Owing the Problem: Opportunistic Dynamic Spectrum Access

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Microsoft Research
Starting with the Big Picture

Healthcare

Education

Rural Connectivity

Science & Eng. Innovation

Energy & Environment

Broadband Foundation
What technologies you need to create to make these scenarios real? What Govt. policies will enable you to move forward and make the breakthroughs?
Worldwide, Internet and broadband use are concentrated in Asia-Pacific, Europe, and North America.

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

Computing Growth Drivers Over Time, 1960 – 2020E

- More than Just Phones
  - Smartphone
  - Kindle
  - Tablet
  - MP3
  - Cell phone / PDA
  - Car Electronics
  - GPS, ABS, A/V
  - Mobile Video
  - Home Entertainment
  - Games
  - Wireless Home Appliances

- 10B+ Units???
- Mobile Internet
- Desktop Internet
- PC
- 1B+ Units / Users
- 100MM+ Units
- Minicomputer
- 10MM+ Units
- Mainframe

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 not enough for next generation applications

http://www.eecs.umich.edu/3gtest
Cisco Visual Networking Index – Mobile Data Traffic Forecast, 2008-2013, 2/09

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)

FCC warns of mobile’s looming spectrum crisis
Predicted jump in wireless traffic will require more bandwidth for devices

AT&T: Give Us Spectrum, Not Rules

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

4/8/2010
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
What can we do?

- Extract greater juice, push new network architectures
- Fatten the pipes - open up additional spectrum
- Promote secondary market place
  - Fairness? Engineering?
  - But can be a win-win situation
- Promote opportunistic and dynamic spectrum access technologies

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

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

Wireless at warp speed
Nov 7th 2008
From Economist.com

White space promises to put WiFi on steroids

Tech firms win victory with FCC 'white spaces' vote

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

Will 'White Space' ruling stimulate our sagging economy?
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.
<table>
<thead>
<tr>
<th>Details...</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Channels (6 MHz each)</strong></td>
</tr>
<tr>
<td>Fixed Devices w. Sensing &amp; Geolocation</td>
</tr>
<tr>
<td>21-51 (except 37); fixed-2-fixed: 2 &amp; 5-20 with exceptions</td>
</tr>
<tr>
<td><strong>Transmit Power</strong></td>
</tr>
<tr>
<td>1 W (up to 4W with antenna gain)</td>
</tr>
<tr>
<td><strong>Detection thresholds for ATSC, NTSC, &amp; Wireless Microphones</strong></td>
</tr>
<tr>
<td>-114 dBm</td>
</tr>
<tr>
<td><strong>Database Registration</strong></td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td><strong>Beaconing for identification</strong></td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td><strong>In-service monitoring / Channel move times</strong></td>
</tr>
<tr>
<td>Every 60 seconds / 2 seconds</td>
</tr>
<tr>
<td><strong>Channel availability time</strong></td>
</tr>
<tr>
<td>30 seconds</td>
</tr>
<tr>
<td><strong>Location Accuracy</strong></td>
</tr>
<tr>
<td>50 meters</td>
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</tbody>
</table>
Digital Switchover (DSO) in the UK will complete in 2012
- 128 MHz in UHF band (470-862MHz)  [versus 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
How should nodes connect?

Which protocols should they use?

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

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 protocols should they use?
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**

- **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 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: Major Innovations

- Eliminated Control Channel & reused Wi-Fi
  - Enables AP to pick a channel that is free for all clients AND pick the best possible channel width

- Spectrum Assignment Algorithm
  - Enable clients to quickly discover an AP over all \( \langle \text{channel}, \text{width} \rangle \) pairs

- Discovery Mechanism
  - Enable clients to quickly discover an AP over all \( \langle \text{channel}, \text{width} \rangle \) 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)
**WhiteSpaceFinder: White Space Geo-Location Service**

http://whitespaces.msresearch.us

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**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 across 1500 miles in WA state
- Includes analysis of white space availability
- (forthcoming) Internationalization of TV tower data

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**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 transmitting at 40 mW

WhiteFi (Ch. 40)
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
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 Reactions and Perspectives, National Science Foundation Workshop on Future Wireless Communication Networks, Arlington, VA (Nov. 2-3, 2009)
Good Press Helps

White Fi, Long-Range Wireless Internet Using White Spaces
A new research project from Microsoft and Harvard could pave the way for long range wireless networking.

WhiteFi: Broadcasting wireless Internet over TV airwaves

Wi-Fi via White Spaces
A network design that uses old TV's long-range wireless connectivity.

BusinessLine
Tapping space between used spectrum
White-Fi tech from Microsoft

ars technica
WiFi on steroids? First "WhiteFi" prototypes hit testing stage
By Nate Anderson | Last updated August 27, 2009 8:23 AM

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 8:11 AM

Gigaom
Microsoft details a fix for 'white space' interference

‘White-Fi’ making waves
Sunday, January 31, 2010 2:49 PM

iStockAnalyst
Microsoft透露新的WhiteFi无线技术

'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
A Comprehensive Approach

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

- Greater access
- Bridging the Digital Divide
- Valuable services

- Lobbying the Regulators for open spectrum
- Formulating policies that let business flourish

- DSA
  - Harmonious existence
  - Interoperability

- Standards
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
Thanks

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

Q/A