TechFest
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White Space Networking

Part I: Introduction

Victor Bahl

June 26, 2014

ground truths

- wireless use continues to rise
  - look at any data that pertains to smartphone, tablet, wearable's, m2m adoption
- consumption of data / user continues to rise
  - social networking (e.g. micro-blogging), multimedia downloads (e.g. Hulu, YouTube), cloud gaming (e.g. Xbox Live), video conferencing (e.g. Skype), file sharing & collaboration (e.g. SharePoint), cloud Storage (e.g. Azure),…
- nextGen apps need more bandwidth with lower latency
  - augmented reality, streaing applications, immersive video conferencing, 3D telemedicine, virtual immersive classrooms, remote health monitoring, memory assistance, natural gesture computing, collaborative development,…..
- LTE latency (70-100 msec) is a concern
- cost of connectivity is a concern
- broadband is the prime lever of Internet activity growth

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spectrum crisis - can it be managed?

THE HILL NEWS ALERTS
SIGN UP NOW
Enter Email GO
Home
Senate
House
Administration
Campaign
Polls
Business &

THE HILL'S Congress Blog
Where lawmakers come to blog

The spectrum crisis is upon us
By Brent Skorup - 06/20/13 12:00 PM ET

Tweet 14 Like 32 Send

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EMAIL
PRINT
SHARE

InformationWeek Government

NEWS
FCC Chair Cites 'Spectrum Crisis'

HOME PAGE | TODAY'S PAPER | VIDEO | MOST POPULAR | U.S. Edition

The New York Times

Business Day
Technology

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

Carriers Warn of Crisis in Mobile Spectrum

CTIA Blog
The Wireless Association®
CTIA is an international nonprofit trade association that has represented the wireless communications industry since 1984.

CYBERSECURITY | ENVIRONMENT | SPECTRUM & TOWERS | STATS & FACTS | TAXES & FEES

Home > Public Policy > It is No Trick – There is a Spectrum Crisis

OCTOBER 23, 2012 Print Preview

It is No Trick – There is a Spectrum Crisis

Like Send 36 people like this. Be the first of your friends.

Yes, I'm the cybersecurity guy, but I'm also an engineer by trade, a Bell Labs alumnus and a patent holder who has worked o

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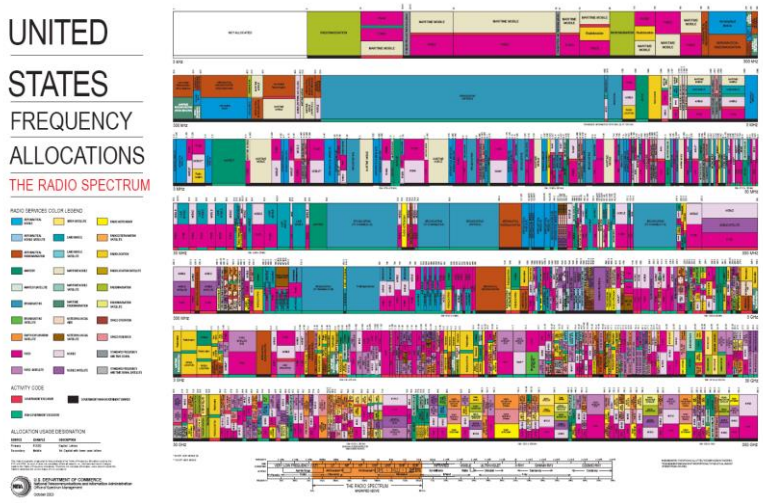
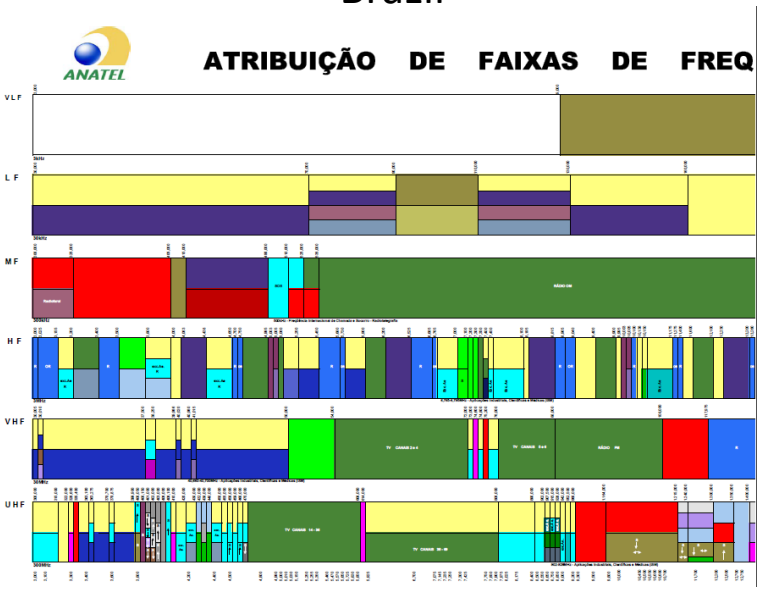
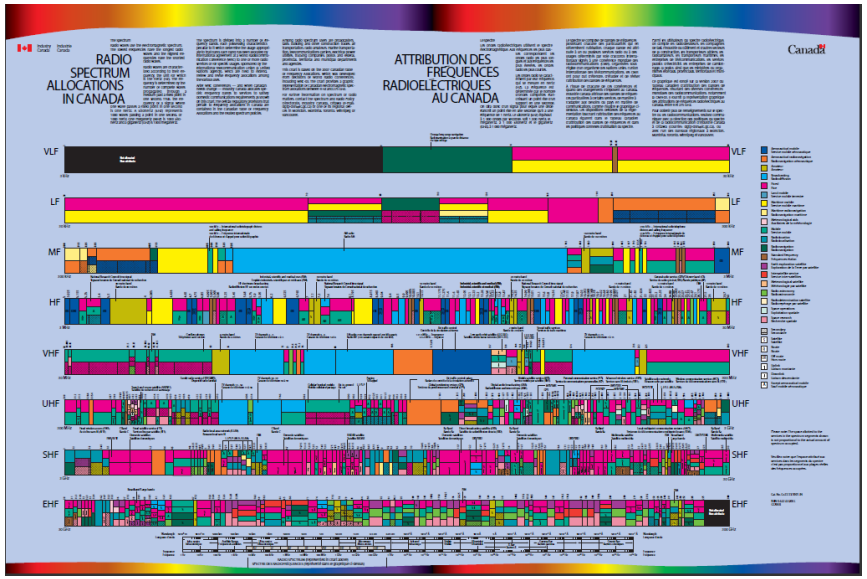
wireless requires spectrum, but how to get it?



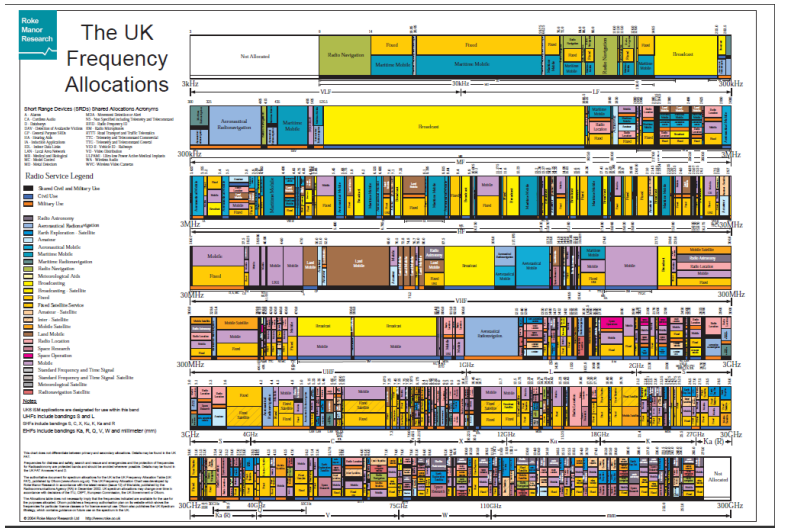
Brazil



Canada



U.K.



what can we do?

- fatten the pipes - open up additional spectrum (change allocation)
- extract greater juice (more bits/hertz)
  - capacity is finite, limit set by thermal noise (~20 dB); e.g. Turbo coding already within a few dBs of Shannon limit; MIMO etc.
- Increase spatial reuse with new network architectures (e.g. small cells)
- promote secondary market place
- promote opportunistic and dynamic spectrum access

in 2003, I had my first exposure to the breadth & complexity of the issues involved with spectrum

everyone wanted more of it

debate was licensed or unlicensed

I learned about:

Ronald Harry Coase

29 Dec. 1910 – 2 Sept. 2013

noble laureate & "father" of reform in spectrum allocation policies

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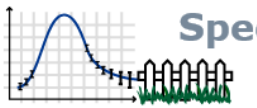
licensed or unlicensed

STANFORD UNIVERSITY



Spectrum Policy: Property or Commons?

Location & Travel | Schedule | Speakers | Sponsors & Organizers | Resources/Blogs

WHO
Stanford Law School Center for Internet and Society and the Manhattan Institute

WHAT
Should spectrum be treated as property or a commons?

WHEN
Saturday, March 1 and Sunday, March 2, 2003

WHERE
Stanford Law School, Stanford, CA, USA [directions]

Video and audio archives of Spectrum Allocation: Property or Commons are now available in the Schedule section of the site.

Spectrum policy is undergoing a fundamental reorientation in the United States and elsewhere. An emerging consensus holds that the traditional system of governmentally-allocated spectrum rights inhibits innovation and competition. The central question now facing policy makers is what form of spectrum management should replace the existing system. These issues will be discussed and debated at:

Spectrum Policy:
Property or Commons?
Stanford Law School
Stanford, California
Saturday, March 1 and Sunday, March 2, 2003

Sponsored by
Thomas Hazlett, the Manhattan Institute, and
Lawrence Lessig of the Stanford Law School Center for Internet and Society

Work-in-Progress
Version 1.1

Draft Proposal for Comment
Etiquette Rules and Procedures for Unlicensed Bands

Victor Bahl
Microsoft Research

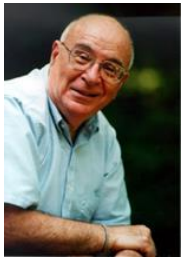
I. Abstract

This document is a draft for discussion of etiquette rules for short range wireless devices operating in the unlicensed frequency bands. Regulators like the Federal Communications Commmission (FCC) can be invited to apply these rules to the operation of 'unlicensed' wireless devices. The wireless devices may support asynchronous and isochronous digital communications. The proposed set of rules builds on rules that govern operation of wireless devices in Europe [11] and Japan and enhances them for adoption in the United States. It is our belief that these rules will enable the regulators of our spectrum to set an etiquette that enforces fair sharing of our precious national resource, while still allowing people to innovate at all levels of the protocol stack.

spectrum etiquette is not enough!


Lawrence Lessig


Thomas Hazlett


David Farber


Judge Alex Kozinski


Gerald R. Faulhaber


Stuart Benjamin


Tom Freeburg

.....

If you want a seat on the table, bring a proposal

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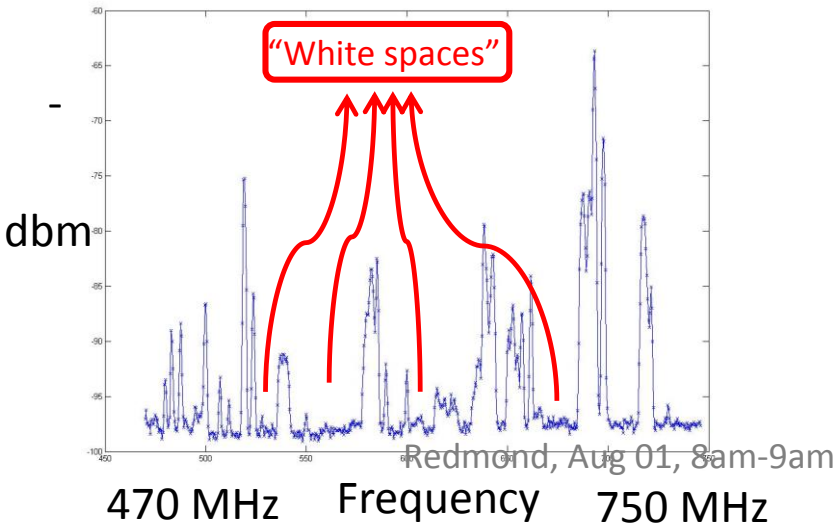
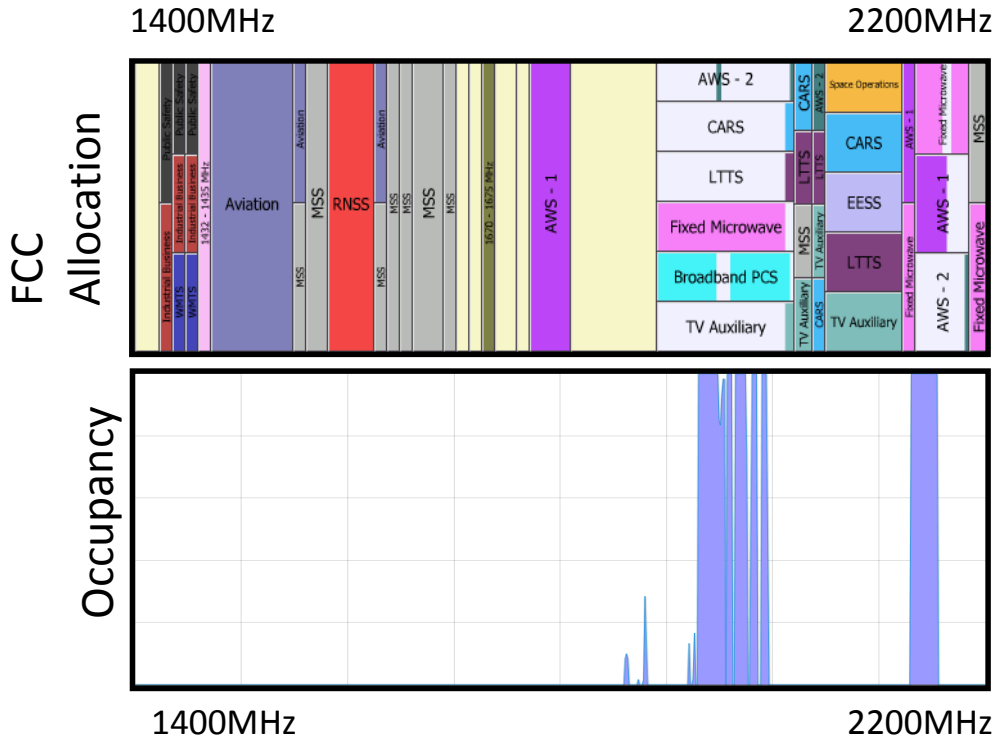
not everything allocated is being used



Redmond, Aug 01, 8am-9am



Redmond, Aug 01, 2013 8am-9am

the idea of dynamic spectrum access was in the air but someone needed to step up and prove that the DSA concept works

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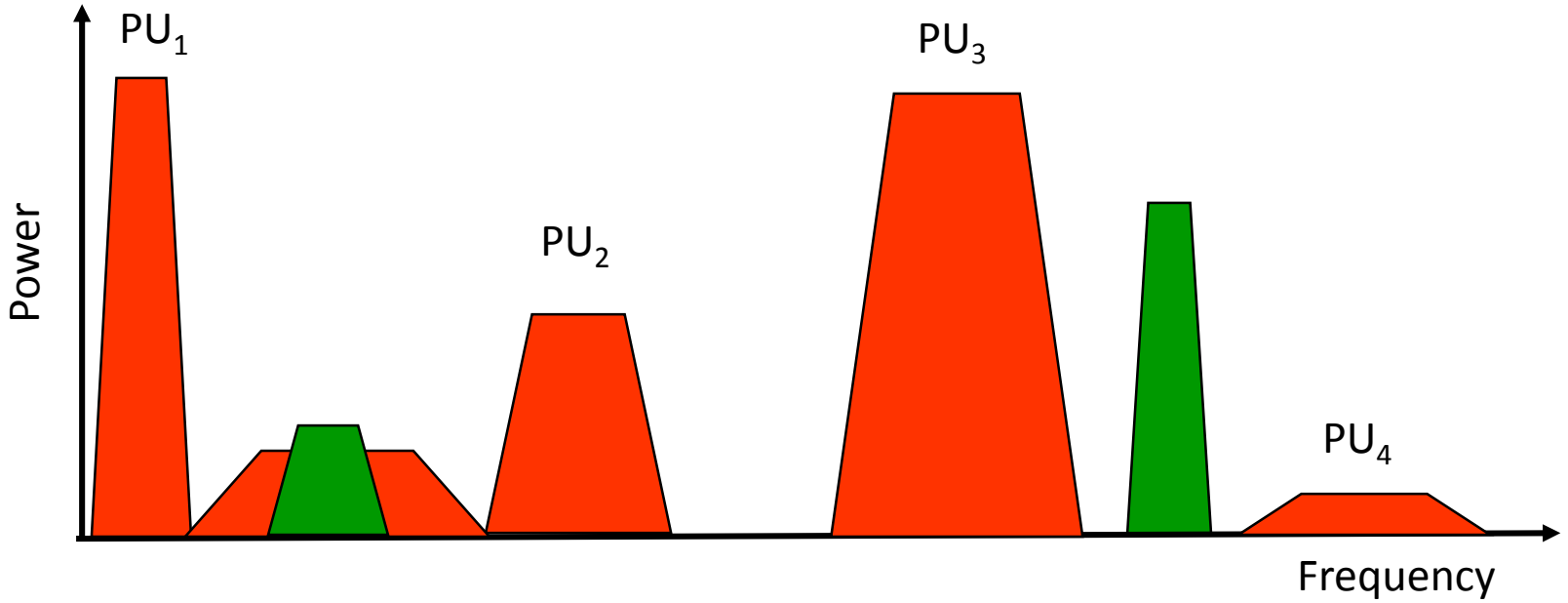
DSA, a way to harvest unused spectrum



- **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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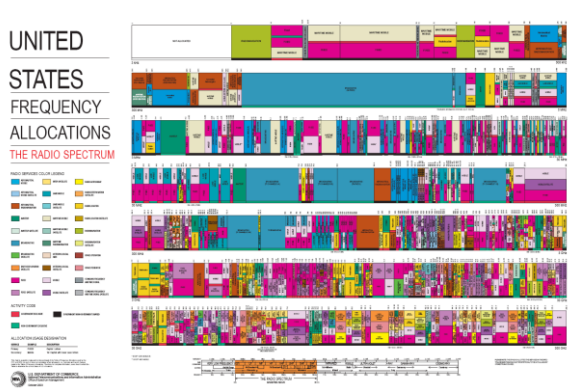
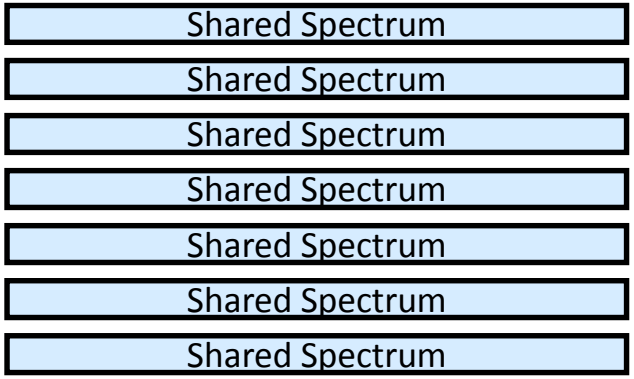
think boldly….

- fixed frequency spectrum allocation is flawed





- does not exploit time, space and frequency degrees of freedom

- DSA could allow essentially “unlimited capacity”

also at stake were “TV white spaces”

“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.

- They set June 12, 2009 as the deadline for full power television stations to stop broadcasting analog signal

….opening up new spectrum

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UHF TV bands

highly desirable for data 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 technica

Proponents believe the TV spectrum can be used for

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

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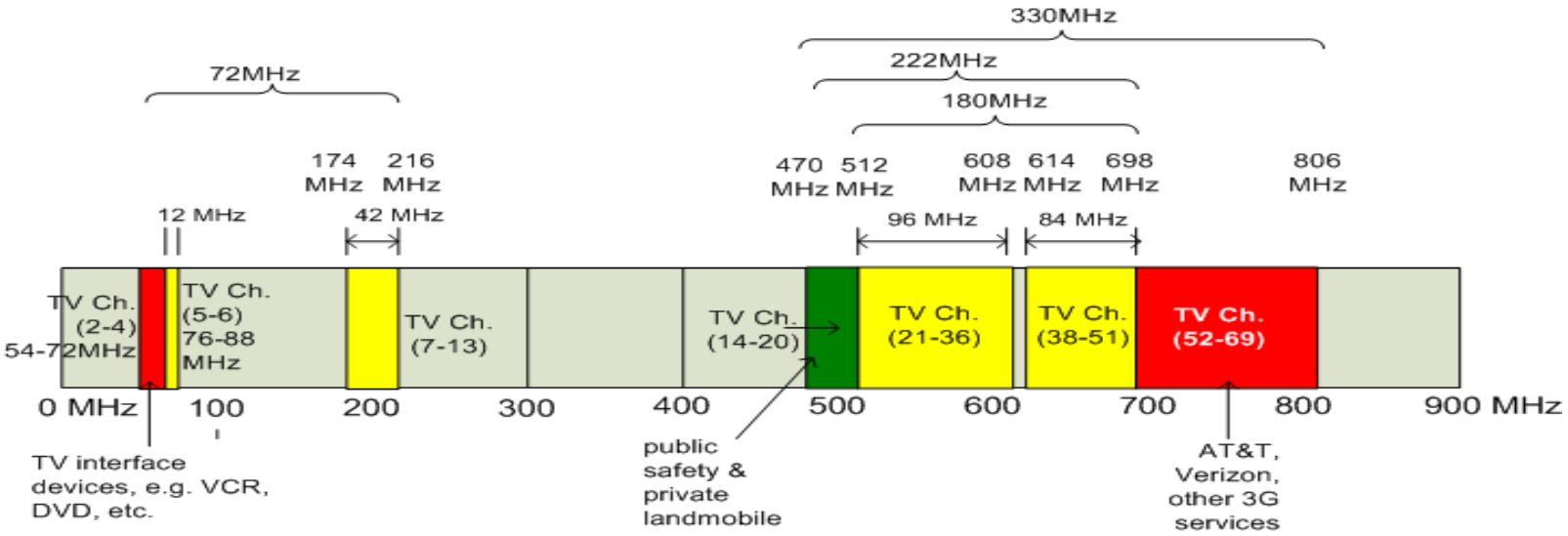
TV white spaces

gaps left between broadcast channels, occur in different places on different channels



properties

- unlicensed
- long range
- deep penetration

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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

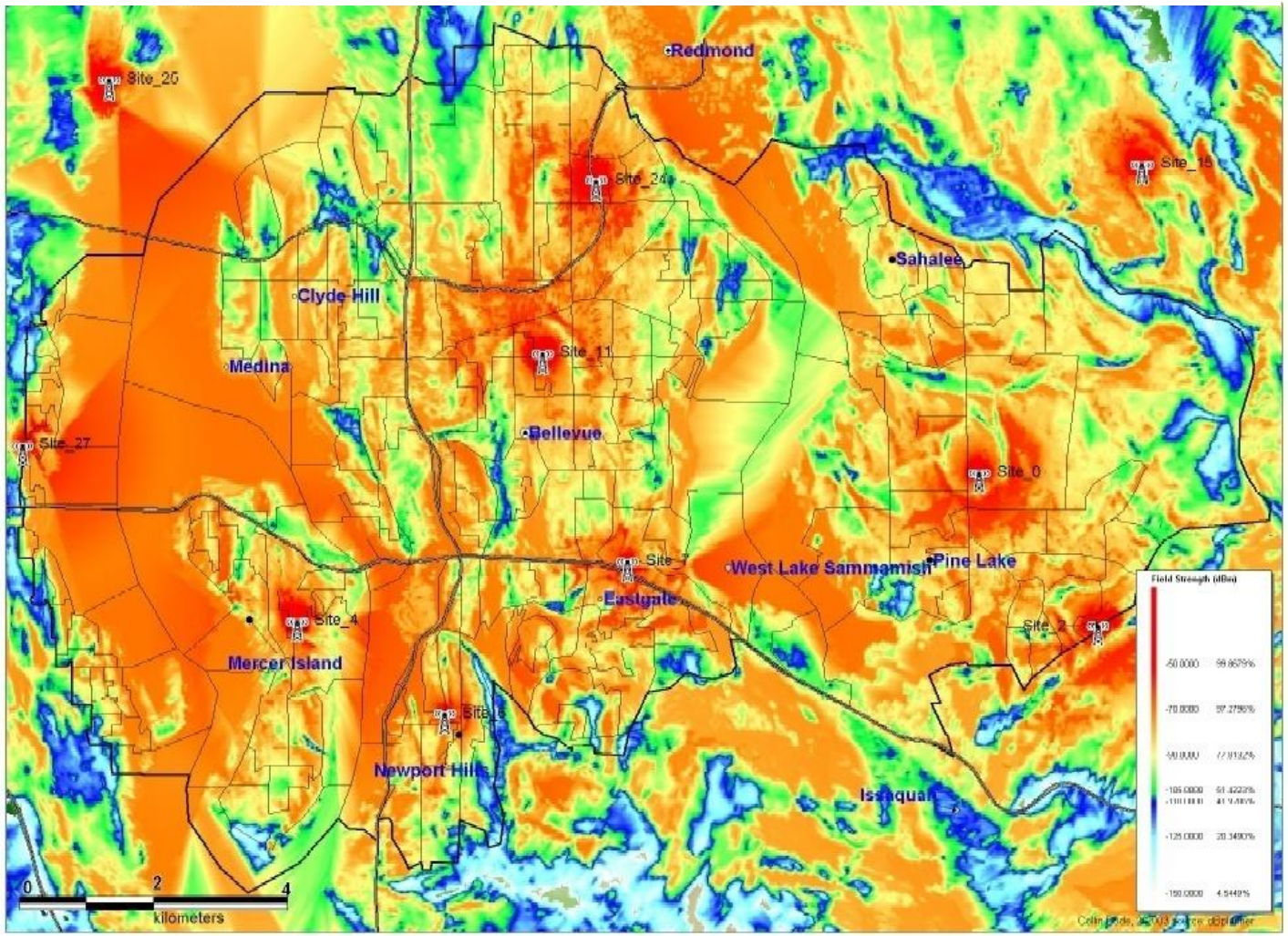
$$L_{fs} = 32.44 + 20\log d + 20\log_{10} f - G_T - G_R$$

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

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

propagation at 2600 MHz: 10 Sites

Seattle Eastside: Bellevue and Sammamish



~ 250 km²

Good Coverage

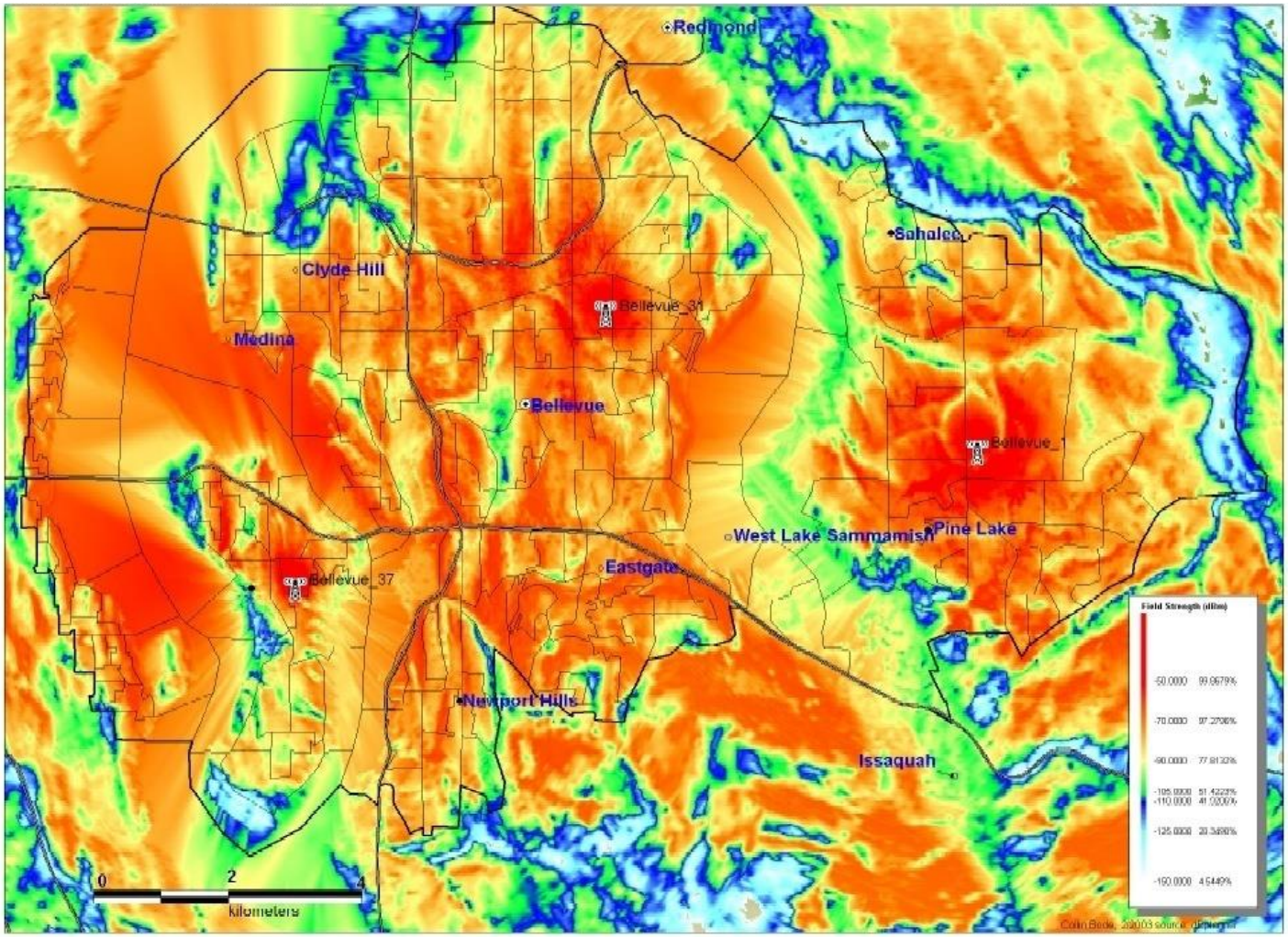
Bad Coverage

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

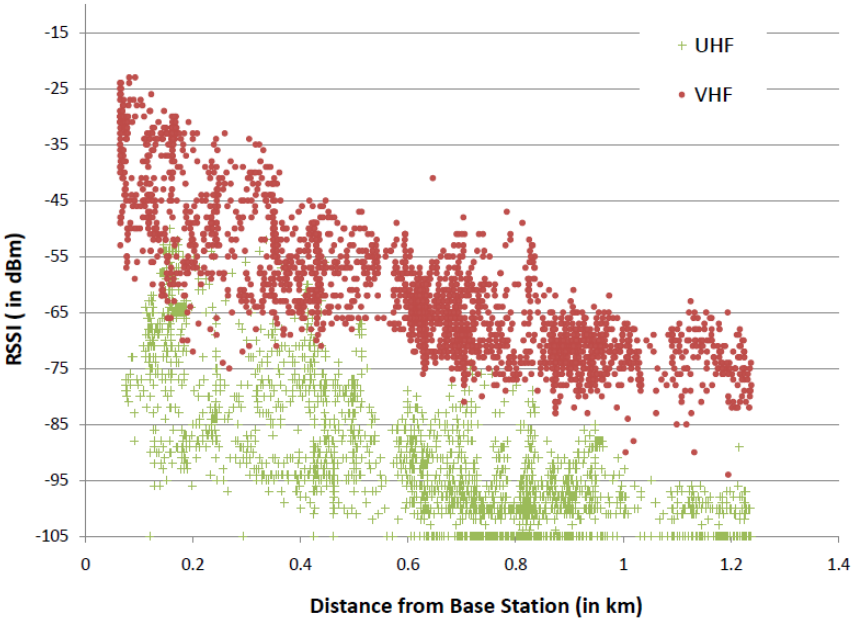
range, does theory match up?

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

reality check: range?

Microsoft Redmond Campus

route taken by the shuttle (0.95 miles x 0.75 miles)

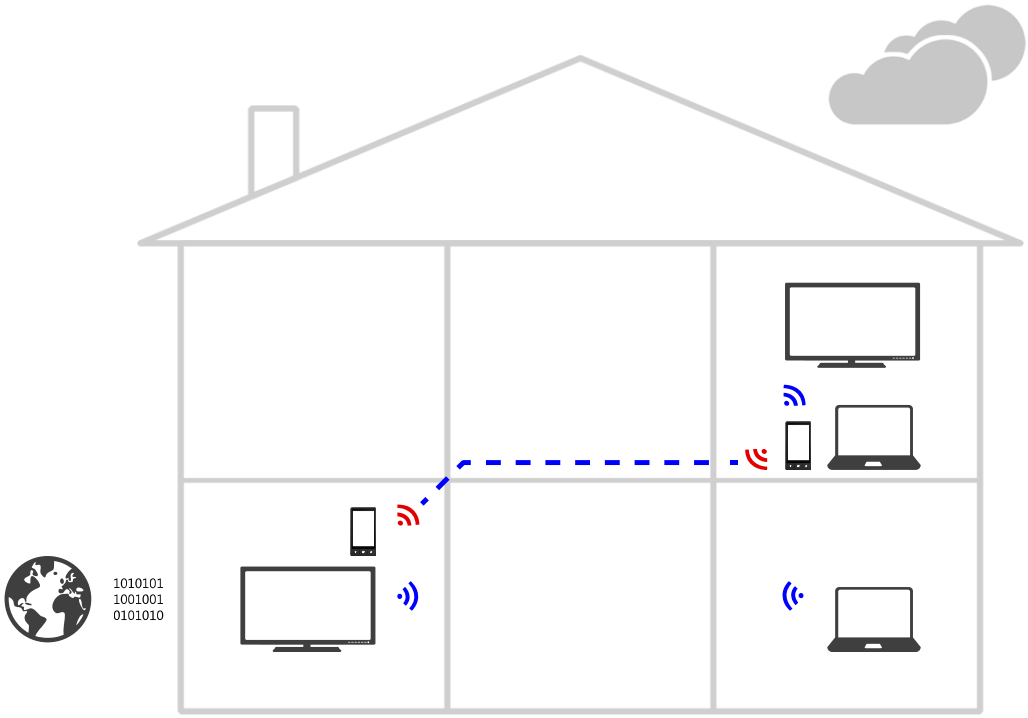


Raw received power at different Distances from the transmitter

4-5 white space base stations can cover the entire Redmond campus

Microsoft

reality check: signal penetration?



in a typical home, a Wi-Fi signal can penetrate up to two walls.

at the same power, a UHF signal can penetrate more walls and obstacles.

this simplified and enriches in-home/in-building networking.

this also makes mesh networking feasible.

Microsoft

...but how do we know if spectrum is available?

sense the channel?

but we are not able to make sensing work reliably

is there another way?

Sense*Less*: A Database-Driven White Spaces Network

Rohan Murty
Harvard University
rohan@eecs.harvard.edu

Ranveer Chandra
Microsoft Research
ranveer@microsoft.com

Thomas Moscibroda
Microsoft Research
moscitho@microsoft.com

Paramvir Bahl
Microsoft Research
bahl@microsoft.com

***Abstract*—The most recent FCC ruling proposes relying on a database of incumbents as the primary means of determining white space availability at any white spaces device (WSD). While the ruling provides broad guidelines for the database, the specifics of its design, features, implementation, and use are yet to be determined. Furthermore, architecting a network where all WSDs rely on the database raises several systems and networking** database of incumbents *and* WSDs in active operation, (2) predicts the availability of white spaces at any WSD's location using sophisticated propagation modeling (including high-resolution terrain-data as well as TV-tower-specific parameters, such as antenna-height, etc.), and (3) provides a framework to dynamically manage all WSD devices connected to the

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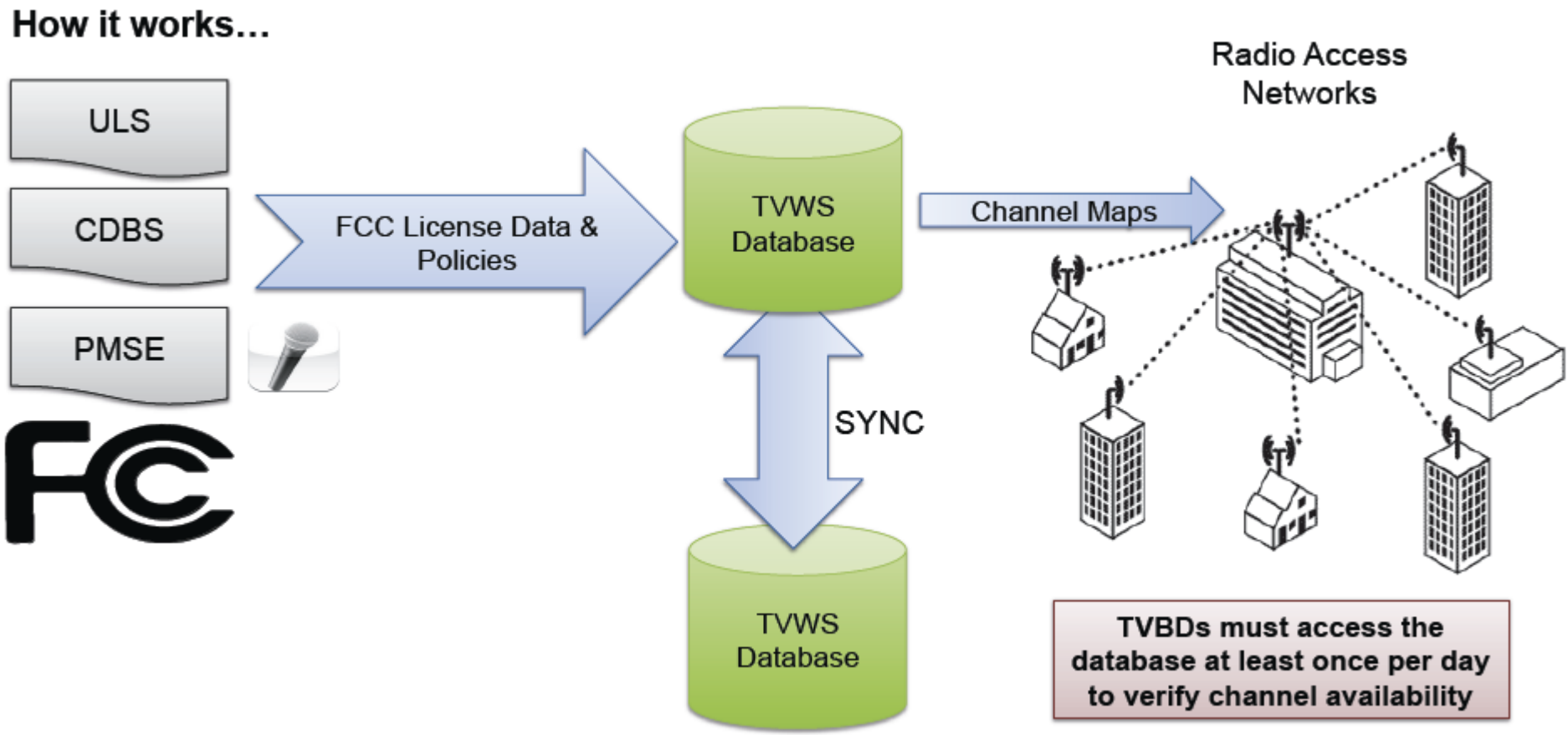
using WSDB

- devices only use the channels specified by the database.
- devices re-check the DB periodically.
- DBs maintain up-to-date lists of protected operators
- DBs can block newly occupied channels to prevent further device access.

spectrum availability database



CDBS: Consolidated Database System
ULS: Universal Licensing Systems

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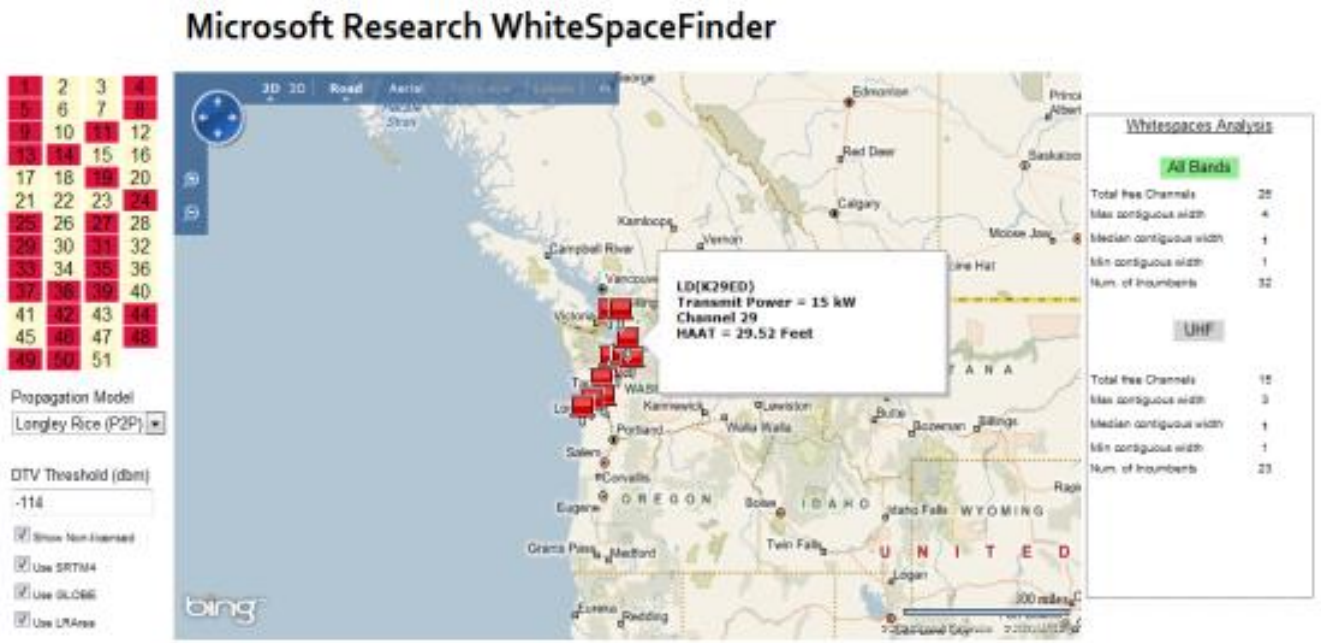
MSR's spectrum database (2010 -)



	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	848.5	8.781	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	38	-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	-43.5	239.8	2328	12.46	SRTM41	Line-Of-Sight Mode	

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MSR's DB is pretty good!

TV/MIC data (FCC CDBS, others)

Location *(Latitude, Longitude)*

Terrain Data (Globe, SRTM)

Propagation Modeling

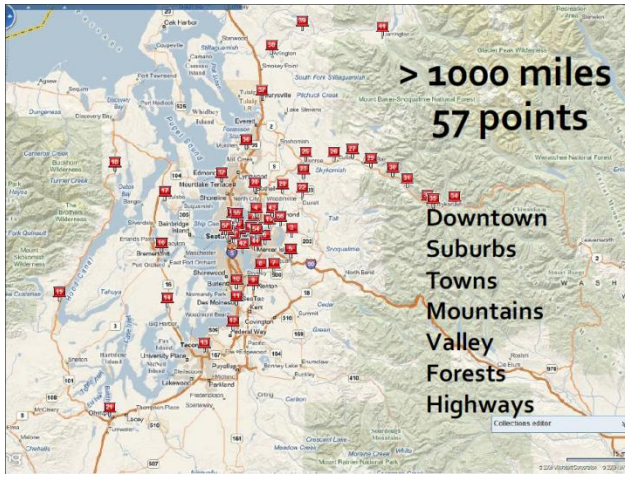
Irregular Terrain Model (ITM)
Longley-Rice (1968)

- **20 MHz to 20 GHz**

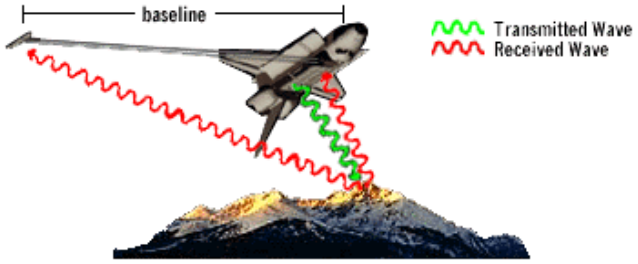
The Egli model is formally expressed as:

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

John Egli (1957)



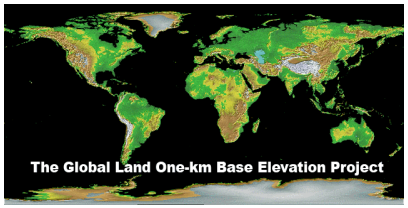
Shuttle Radar Topography Mission (SRTM)



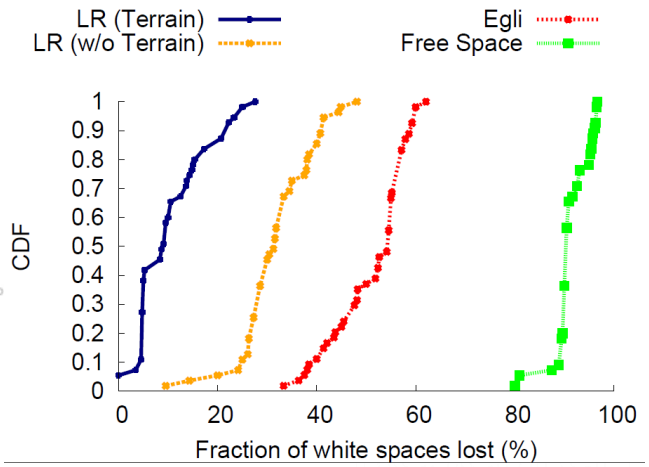
Radar signals being transmitted and recieved in the SRTM mission (image not to scale).

Joint Project between NASA and NIMA

Globe



NOAA NATIONAL GEOPHYSICAL DATA CENTER



reality check: available bandwidth

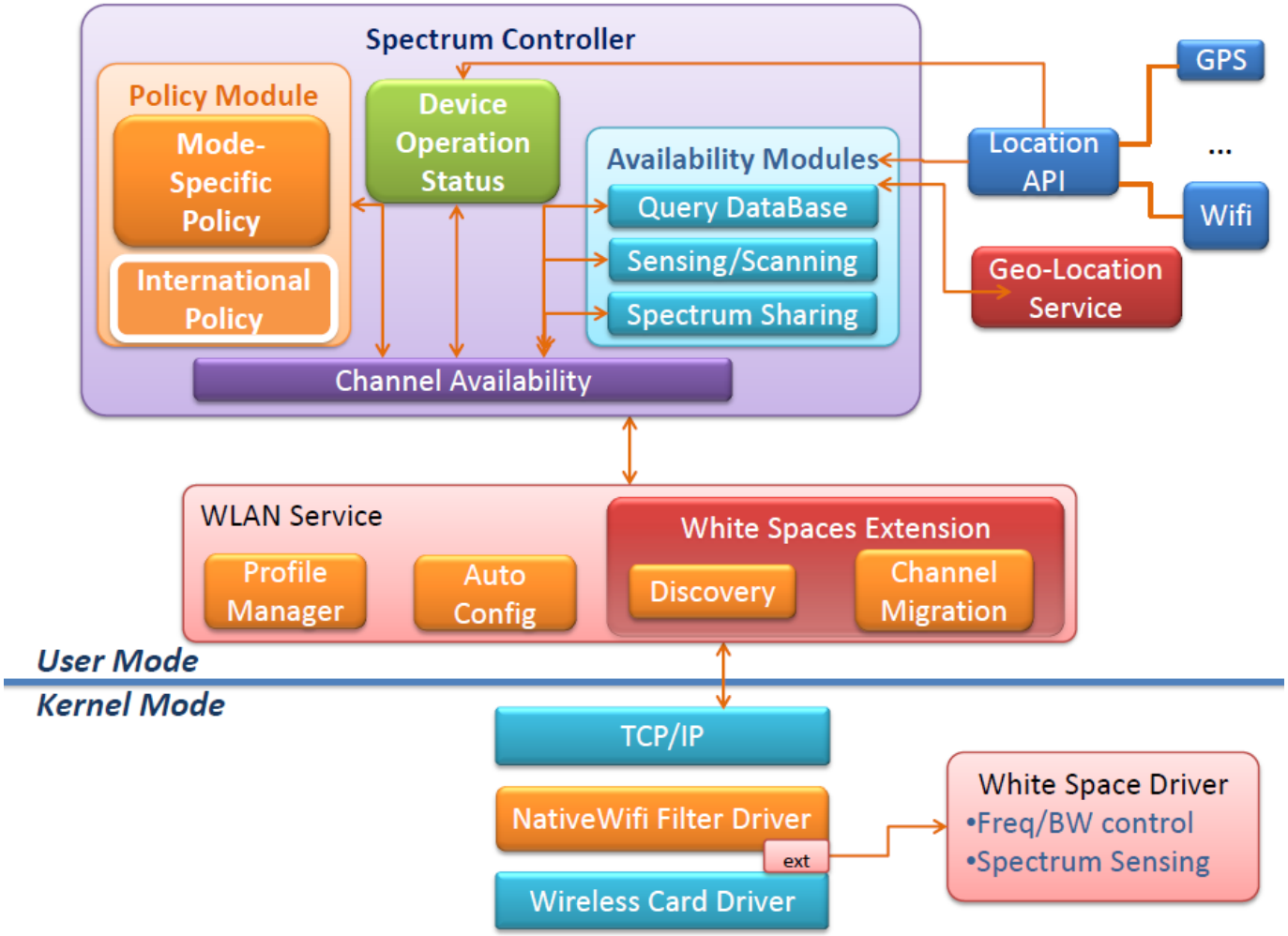
City Hall	Available Channels	Bandwidth	Capacity Est.
Redmond	28	168 MHz	672 Mbps
Bellevue	26	156 Mhz	624 Mbps
Seattle	26	156 MHz	624 Mbps
Sammamish	28	168 MHz	672 Mbps
New York	2	12 MHz	48 Mbps
Boston	10	60 MHz	240 Mbps
San Francisco	5	30 MHz	120 Mbps
Kansas	19	114 MHz	456 Mbps
Miami	5	30 MHz	120 Mbps

Sample of bandwidth availability

Smaller cell sizes and frequency reuse is a way to manage densely populated regions with lower no. of available channels

Location of incumbents

networking stack has to change



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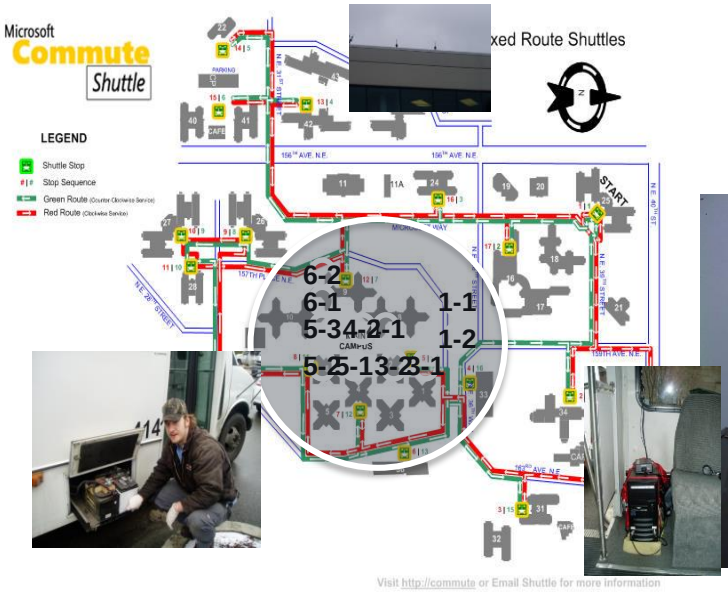
the first urban white space network in the world

Oct. 16, 2009

White Space Network Setup in Bldg. 99

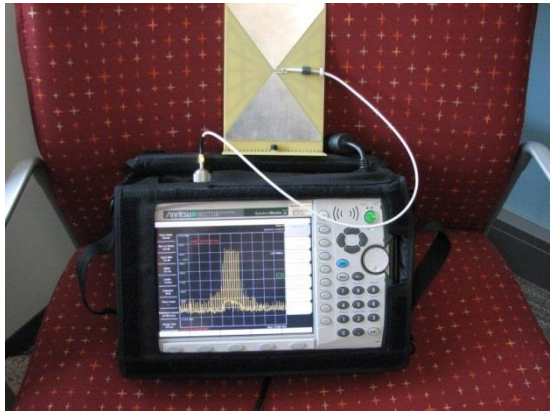


Campus-Wide Deployment

WS Antenna on Bldg 42

WS Antenna on MS Shuttle

Shuttle Setup



Data packets over UHF

Microsoft

success!

Aug 14, 2010

THE WALL STREET JOURNAL.
Digital Network

MAY 11, 2010, 6:59 P.M. ET

FCC Officials Visit Microsoft To Examine Experimental Network

Chairman Genachowski & Microsoft's CTO Craig Mundie, August 14, 2010

Chairman Genachowski and FCC Managing Director Steven VanRoekel Climb aboard the MS Shuttle to look at our WhiteFi Network

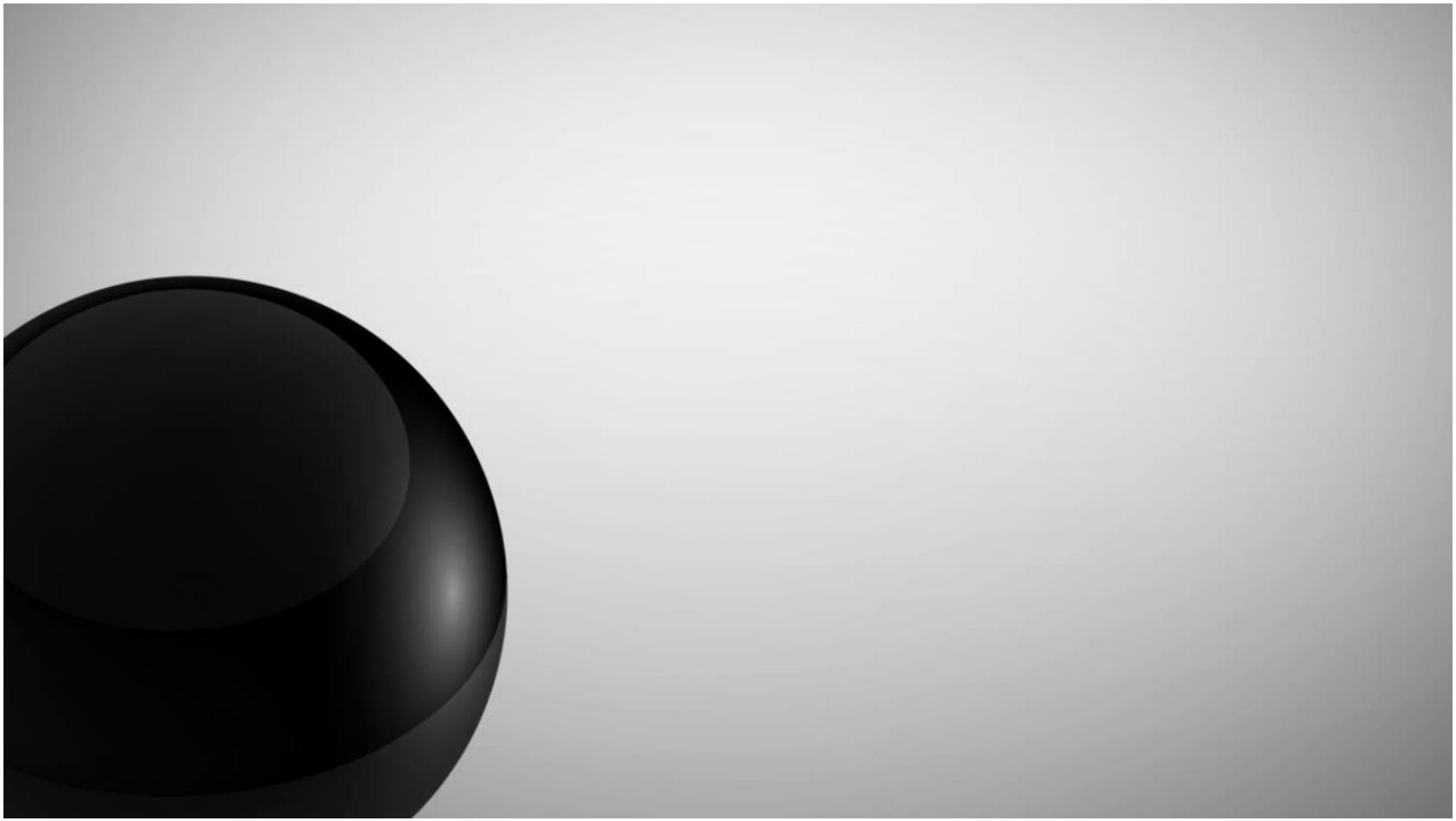
The New York Times

F.C.C. Opens Unused TV Airwaves to Broadband

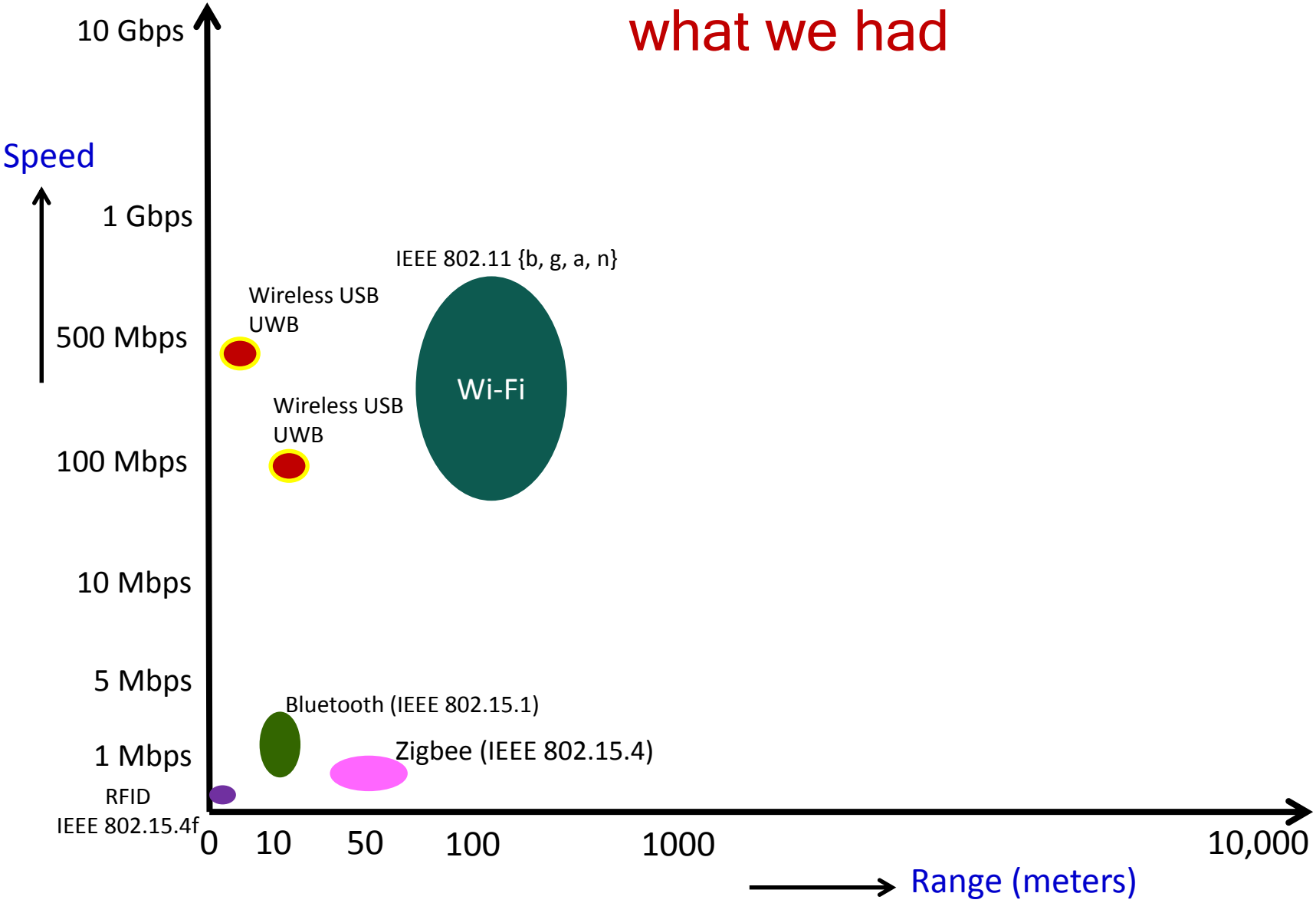
By EDWARD WYATT
Published: September 23, 2010

Microsoft

white spaces explained

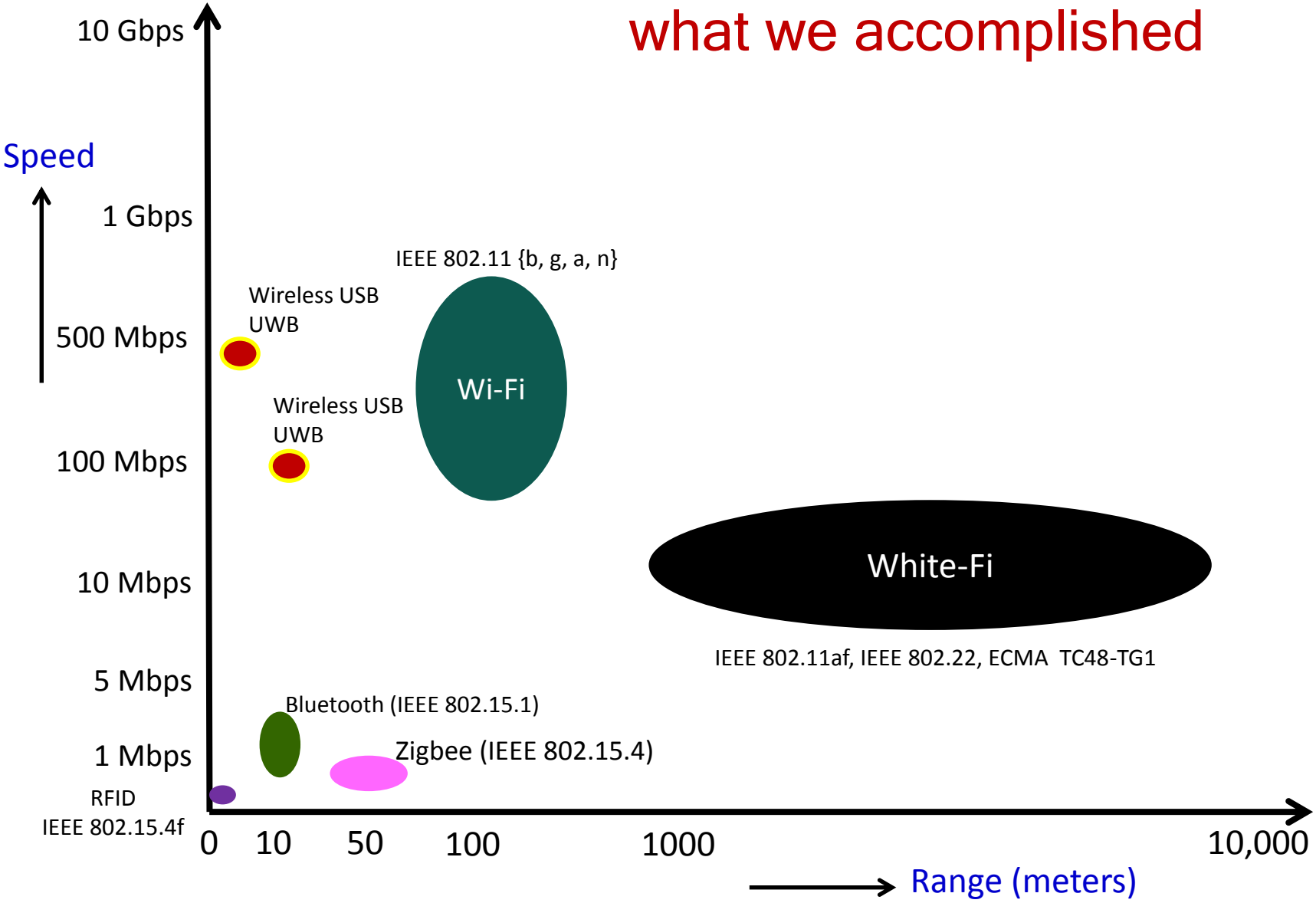


connectivity options over unlicensed frequencies



connectivity options over unlicensed frequencies

what we accomplished



business opportunities

- campus and city-wide connectivity
  - seamless handoffs while moving between buildings in corporations, universities, industrial parks etc.
- giant hot-spots (to relieve spectrum congestion)
- content distribution networks (should work great in suburban communities & rural America)
- direct connectivity to retailer portals (without involving cellular providers)
  - E.g. BestBuy, Walmart, Home Depot, Sears, etc. put up WS BSs and provide direct access to their store up to a few mile radius
- home wireless multimedia

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world-wide influence on spectrum policy

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

India
October 22, 2009

Federal Communications Commission
April 28, 2010

Ofcom

Office of Communications (UK)
June 10, 2010

iDA SINGAPORE

Singapore
Apr. 8, 2010

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

China
January 11, 2010

ANATEL
Provedor Licenciado pela Anatel

Brazil
Feb. 2, 2010

IEEE

Standards

KOMO 4

Fisher Communications Inc.
January 14, 2010

NSF Workshop on Future Wireless Communication Networks

US Research Funding
November 9 2009

BROADBAND.GOV

Workshop: Research Recommendations for the Broadband Task Force

MOBILE BROADBAND FOCUS OF SAN DIEGO FIELD HEARING THURSDAY
Hearing for National Broadband Plan Explores Spectrum, Mobile Applications

PhD Thesis

- Rohan Narayan Murty, *Opportunistic Wireless Network Architectures*, Harvard University (June 2011)

- Yuan Yuan, *Enabling Dynamic Spectrum Allocation in Cognitive Radio Networks,* University of Maryland College Park (Sept. 2007)

Microsoft

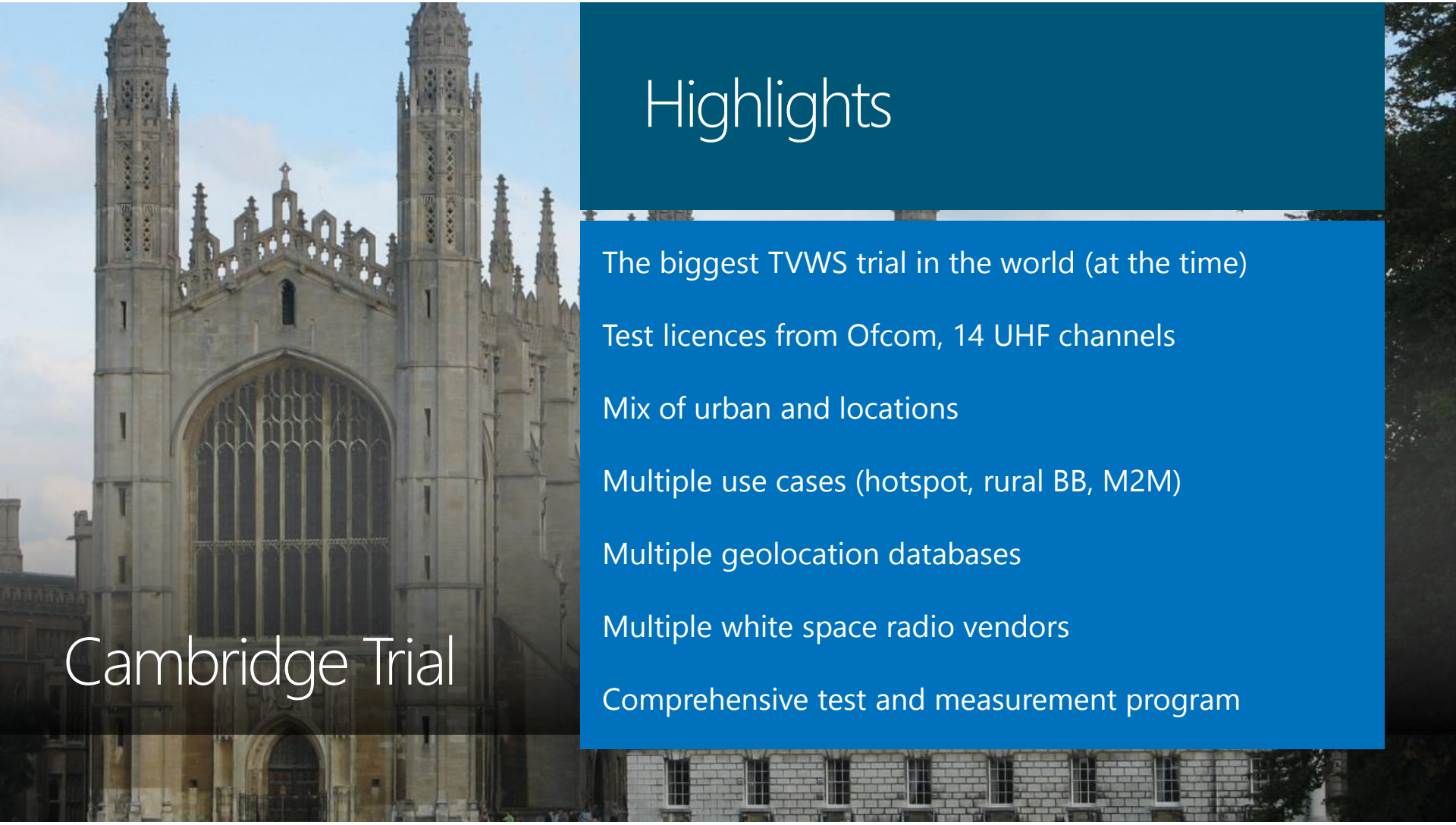
world-wide trials and demonstrations

Microsoft

engadget

Cambridge becomes UK's first White Space city as trials declared a success

By **Daniel Cooper** posted Apr 25th, 2012 at 11:19 AM



Cambridge Trial

Highlights

- The biggest TVWS trial in the world (at the time)
- Test licences from Ofcom, 14 UHF channels
- Mix of urban and locations
- Multiple use cases (hotspot, rural BB, M2M)
- Multiple geolocation databases
- Multiple white space radio vendors
- Comprehensive test and measurement program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Microsoft launches 4Afrika initiative with Huawei W1 variant, TV white space broadband project

By Richard Lawler posted Feb 4th, 2013 at 8:09 PM

Kenya pilot

Africa's largest white spaces network

demonstrates WSN with two white space base stations and twenty Wi-Fi hotspots at community anchors.

launched in February 2013

Education

Agriculture

Healthcare

Government Services

Steven Mwaniki. - 6 hours ago

As one of the lucky student of Gakawa secondary school am so humbled by the kind of Noble project that you guys have brought to our school. That is so kind of you. We promise to take great care of precious project. We are so greatful of you and may our Mighty Lord Bless you Forever.

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current status:
regulatory landscape

Country/ Region	Law	Regulation	Policy Guidance	Trials/Pilots
United States	Done	Done	Done	Trials complete/Pilots ongoing
UK	Pending	Pending	Done	Trials complete/Pilots planned
Finland	Done	Done	Done	Trials complete/Pilots planned
Canada	Pending	Pending	Done	Trials ongoing
European Commission		Pending	Done	Trials ongoing
China				Trials ongoing
Singapore	**Pending**	Pending	Done	Trials complete/Pilots planned
South Korea				Trials ongoing
Japan				Trials ongoing
Brazil				Trials ongoing

Microsoft

current status:
standardization activities

standards body	scope
Wi Fi ALLIANCE	Device interoperability and certification
IEEE	802.11AF wireless LAN TV Band channelization 802.11AC non-contiguous channel bonding for wireless LAN 802.19 coexistence of technologies 802.22 higher powered WAN 1900.6 spectrum sensing 802.15 TG4M low rate WPAN
IETF	PAWS WG on database to device interface
ETSI	device to WSDB interface standards and radio interface standards
CEPT SE43 work group	White Spaces implementation Cognitive radio systems 470-790 MHz
U.S. Database Administrators Group	Database to database interoperability

Microsoft

current status:

certification of (national) databases

FierceBroadband Wireless

NEWS TOPICS ANALYSIS FEATU

FCC names nine white-space database providers

January 27, 2011 | By Lynnette Luna

FierceBroadband Wireless

NEWS TOPICS ANALYSIS

FCC approves latecomer Microsoft as white-space database provider

August 3, 2011 | By Lynnette Luna

telecompetitor

Google Strives To Be Third Approved White Spaces Administrator

3/5/13 at 3:23 PM *by* Joan Engebretson

BroadcastEngineering

HOME > NEWS > REGULATION > KEY BRIDGE GLOBAL DATABASE TRIAL TO BEGIN MARCH 11

Key Bridge Global database trial to begin March 11

Phil Kurz *Mar. 7, 2013*

COMPUTERWORLD

News

FCC begins trial of Google white spaces database

A 45-day test run will check on the accuracy and functionality of the spectrum database

By Grant Gross

March 4, 2013 11:27 AM ET 1 Comment

TVTechnology

DEBORAH D. MCADAMS /
03.04.2013 03:00PM

White Space Databases Go Live Nationwide

Devices can now be introduced into the market

Microsoft

current status:
certification of WS devices

KTS Wireless Receives FCC Certification for White Space With the Agility Data Radio

Posted on December 26, 2011 by andy

RF Globalnet

telecompaper:::

FCC opens up TV white space for unlicensed devices

Monday 4 March 2013 | 15:57 CET | News

News

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Adaptrum Announces FCC Certified 'Super Wi-Fi' Solution And Launch Of Commercial Trial In Virginia

April 23, 2012

August 29, 2012 08:00 ET

Spectrum Bridge Launches TV White Space Certification Program to Help Radio Manufacturers Navigate FCC Approval Process

ars technica

FCC green lights first white space broadband device

After four years of fighting, debating, planning, and testing, the first FCC …

by **Matthew Lasar** - Dec 22 2011, 6:11pm PST

Microsoft

Microsoft project Istanbul

a researchers playground

objective

- campus-wide network with VoIP support
- 24x7 live camera feed for physical security
- digital displays with personalized live feed (a content distribution network)
- backhaul for small cell base stations

equipment

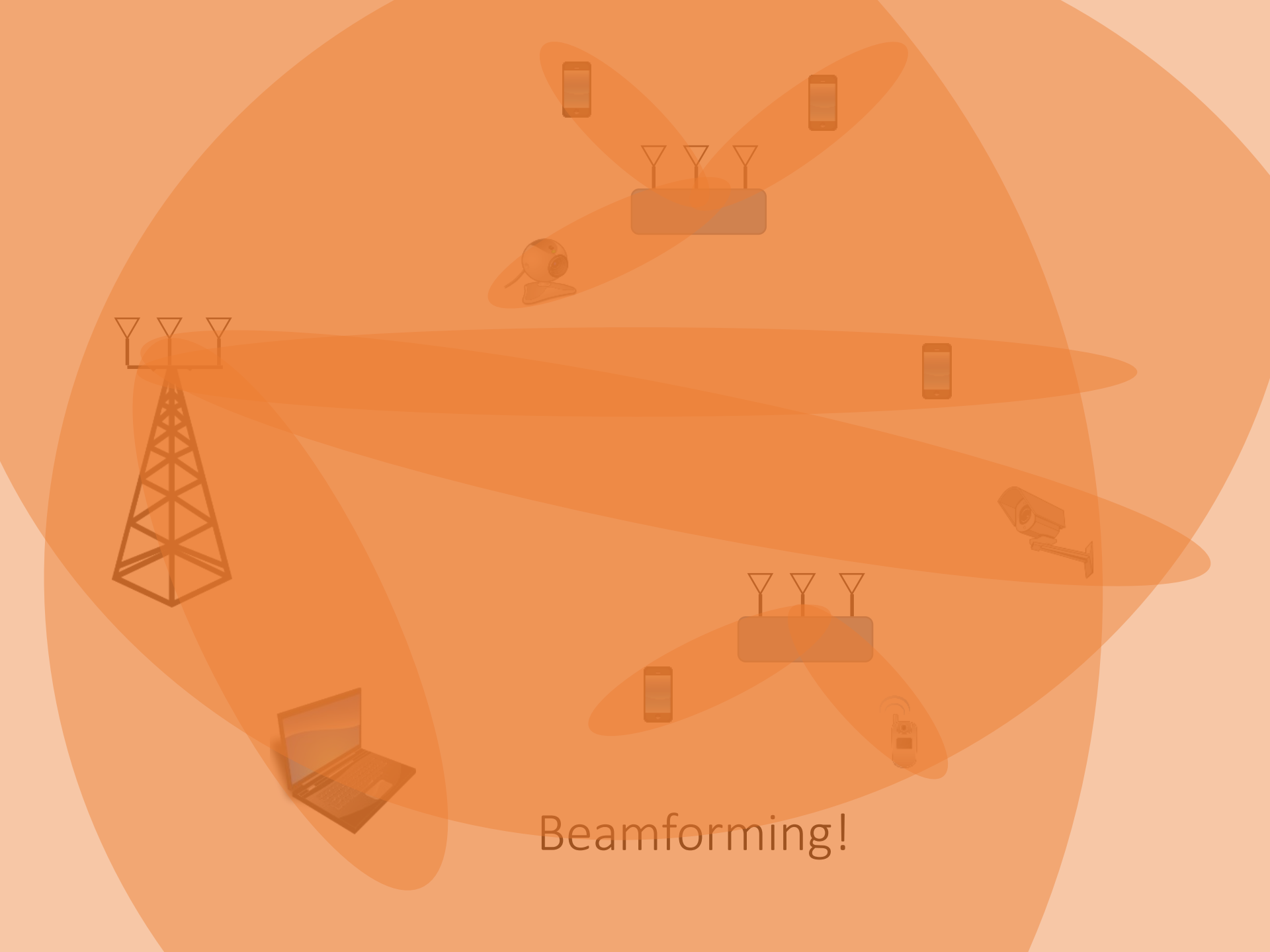
- in-house SDR - SORA
- Rice university (WARP)
- commercial (Adaptrum)

powered by MSR's WS database and Networking software

Microsoft

Project Istanbul

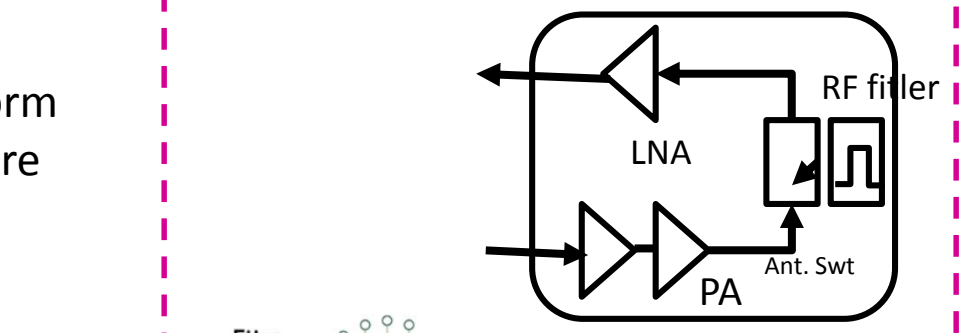
Redmond Campus TVWS (TV White Space) Network


Beamforming!

base station

in-house software radio

high-performance software radio platform on standard multi-core Windows PC



SORA RCB

PCIe
Interface

WBX RF Front End
50MHz -2.2GHz Rx/Tx
100 mW output power

Output power: peak 2W;
average (OFDM) 640mW

Antenna

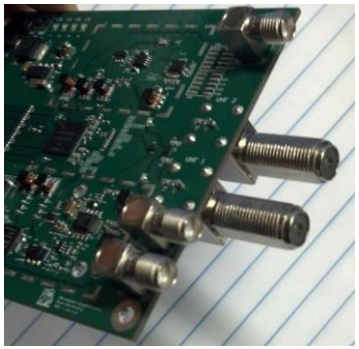
fast enough to support pure software implementation of the latest wireless standards (W-iFi, LTE, …)

added for Project Istanbul

Microsoft

Hardware platforms

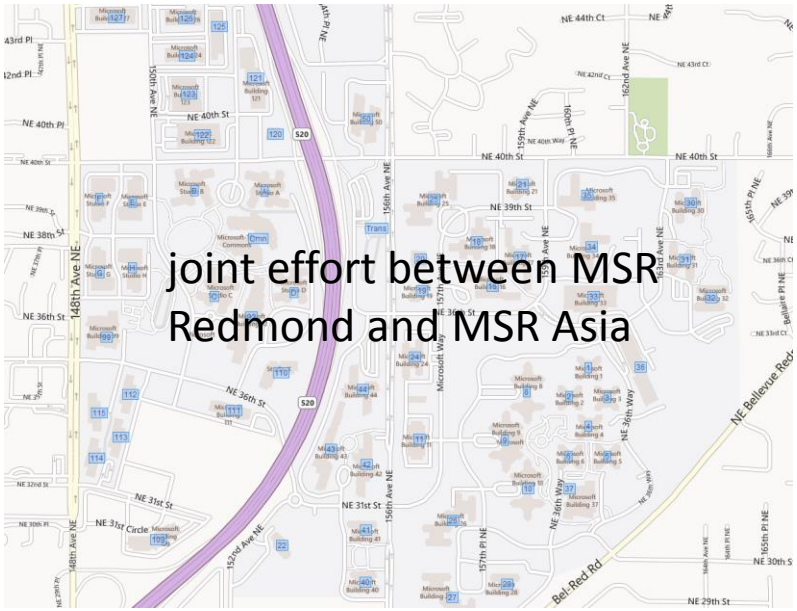
mango communications



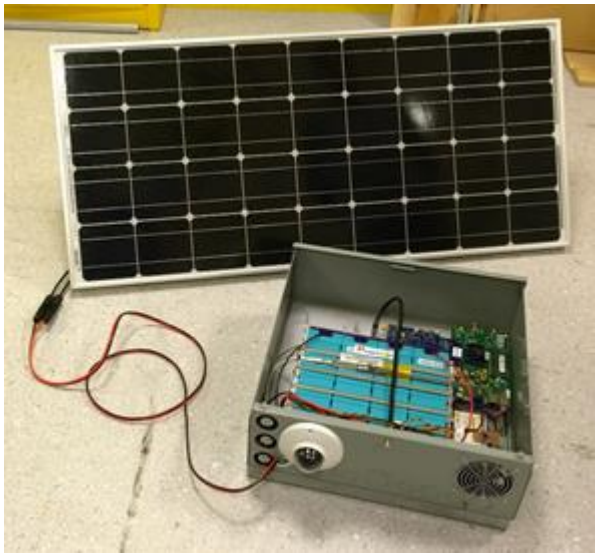
VOLO WIRELESS

ADAPTRUM

project Istanbul: a campus-wide wsn

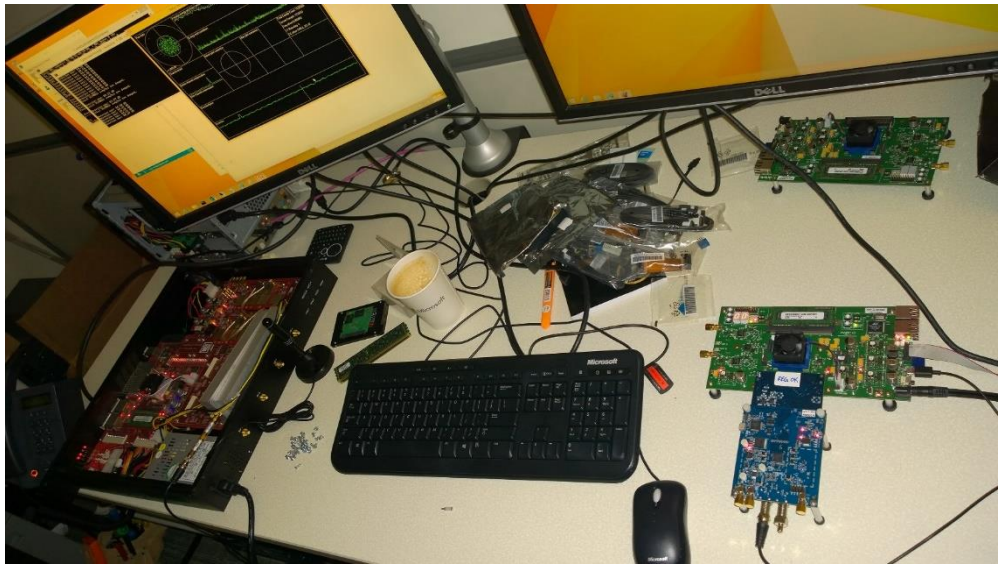


base station



Microsoft

client



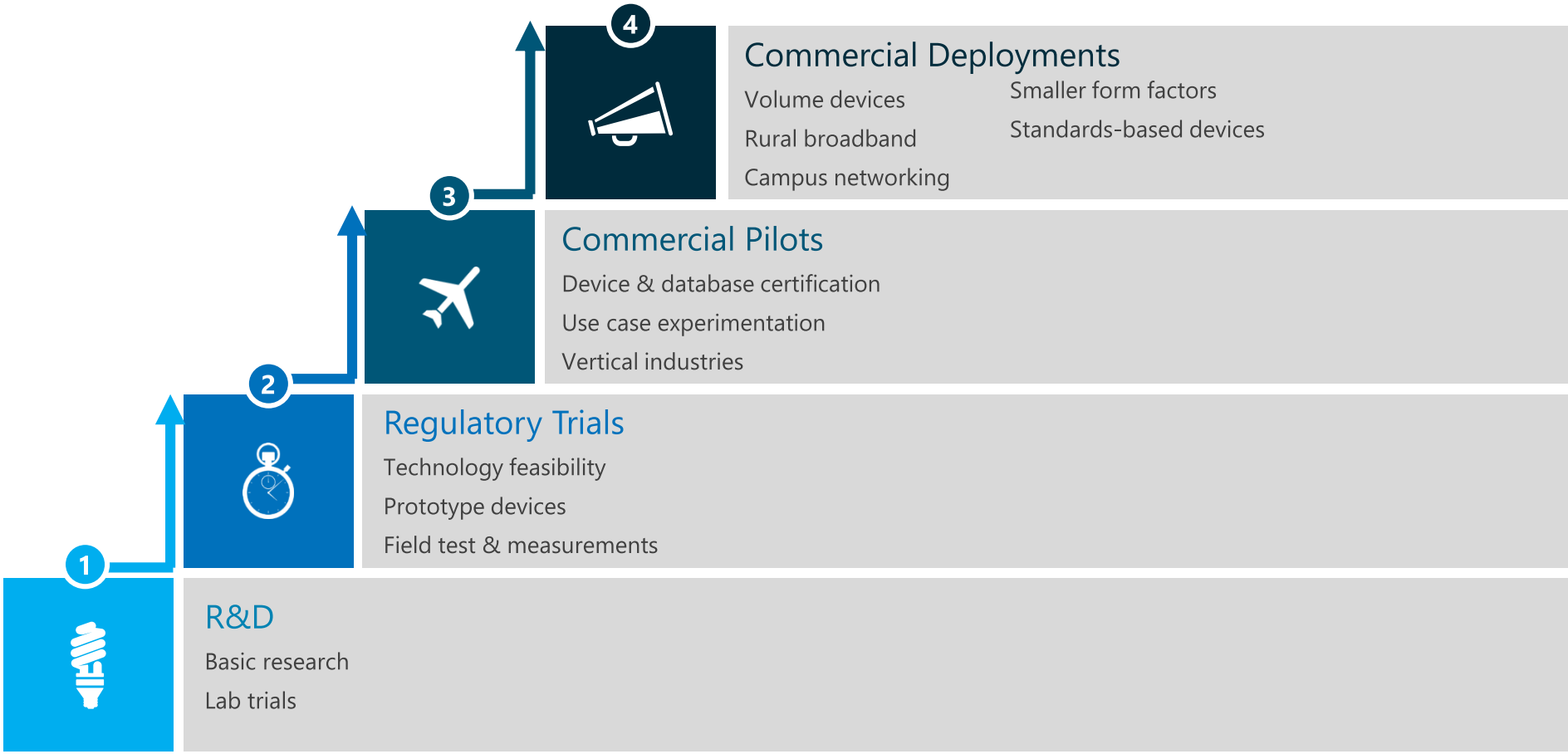
Microsoft

COURTESY: KUN TAN

demo!

Microsoft

where are we headed. . .



Microsoft

Thanks!