Owing the Problem in Wireless Research

Victor Bahl
Microsoft Research
Keep the Big Picture in Mind

Healthcare

Education

Rural Connectivity

Science & Eng. Innovation

Energy & Environment

Broadband Foundation
Think hard about scenarios

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

- Business
- Policy
- Society
- Technical
Worldwide, Internet and broadband use are concentrated in Asia-Pacific, Europe, and North America.

Worldwide, 1 Billion Internet Users Worldwide

Worldwide Internet Penetration Is Growing (any device)

Worldwide Broadband versus Narrowband Penetration (% Internet accounts)

Broadband Users Worldwide (Millions)

- Western Europe: 87 million (31%)
- Latin America: 13 million (5%)
- Africa and ME: 11 million (4%)
- Asia-Pacific and Japan: 124 million (45%)

Internet Penetration by Region (% of Households)

- Japan: 90%
- North America: 79%
- Europe: 38%
- Worldwide: 27%
- Latin America: 20%
- APeJ: 19%
- Africa-Middle East: 7%

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.
Societal Impact

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

Wi-Fi World Record: 382 kms
Pico El Aguila, Venezuela
Elevation: 4200 meters
Business Impact

- Ubiquitous Services
- Pervasive Internet Access
- Ease-of-Use & end-user experience
Number of users is going up, consumption of data / 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,.....

Wireless use is on the rise: 56% of Americans have accessed Internet via wireless networks (Pew Internet & American Life Project, April 2009)
- 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

3G WAN throughput & Latency are not enough for next generation applications
What’s the way out?

- Improve Technology
  - Handle Shannon?

- Fatten the Pipes
  - Open up additional spectrum?

- Improve spectrum policies & rules
  - Licensed versus unlicensed and the rules that govern them
Questions....

- How much additional Capacity is needed?
  - CTIA Sept. 2009 report to FCC > 800 MHz

- Licensed or Unlicensed?
  - What is Economic value of Unlicensed Spectrum?
    - Thanki’s Sept. 2009 Report (Perspective Inc.)
    - FCC Field Hearing Nov. 3, 2009, San Diego, CA

- What can government do to help research
  - FCC Workshops Nov. 20, 2009, Washington DC
Capacity is Finite

Shannon 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 exists
- Turbo coding is within a few dBs of the Shannon limit
- MIMO & Cooperative MIMO
  - Antenna placement & size is an issue
  - Processing power has implications on battery power (battery is not following Moore’s law)

- Network coding
  - Traffic patterns are important, cannot always exploit benefits

- Receiver sensitivity (already quite good, also expensive)

- RF-aware MAC protocols

- Reducing cell size? Increasing BS density & spatial reuse
  - Network management headaches (think interference, channel collisions etc.)
Novel usage scenarios
- Inside homes, offices, buildings, data-center, communities,
- Machine-to-machine, body area sensors, ….

Rapid Deployment
- In hard to reach to areas (rural, sparsely populated)

Allow Licensed Operators to Offload Traffic

Innovations (which helped licensed holders)
- Allowed academics & researchers to build proof-of-concept systems
- Examples of innovations
  - PHY Layer, OFDM & MIMO -- IEEE 802.11 standards first to incorporate
  - Data-driven networking
- Examples of future innovations
  - Network coding, SDR’s and Cognitive Radios, Network management, diagnosis
Economic Value of Unlicensed

- MS Commissioned study recently published found:
  - Wi-Fi broadband access in homes, delivering voice-services and wireless access in hospitals and RID inventory tracking in retail stores could generate anywhere from $16 to $37 Billion / year for next 15 years (only 15% of the total projected market for unlicensed chipsets)

- Wi-Fi Alliance said 387 million chips were sold and they are on target to sell 1 Billion before 2012

- Telcos
  - AT&T offers 20,000 Wi-Fi host-spots in the US
  - Sprint-Nextel announced that they will feature Wi-Fi in all its devices
  - Verizon offers “MiFi” and has made statements similar to above

- WS’s could generate and additional $3.9 billion to $7.3 Billion / year for the next 15 years (~ $109 billion total)
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, Earthlink, and Samsung
## Details

<table>
<thead>
<tr>
<th></th>
<th>Fixed Devices w. Sensing &amp; Geolocation</th>
<th>Personal / Portable Device w. Sensing &amp; Geolocation</th>
<th>Personal / Portable Device w. Sensing Only</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Channels (6 MHz each)</strong></td>
<td>21-51 (except 37); fixed-2-fixed: 2 &amp; 5-20 with exceptions</td>
<td>21-51 (except 37)</td>
<td>21-51 (except 37)</td>
</tr>
<tr>
<td><strong>Transmit Power</strong></td>
<td>1 W (up to 4W with antenna gain)</td>
<td>100 mW (no antenna gain allowed)</td>
<td>50 mW (no antenna gain allowed)</td>
</tr>
<tr>
<td><strong>Detection thresholds for ATSC, NTSC, &amp; Wireless Microphones</strong></td>
<td>-114 dBm</td>
<td>-114 dBm</td>
<td>-114 dBm</td>
</tr>
<tr>
<td><strong>Database Registration</strong></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Beaconing for identification</strong></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>In-service monitoring / Channel move times</strong></td>
<td>Every 60 seconds / 2 seconds</td>
<td>Every 60 seconds / 2 seconds</td>
<td>Every 60 seconds / 2 seconds</td>
</tr>
<tr>
<td><strong>Channel availability time</strong></td>
<td>30 seconds</td>
<td>30 seconds</td>
<td>30 seconds</td>
</tr>
<tr>
<td><strong>Location Accuracy</strong></td>
<td>50 meters</td>
<td>50 meters</td>
<td>50 meters</td>
</tr>
</tbody>
</table>
Policy Challenges

- What to do about (illegal) microphones
- Where to find my bandwidth from
- Correct Sensing Threshold
- Expanding notion of device certification & incorporating cooperative sensing
- Focusing on receivers rather than senders
- Achieving world-wide Harmonization
Wide band receiving
- 200 MHz wide antennas for mobile units (what about battery!)
- 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
- Interference mitigation, power management

…………
Software Challenges

RF Related
- Asymmetry & fragmentation
  - Subcarrier suppression (SS) over a wide band
  - Subcarrier allocation
  - Channel bonding (CB)
- 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, \( \rightarrow \) graph coloring problem.
- With contiguous channels of variable channel-width, coloring is not an appropriate model!
  \( \rightarrow \) Need new models!
Networking Challenges

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…?

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

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

Which protocols should they use?
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 with Geolocation) -> Ongoing
- Provide coverage in MS Shuttles
Demonstrated
- 700 MHz operation
- TV sensing technology
- One-to-one Opportunistic Networking

Version 1: Ad Hoc Networking
The Network Stack

Network Layer (TCP/IP)

CMAC (Collaborative Sensing & Access)

bSMART (Spectrum Allocation Engine)

Resource Allocation Matrix

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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PHY Layer

Reconfiguration Interface

Reconfigurable Radio

Scanner Radio
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 MAC
- Wi-Fi MAC can be modified to accommodate opportunistic networking
KNOWS v1 was a multi-radio system
  Can we build a single-radio WS network?

KNOWS v1 was an 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 & modified semantics of RTS/CTS
  Can we reuse the Wi-Fi MAC?

...can we do better?
Version 2: Infrastructure Based Networking (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
Business Question: Can we Reuse 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**
  - Incumbants can operate in any portion of the spectrum AND secondary cannot interfere with the primary
    - Channels width can vary
Version 2 Innovations

- **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
Determining the frequency and channel width of APs

SIFT: Signal Interpretation before Fourier Transform
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
In most cases, SIFT takes 70% less time in discovery.

Most benefit in rural areas.
Version 3: Campus Wide White Space Networking (WhiteFi w. Geolocation)
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)
# Channel Occupancy Database

## Microsoft Research SpectrumOracle

### DTV (KTBW-TV)
- **Transmit Power**: 89 kW
- **Channel**: 14
- **HAAT**: 1551.44 Feet
- **Area Covered**: 0 sq. miles
- **Antenna**: ~

### Table of Transmitters

<table>
<thead>
<tr>
<th>Type</th>
<th>CallSign</th>
<th>Channel</th>
<th>Signal Strength (dbm)</th>
<th>TX Power (kW)</th>
<th>HAAT (ft)</th>
<th>Distance (miles)</th>
<th>Elevation Data Source</th>
<th>Propagation Mode</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select</td>
<td>DTV</td>
<td>KMTQ</td>
<td>25</td>
<td>-19.2</td>
<td>1000</td>
<td>931.2</td>
<td>7.824</td>
<td>SRTM41</td>
<td>Line-Of-Sight Mode</td>
</tr>
<tr>
<td>Select</td>
<td>DTV</td>
<td>KOMO-TV</td>
<td>38</td>
<td>-22.9</td>
<td>870.9</td>
<td>849.5</td>
<td>9.781</td>
<td>SRTM41</td>
<td>Line-Of-Sight Mode</td>
</tr>
<tr>
<td>Select</td>
<td>DTV</td>
<td>KCTS-TV</td>
<td>9</td>
<td>-26.7</td>
<td>218.7</td>
<td>816.7</td>
<td>7.873</td>
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<td>Line-Of-Sight Mode</td>
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<tr>
<td>Select</td>
<td>DTV</td>
<td>KSTW</td>
<td>11</td>
<td>-27.1</td>
<td>100</td>
<td>904.2</td>
<td>7.897</td>
<td>SRTM41</td>
<td>Line-Of-Sight Mode</td>
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<tr>
<td>Select</td>
<td>DTV</td>
<td>KWDK</td>
<td>42</td>
<td>-33.1</td>
<td>144.5</td>
<td>2279</td>
<td>12.46</td>
<td>SRTM41</td>
<td>Line-Of-Sight Mode</td>
</tr>
</tbody>
</table>

### Current Status
- Loaded New Results. Time taken: 1 s

36th St and 145th NE, Redmond, WA
Spectrum availability mirrors population density

Initial measurements & rudimentary database

Business Issues

What are the Urban Scenarios?

To win Rural must first win Urban!

Spectrum availability mirrors population density
Deployment

White Space Network Setup

Subcarrier Suppression demo

Data packets over UHF

Microphone testing in Anechoic Chamber
PR Helps...

Microsoft still hot for white space, describes WhiteFi wireless tech

Wi-Fi via White Spaces
A network design that uses old TV spectrum could produce better long-range wireless connectivity.

Microsoft Makes White-Spaces Breakthrough for Rural Broadband

WhiteFi: ¿El sucesor de Wifi?
Por: Kir Ortiz @ martes, 25 de agosto de 2009 Nota vista 4479 veces

Microsoft透露新的WhiteFi无线技术
来源:INFAI.COM.CN/硬派网 [原创] 2009-08-20 作者:谢平 编辑:谢平
The Big Picture

**Strategy & Policy**
- Engage with FCC to help them nail down sensible specifications
- World-wide evangelism with regulatory bodies (e.g. OFCOM, TRAI, SARFT)
- Engage with silicon vendors & systems integrators

**Research**
- Identify technical show stoppers & solve the hard problems
- Build prototypes as proof of solution - learn from those & build MS IP
- Help the strategy & policy teams with data
- Help BGs with scenario planning, standardization, & technology assets

**Business**
- Develop application scenarios and revenue models
- Forge strategic & complimentary alliances

**Product**
- Ramp up by gathering requirements & nailing down specifications
- Work to establish a standard that reduces cost of WSDs
- Develop & test software for Windows, harden research code
Key to Success: Take a Comprehensive Approach

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

- Greater access
- Bridging the Digital Divide

- Lobbying the Regulators for open spectrum
- Etiquettes & policies

- DSA
- Harmonious existence
- Interoperability

Microsoft Research
Thanks

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

Q/A
Appendix
October 16, 2009  Deployed a white space network (WSN) between buildings 99 & 112 on the Microsoft's Redmond Campus. The first urban WSN in the world

July 15, 2009  Outdoor tests succeeded. Achieved connectivity between two white spaces devices at 0.5 Km from one another transmitting at 20 dBm with less than 1% BER.

July 6, 2009  Received FCC experimental license to test a white space network.

June 30, 2009, Version 1 of our channel occupancy database came online

January 15, 2009, Demonstrated a fast channel discovery algorithm (a.k.a SIFT) and an efficient channel assignment algorithm to achieve high throughput in a white space network (MCHAM)

October 23, 2008  Demonstrated a network of five nodes communicating over the UHF white spaces. Concepts demonstrated (a) variable channel width (b) wireless microphone sensing and (c) Opportunistic networking
Tech Industry Leaders Join to Develop Guidelines for White Spaces Database Google, Microsoft, Motorola, Others Launch the White Spaces Database Group

Tech giants will create white space database

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

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

- Wide-band RF Tranceiver (150 – 1000 MHz)
- Min tuning size 0.5 MHz
- Max TX output power 1W
- TX Gain control range: 50 dB
- Development board with integrated high-speed ADCs and DACs & a high-density FPGA for sensing and MAC
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
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

Flexible RF Hardware
- LPA/Sampling Convertor/DA C/ADC
- Latency critical radio control (AGC/PD)

Ongoing work in MSR Asia
• Fragment the spectrum
• Temporal variation and spatial (on a wider scale)

One possible detection solution: Beacons

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

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.
Microphone Detection

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

100% detection at -114 dBm

Worst case interference assumption is too conservative

Spectrum occupancy changes during the day and is location specific
Related Effort & Resources

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, ...
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 sensing information with BS

Companies

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