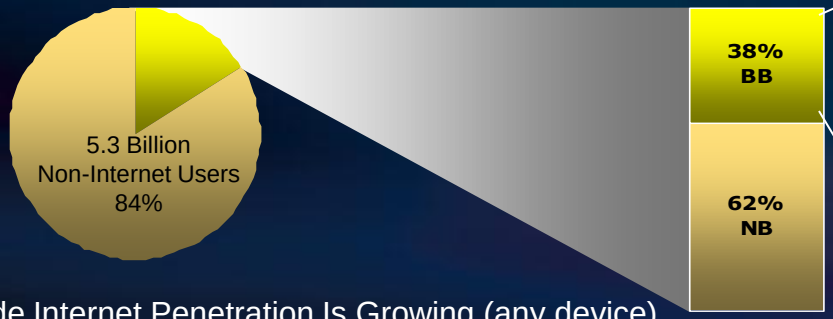
What technologies you need to create to make these scenarios real? What Govt. policies will enable you to move forward and make the breakthroughs?

# The Potential of Connected Services

## Worldwide Internet Penetration < 20%

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

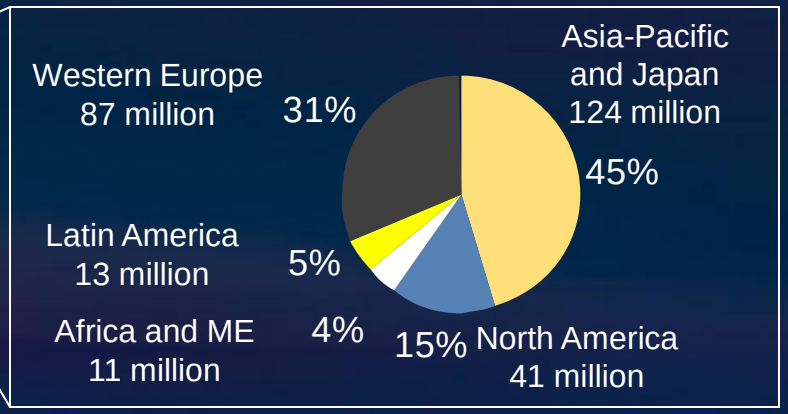
1 Billion Internet Users Worldwide




Worldwide Broadband versus Narrowband Penetration (% Internet accounts)

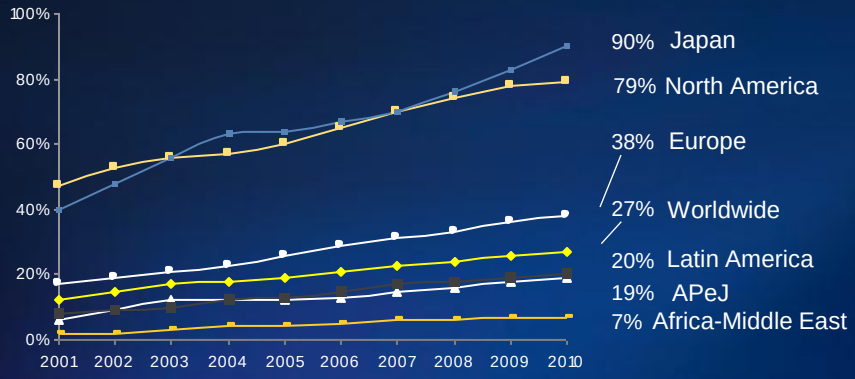



Broadband Users Worldwide (Millions)




Worldwide Internet Penetration Is Growing (any device)

Internet Penetration by Region (% of Households)

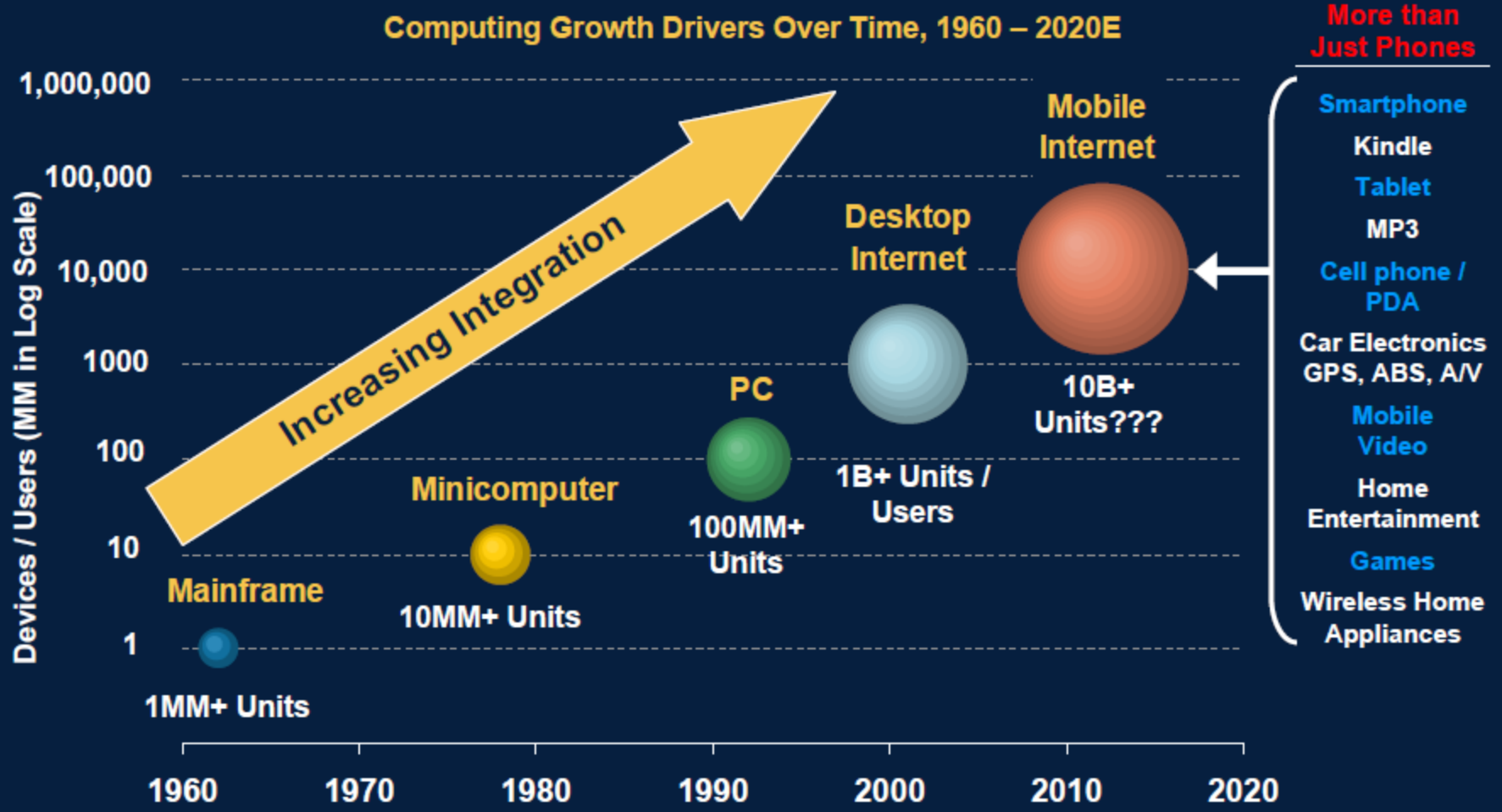



Broadband penetration is the prime lever of Internet activity growth

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

# New Computing Cycle Characteristics

## Reduce Usage Friction Via Better Processing Power + Improved User Interface + Smaller Form Factor + Lower Prices + Expanded Services = 10x More Devices




Source: ITU, Mark Lipacis, Morgan Stanley Research.

# Fact: Usage is Going up!

- Wireless use is on the rise
  - 56% of Americans have accessed Internet via wireless networks
  - 39% of adults access it through wireless laptop; 1/3rd of all Americans through cell phones & SmartPhones; 1/5th of Americans access Internet everyday via a mobile device (Pew Internet & American Life Project, April 2009)

- Consumption of data per user is going up
  - Social networking (e.g. micro-blogging), multimedia downloads (e.g. Hulu, YouTube), Gaming (e.g. Xbox Live), 2D video conferencing (e.g. Windows Live), file sharing & collaboration (e.g. SharePoint), Cloud Storage (e.g. Azure),…

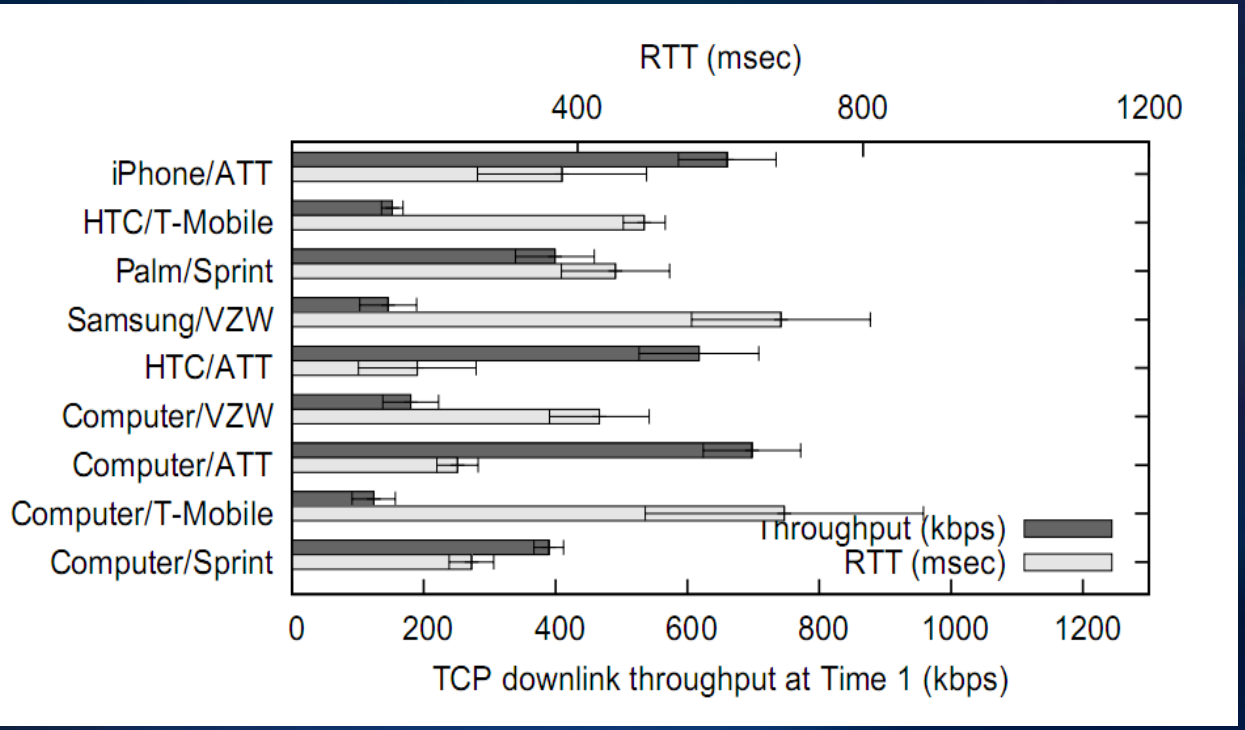
- NextGen Applications at Microsoft Research
  - Immersive video conferencing, 3D Telemedicine, Virtual immersive classrooms, Remote health monitoring,, Augmented reality, Memory assistance, Natural gesture computing, Collaborative development,…..

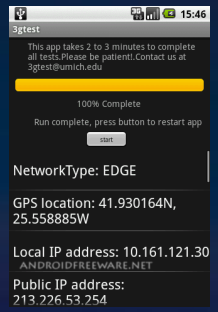
# 3G WAN throughput & Latency

MobiSys 2010

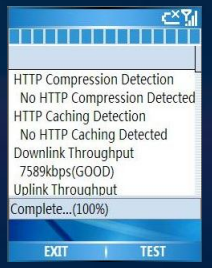
## not enough for next generation applications

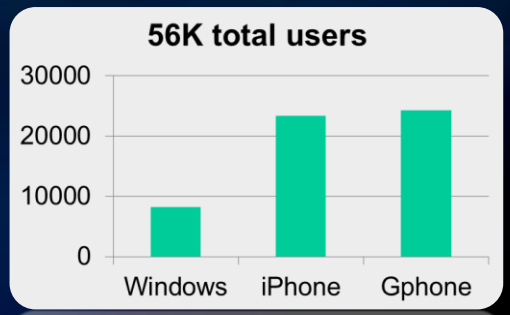
http://www.eecs.umich.edu/3gtest



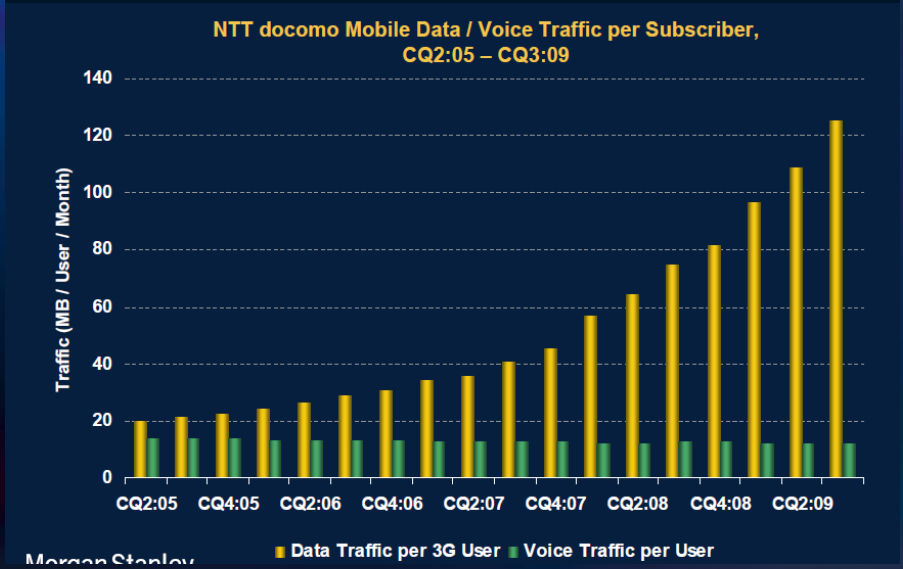







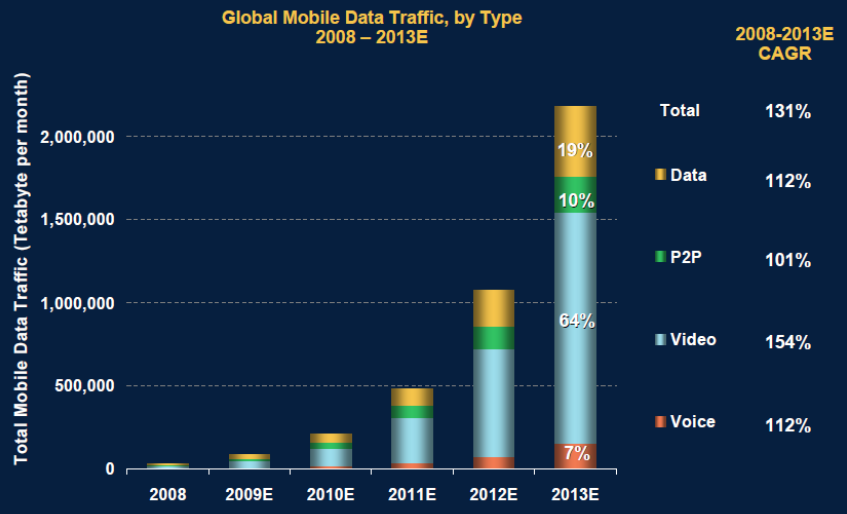



## NTT docomo (Japan) Data Traffic Growing at +54% CAGR, Voice Traffic Declining at -2% CAGR




## Video Driving Rapid Growth in Mobile Internet Traffic

Mobile Data Traffic to Rise 66x by 2013E (131% CAGR)




Cisco Visual Networking Index – Mobile Data Traffic Forecast, 2008-2013, 2/09

msnbc

**FCC warns of mobile's looming spectrum crisis**

**Predicted jump in wireless traffic will require more bandwidth for devices**

PCMAG.COM

**AT&T: Give Us Spectrum, Not Rules**

CTIA The Wireless Association®

**CTIA: 800 MHz of more spectrum needed to meet capacity needs**

# Fact: Capacity is Finite!

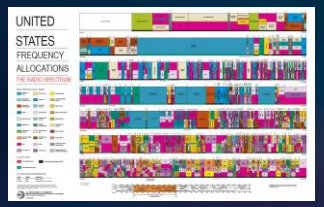
- Shannon's law sets a limit to what is achievable
  - Limit set by thermal noise (~20 dB) ; SNR is a function of B
- Engineering innovations help but the limit still exist
  - Turbo coding is within a few dBs of the Shannon limit
  - MIMO & Cooperative MIMO still has issues
    - Antennas placement & size is an issue AND Shannon limit still holds
    - Greater Processing = battery drain
  - Network coding
    - Depends heavily on traffic patterns
  - Receiver sensitivity is already quite good (also expensive)
  - MAC and transport protocols (TCP) are wireless aware, Limited improvement possible
  - Reduce cell size & increase spatial reuse
    - Network management headaches (interference, channel collisions etc.)
    - Expensive

AT&T Femtocell

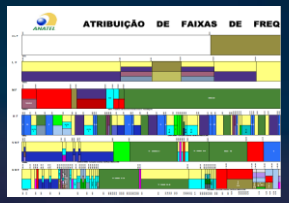
# What can we do?

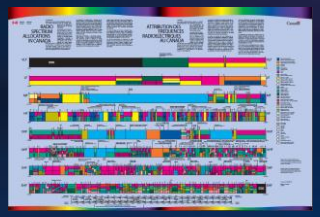
- Extract greater juice, push new network architectures
- Fatten the pipes - open up additional spectrum

US

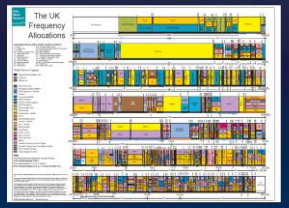



Brazil



Canada

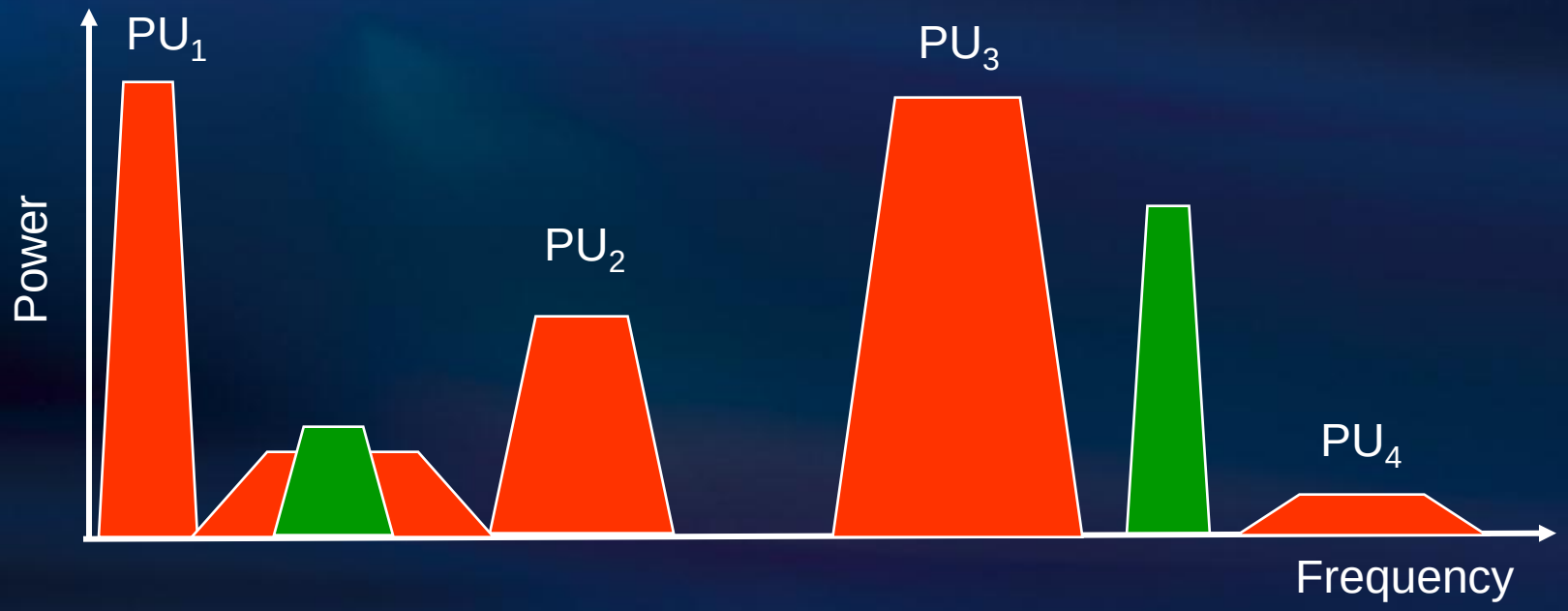



U.K.

A mix of licensed and unlicensed spectrum
Set policies & rules that lead to world-wide harmonization

- Promote secondary market place
  - Fairness? Engineering?
  - But can be a win-win situation
- Promote opportunistic and dynamic spectrum access technologies

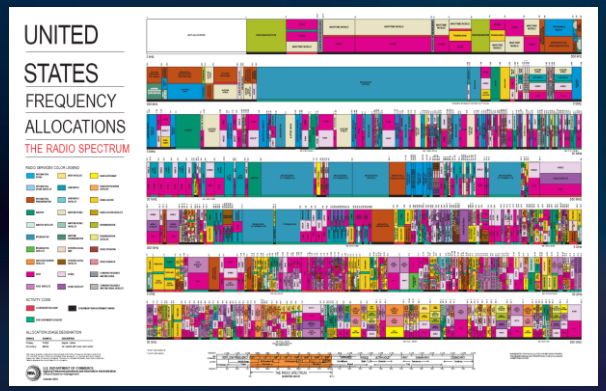
# Opportunistic Use

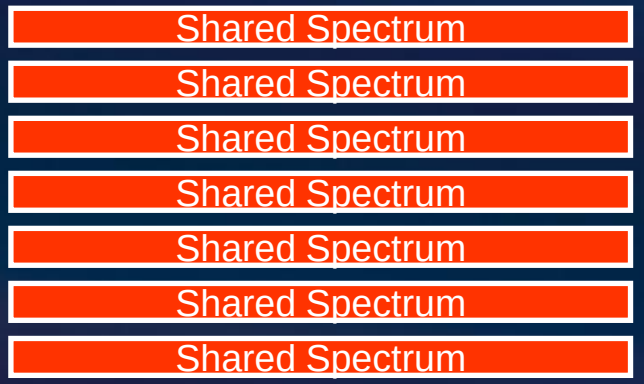



- **Sense** the spectral environment over a wide bandwidth
- **Transmit** in “White Space”
- **Detect** if primary user appears
- **Move** to new white space
- **Adapt** bandwidth and power levels to meet requirements

# Thinking Boldly….

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




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

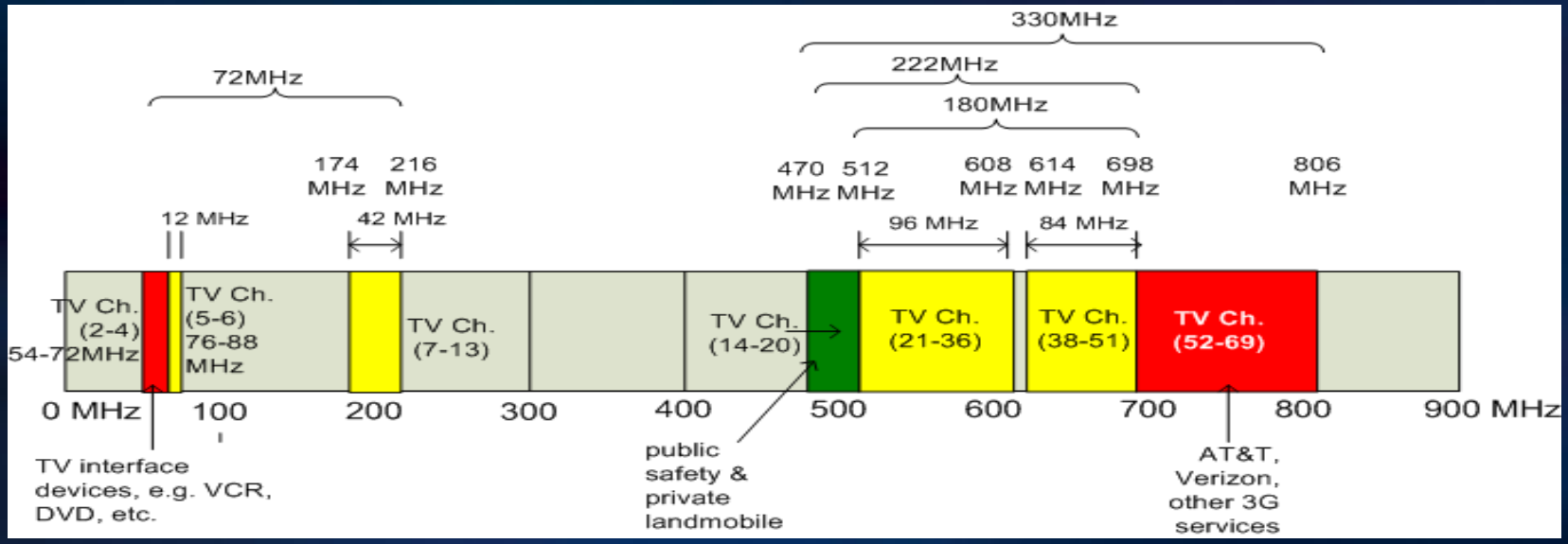
- Exploiting these new approaches could allow essentially “unlimited capacity”

Microsoft Research

White space data networking is the first main-stream manifestation of an opportunistic dynamic spectrum access network. It has captured the imagination of the world - let's get it right!

# US White Spaces

Unused VHF & 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)

# FCC Adopts Rules For Unlicensed Use Of Television White Spaces

November 4, 2008


msnbc

search site

Web

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

MarketWatch

MarketWatch Holiday Gift Guide - Read it now

FRONT PAGE NEWS & COMMENTARY INDUSTRY NEWS TECHNOLOGY

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


Wednesday, December 3, 2008

Will 'White Space' ruling stimulate our sagging economy?


TV TECHNOLOGY

THE DIGITAL TELEVISION AUTHORITY

Serving the Broadcast, Cable, Production, Postproduction, Business and New Media Markets

CHANNELS AUDIO ENG OPERATIONS INFRASTRUCTU

RESOURCES

RF TechnologyProduction Manager

A Landslide for White Spaces

by Sanjay Talwani, 12.03.2008

# 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.

Microsoft Research

# 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 |

# Around the World

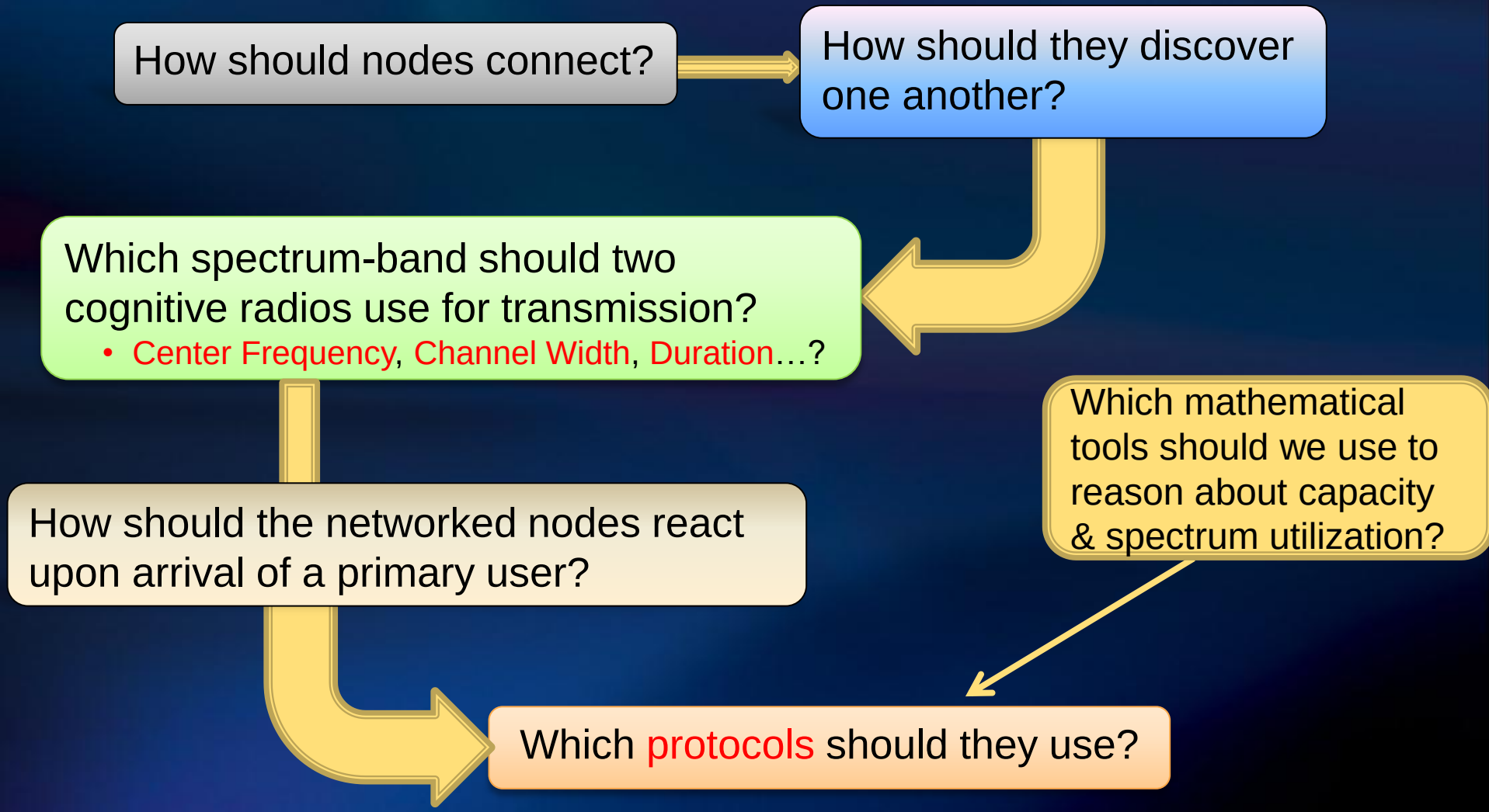
- Digital Switchover (DSO) in the UK will complete in 2012
  - 128 MHz in UHF band (470-862MHz)  [verus 282 MHz in the US]
  - 8 MHz / channel; channels  21-30 , 63-68
  - Referred to as "interleaved spectrum"
- Sweden, Finland, Norway, France and Switzerland have announced their digital dividends
- Other countries likely to follow: Germany, Denmark, Netherlands, Czech Republic, Hungary, Ireland

# White Spaces Explained - Video

# MSR's KNOWS Research Program

## Networking Challenges

MobiHoc 2007



# MSR's KNOWS Program
## Prototype Development

### Version 1: Ad hoc networking in white spaces

- 700 MHz operation, TV sensing capability, one-to-one opportunistic networking, control-channel based MAC, varying channel width operation, multi-radio design, design analysis through simulations

### Version 2: Infrastructure based networking (WhiteFi)

- White Space freq. operation TV sensing Capability, limited microphone sensing, one-to-many opportunistic networking, Wi-Fi MAC, time-domain analysis (SIFT), demo-ed at internal events (e.g. TechFest 2009)

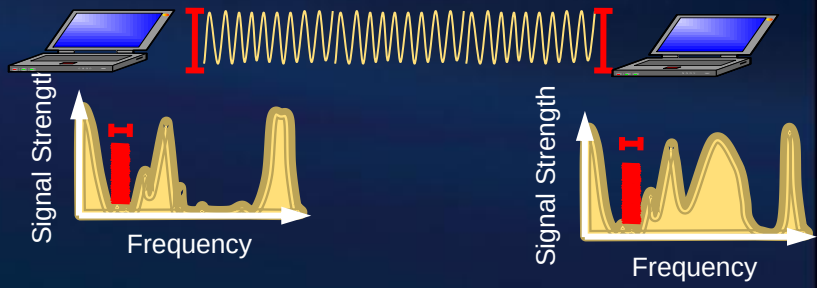
### Version 3: Campus-wide backbone network (WhiteFi with Geolocation)

- All of V2 + geolocation DB, Windows network stack improvements, bridging between Wi-Fi and WhiteFi, coverage in MS Shuttles

# Version 1: Major Innovations

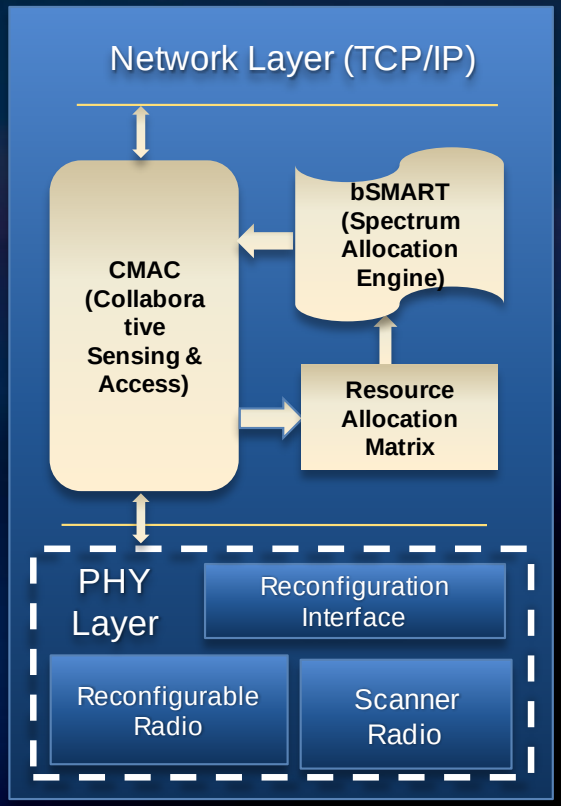
SIGCOMM 2007, DySPAN 2007

- Dynamic Channel Width
  - Varying channel width can reduce energy consumption, increase range & improve spectrum utilization




- Time Spectrum Block
  - Communicate by allocating TSBs defined as $\{F_c, dF\}$ & $\{T_b, dT\}$. A distributed (fair) algorithm for determining TSBs is possible

- Control Channel based Medium Access Control
  - Wi-Fi MAC modified to accommodate opportunistic networking



# Lingering Questions

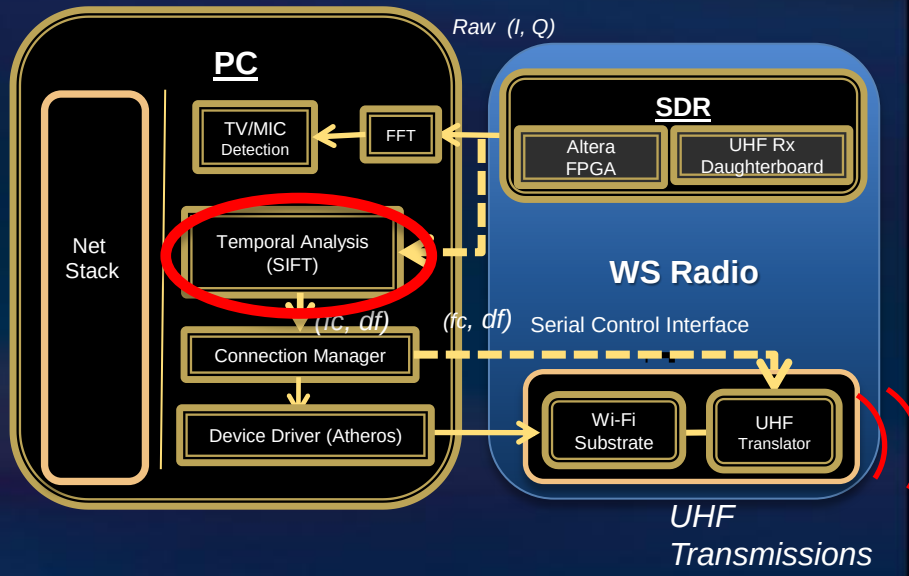
- KNOWS v1 was a multi-radio system
  - Can we build a single-radio WS network?
- KNOWS v1 was a ad hoc network for portable devices
  - Is the design optimum for fixed WS networks?
- KNOWS v1 required a control channel that can be compromised easily
  - Can we do without a control channel?
- KNOWS v1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

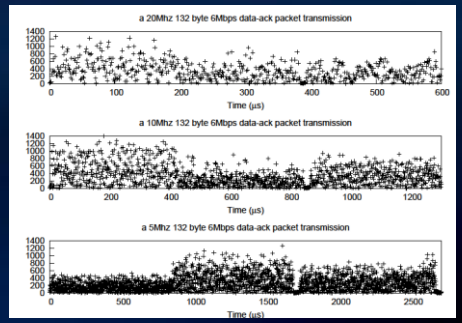
…can we do better?

# Version 2: Major Innovations

Best Paper
SIGCOMM 09

- Eliminated Control Channel & reused Wi-Fi
- 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

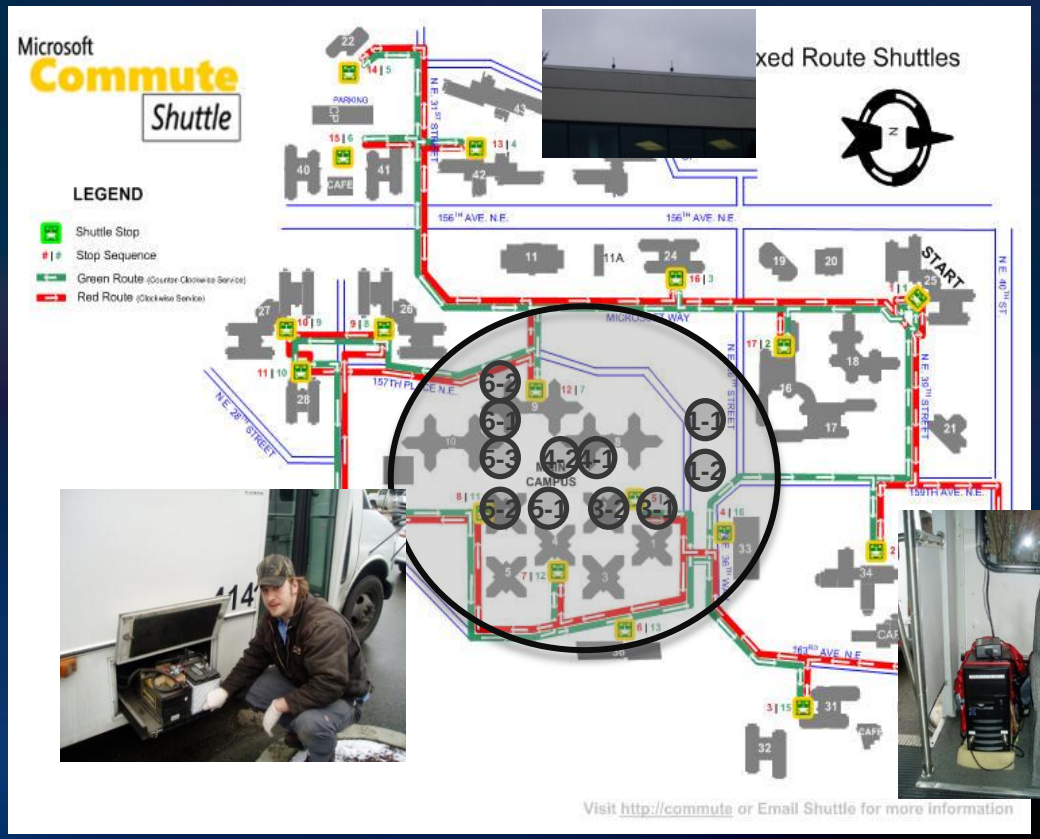


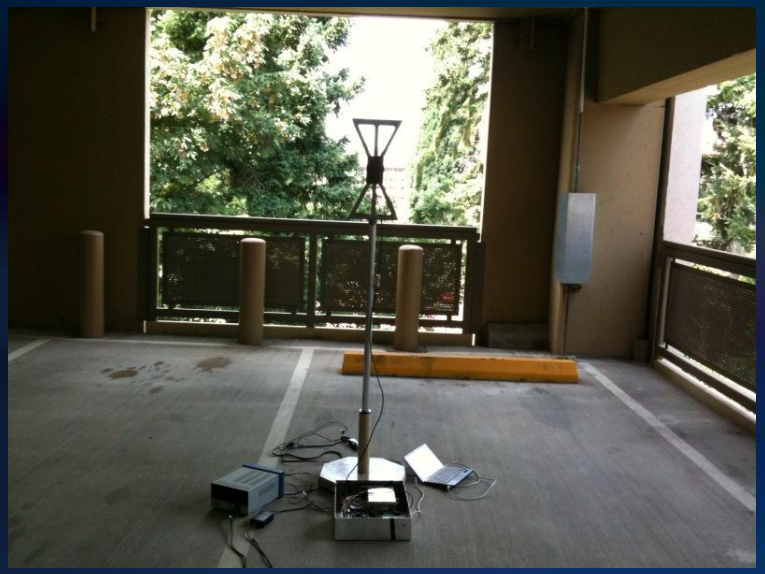
# Version 3: Campus Wide White Space Networking (WhiteFi w. Geolocation)

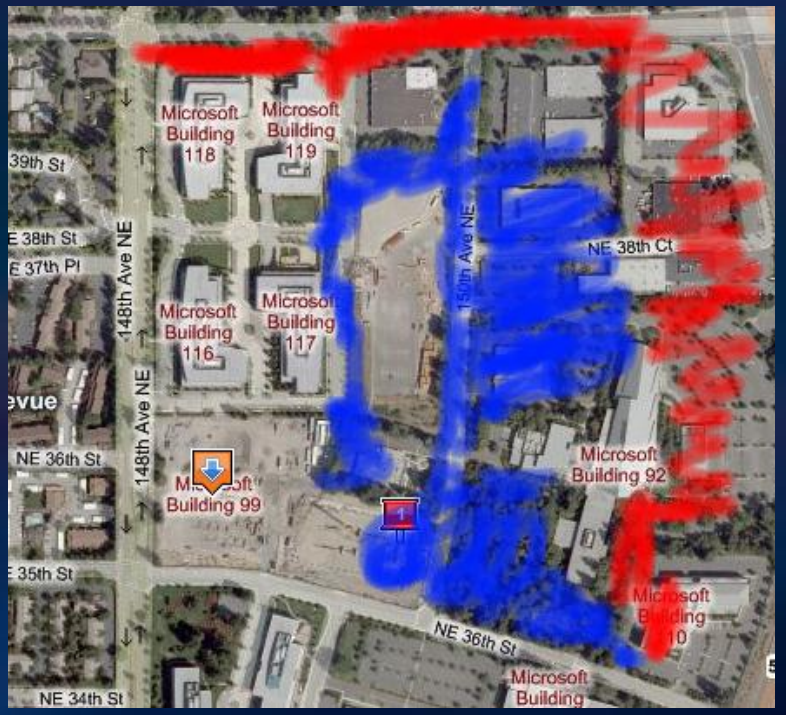
## FCC Experimental License **(Granted: July 6, 2009)**

- 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 2 W EIRP
- WSD inside shuttles at 63 mW

# Range: Does Theory match up?



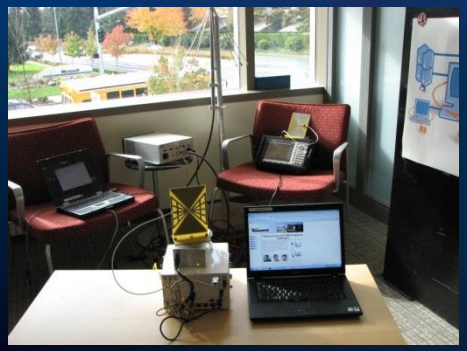



Real life: Range is > 5 times Wi-Fi range
(using the same parameters)

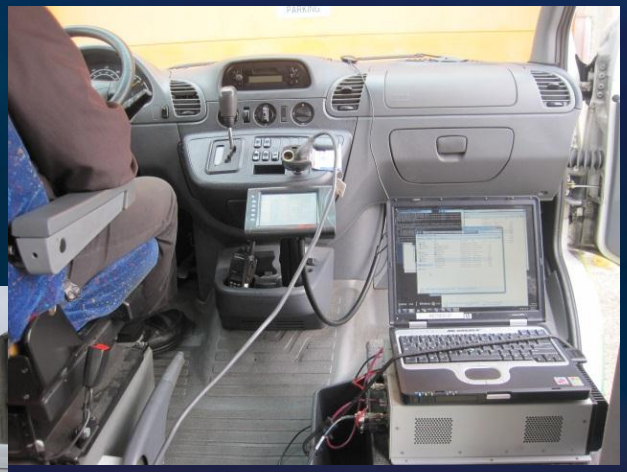
# First White Space Network in the World

Oct. 16, 2009

White Space Network Setup



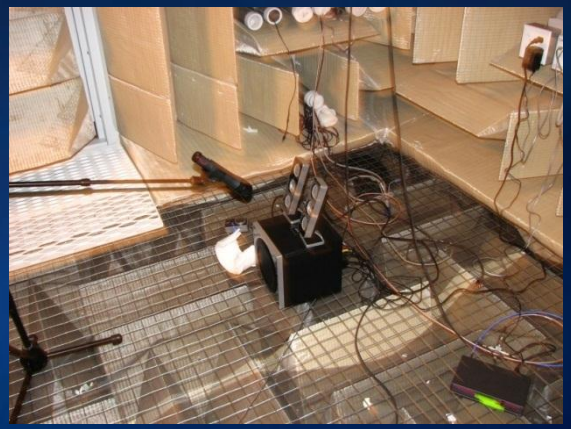
Shuttle Deployment



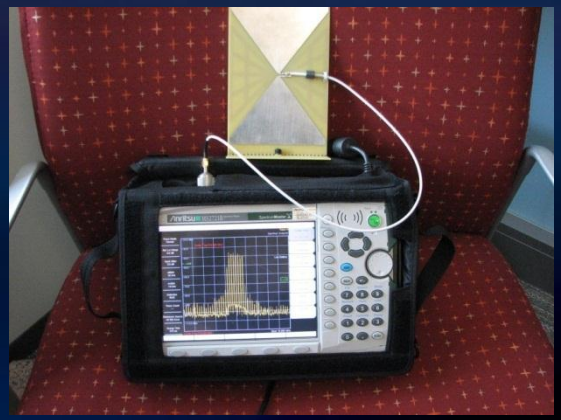
WS Antenna on Bldg 42


WS Antenna on MS Shuttle

Subcarrier Suppression demo



Microphone testing in Anechoic Chamber

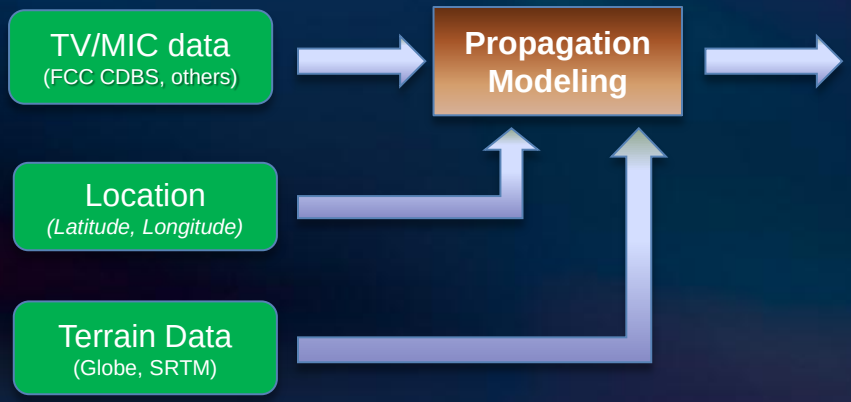


Data packets over UHF

# WhiteSpaceFinder: White Space Geo-Location Service

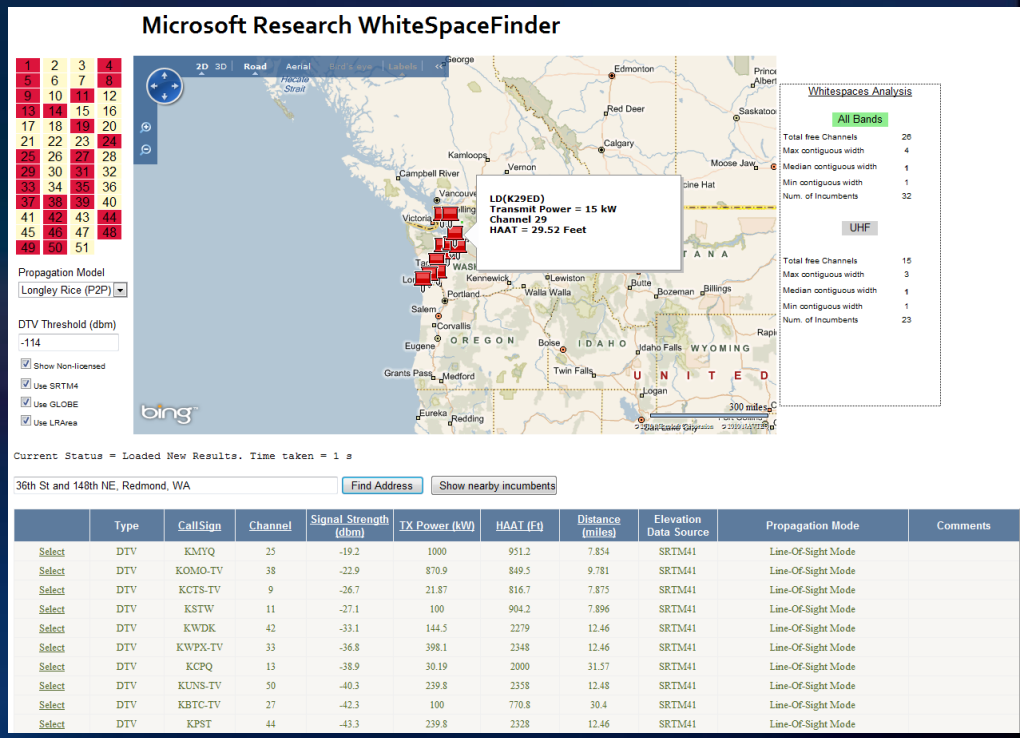
http://whitespaces.msresearch.us

April 7 2010




<primary user [ ], signal strength [ ] at location>

**ASP.NET implementation using SOAP extensions**




| | Type | CallSign | Channel | Signal Strength (dbm) | TX Power (kW) | HAAT (Ft) | Distance (miles) | Elevation Data Source | Propagation Mode | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| Select | DTV | KMYQ | 25 | -19.2 | 1000 | 951.2 | 7.854 | SRTM41 | Line-Of-Sight Mode | |
| Select | DTV | KOMO-TV | 38 | -22.9 | 870.9 | 849.5 | 9.781 | SRTM41 | Line-Of-Sight Mode | |
| Select | DTV | KCTS-TV | 9 | -26.7 | 21.87 | 816.7 | 7.875 | SRTM41 | Line-Of-Sight Mode | |
| Select | DTV | KSTW | 11 | -27.1 | 100 | 904.2 | 7.896 | SRTM41 | Line-Of-Sight Mode | |
| Select | DTV | KWDK | 42 | -33.1 | 144.5 | 2279 | 12.46 | SRTM41 | Line-Of-Sight Mode | |
| Select | DTV | KWPX-TV | 33 | -36.8 | 398.1 | 2348 | 12.46 | SRTM41 | Line-Of-Sight Mode | |
| Select | DTV | KCPQ | 13 | -38.9 | 30.19 | 2000 | 31.57 | SRTM41 | Line-Of-Sight Mode | |
| Select | DTV | KUNS-TV | 50 | -40.3 | 239.8 | 2358 | 12.48 | SRTM41 | Line-Of-Sight Mode | |
| Select | DTV | KBTC-TV | 27 | -42.3 | 100 | 770.8 | 30.4 | SRTM41 | Line-Of-Sight Mode | |
| Select | DTV | KPST | 44 | -43.3 | 239.8 | 2328 | 12.46 | SRTM41 | Line-Of-Sight Mode | |

## Features

- Can configure various parameters, e.g.
  - — propagation models: L-R, Free Space, Egli
  - — detection threshold (-114 dBm by default)
- Protection for MICs by adding as primary user
- Accuracy:
  - combines terrain sources for accurate results
  - results validated across1500 miles in WA state
- Includes analysis of white space availability
- (forthcoming) Internationalization of TV tower data

## Collaborators

Chanel occupancy database design & related issues

White space mesh networks for rural communities

Harmonization between heterogeneous white space networks

Security & Privacy In white space networks

# WhiteFi and Broadcast TV

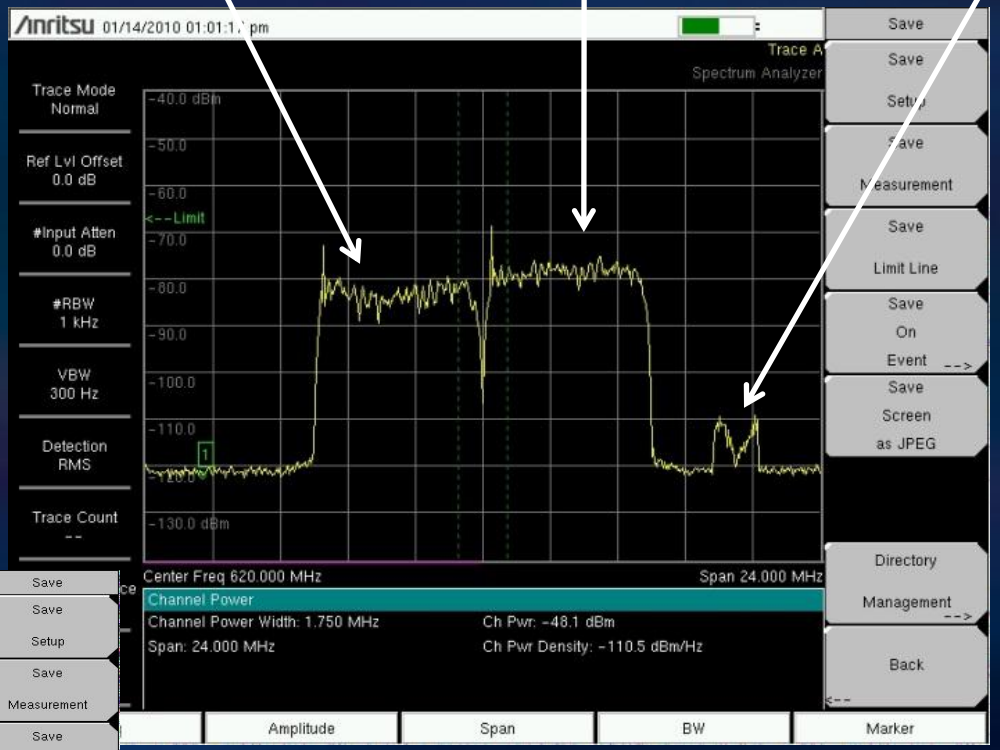
WhiteFi Antenna

TV Antennas

KOMO (Ch. 38)

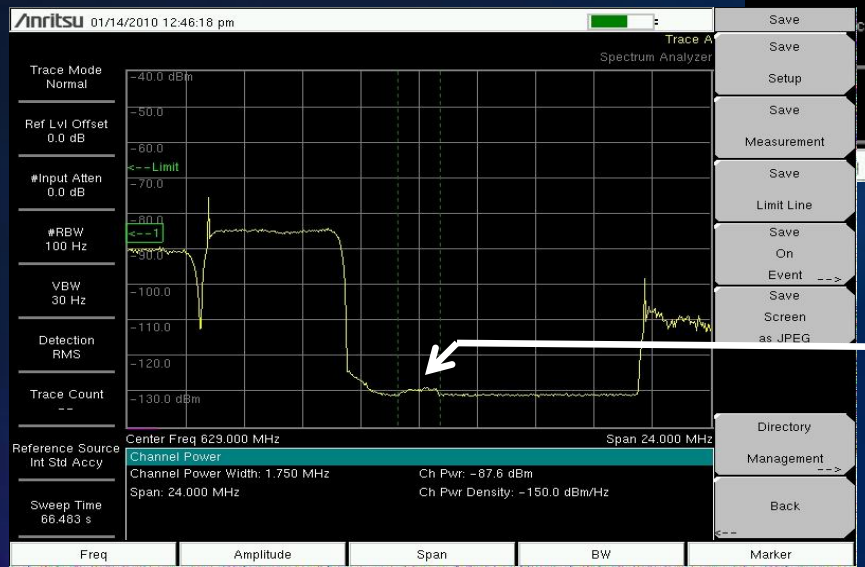
KIRO (Ch. 39)

WhiteFi (Ch. 40)



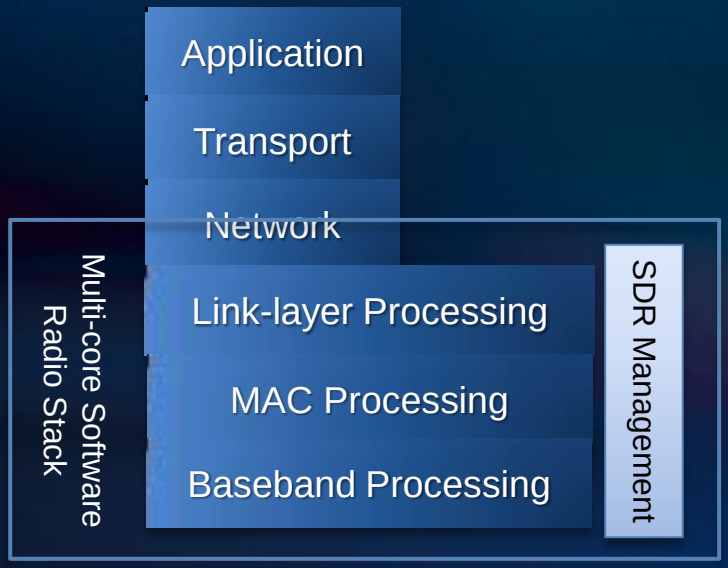

WhiteFi transmitting at 40 mW

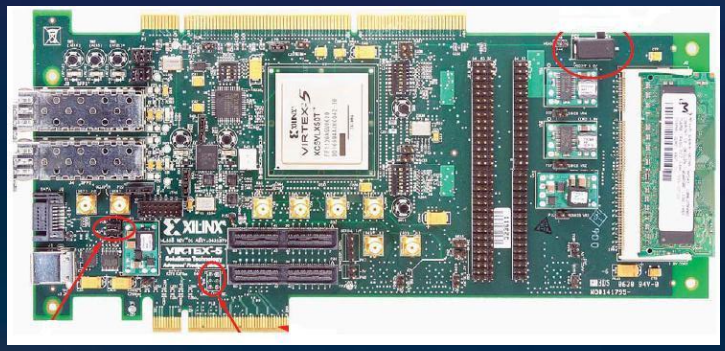
WhiteFi (Ch. 40)



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

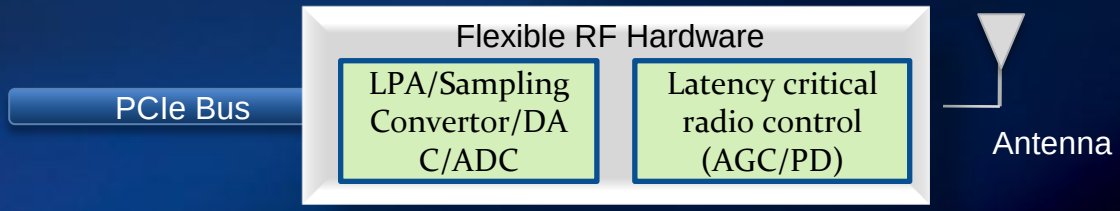
Best Paper
NSDI 2009



**Multi-core Processors**

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




Ongoing work in MSR Asia

# Policy & Research Funding Engagement

- Panel on "*Broadband Spectrum: A Looming Crisis*?" FCC's National Broadband Plan -- Field Hearing on Mobile Broadband, San Diego, CA, Oct. 8, 2009

- Panel on "*Innovating in Spectrum Access—Technological Advances and Other Approaches to Facilitate More Productive Spectrum Use*" FCC's National Broadband Plan -- Spectrum Workshop, Washington D.C. Sept. 17, 2009

- Panel on "*Research Recommendation for Broadband Task Force*," Federal Communications Commission's National Broadband Workshop, Washington, DC (Nov. 23, 2009)

- Panel on *Reactions and Perspectives*, National Science Foundation Workshop on Future Wireless Communication Networks, Arlington, VA (Nov. 2-3, 2009)

# Public Demos & Policy Influence

Telecom Regulatory Authority of India
(An ISO 9001-2000 Certified Organisation)

India

Federal Communications Commission

ITU International Telecommunication Union

Radiocommunication Sector

iDA SINGAPORE

国家广播电影电视总局
SARFT THE STATE ADMINISTRATION OF RADIO FILM AND TELEVISION
WWW.SARFT.GOV.CN

China

ANATEL
Provedor Licenciado pela Anatel

Brazil

IEEE

Standards

KOMO 4

Fisher Communications Inc.

LABS hp

Industry Partners

FCC Federal Communications Commission

Policy

# Collaborations

Chanel occupancy database design & related issues

White space mesh networks for rural communities

Harmonization between heterogeneous white space networks

Security & privacy in white space networks

Smart antennas, interference mitigate & internationalization

The SORA Program

Steering Committee

Special Issue Editor

MSR Event

# Good Press Helps

SOFTPEDIA®

White Fi, Long-Range Wireless Internet Using White Spaces

A new research project from Microsoft and Harvard could pave the w long-range wireless networking

seattlepi

WhiteFi: Broadcasting wireless Internet over TV airwaves

Business Line

Tapping space between used spectrum

White-Fi tech from Microsoft

homas K. Thomas
*New Delhi, Dec. 3*

According to Mr Mitchell, White-Fi is much more pow-

Technology Review
PUBLISHED BY MIT

Wi-Fi via White Spaces

A network design that uses old TV s long-range wireless connectivity.

By Erica Naone

ars technica

WiFi on steroids? First "WhiteFi" prototypes hit testing stage

By Nate Anderson | Last updated August 27, 2009 8:23 AM

GIGAOM

Microsoft Makes White-Spaces Breakthrough for Rural Broadband

By Simon Juran | Aug. 18, 2009, 10:56am PST | 1 Comment

engadget

Microsoft still hot for white space, describes WhiteFi wireless tech

*By Tim Stevens posted Aug 19th 2009 8:11AM*

cnet

August 19, 2009 3:56 PM PDT

Microsoft details a fix for 'white space' interference

iStockAnalyst

'White-Fi' making waves

Sunday, January 31, 2010 2:49 PM

WhiteFi: ¿El sucesor de Wifi?

*Por: Kir Ortiz @ martes, 25 de agosto de 2009 Nota vista 4479 veces*

硬派 INPAI .com.cn

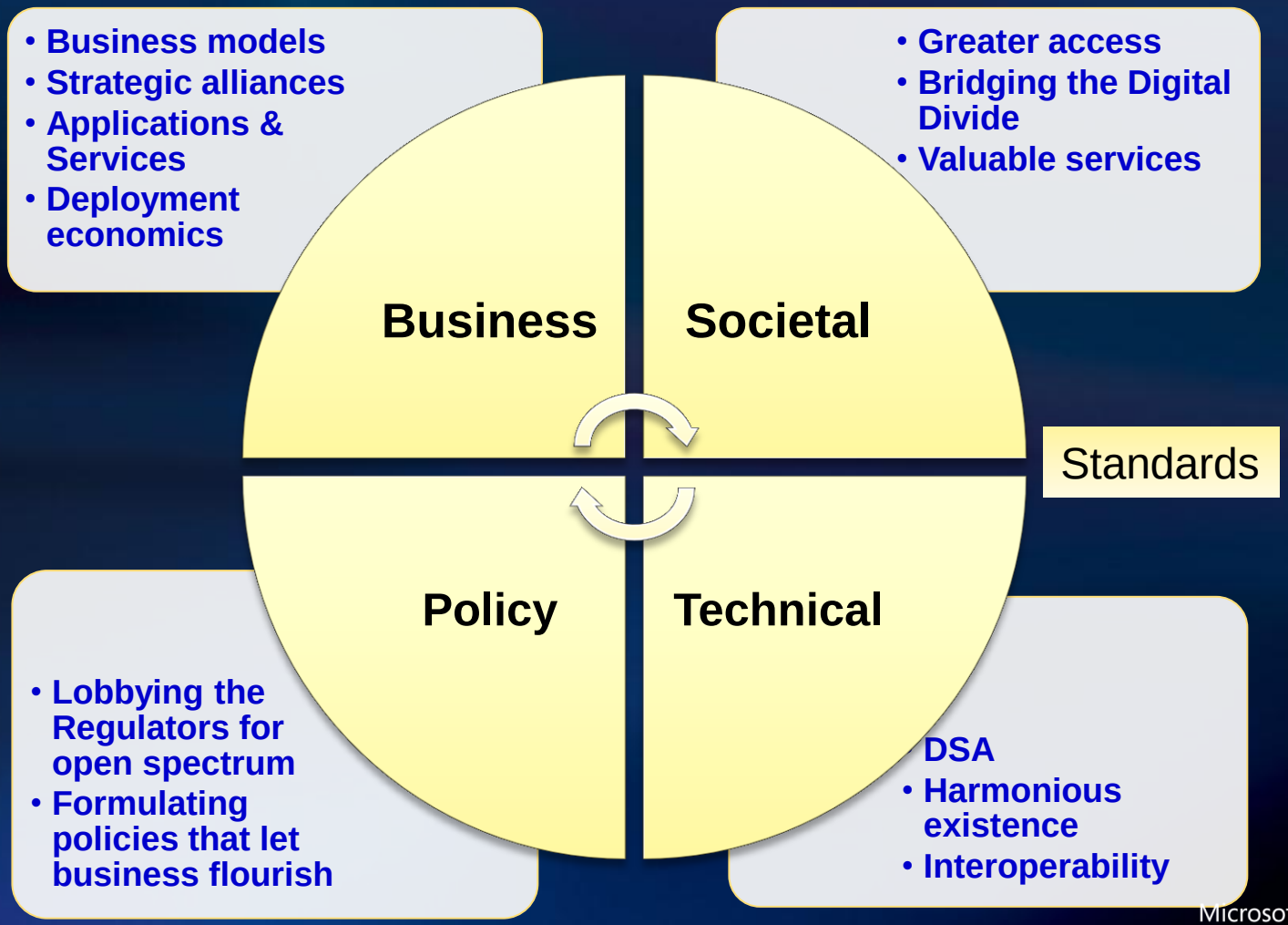
Microsoft透露新的WhiteFi无线技术

来源:INPAI.COM.CN/硬派网 [原创] 2009-08-20 作者:谢平 编辑:谢平 我要投稿

Microsoft透露新的WhiteFi无线技术

来源:INPAI.COM.CN/硬派网 [原创] 2009-08-20 作者:谢平 编辑:谢平 我要投稿

# A Comprehensive Approach



# Summing up

- Spectrum is Scarce!
  - Capacity is limited & consumer needs are going up, technology with small pies will not be able to keep-up and enable next-gen applications
- Spectrum Scarcity must be handled!
  - Opportunistic DSA networks is a promising approach
- White Space Networking is First instantiation of Opportunistic DSA
  - Let's get it right

Microsoft Research

# Thanks

Q/A

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