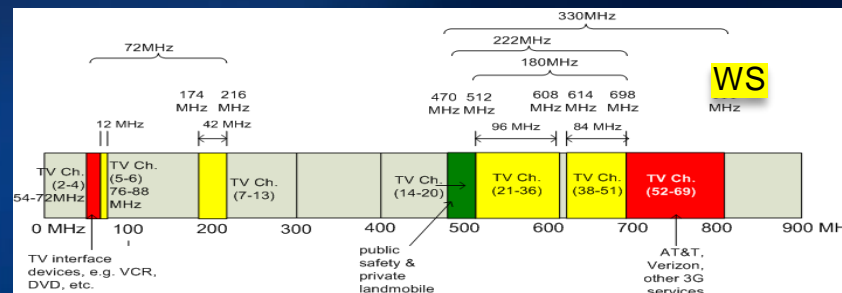


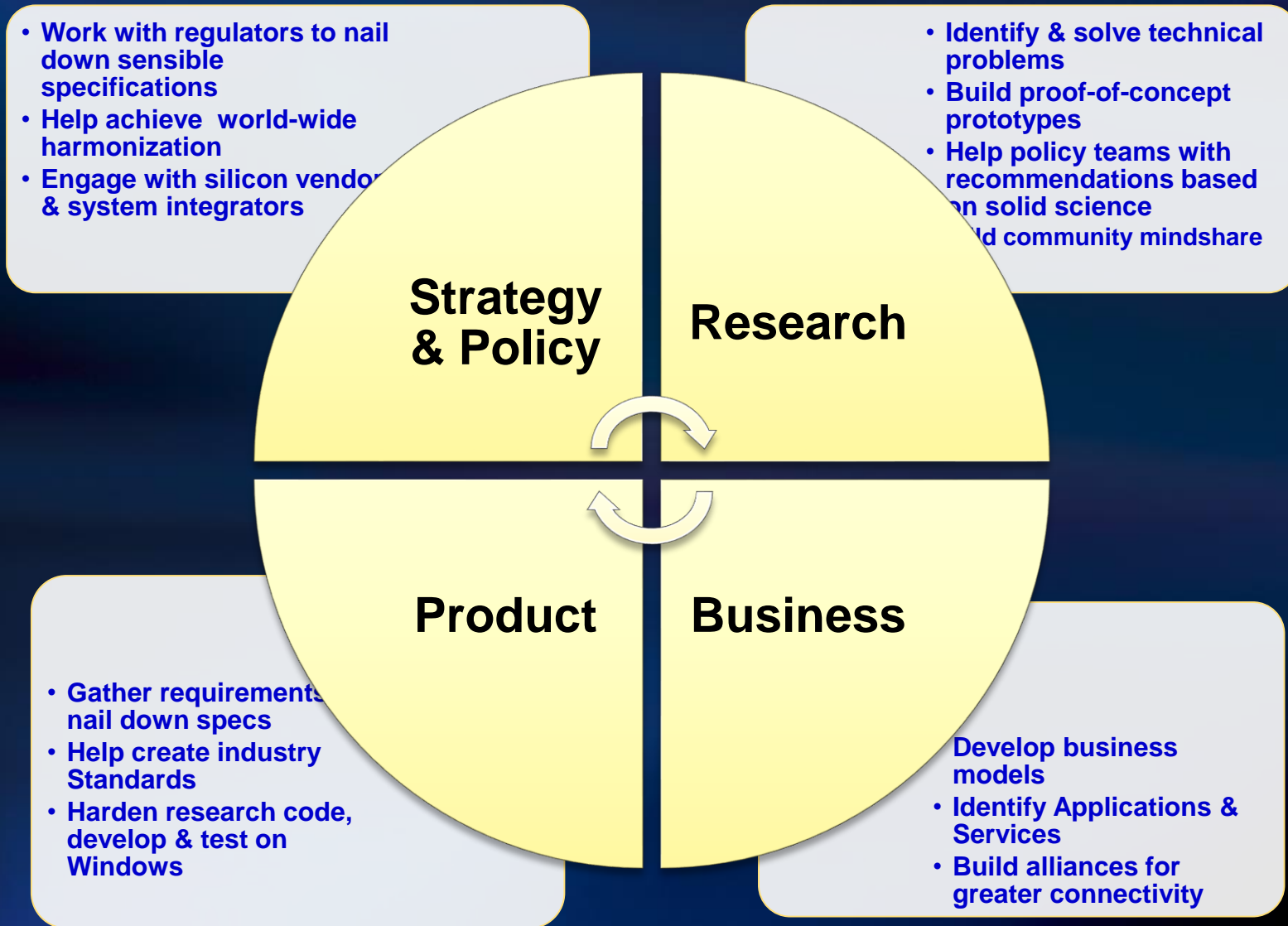
# White Space Networking Status Update

Victor Bahl

Joint work with Paula Boyd, Ranveer Chandra, Paul Garnett, Thomas Moscibroda, and MSR Interns (Rohan Murty, George Nychis, Xiaohui Wang, Yuan Yuan)



# A Comprehensive Approach



# Microsoft's Cognitive Networking Research Program (2005-...)

## 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)

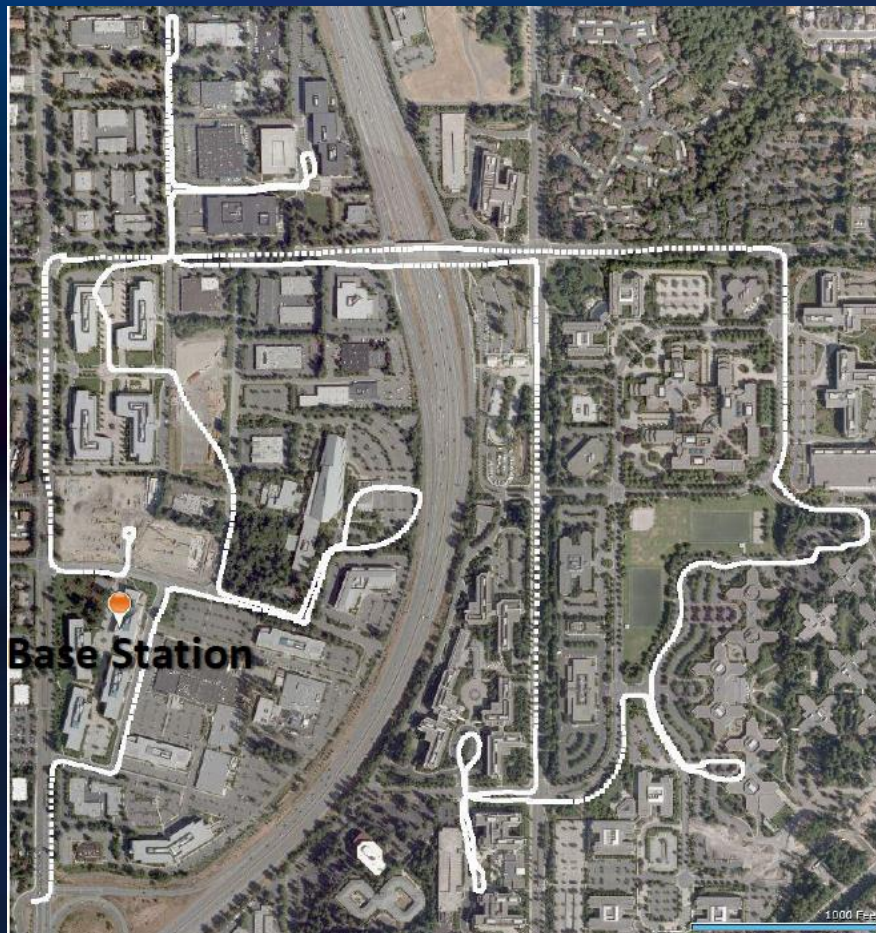
- White Space freq. operation, TV sensing Capability, limited microphone sensing, one-to-many opportunistic networking, Wi-Fi MAC, time-domain analysis (SIFT), demo-ed at Microsoft events (e.g. TechFest 2009)

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

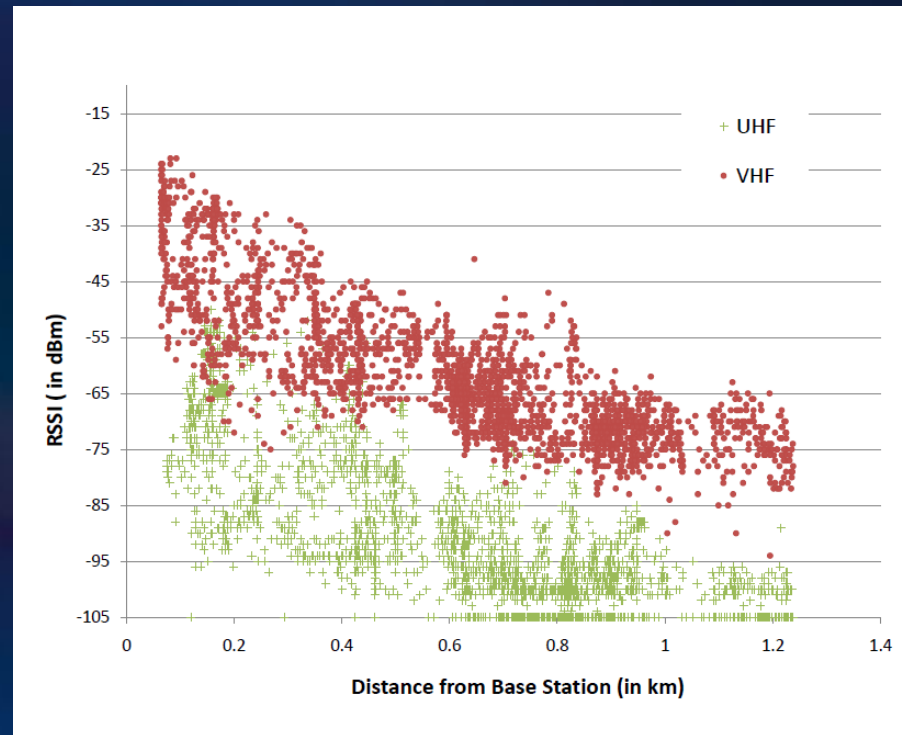
- All of V2 + geolocation DB, Windows network stack improvements, bridging between Wi-Fi and WhiteFi, coverage in MS Shuttles



# Range Experiments



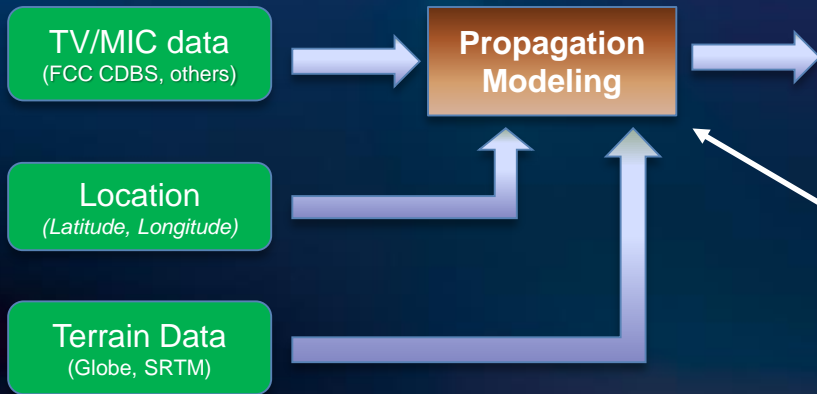
MSR's Redmond Campus  
Route taken by the shuttle (0.95 miles x 0.75 miles)



Raw received power at different  
Distances from the transmitter

~4x range compared to 2.4 GHz (Wi-Fi) with same transmit power and receiver sensitivity

# Microsoft's Database Service



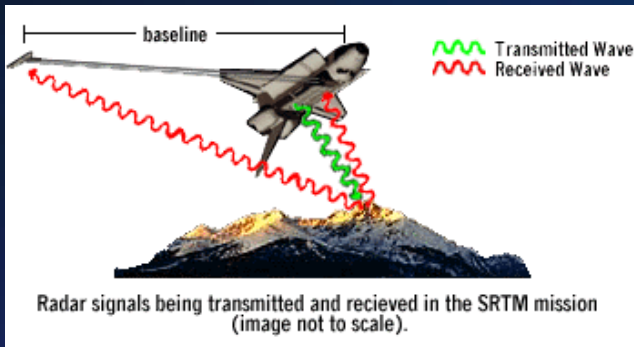
**Irregular Terrain Model (ITM) Longley-Rice (1968)**  
 • 20 MHz to 20 GHz

The Egli model is formally expressed as:

$$L = G_B G_M \left[ \frac{h_B h_M}{d^2} \right]^2 \left[ \frac{40}{f} \right]^2$$

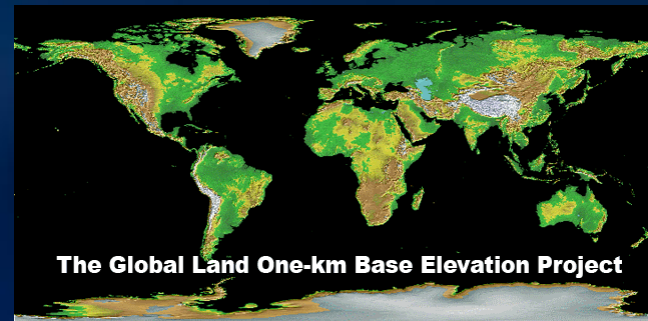
**John Egli (1957)**

Shuttle Radar Topography Mission (SRTM)

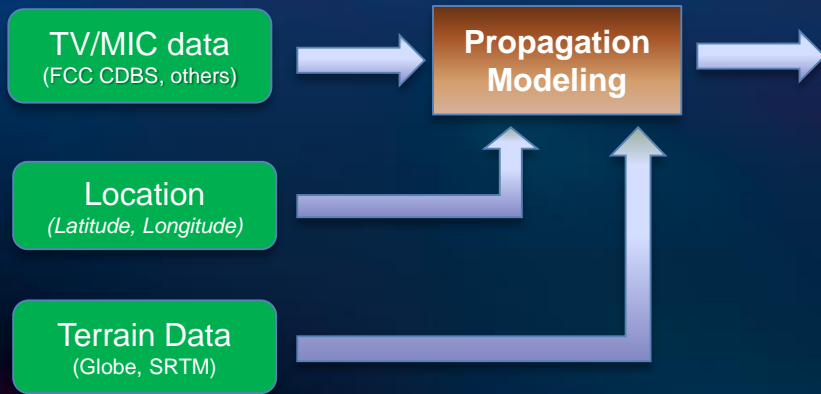


Joint Project between NASA and NIMA

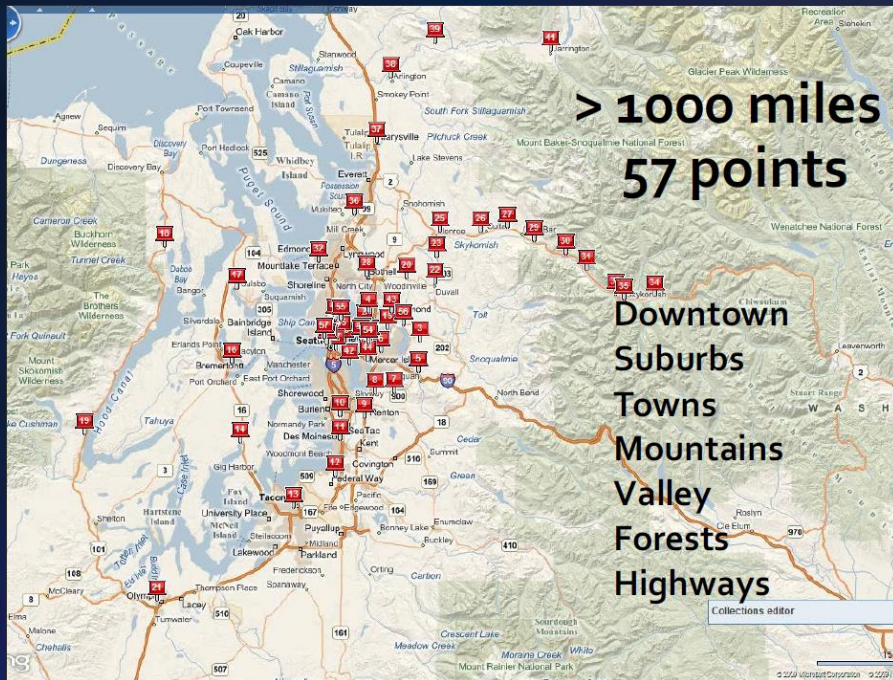
Globe



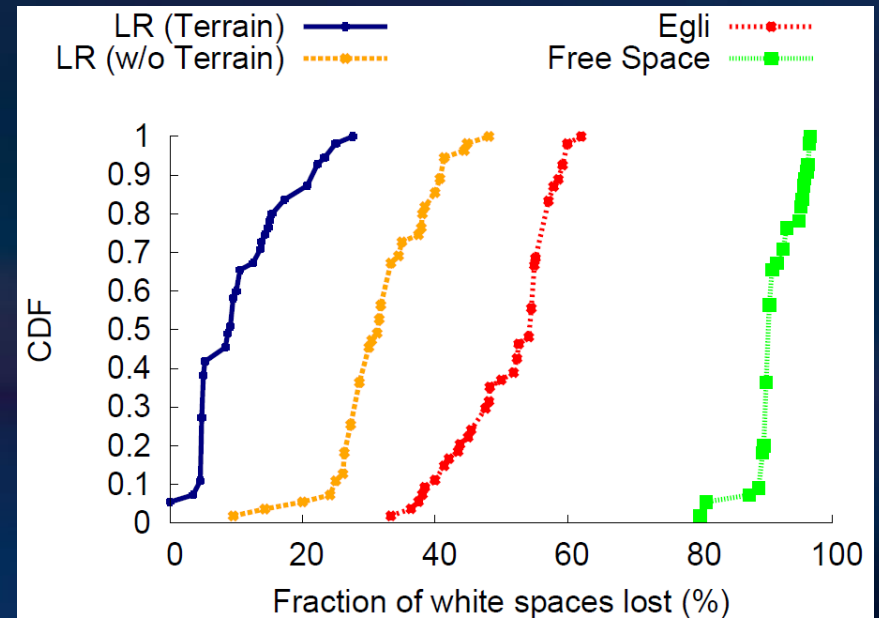
# Microsoft's Database Service



ASP.NET implementation using SOAP extensions



Checking for Accuracy



Fewer White Spaces lost with Longley-Rice + SRTM

# WhiteSpaceFinder Announcement

<http://whitespaces.msresearch.us>

April 7 2010



Dan Reed, announces availability of MS White Space DB for the research community

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

Microsoft Research WhiteSpaceFinder

Current Status = Loaded New Results. Time taken = 1 s

36th St and 148th NE, Redmond, WA

	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

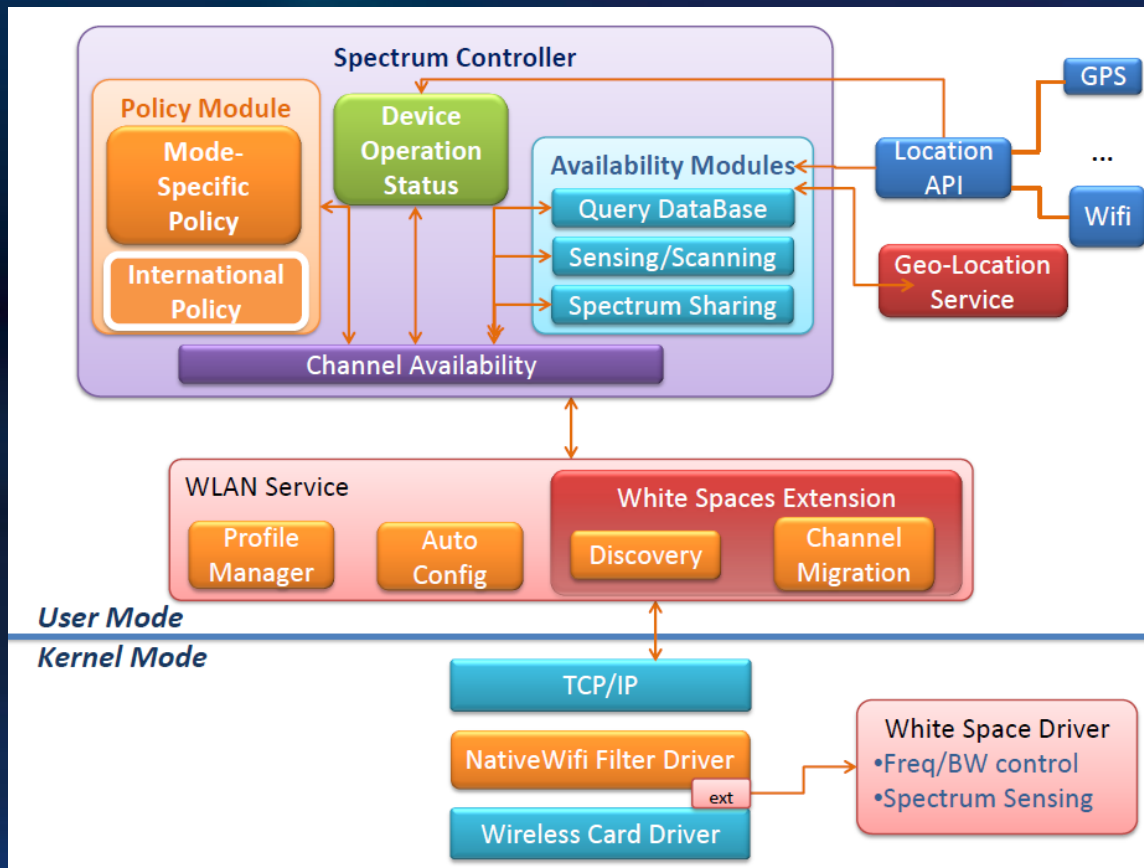
- Configurable parameters
  - Propagation models: L-R, Free Space, Egli
  - detection threshold (-114 dBm by default)
- Includes analysis of white space availability
- (forthcoming) Internationalization of TV tower data

## Collaborators





# Windows 7 Software Stack Improvements



# First Urban White Space Network in the World



Oct. 16, 2009

## White Space Network Setup



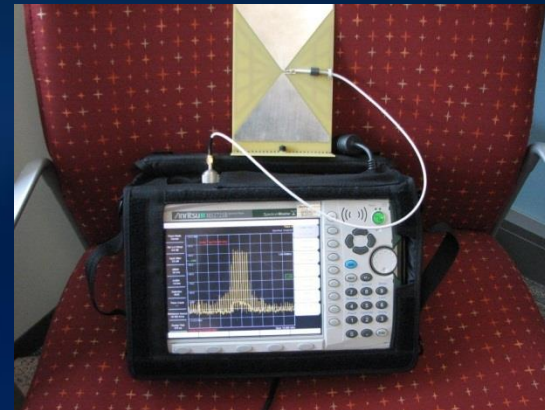
Shuttle Deployment



WS Antenna on Bldg 42



WS Antenna on MS Shuttle



Data packets over UHF

# Public Demos & Policy Influence



India  
Oct. 22, 2009



USA  
Apr. 28, 2010



Office of Communications (UK)  
June 10, 2010



Singapore  
Apr. 8, 2010



China  
Jan. 11, 2010



Brazil  
(Feb. 2, 2010)



US Research Funding  
Nov. 9 2009



Fisher Communications Inc.  
Jan. 14, 2010



Industry Partners  
Jan. 5, 2010

Microsoft  
**Research**

# WhiteFi and Broadcast TV

WhiteFi Antenna

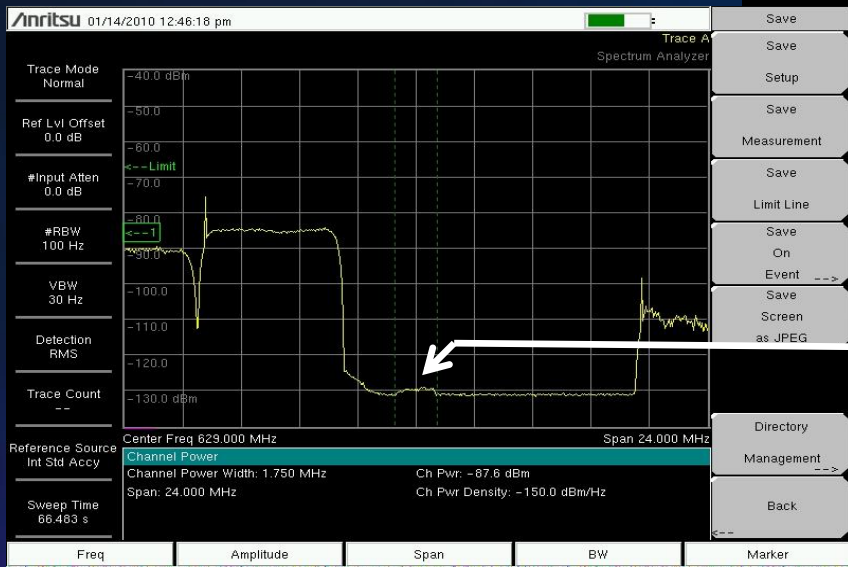
TV Antennas



KOMO (Ch. 38)

KIRO (Ch. 39)

WhiteFi (Ch. 40)



WhiteFi transmitting at 40 mW

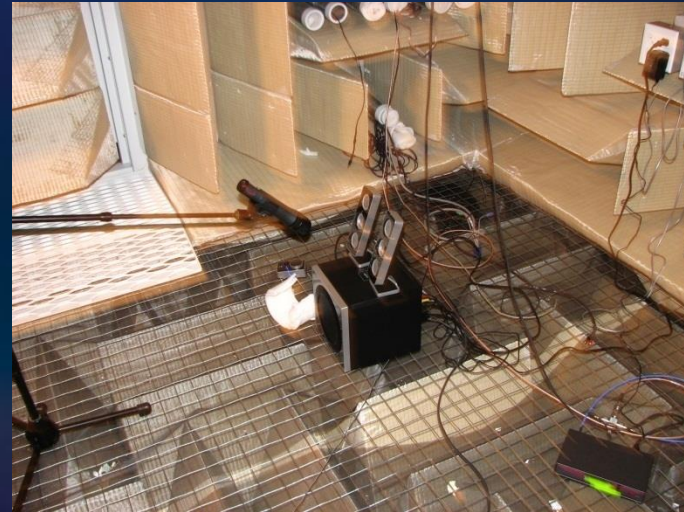
WhiteFi (Ch. 40)

# Co-existing with Microphones

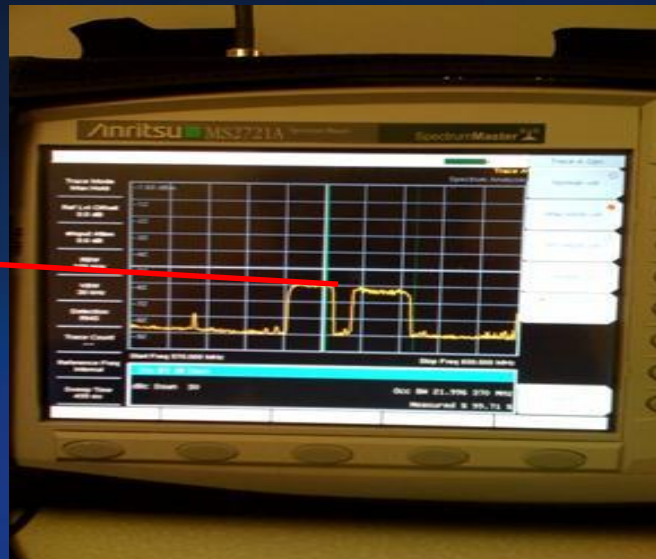
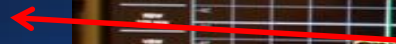
Subcarrier Suppression setup






Microphone recording in Anechoic Chamber



Subcarrier  
Suppression



## Results

-  Original
-  Without SCS
-  With SCS

# Looking Internationally (Europe)

- Digital Conversion in Europe

- UK: End of 2012 – London region is the last to convert
- Finland – Complete
- Spain – Complete
- Germany – Complete
- France – End of 2011

- United Kingdom (OFCOM)

- Geo-location OR sensing permitted.
- Consultations on enabling legislation and geolocation-database services expected this fall.



- Other Countries

- European Commission's CEPT SE43 group addressing technical issues.
- Finland's Ministry of Transport and Communications has invited proposals for white space trials.
- Sweden's National Post and Telecoms Agency is looking into enabling access to TV white spaces.

# Looking Internationally (Others)

- Singapore, IDA

- 7 April 2010, IDA announced the *'White Space Technology Information Package and Test Plan'*
- July 31, announced white space trials, named Cognitive Radio Venues ("CRAVE")
- Investigating WS applications to show commercial value



- Brazil, Ministry of Communications and Anatel

- Considering pilot projects, along the lines of Microsoft's WhiteFi Campus deployment



- Japan, Ministry of Internal Affairs and Communications

- Considering proposals for white spaces trials. 103 proposals received.



# Standardization Status

- **Goal:** Align industry towards a commercially feasible solution
  - Develop usage models & marketing requirements
  - Agree on a technical solution
- **Participants:** Diverse group of network operators, chip vendors, device manufacturers, and others.

## Direction

- **IEEE 802.11af:** Task Group Formed
  - Define the PHY
  - Minimum MAC enhancements
- **Wi-Fi Alliance:** TV White Spaces Marketing Task Group Formed
  - Develop roadmap for a certification program
  - MAC enhancements + database specifications



# Global Standardization Status



## ECMA – 392 (CogNEA Group) Edition 1, December 2009

- New MAC and PHY for Operation in TV White Space
- BT, Cambridge Consultants, ETRI, Philips, Samsung Electro-Mechanics, MaxLinear, Georgia Electronic Design Center (GEDC) and Motorola



## IEEE 802.22: Wireless Regional Area Network (WRAN) utilizing white spaces

- Point to multi-point operation (star topology)
- Clients are homes equipped with antennas (EIRP @ BS 4W - Range about 30 km)
- Distributed Sensing - CPEs share sensing information with BS



## IEEE 802.11af Task Group:

- **Want to adapt 802.11 for TV white space**
- OFDM PHYs with 5-, 10- and 20-MHz channel widths to specify the basis for a system that the regulators can approve
- Working closely with WS Alliance

# Status of Industry Products

## Hardware OEMs

Have some operational hardware

- Adaptrum Inc., Shared Spectrum Inc., Cambridge Consultants, Neocific Inc., Ubiquity XR7, TI Lyrtech, ...



Shared Spectrum



Adaptrum



Lyrtech



Neocific

## Potential Database Providers

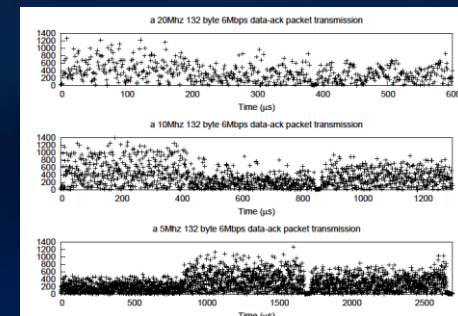
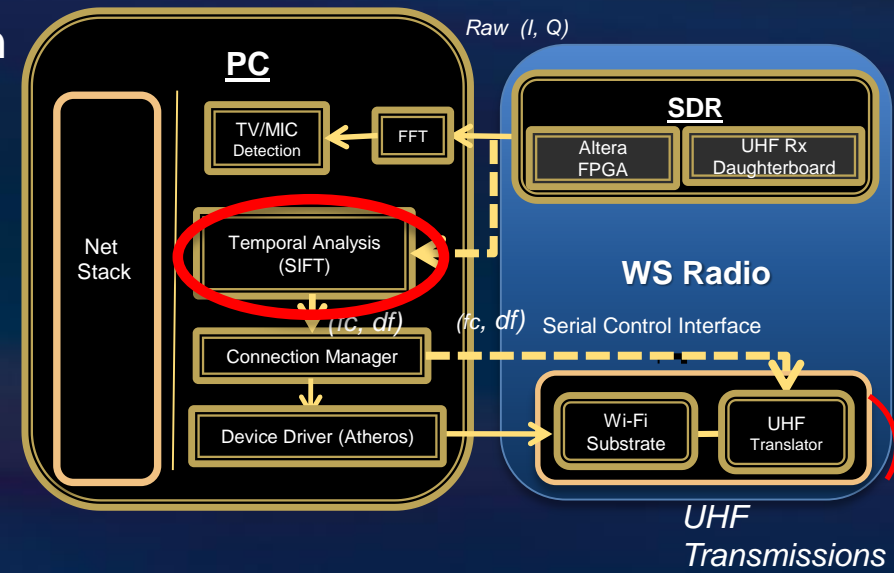
Have filed with the FCC

- Google, Comsearch, Frequency Finder, KB Enterprises, Neustar, Spectrum Bridge, Telecordia, White Spaces DB, LLC.

# Our Contributions to Standards

Best Paper  
SIGCOMM 09

- Fast discovery mechanism
  - Enable clients to quickly discover an AP over all  $\langle \text{channel}, \text{width} \rangle$  pairs
- Fast recovery mechanism on disconnection
  - Re-connects quickly on a new available channel upon sensing a primary user on existing channel
- Spectrum assignment algorithm
  - Enables AP to pick a channel that is free for all clients AND pick the best possible channel width



# Our Contributions to the Community (1)

Open about identifying problems and sharing research results

Research Results & Technology	Publication Venue
1. Co-existence with wireless microphones	In-preparation
2. Harmonious operation in heterogeneous environment	In-preparation
3. Enhancements to the software stack	White paper (Tech Report)
4. Fast discovery & connectivity in ad hoc mode	In-preparation
5. Secure collaborative sensing	IEEE DySPAN 2010
6. Temporal analysis (SIFT) & Spectrum assignment for AP Operation (MCham)	ACM SIGCOMM 2009 ( <b>Best paper</b> )
7. Dynamic channel width operation	ACM SIGCOMM 2008
8. Load aware spectrum distribution	IEEE ICNP 2008
9. Dynamic time spectrum blocks	ACM MobiHoc 2007
10. Control channel medium access protocol	IEEE DySPAN 2007
11. Spectrum leasing	IEEE DySPAN 2006
12. Separation of control & data	IEEE BroadNets 2006

Microsoft

Research

# Our Contributions to the Community (2)

- Founding Member & Steering Committee Member *IEEE DySPAN* (since inception in 2005)
- Organized MSR Cognitive Wireless Networking Summit 2008, June 2008 (Snoqualmie, WA)
- Guest Editor, IEEE Journal on Selected Areas in Communications, Special Issue on Advances in Cognitive Radio Networking and Communications
- Tutorial on White Space Networking, Summer School in Networking, Bangalore, India (June 2009)
- General Co-Chair of IEEE *Workshop on Cognitive Wireless Communications and Networking*
- General Chair of IEEE DySPAN 2012 (*Committed*)
- Program Committee Member, IEEE DySPAN 2005, 2007, 2008, 2010



Steering Committee



Special Issue Editor



MSR Event



Microsoft  
Research

# Our Collaborations with Universities



Channel occupancy  
database design & related  
issues



White space mesh  
networks for rural  
communities



Harmonization between  
heterogeneous white space  
networks



**ECE ILLINOIS**

Department of Electrical and Computer Engineering

Security & privacy in white space  
networks



Smart antennas, interference  
mitigate & internationalization



The SORA Program

# Sharing Vision and Research Directions

## Keynotes on WS Networking

- *The Fifth International Conference on Mobile Computing and Ubiquitous Networking (ICMU 2010), Seattle, Washington, US (April 2010)*
- *The 7th IEEE/IFIP International Conference on Embedded and Ubiquitous Computing (EUC 2009), Vancouver, Canada, August 31, 2009*
- *The Fifth Euro-NGI Conference on Next Generation Internet Networks, July 2, 2009*
- *The Sixth International Conference on Wireless On-demand Network Systems and Services, Salt Lake City, Utah, February 2, 2009*
- *Workshop on Wireless Broadband Access for Communities and Rural Developing Regions, December 11, 2008*
- *Second IFIP International Symposium on Wireless Communications and Information Technology in Developing Countries, October 7, 2008*
- *MSR's Cognitive Wireless Networking Summit, Snoqualmie, Washington, USA, June 4, 2008*
- *First International Workshop on Cognitive Dynamic Systems and Their Applications, May 27, 2008*
- *Intel's Communications Internal Senior Leadership Conference (ICOMM 2008), April 9, 2008*
- *The Third International Conference on Communication System Software and Middleware (COMSWARE 2008), January 8, 2008*
- *The Ninth International Conference on Distributed Computing and Networking (ICDCN), January 6, 2008*

# Sample Press

Over 50 articles (that we have tracked)

SOFTPEDIA®

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

BusinessLine

Tapping space between used spectrum

White-Fi tech from Microsoft

Thomas 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 channels for long-range wireless connectivity.

By Erica Naone



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



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

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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



# Accolades from Mainstream Media

*The project, dubbed “White Fi,” **is one of the most advanced in the field**, both dealing with the hardware side but also creating the networking protocols to handle the specific challenges.*

Softpedia (Aug. 19, 2009)

***Microsoft researchers have taken a step closer to** finally turning unused analogue TV spectrum, known as “white spaces”, into unlicensed spectrum that can be used to deliver new wireless broadband service*

CNET.COM (Aug. 19, 2009)

***The Microsoft Research team has addressed many** of these issues with WhiteFi. —that early promise of “WiFi on steroids” might turn out to be surprisingly accurate, after all.*

Nate Anderson, Ars technica, August 27, 2009

*The actual engineering requirements to accomplish this frequency switch are non-trivial. Microsoft Research’s “KNOWS” project **has taken up the task and made some pretty remarkable advances.***

Scott Merrill, Crunchgear, August 28, 2009

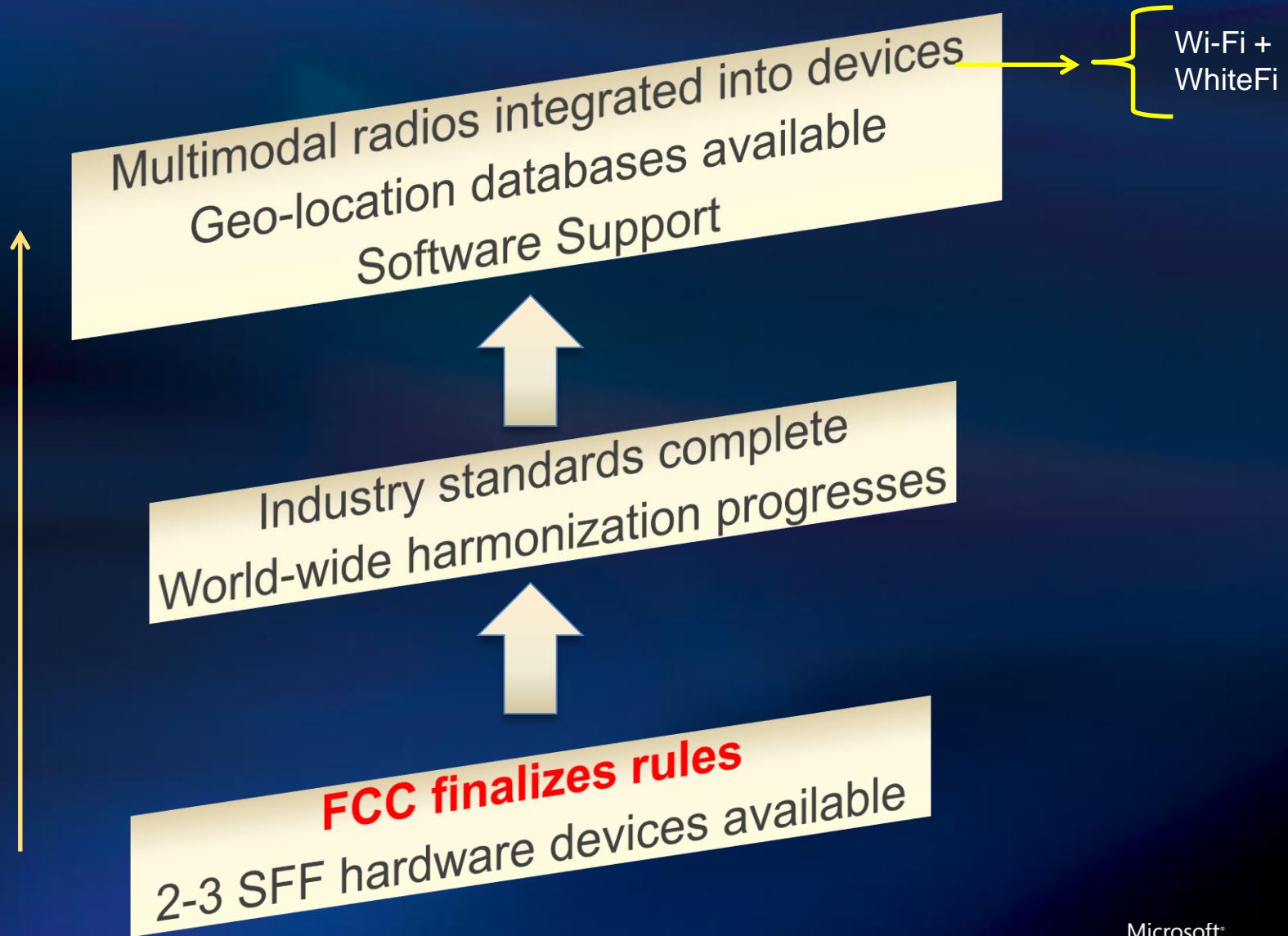
***One of the best prospects for the future** is the opening up of “white spaces,” unused parts of the spectrum. **One of the most advanced research projects.....***

Lucian Parfeni, Web News, August 18, 2009

***Microsoft researchers have taken the next step** toward turning old UHF analog TV spectrum into rural wireless broadband networks that would operate like Wi-Fi but with greater range.*

Simon Juran, GigaOm, August 18, 2009-09-02

# To Succeed



# Thanks



<http://research.microsoft.com/en-us/projects/knows/>