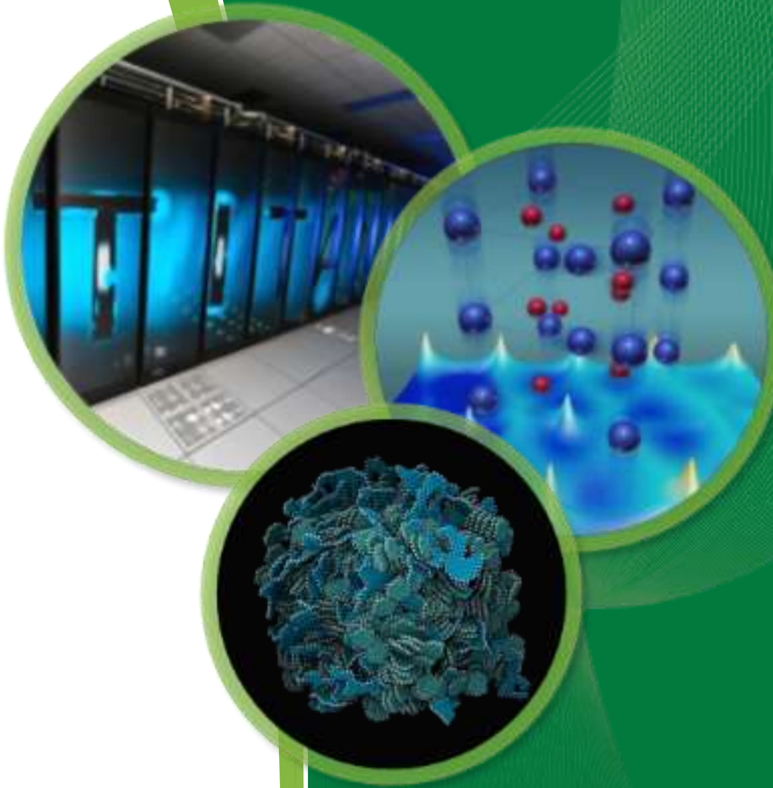
Shared Spectrum: Implications for Dense Deployment of IoT Devices and Systems in Utility Settings



Peter Fuhr, Ph.D.

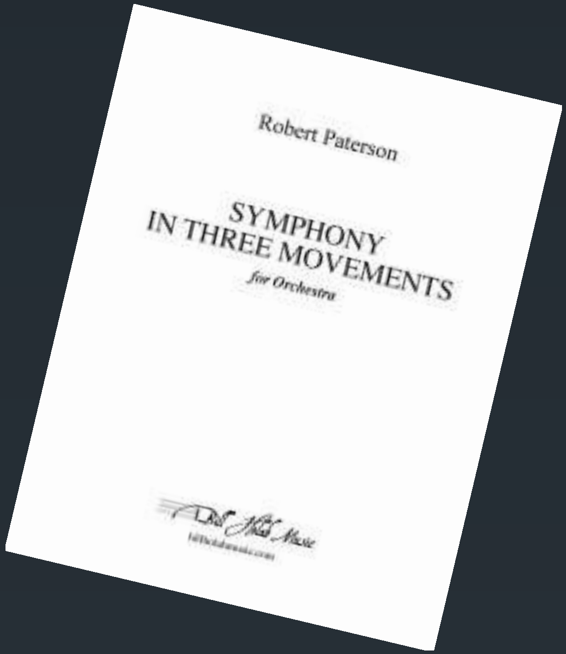
Distinguished Scientist

Tech Director UAS Research Center

ORNL is managed by UT-Battelle
for the US Department of Energy

Oak Ridge National Laboratory

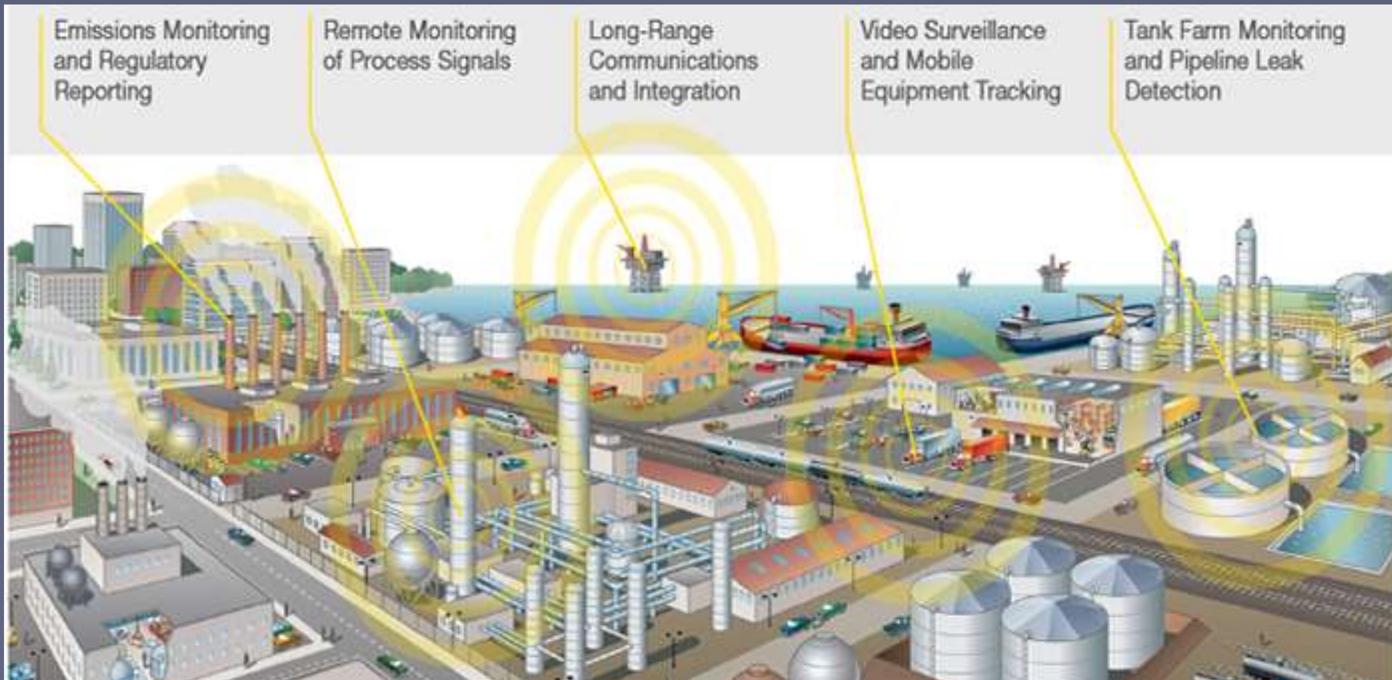
Cyber – in today's world…

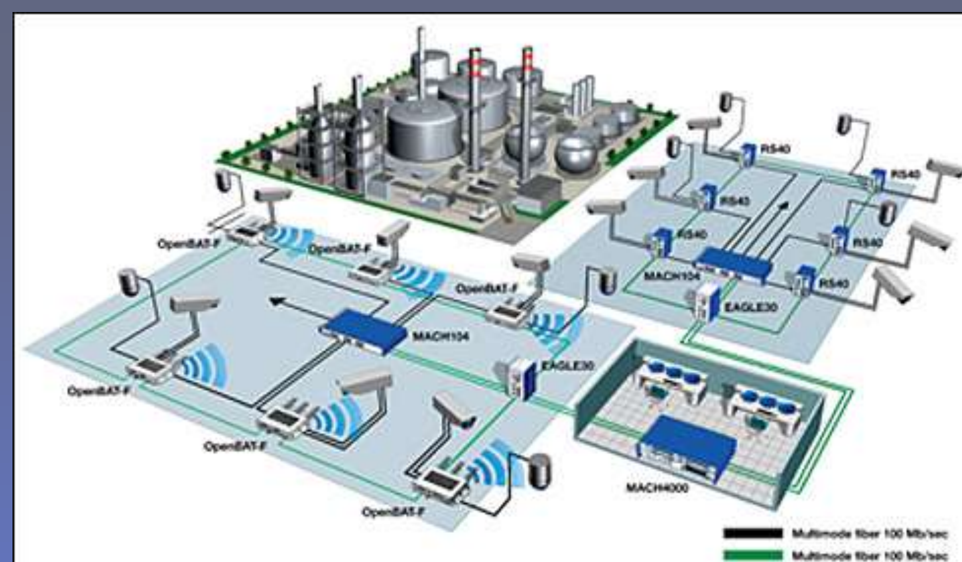


A Presentation in Three Movements

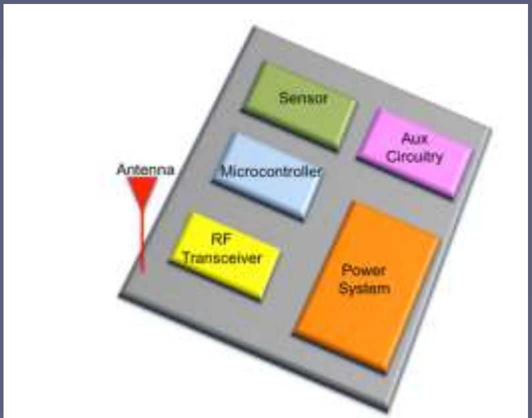
‘cause here we go!

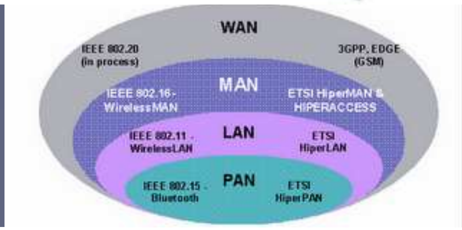
“non Carpet-land” Wireless

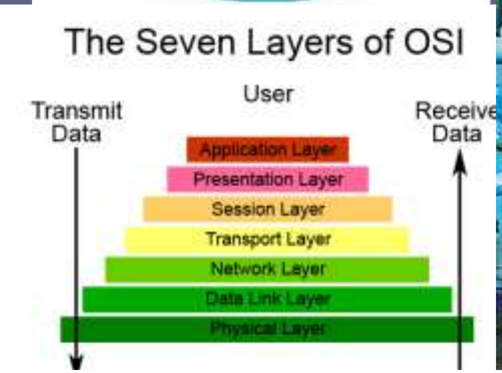




This is Industrial Wireless

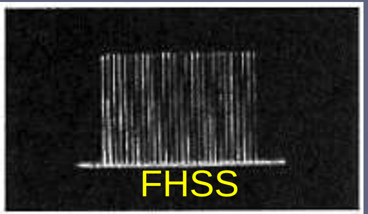


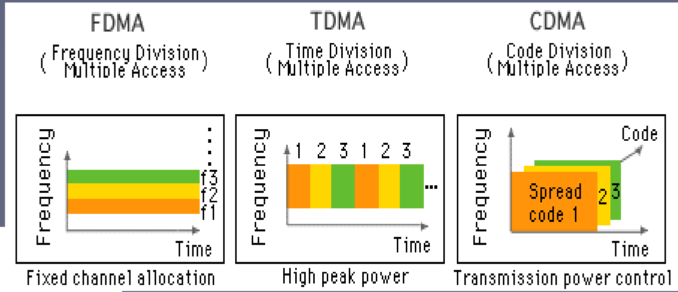


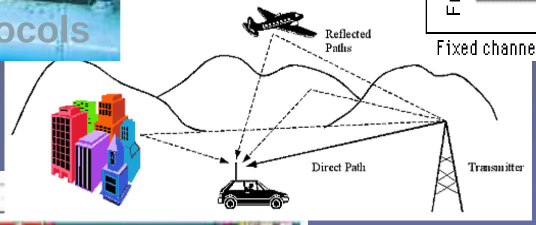


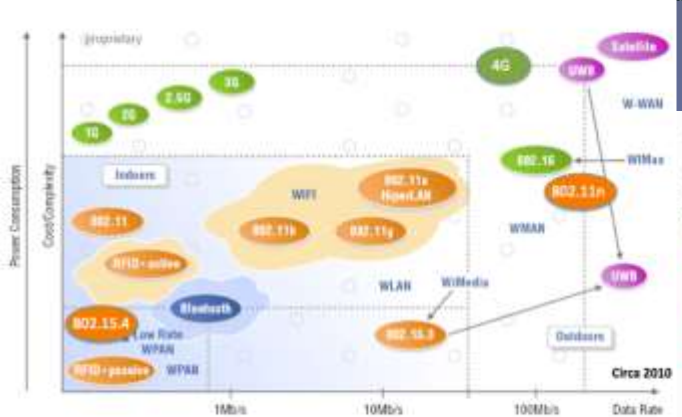

Hedy Lamarr and George Antheil. Photo of Hedy Lamarr courtesy of the Academy of Motion Picture Arts & Sciences. Photo of George Antheil courtesy of the Estate of George Antheil.

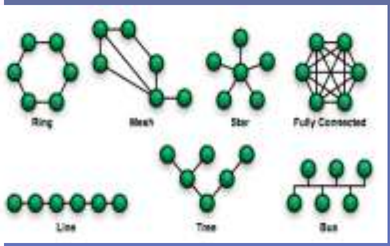
$$E(t) = A(t)\, e^{[j\omega t + \phi(t)]}$$

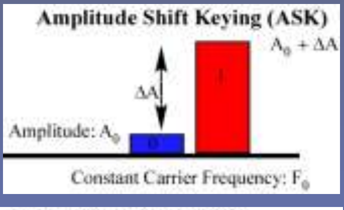


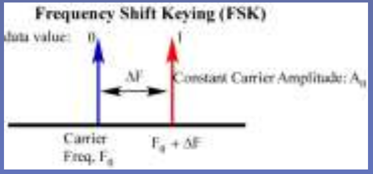






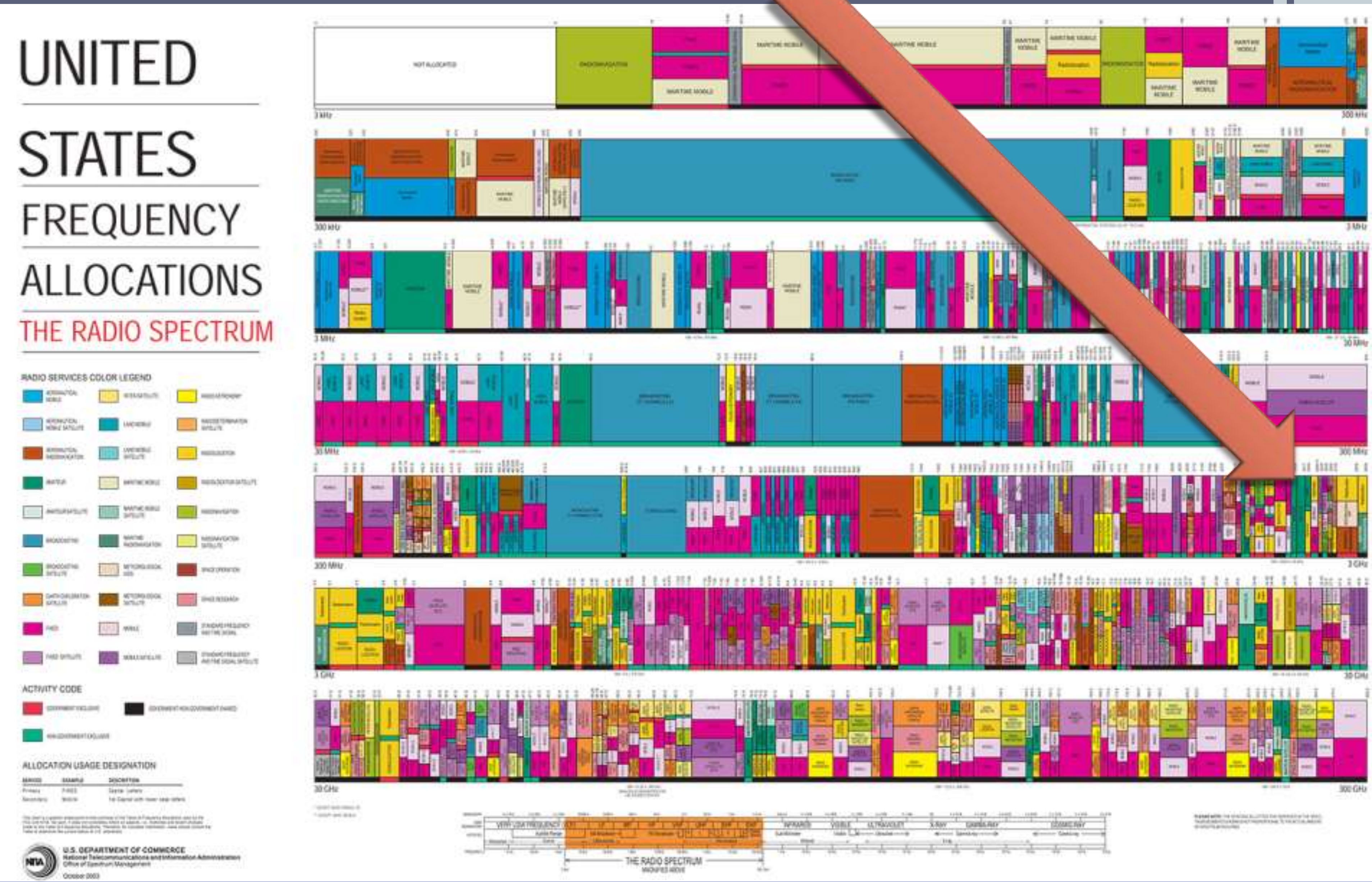




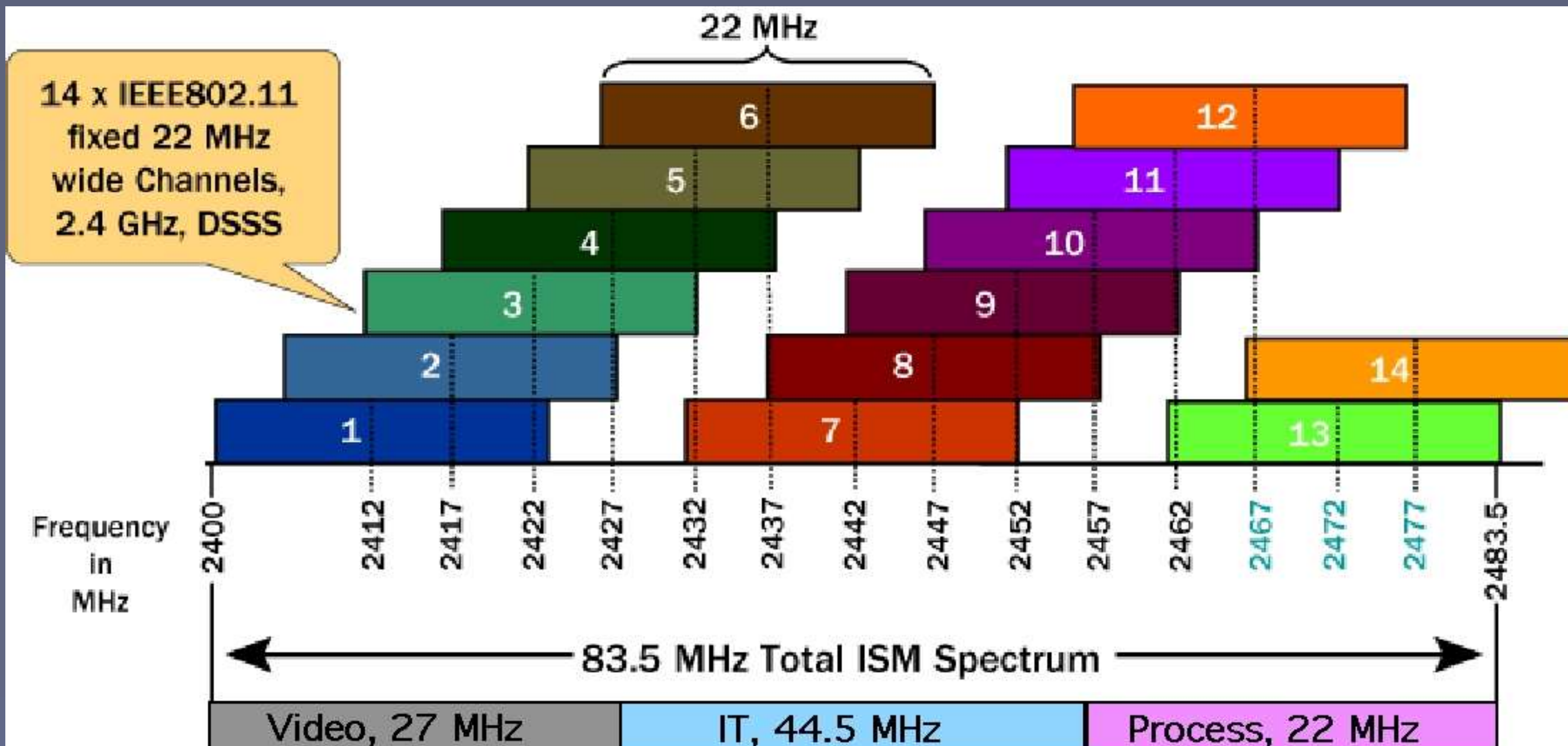


Industrial Wireless operates here

So does bluetooth, wif-fi, other stuff



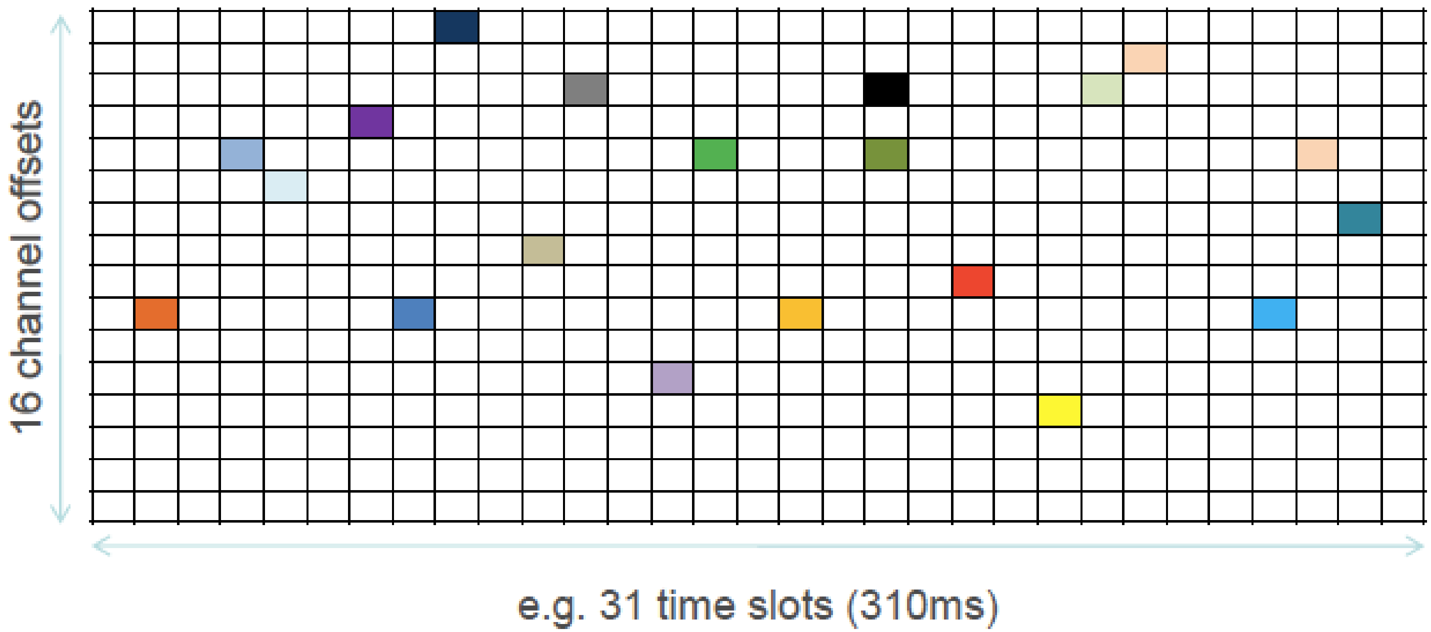
Industrial Wireless

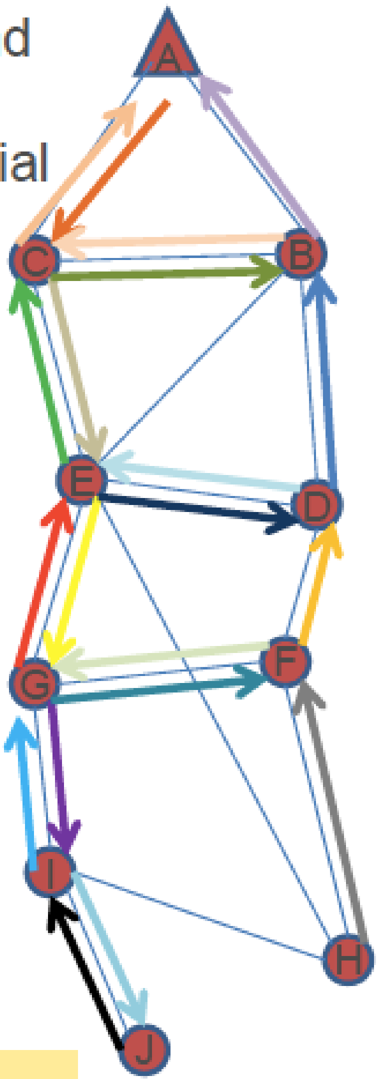


All sensors are jammed in here

TimeSlotted Channel Hopping (TSCH) MAC

- Schedule => direct **trade-off** between throughput, latency and power consumption.
- A **collision-free** communication schedule is typical in industrial applications.
- IEEE802.15.4e **published** April 2012.





Unnatural acts to minimize congestion

IoT Enabling Technologies

Sensor Technologies

To collect and process the data to detect the changes in the physical status of things	**Microcontrollers**	**RFID**	**Energy harvesting technologies**

Wireless Communication and Networking

To enable the communication between the sensors and the system	**machine-to-machine interfaces and protocols of electronic communication**

Smart Technology and Computing

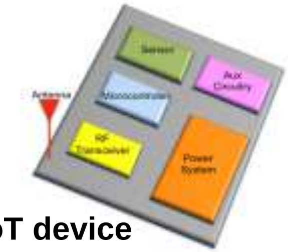
Cloud	Big Data	To enhance the power of the network by devolving processing capabilities to different part of the network

Actuators (NANO TECH)

To make the smaller and smaller things have the ability to connect and interact.(nano-tech

OAK RIDGE National Laboratory

What language (protocol) does an IoT device speak?



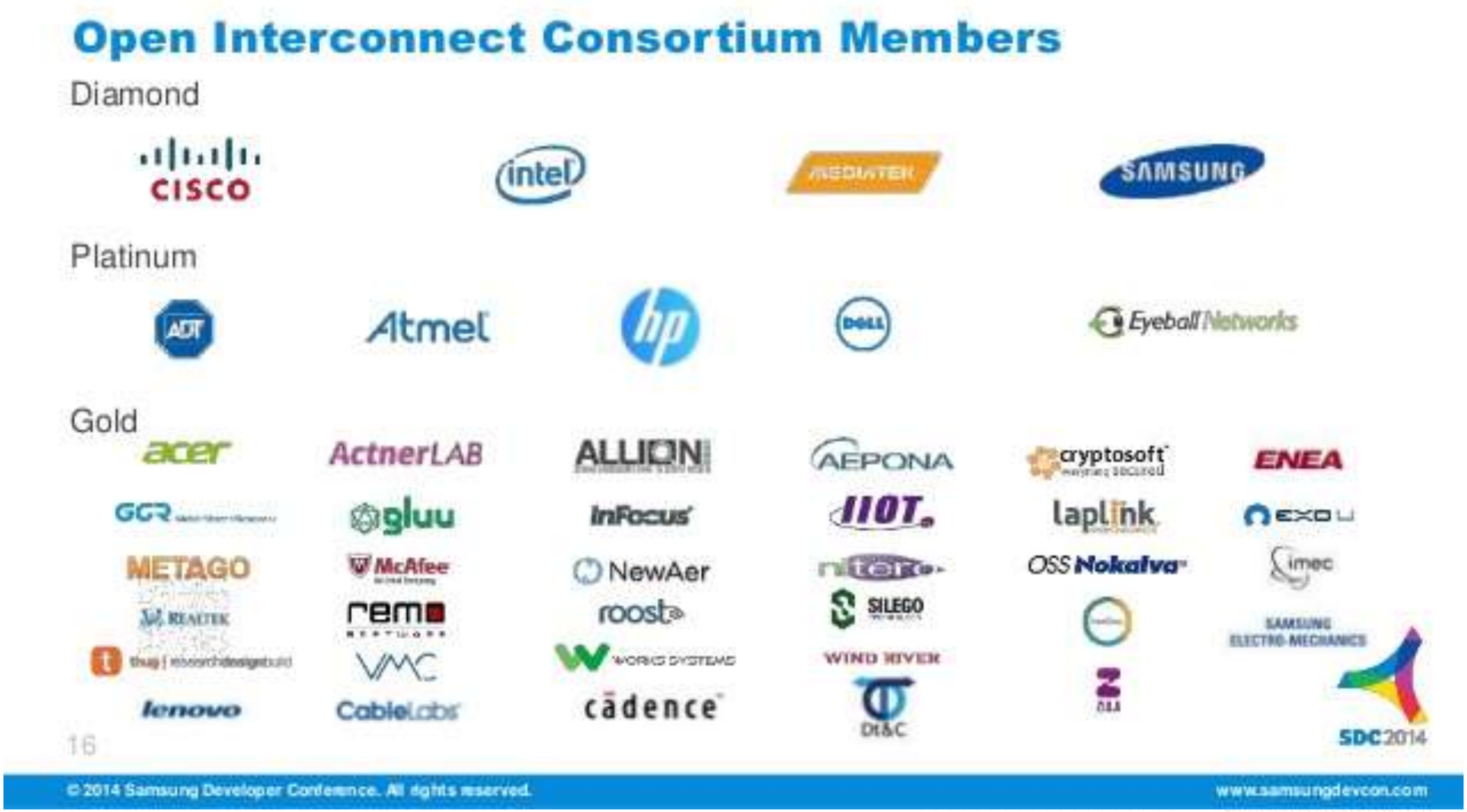
IoT device

B	I	N	G	O
JavaScript	Objective-C	Modula-2	Erlang	Prolog
Forth	Scheme	Fortran	Lisp	BASIC
Ada	Perl	FREE SPACE	PL/I	Ruby
Scala	PHP	C++	Haskell	COBOL
REXX	Smalltalk	C	Eiffel	Python

- Afrikaans
- Akan
- Albanian
- Arabic (Contextual)
- Arabic (General)
- Arabic (Full)
- Armenian
- Azerbaijani
- Balochi Roman script
- Balochi Urdu Arabic
- Bengali
- Berber (Northern)
- Burmese (Basic)
- Catalan
- Croatian
- Custom
- Czech
- Danish
- Devanagari (Hindi)
- Dutch (Common)
- Dutch (All)
- English
- Ethiopic
- Finnish
- French (Common)
- French (All)
- Fula
- Georgian
- German
- Gikuyu
- Greek (Common)
- Greek and Coptic
- Guaraní
- Gujarati
- Hausa
- Hebrew
- Hungarian
- Igbo
- IPA
- Irish Gaelic
- Irish Modern
- Javanese script
- Italian
- Kannada
- Khmer
- Kurdish Arabic
- Kurdish Hawar
- Malayalam
- Mathematics (Common)
- Mathematics (All)
- Mongolian
- Norwegian (Common)
- Norwegian (All)
- Ol Chiki (Santali)
- Oriya
- Pashto
- Polish
- Portuguese
- Romanian
- Russian (Common)
- Russian (All)
- Scottish Gaelic
- Sindhi
- Sinhala
- Slovak
- Spanish
- Swedish
- Tajik
- Tamil
- Tatar Cyrillic
- Thai
- Tibetan
- Turkish
- Turkmen Latin
- Ukrainian
- Vietnamese
- Yoruba

What language/protocol?

Open Interconnect Consortium



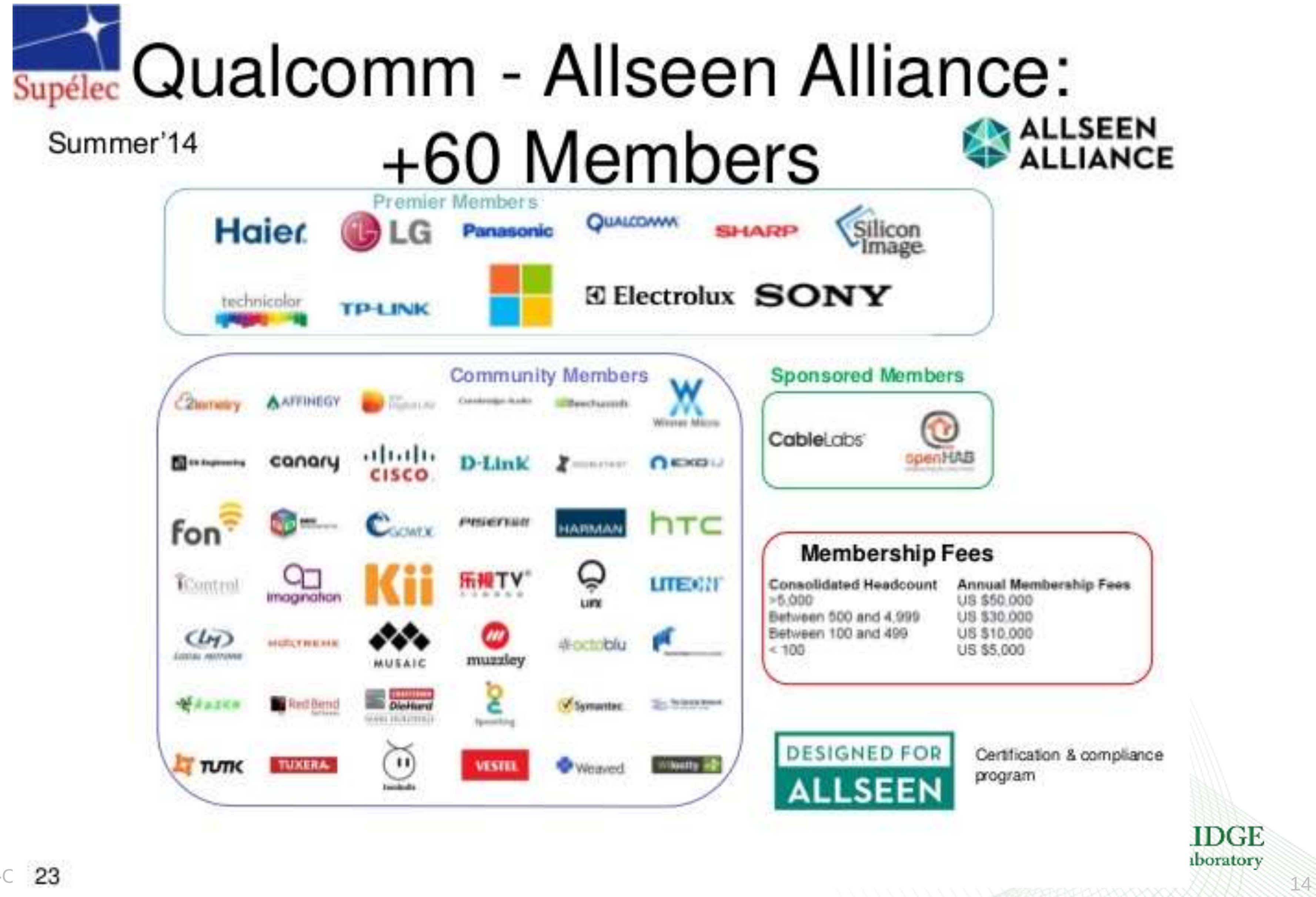
What language/protocol?

HyperCat (UK centric)

Logos are trademarks or registered trademarks and are the property of their respective owners

What language/protocol?

Allseen Alliance

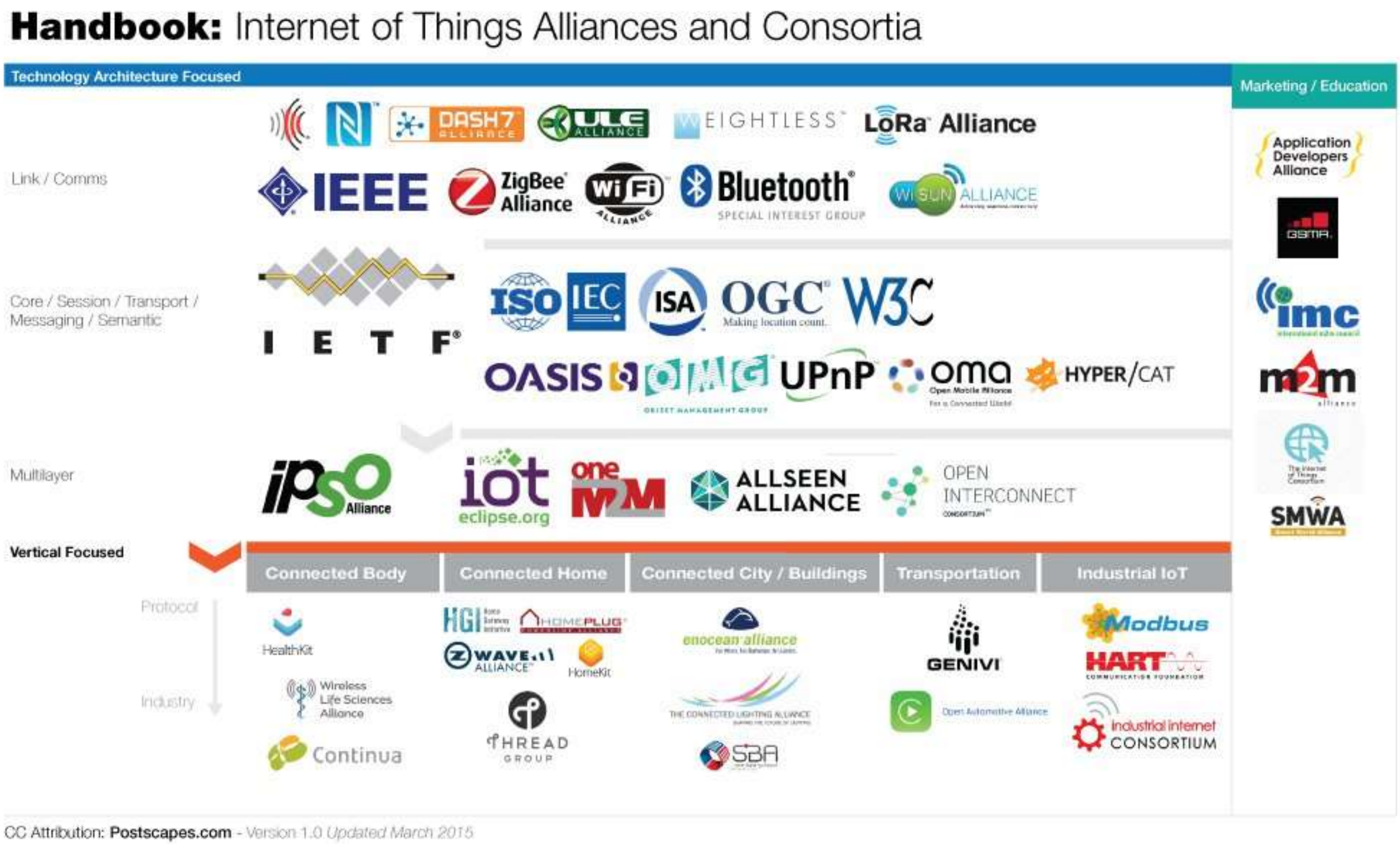


What language/protocol?

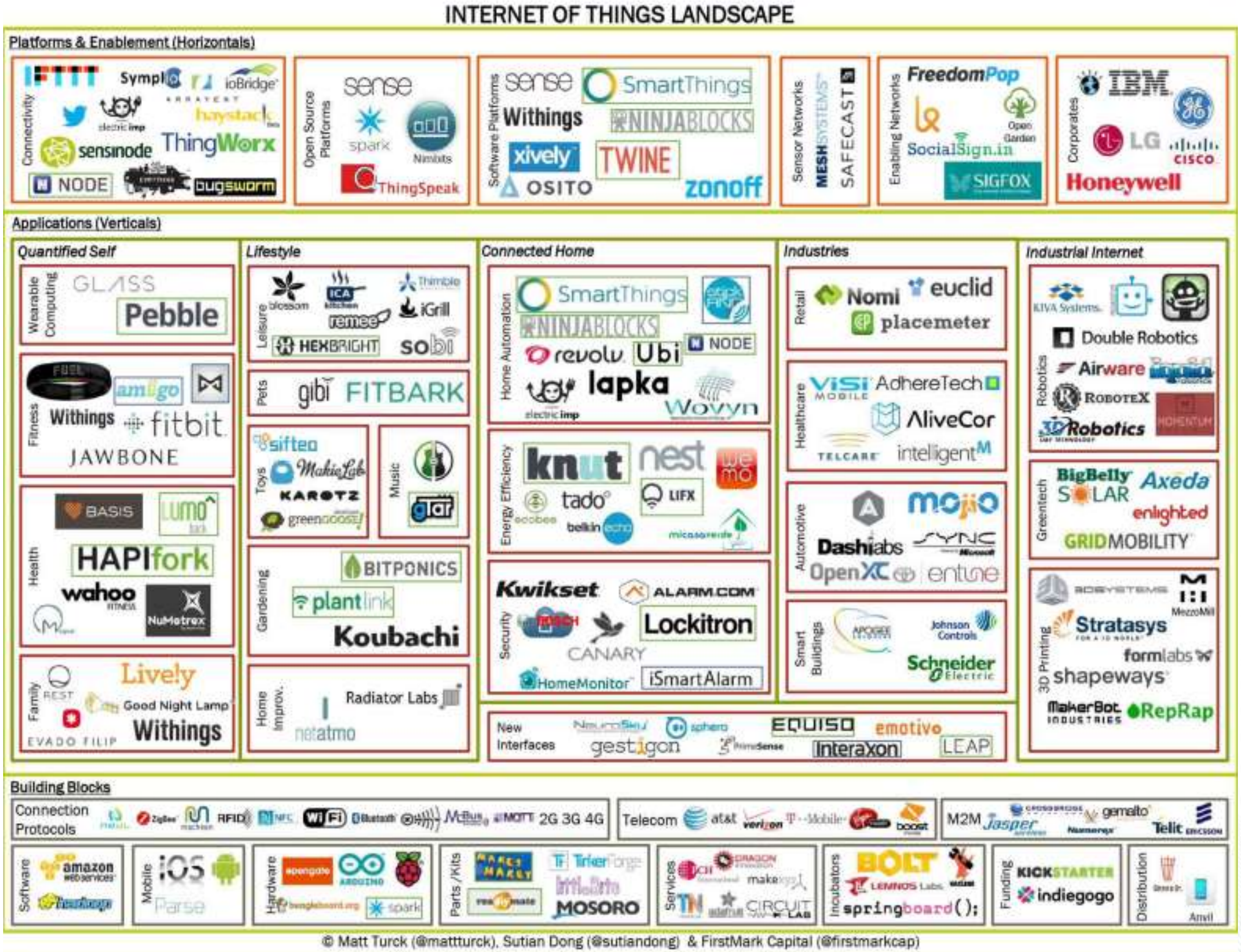
Industrial Internet Consortium

What language/protocol?

The Big List



IoT Companies

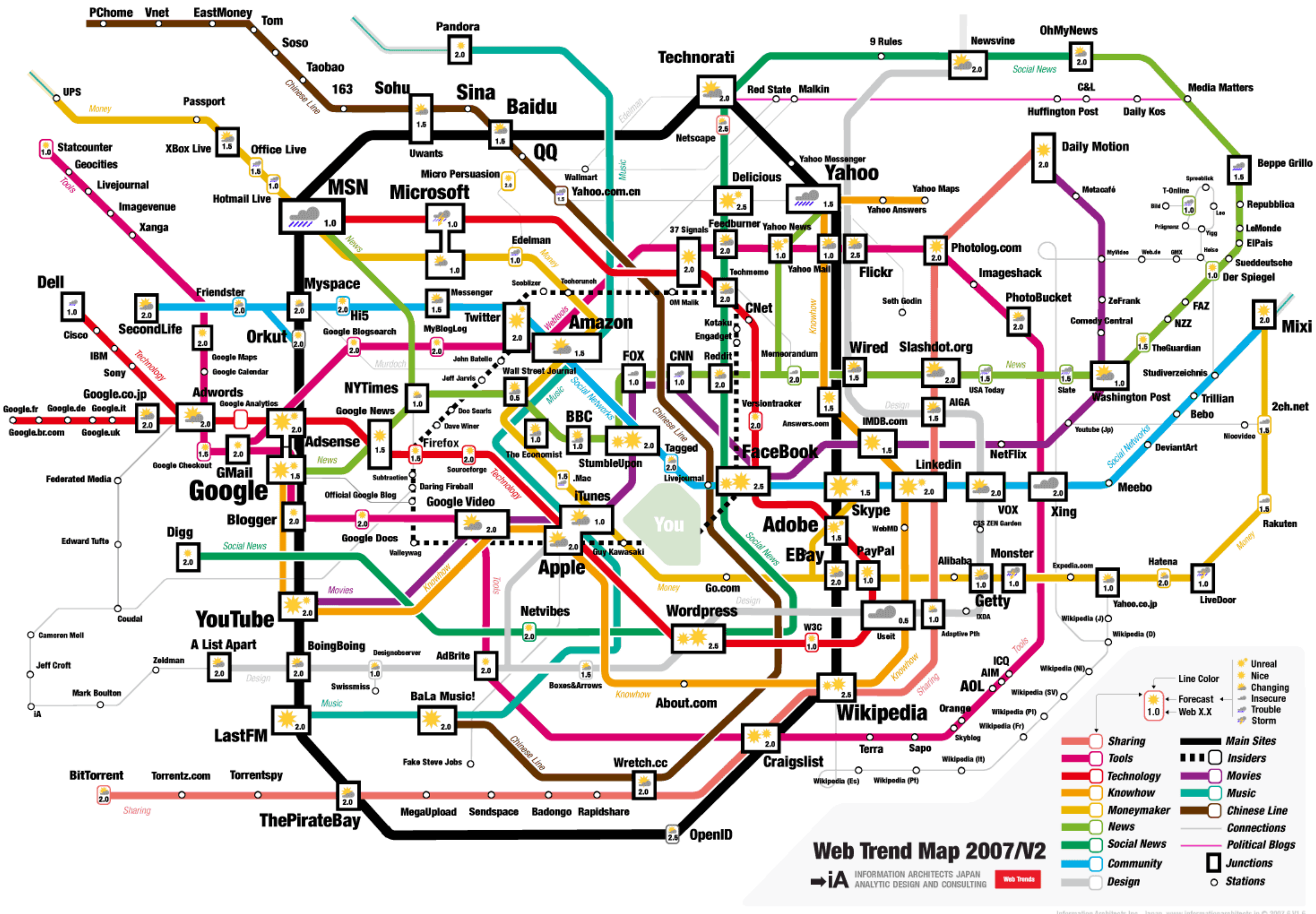


HW

SW/FW

Some of the companies and organizations—private, public. and academic—espousing their "solutions and developments" for IoT devices and systems. (Used with permission from Matt Turck.)

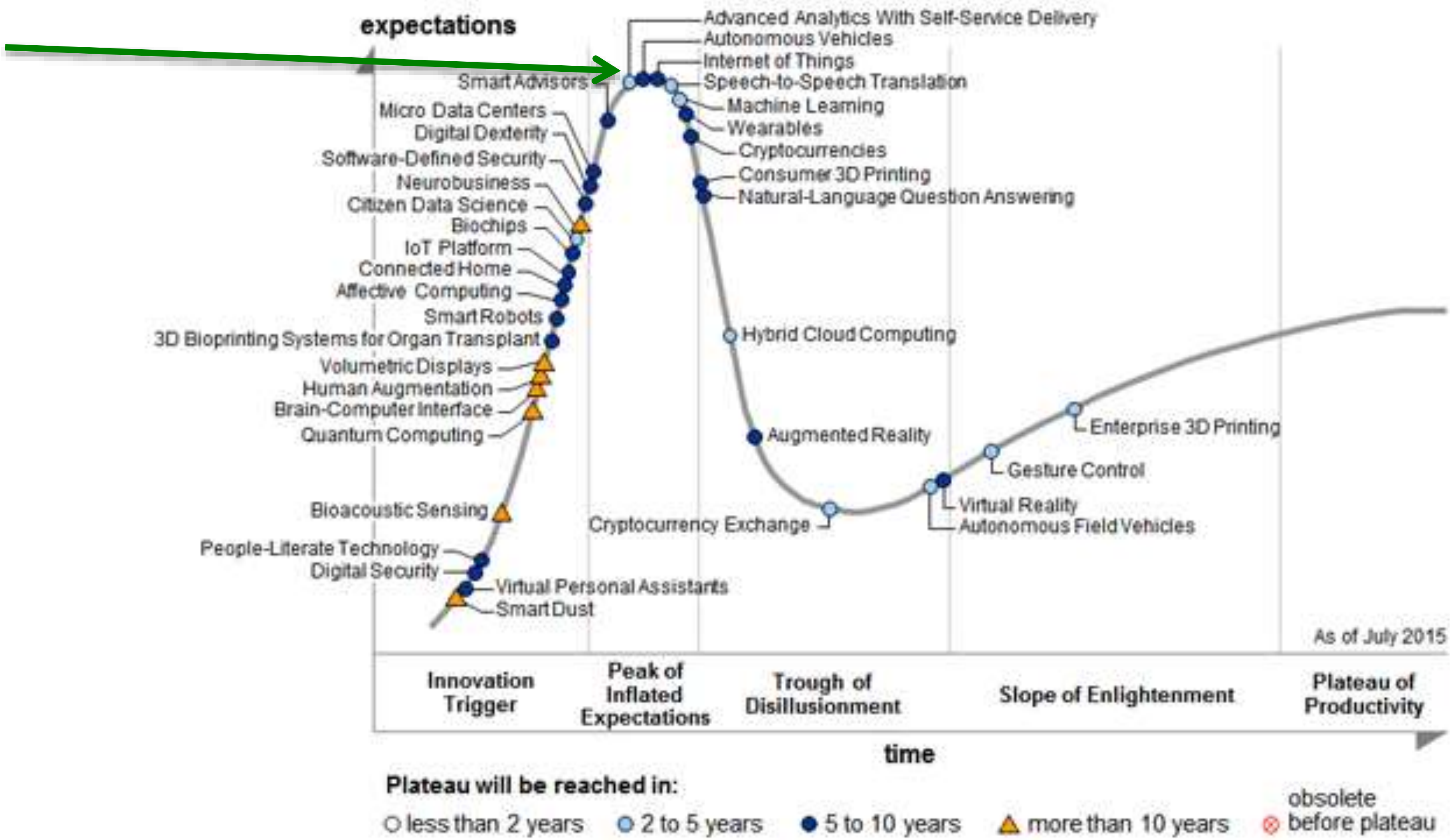
IoT…Companies circa 2007



Peter Fuhr
Ph: (865) 574-5206, E-mail: fuhrpl@ornl.gov

IoT - Analysts

Gartner's Hype Cycle - 2015



Presentation Summary

- We have essentially run out of frequencies to be used for wireless devices. Yet, the Internet of Things (IoT) is forecasting by the end of this decade having billions- if not trillions - of devices broadcasting over the airwaves. The situation becomes even more severe in areas where dense deployments of IoT devices encounter substantial amounts of radio frequency interference (RFI). The realm of "shared spectrum" will be discussed from a technological and logistical perspective culminating in "a suggestion" as to what applications may benefit from the realization of cognitive radio (CR) - software defined radio (SDR) modeling and implementation in municipal and utility settings.

Peter L. Fuhr, Ph.D.

- Distinguished Scientist, Tech Director UAS Research Center, U.S. Department of Energy, Oak Ridge National Laboratory
- Activities:
  - Chair Secure Infrastructure Controls Society,
  - 850+ technical papers and presentations
  - Director, International Society for Automation (ISA) Communication Division
  - ISA100.WG5/6 (interoperability and coexistence), ISA100.WG21 (industrial asset tracking), ISA100.19 (founder)
- Recent Related Wireless/SCADA/DCS Presentations/Panels:
  - Security Threats and Counter Measures in Process Industries with Wireless Sensor Networks, IFPAC, Washington,
  - Special Forum on Industrial Security: Is It Secure? Security Aspects of Hybrid Wireless and Wired Deployments in Industrial Settings, ISA Expo, Chicago,
  - Industrial Networking and Control Systems Security, ISA Auto West
  - Next Gen Embedded Control Systems, an NSF/DHS/NSA workshop, Washington DC,
  - Congressional Briefing "Wireless and Smart Manufacturing", Washington, DC,
  - Etc, etc

Integrated Wireless

Sensors+RF in Nukes

Fuel Gauge System

Smart Structures

Wireless Offshore

Sensors+RF in Space

RFID+Sensors

A Presentation in Three Movements

On to The Second Movement

The Current State of Industrial Wireless

802.15.1

802.15.3

802.15.4

802.11

802.16

802.20

others…

Licensed frequencies

Unlicensed frequencies

RF Coexistence – in the 2.4 GHz space

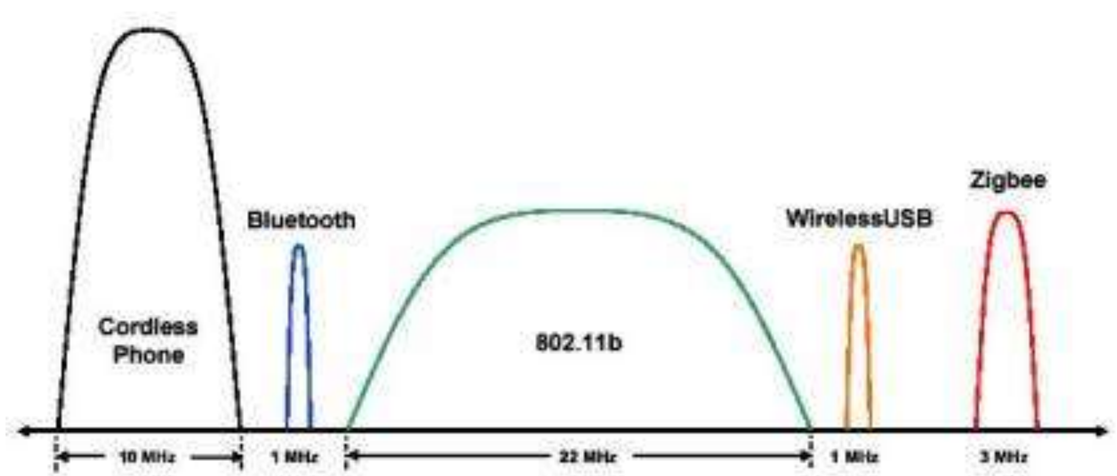
ISA100.11a

Wireless HART

Bluetooth IE

ZigBee Industrial

others….



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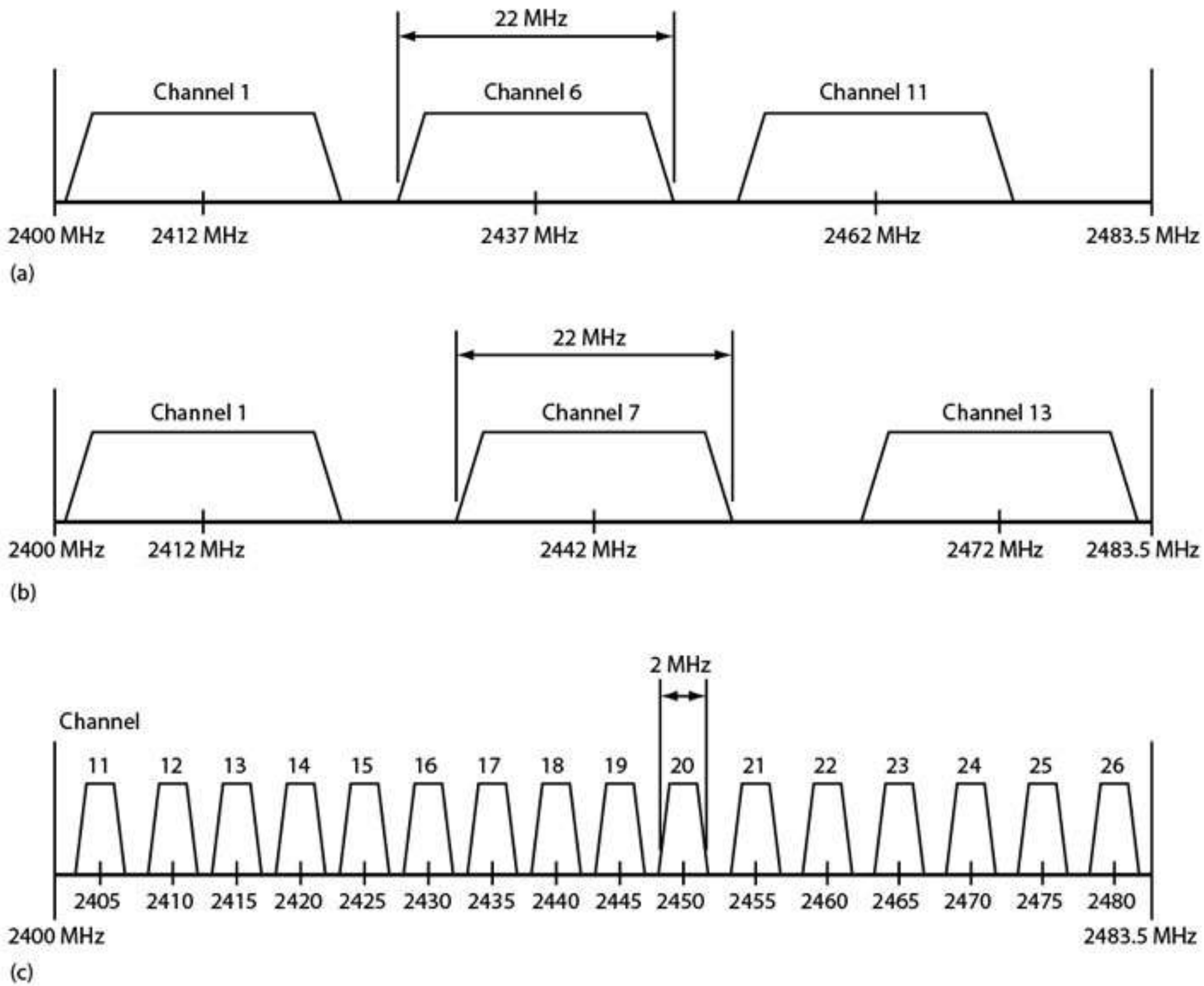

The operational channels for 802.11 Wi-Fi and 802.15.4 ZigBee overlap, which could cause interference problems. However, the RF4CE standard includes frequency agility in the remote control and its targets to mitigate this problem. Shown are the channel selections for IEEE 802.11b North America, non-overlapping (a), IEEE 802.11b European, non-overlapping (b), and IEEE 802.15.4, 2400-MHz PHY (c). (source: IEEE 802.15.4-2003 Specification)

Telcos: I want more spectrum

The New York Times

TECHNOLOGY

Carriers Warn of Crisis in Mobile Spectrum

AT&T, Verizon, T-Mobile and Sprint say they need more radio spectrum, the government-rationed slices of radio waves that carry phone calls and wireless data.

The wireless carriers say that in the next few years they may not have enough of it to meet the exploding demands for mobile data. The result, they ominously warn, may be slower or spotty connections on smartphones and tablets. They imply in carefully couched language that, given the laws of supply and demand, the price of cellphone service will soar.

WIRELESS INTERNET PROVIDERS STRESS NEED FOR MORE SPECTRUM

Submitted by Rick Harnish on May 18, 2012
in auction Bowles caf Commerce FCC Harnish Spectrum Unger usf White Space Wisp wispa

TRDaily

May 16, 2012

By Paul Kirby

The FCC should make the 3550-3650 megahertz band available through the same "licensed-light" regime as it did the 3650-3700 MHz band, which would allow wireless Internet service providers (WISPs) to use the frequencies to meet the increasing data demands of their customers, leaders of the Wireless Internet Service Providers Association (WISPA) said today.

The group is also urging the government to free up additional spectrum for unlicensed use in the 5 gigahertz band, and it says those frequencies should be accessible for outdoor use. And it says the FCC should not let wireless carriers warehouse spectrum in rural areas.

WISPA members discussed their policy priorities during a luncheon today that coincided with a Washington fly-in of about 30 group members who scheduled visits with Capitol Hill offices and FCC and White House officials.

The group was founded in 2005 and has about 700 members across the U.S. and Puerto Rico that serve a total of about three million customers. Most serve rural areas using unlicensed spectrum in the 900 MHz, 2.4 GHz, and 5 GHz bands and "lightly licensed" spectrum in the 3.65 GHz band. However, group representatives said some of their members would be interested in licensed spectrum if the FCC would make frequencies available in small-enough blocks.

"From an industry perspective, our primary challenge is the lack of spectrum," said WISPA President Elizabeth Bowles, adding that the problem is getting more severe as consumers use more data. "We have members who are serving the same number of customers that they had four years ago, but they need four times the amount of broadband [spectrum] as they did to serve the same number of customers. It is essentially a crisis."

What's c

Spectrum Need Fuels Tension Between Wireless Industry, FCC

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By: Jeffrey Burt
2012-05-08

There are 0 user comments on this Enterprise Networking story.

At the CTIA Wireless show, industry officials and the FCC said more work needs to be done to find more spectrum to meet the mounting demand for wireless services.

NEW ORLEANS — Despite talk of greater innovation and efficiency, the key concern in the wireless industry is the need for more spectrum. And while both the wireless industry and the government's largest wireless regulator tout the work each has done to deal with the issue, tensions between the two sides persist.

During the morning keynote presentation at the CTIA Wireless 2012 show here May 8, those tensions were evident. Steve Largent, president and CEO of CTIA, talked about the $25 billion that carriers spent last year to improve their networks and the 12 percent increase in the number of carrier cell sites. This comes at a time when the number of data-capable devices in 2011 grew 9 percent from the previous year and the number of wireless subscriptions jumped 7 percent.

The industry is doing its part in addressing the skyrocketing demand for wireless services, Largent said during the event.

"We also need government to do their part," he said, pointing to Congress, regulators and the Obama Administration. "They simply need [to release] more spectrum. ... Getting more spectrum is the No. 1 goal at CTIA.

However, Julius Genachowski, chairman of the Federal Communications

Table 5. Global Mobile Data Traffic, 2011–2016

	2011	2012	2013	2014	2015	2016	CAGR 2011–2016
By Application Category (TB per Month)							
Data	174,942	329,841	549,559	864,122	1,349,825	2,165,174	65%
File sharing	76,764	114,503	154,601	204,617	261,235	361,559	36%
Video	307,869	736,792	1,545,713	2,917,659	4,882,198	7,615,443	90%
VoIP	7,724	10,327	12,491	15,485	22,976	35,792	36%
Gaming	6,957	13,831	24,388	40,644	77,568	118,330	76%
M2M	23,009	47,144	92,150	172,719	302,279	508,022	86%
By Device Type (TB per Month)							
Nonsmartphones	22,686	55,813	108,750	196,262	357,797	615,679	94%
Smartphones	104,759	364,550	933,373	1,915,173	3,257,030	5,221,497	119%
Laptops and netbooks	373,831	612,217	917,486	1,340,062	1,963,950	2,617,770	48%
Tablets	17,393	63,181	141,153	300,519	554,326	1,083,895	129%
Home gateways	55,064	108,073	180,562	267,545	376,494	514,777	56%
M2M	23,009	47,144	92,150	172,719	302,279	508,022	86%
Other portable devices	525	1,460	5,429	22,966	84,204	242,681	241%
By Region (TB per Month)							
North America	118,972	259,283	493,323	844,416	1,304,870	1,964,477	75%
Western Europe	180,370	365,722	683,843	1,160,571	1,704,596	2,437,922	68%
Asia Pacific	205,624	437,601	831,616	1,502,748	2,614,055	4,322,879	84%
Latin America	40,171	77,242	145,794	267,327	455,463	737,808	79%
Central and Eastern Europe	34,317	67,722	133,716	252,930	439,143	706,469	83%
Middle East and Africa	17,810	44,868	90,610	187,254	377,953	634,765	104%
Total (TB per Month)							
Total Mobile Data Traffic	597,266	1,252,438	2,378,903	4,215,246	6,896,080	10,804,321	78%

Source: Cisco, 2012

Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2011–2016

The Mobile Network Through 2016

Mobile data traffic will reach the following milestones within the next five years.

- Monthly global mobile data traffic will surpass 10 exabytes in 2016.
- Over 100 million smartphone users will belong to the "gigabyte club" (over 1 GB per month) by 2012.
- The number of mobile-connected devices will exceed the world's population in 2012.
- The average mobile connection speed will surpass 1 Mbps in 2014.
- Due to increased usage on smartphones, handsets will exceed 50 percent of mobile data traffic in 2014.
- Monthly global mobile data traffic will surpass 10 exabytes in 2016.
- Monthly mobile tablet traffic will surpass 1 exabyte per month in 2016.
- Tablets will exceed 10 percent of global mobile data traffic in 2016.
- China will exceed 10 percent of global mobile data traffic in 2016.

FCC Proposes Allocating Wireless Spectrum Band Exclusively for Medical Devices

by SCOTT JUNG *on* May 21, 2012 · 11:33 am

Wireless medical devices might receive a little more love, thanks to a proposal from the U.S. Federal Communications Commission that was unveiled last week that would set aside the 2.36-2.40 gHz band for exclusive use by Medical Body Area Network (MBAN) devices. The goal, of course, would be that physicians would be able to remotely monitor a patient at home or in the hospital using wireless sensors attached to the body, giving patients the mobility to move around and doctors the ability to provide care while physically away from their patients.

According to the FCC, the specific benefits of the spectrum allocation are:

- Provide more reliable service and increased capacity for the use of MBANs in hospital waiting rooms, elevator lobbies, preparatory areas, and other high-density settings.
- Dramatically improve the quality of patient care with more effective monitoring, catching patients before critical stages, improving patient outcomes, and ultimately saving lives.
- Decrease expenses while increasing competition and innovation, easing entry for companies that are developing new wireless medical devices.

The mobile health industry is expected to grow to $2 to $6 billion by 2015, and setting aside part of the radio spectrum could fuel it even further by giving medical device manufacturers a large and reliable wireless band to use instead of developing devices on a variety of frequencies that aren't compatible with each other.

Presidental Decree…

the WHITE HOUSE *PRESIDENT BARACK OBAMA*

THE WHITE HOUSE
WASHINGTON

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For Immediate Release

June 28, 2010

Presidential Memorandum: Unleashing the Wireless Broadband Revolution

MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

SUBJECT:Unleashing the Wireless Broadband Revolution

America's future competitiveness and global technology leadership depend, in part, upon the availability of additional spectrum. The world is going wireless, and we must not fall behind. The resurgence of American productivity growth that started in the 1990s largely reflects investments by American companies, the public sector, and citizens in the new communications technologies that are what we know today as the Internet. The Internet, as vital infrastructure, has become central to the daily economic life of almost every American by creating unprecedented opportunities for small businesses and individual entrepreneurs. We are now beginning the next transformation in information technology: the wireless broadband revolution.

View the To-Do List

BLOG POSTS ON THIS ISSUE

June 05, 2012 6:55 PM EDT

OAK RIDGE
National Laboratory

JOURNAL OF INFORMATION POLICY 1 (2011): 36-56.

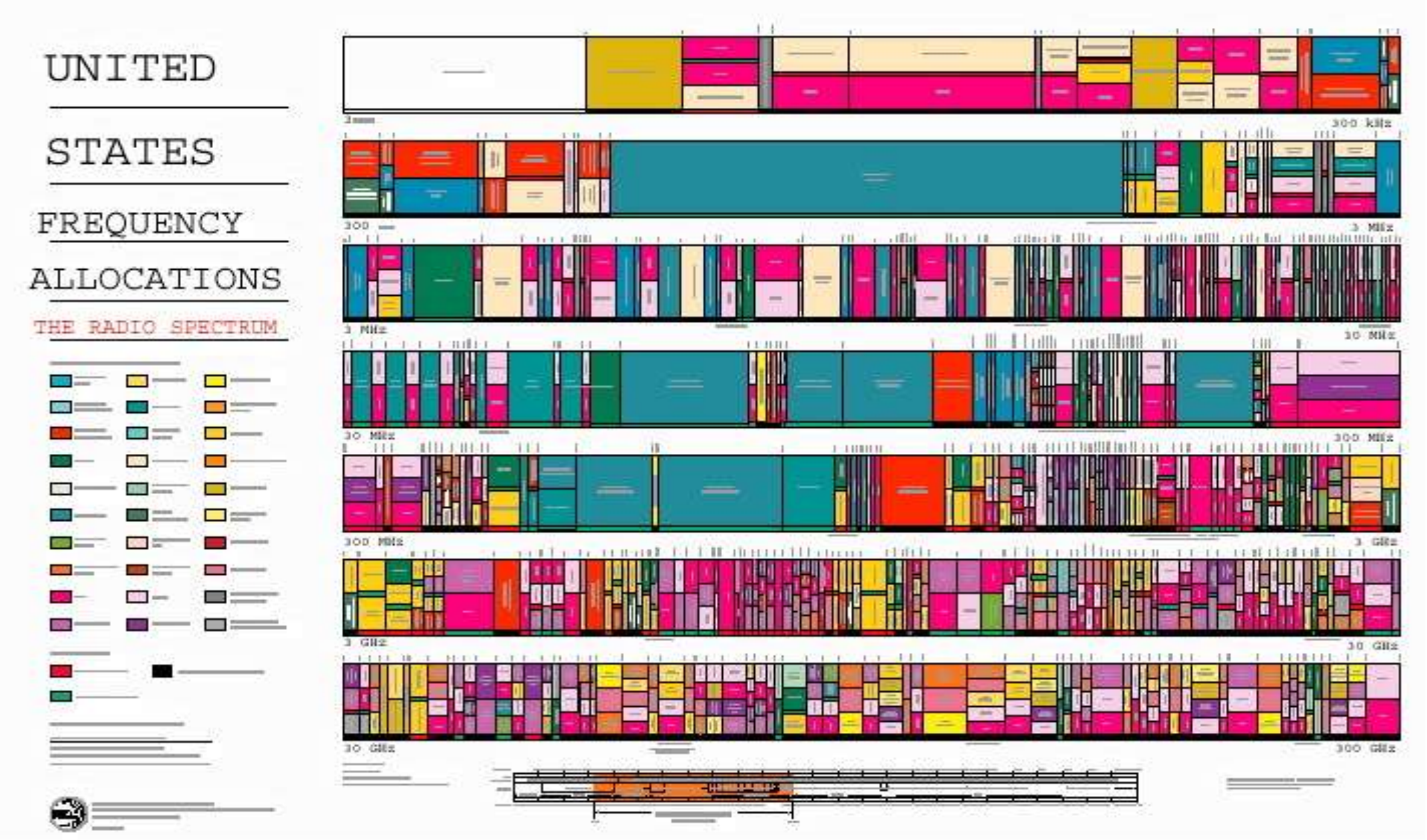
THE NEXT BROADBAND CHALLENGE: WIRELESS

BY CATHERINE A. MIDDLETON* AND JOCK GIVEN+

Is fiber optics to virtually all homes a sensible policy goal? Perhaps not. At least, so argue Professors Middleton and Given, who suggest that, although wireless broadband may not be as fast as fiber, its adoption will be more rapid because it offers other attractive characteristics. Mobile broadband may have a disruptive effect on the overall broadband market, making fiber to the home less attractive. If this is so, should universal service obligations be extended to mobile broadband? And should governments rethink their plans for a ubiquitous fiber optic infrastructure? Middleton and Given argue that they should.

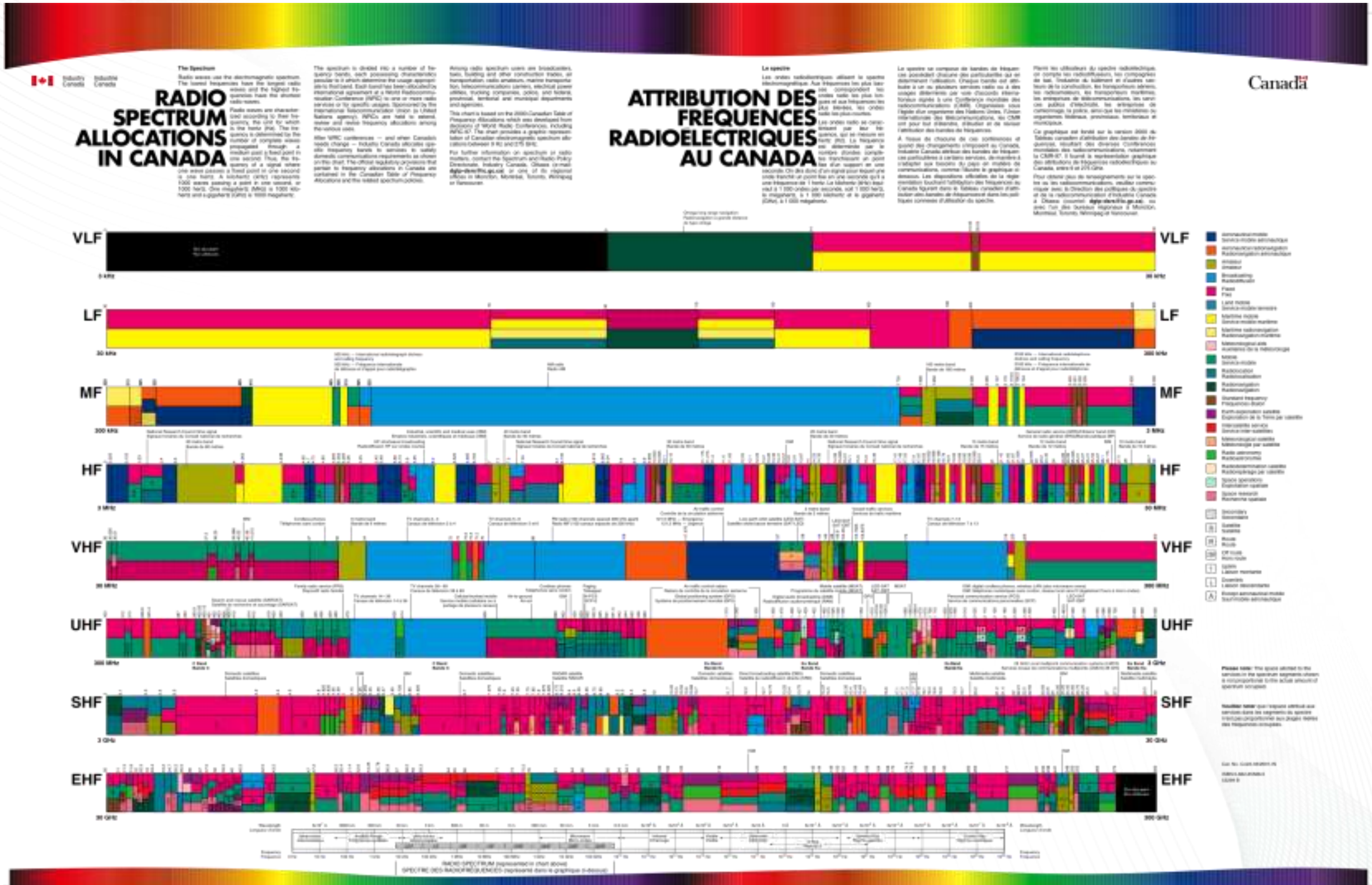
Legal Frequencies

- The FCC assigned frequencies
- www.fcc.gov

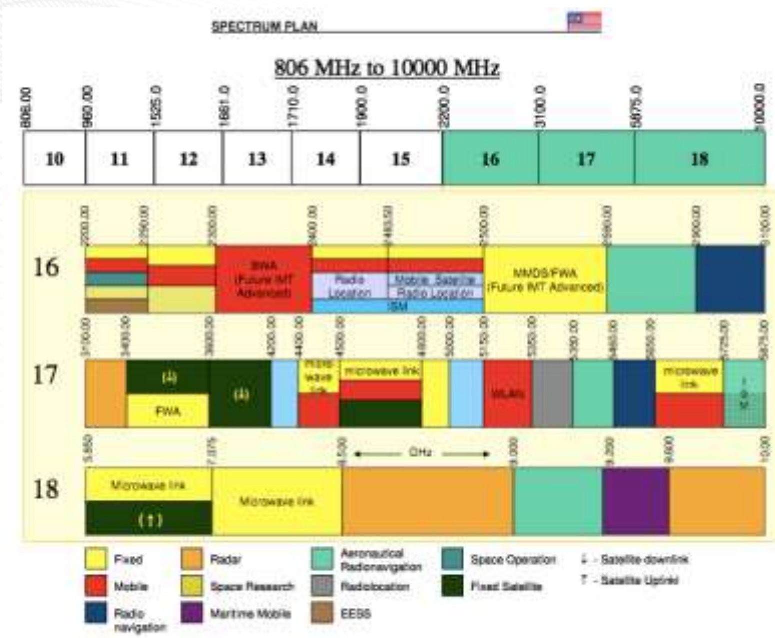


First Up: Look at frequencies…

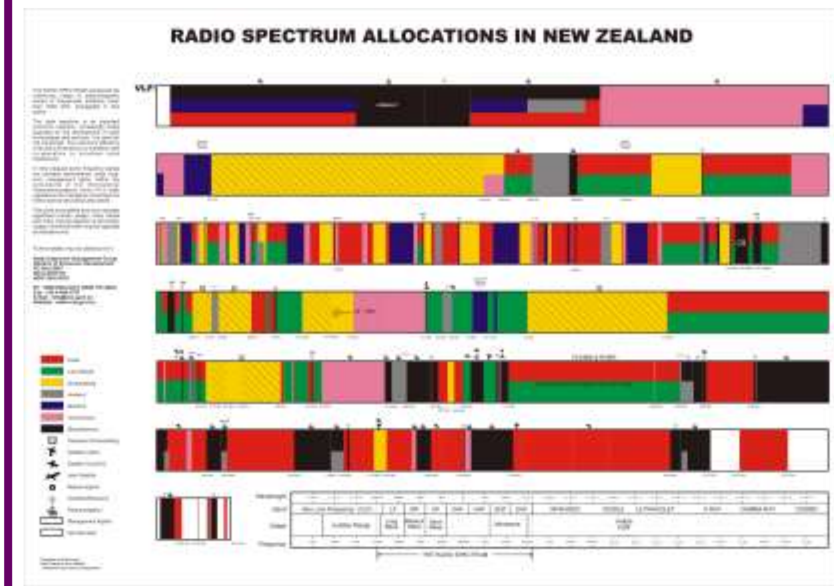
- **Canadian Frequency Allocation Table**



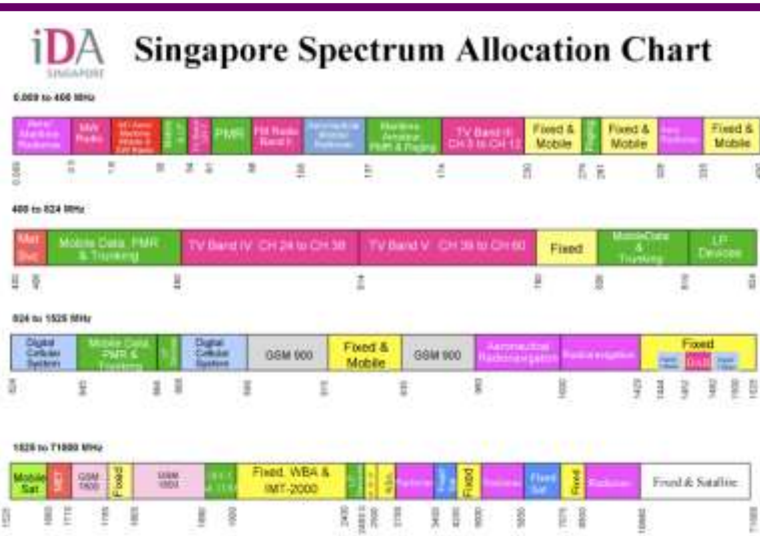
Frequencies Around the World



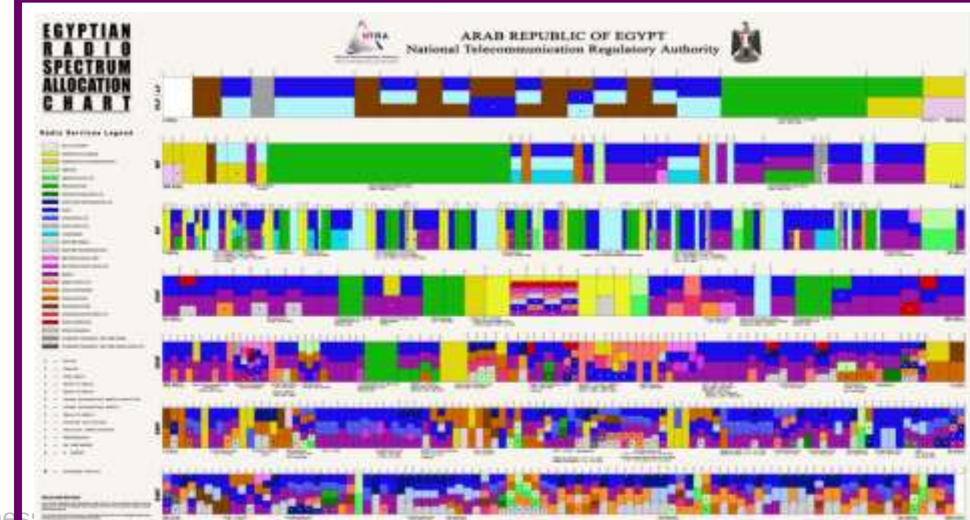
Malaysia



New Zealand

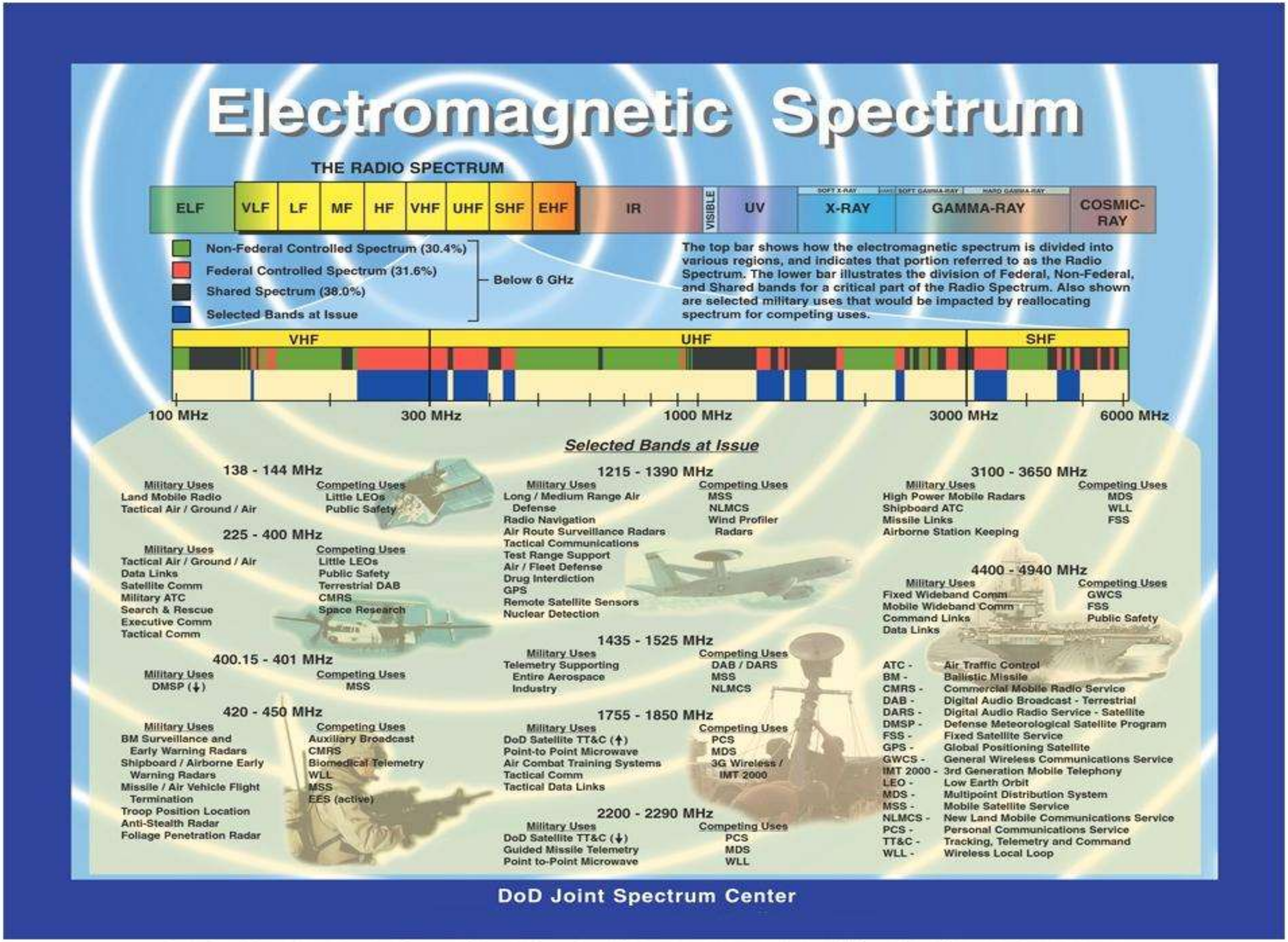


Singapore

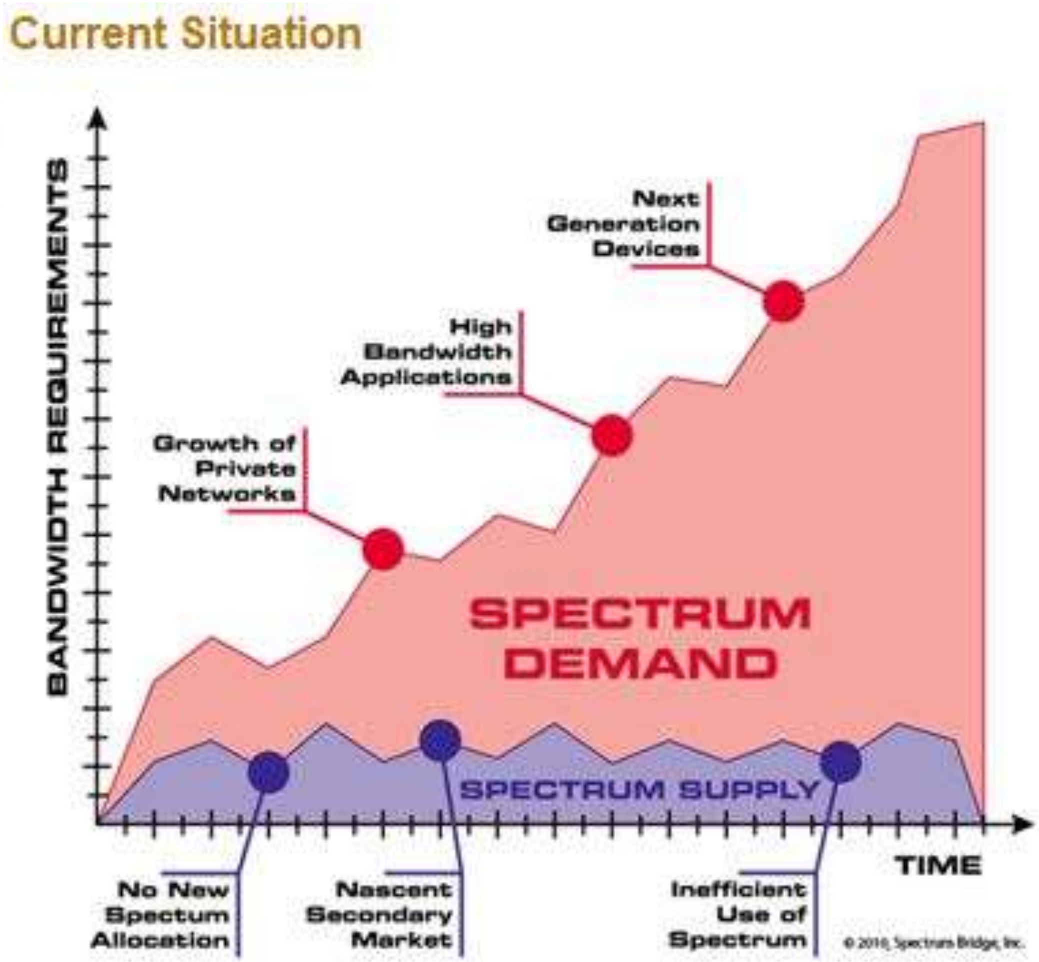


Egypt

RADAR and Commercial Comms



Current Spectral Situation:



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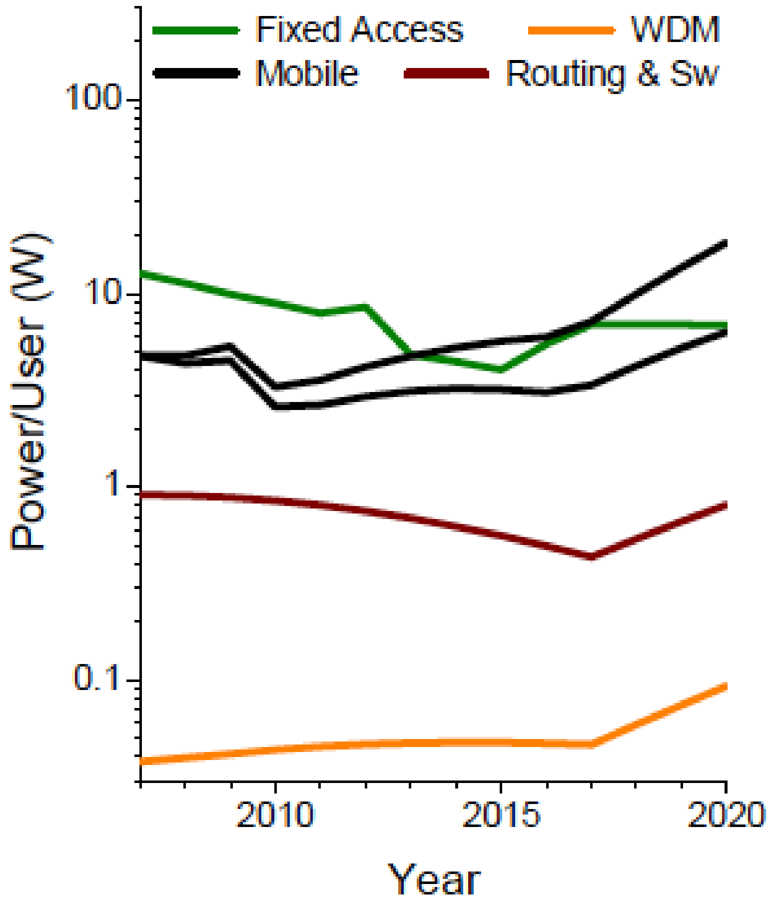
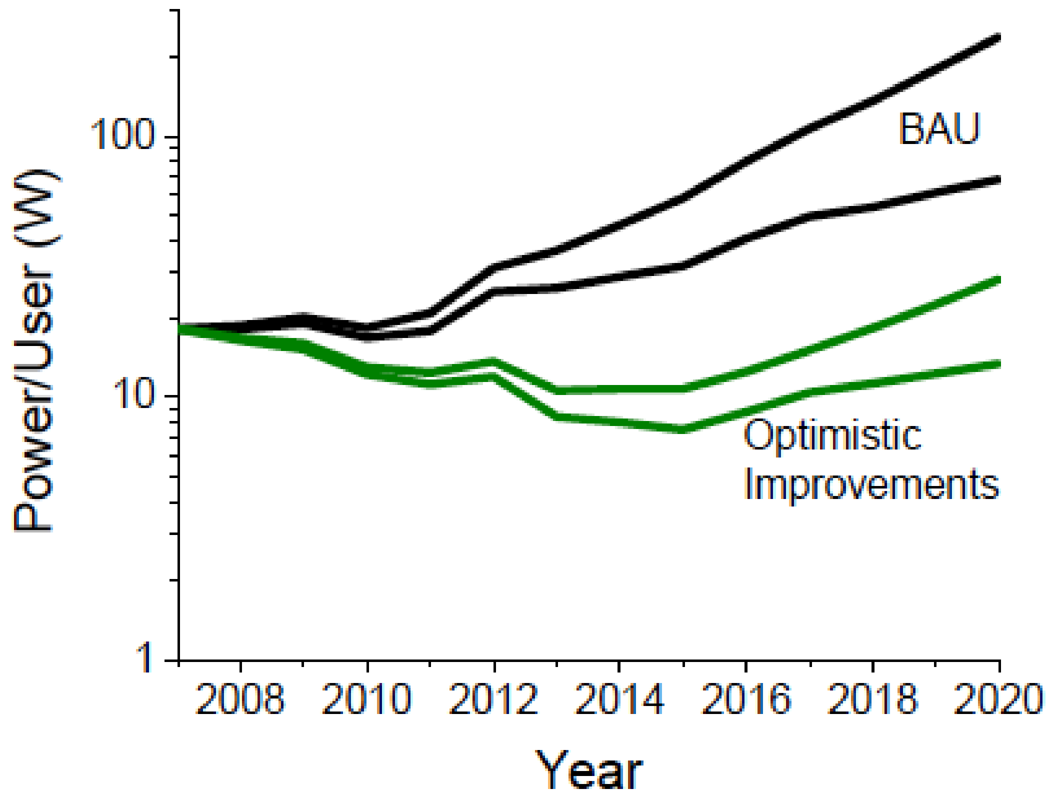
Trending Shows That Despite Increasing Efficiency, Energy/User in Network is Rising



- Can we change this trend?
- What is the best we can do?



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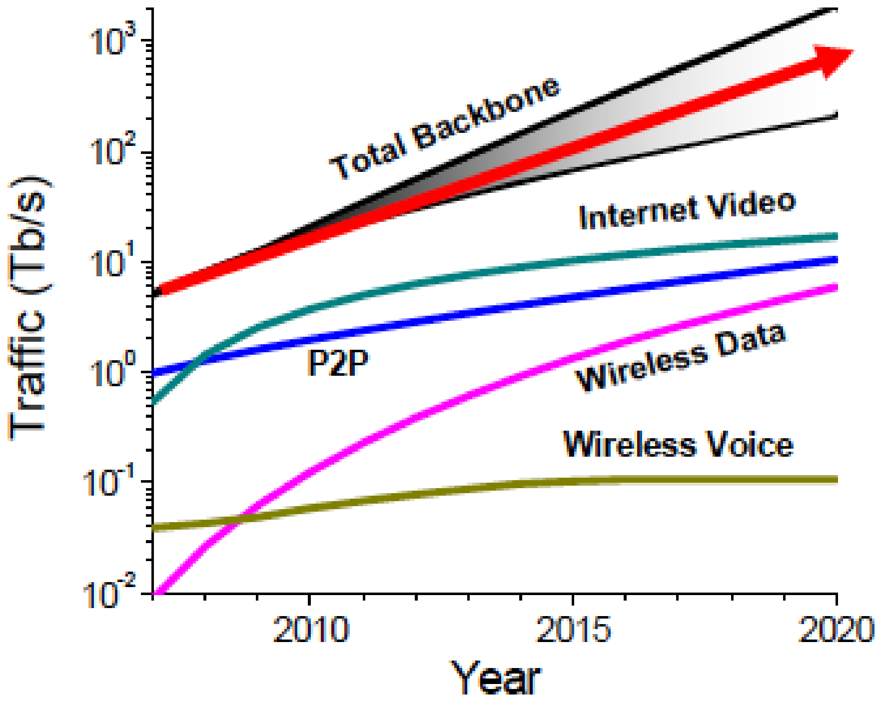
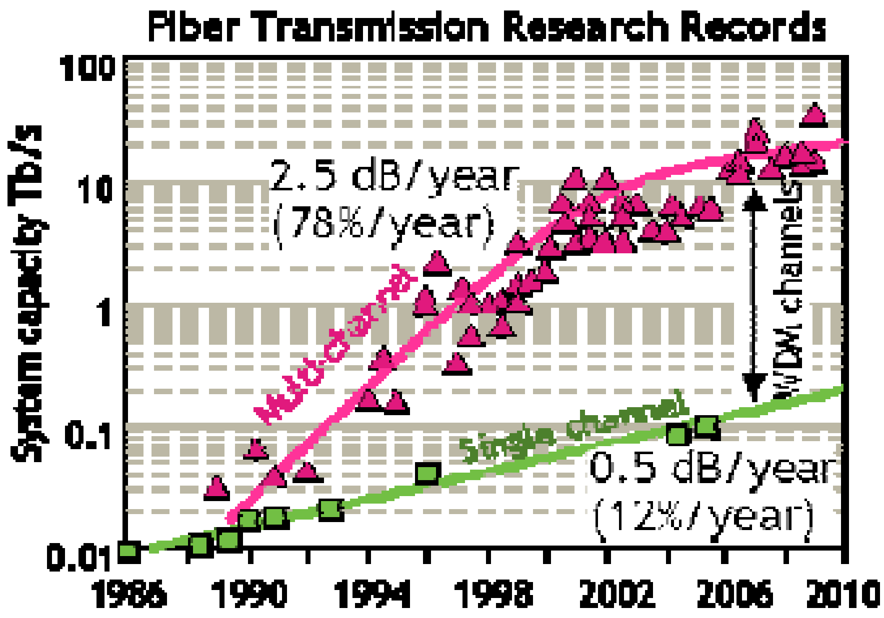
Greentouch…

Traffic is growing **While** Innovation is slowing





NITRD Networking and Information Technology Research and Development

Subcommittee on Networking and Information Technology Research & Development (NITRD)

Wireless Spectrum R&D Senior Steering Group Interim Report #1

June 2011

OAK RIDGE National Laboratory

Table 1: Summary of Federal Wireless R&D projects by Topic Area	Federal Agencies								
	Department of Commerce	Department of Defense	Department of Energy	Department of Homeland Security	Department of Justice	Federal Aviation Administration	Federal Communications Com.	National Aeronautics and Space Administration	National Science Foundation
(1) Advancing dynamic mechanisms to share spectrum, including both cooperative and non-cooperative models, and mechanisms to manage spectrum resources across functions and systems	8	8	2		1				101
(2) Advancing situational awareness, including spectrum sensing, geo-location, real-time monitoring		1	3						37
(3) Create wireless test beds and demonstrate new concepts	2	7	7	2					15
(4) Development of methods to create and maintain a comprehensive spectrum survey and inventory	1	1	1						2
(5) Development of programs to promote collaboration among spectrum stakeholders (e.g., industry, academia, government agencies)	1	1	1						5
(6) Development of simulation tools relevant to spectrum efficiency, access, and sharing	6	1	2						1
(7) Development of systems and models to transition from legacy architectures to new spectrum-sharing architectures, hardware, protocols and policy		3	1						5
(8) Energy-efficient or "green" spectrum technology		3	1		1				10
(9) Enforcement of spectrum rules									
(10) Integration of DSA networks and the Internet or other communications infrastructure		2							3
(11) Mechanisms to make better use of the spectrum allocations and assignments	2	1				1		3	6
(12) Methods to improve spectrum efficiency, including antenna design, modulation, interference mitigation,		6	1		2				164

An assessment of national resources was conducted by NITRD

Testbed Name	*NRL Cognitive Radio Test Laboratory*	*NRL Tactical Edge Network Testbed*	*Calit2 Wireless System Lab*	*ORBIT*	*Spectrum Sharing Innovation Test-bed and Public Safety Communications Research (PSCR) Lab demo network*	*ORNL Communications Test Bed*	*INL Wireless Testbed*	*US Army Test Ranges*	*Army C4ISR and Radio Analysis and Experimentation Facilities*	*Global Environment for Network Innovation (GENI)*	*AFRL Aerial Layer Networking Experimentation Facilities*	Cognitive Radio Network (CoRNet)
Agency	U.S. Naval Research Laboratory	U.S. Naval Research Laboratory	Calit2/UCSD	NSF	Department of Commerce	Department of Energy	Idaho National Laboratory (INL) Department of Energy (DOE) Federally Funded Research and Department Center (FFRDC)	US Army	US Army	NSF	US Air Force Research Laboratory	Virginia Tech
Location	Washington, DC	Washington, DC	La Jolla, CA	671 Rt. 1 South, North Brunswick, NJ	Boulder, CO	Oak Ridge, Tennessee	Idaho Falls, ID 83415	Fort Huachuca, AZ; White Sands Missile Range, NM; Yuma Proving Ground, AZ; Aberdeen Proving Ground, MD; Redstone Arsenal, AL;	Aberdeen Proving Ground, MD; and Fort Dix/Lakehurst, NJ	Approximately 46 university and industry sites across the continental U.S. and Alaska	Rome, New York with facilities in Stockbridge and Newport, NY	Blacksburg, VA
Name of facility	NRL Cognitive Radio Test Laboratory	NRL Tactical Edge Network Testbed	Calit2 Wireless System Lab	ORBIT	Institute for Telecommunication Sciences	Oak Ridge National Laboratory	INL Wireless Testbed	US Army Test Ranges including Electronic Proving Ground, White Sands Missile Range, Aberdeen Test Center, Yuma Test Center, and Redstone Test Center	Various C4ISR and Radio Analysis and Experimentation facilities including Radio Evaluation and Analysis Lab (REAL), 64 Channel GNU Radio Experimentation Platform, C4ISR & Network Modernization environment/venu e	Global Environment for Network Innovation (GENI)	Newport Research Facility; Stockbridge Research Facility; Rome Research Site	CoRNet
Operator of facility	U.S. Naval Research Laboratory	U.S. Naval Research Laboratory	Calit2	WINLAB, Rutgers University	National Telecommunication s and Information Administration and NIST	UT-Battelle, LLC	Battelle Energy Alliance (BEA)	US Army Developmental Test Command (DTC), which reports to the United States Army Test and Evaluation Command (ATEC).	US Army Communications-Electronics Research, Development and Engineering Center (CERDEC)	Raytheon BBN Technologies/GEN I Project Office	US Air Force Research Laboratory	Virginia Tech
Available to industry	Yes, with cooperative research agreements	Yes, with cooperative research agreements	Yes	Yes	Yes, via Cooperative Research and Development Agreement (CRADA) under the Technology Transfer Act of 1986	Yes; through user agreements (providing access to experimental user facilities), work for others (WFO) agreements, and cooperative research and development agreements (CRADAs)	Yes. Note: Currently available for industry on government agency request or directly for industry with an FCC STA request. FCC licensing (pending new rule making on	Yes	Yes	Yes	Yes, with Commercial Test Agreement	Yes

White House -> Office of Science and Technology Policy -> National Information and Telecommunication R&D -> Wireless Spectrum Research and Development (WSRD)

Toward Innovative Spectrum Sharing Technologies:

A Technical Workshop on Coordinating Federal Government/Private Sector R&D Investment

Authors:

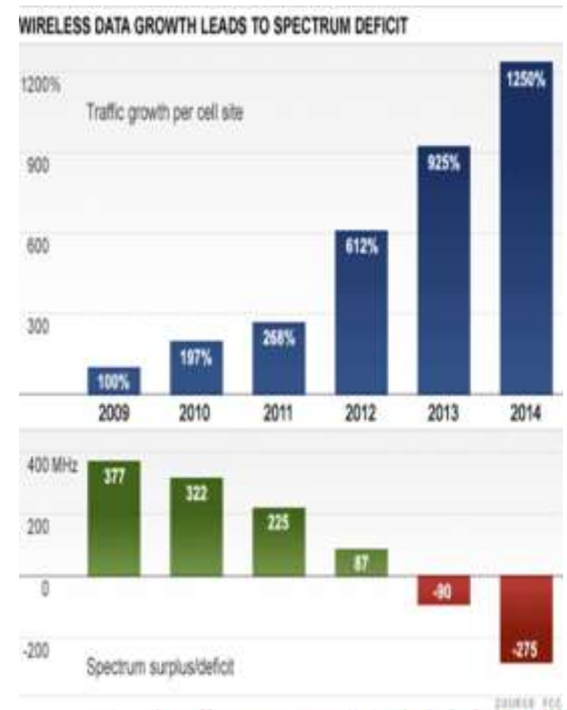
Dr. Andrew Clegg, Mr. Byron Barker,

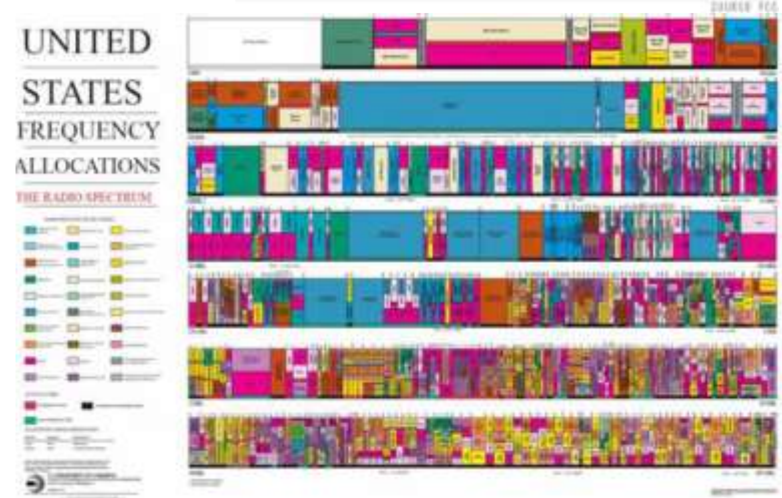
Dr. Rangam Subramanian, Dr. Paul Kolodzy

November 2011

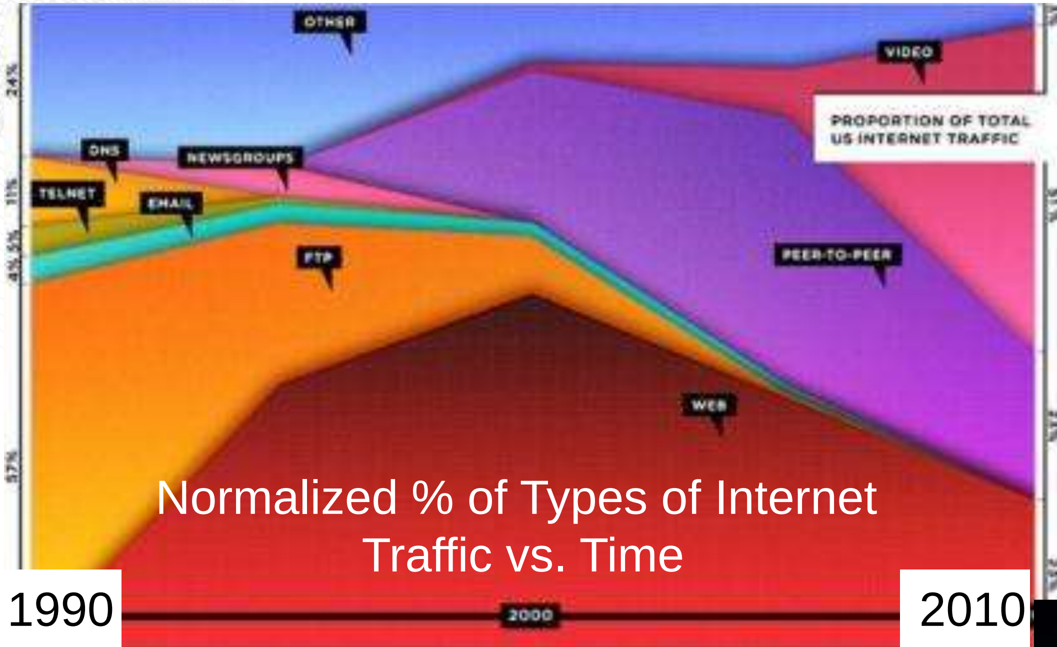
Why Do We Need to Repurpose Spectrum?

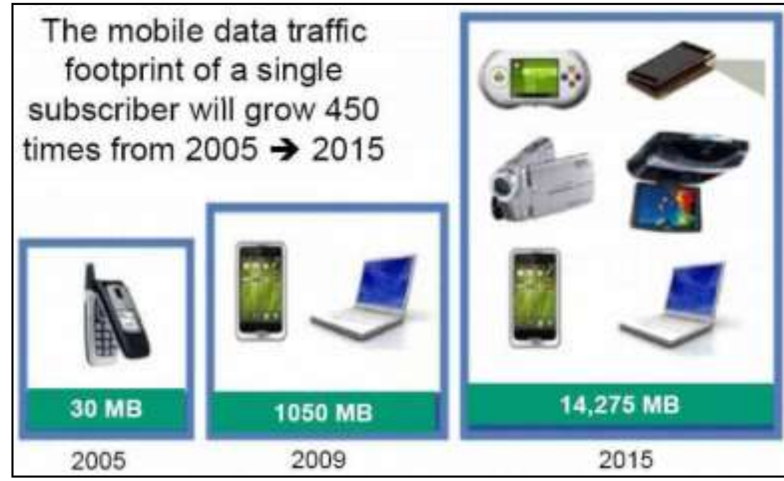
- **Huge WW Mobile Device Growth Opportunity (2020)**
  - **$4.5T Global Value**
  - **M2M Wave next**
  - **50B devices**
  - **Zetta-bytes of Data**
- **Enhanced Mobile Devices are Already Leading to a US Spectrum Deficit**
  - Data more than doubled 4 years in a row
  - Smartphones generate 24X data of basic-feature cell phones
  - Tablets create 5X more traffic than smartphones
- **Fragmentation of spectrum** for exclusive Federal use leads to inefficiency, artificial scarcity, and constraints on current and future users.



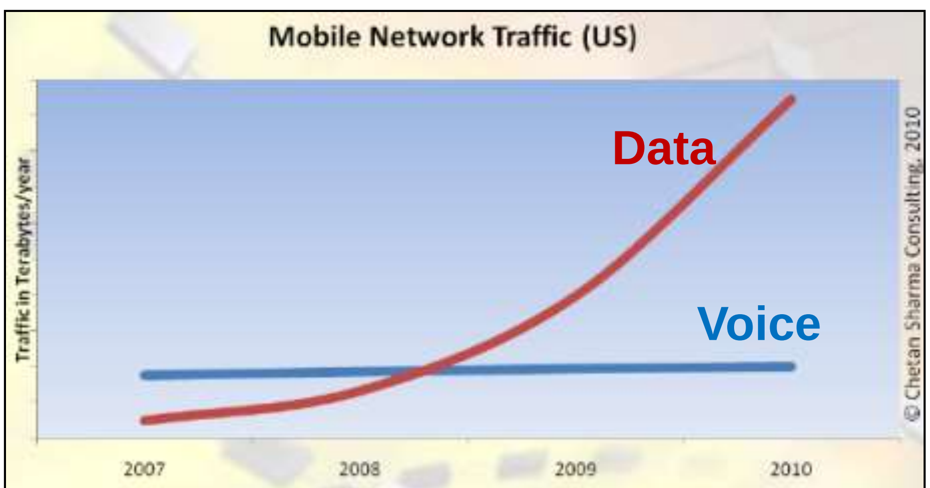


Growth in Spectrum Requirements





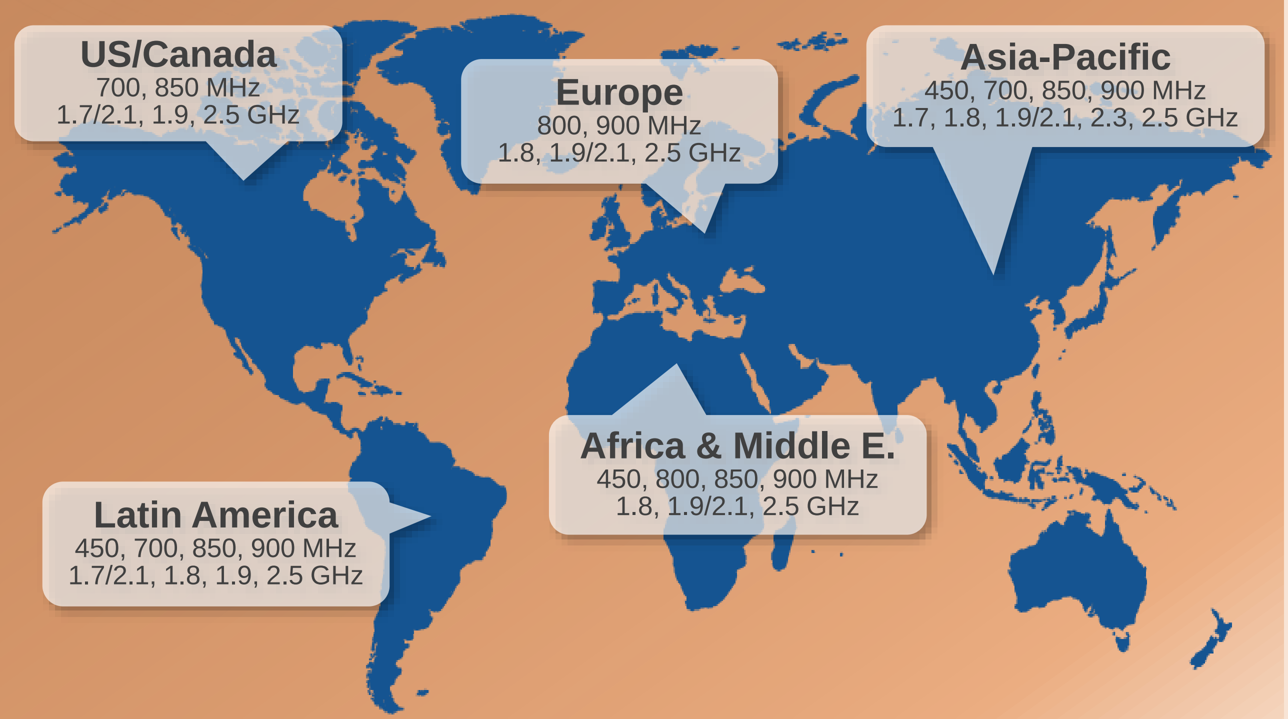
A. Gothard, "Managing Femtocells and the Evolved Packet Core"



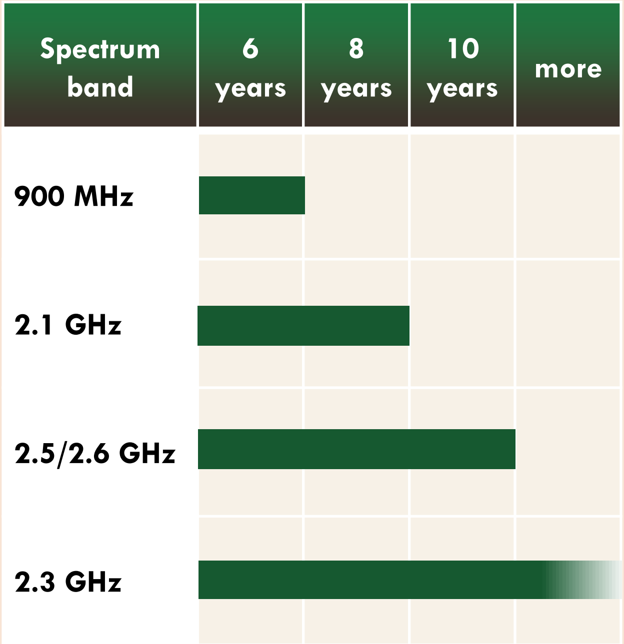
http://www.chetansharma.com/usmarketupdateq12010.htm

A. Gothard, "Managing Femtocells and the Evolved Packet Core"

A New Paradigm is Required for Granting Spectrum Access and Use Rights



Increasing delays in making harmonized spectrum available for mobile broadband*



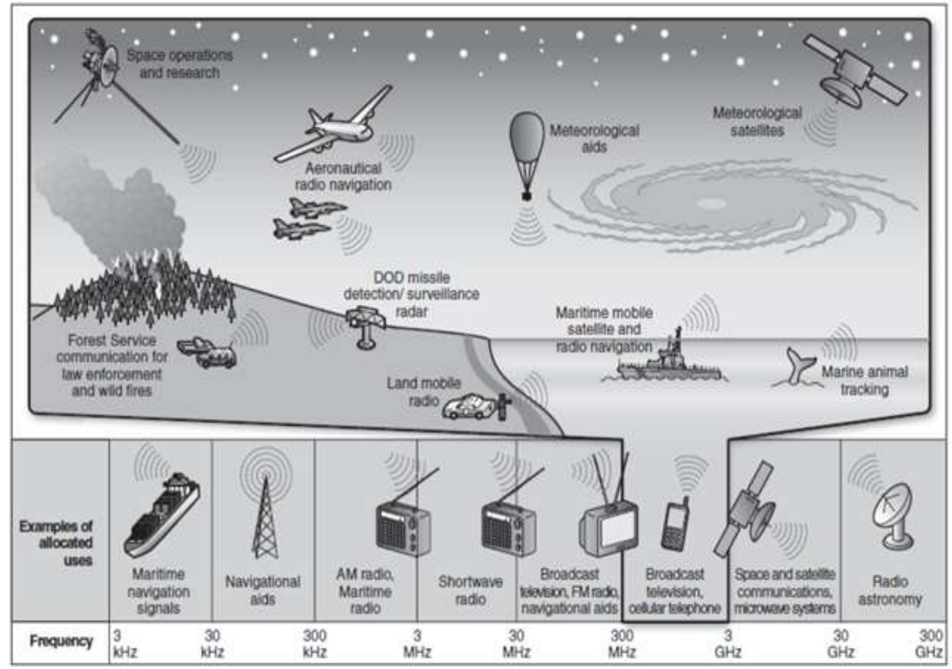
* In Europe (timeline between spectrum identification and European wide availability

Recent Events -- New Spectrum Bill

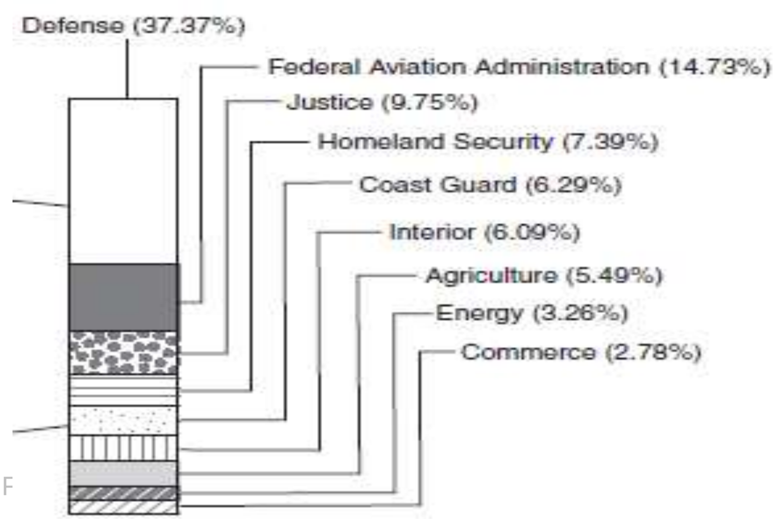
- Congress passed legislation that authorizes the FCC to hold voluntary incentive spectrum auctions.
- Expands the U-NII program at 5 GHz to include the 5350 MHz to 5470 MHz band.
- Gives 10MHz block of spectrum -- the so-called D block in the 700 MHz band -- to public safety agencies for use in a nationwide mobile broadband network for public safety
- Provides an estimated $7 billion from the proceeds of incentive auctions to build the nationwide network.   Up to $300 M in R&D funding

PCAST Study Concentrated on Federal Spectrum

- **Clearing and Reallocation of Federal Spectrum is Not Sustainable.**
  - Recent Study - Clearing of just one 95 MHz band will take 10 years, **cost $18 billion**, and cause significant disruption.
  - Net revenue from last successful auction of 45 MHz realized a **net income of just $5.35 billion** for the government.
  - Most Federal Bands not highly valued if they need to be cleared.
- **More Efficient Use of Federal Spectrum will be Obtained through Sharing**

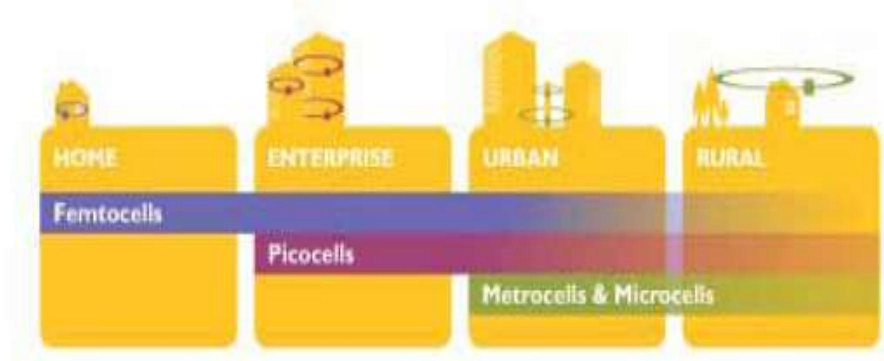


Source: GAO analysis of NTIA, federal agencies, and industry information.



New Technologies Allow for A New Federal Spectrum Policy

- **New Cognitive Technologies**
  - Agile Radios
- **Small Cell Technologies**
  - Optimized Aggregate Capacity
- **New Spectrum Architecture**
  - Divide spectrum into substantial blocks with common characteristics
  - Make sharing by Federal users with commercial users the norm
  - Make spectrum access available and affordable to a wide range of services and applications.
- **New Metric for Utilization**
  - Measure spectrum effectiveness
  - Potential impact that could be 1,000's times current capacity.



Overarching Recommendation

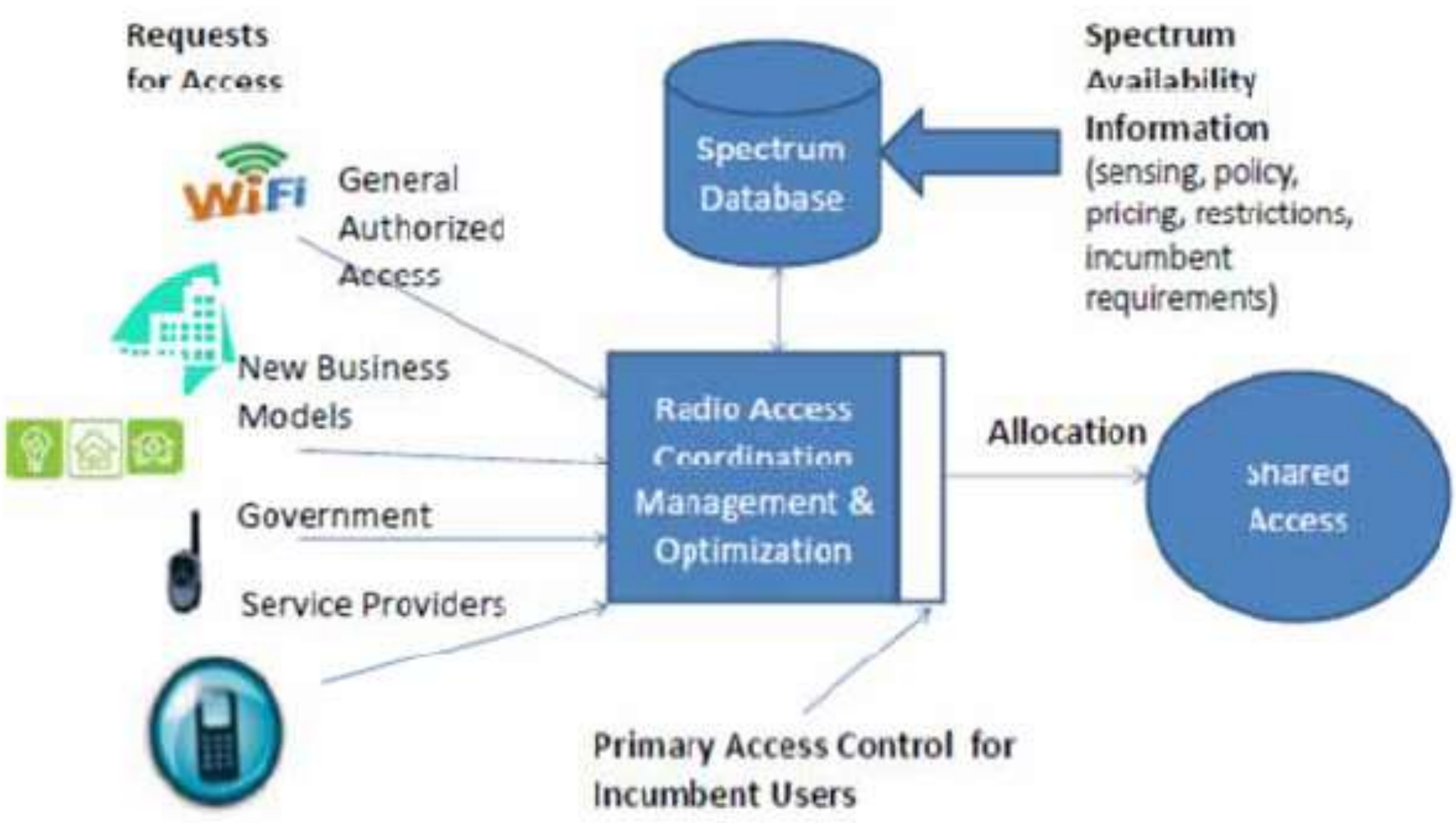
PCAST recommends the President:

- **Issue a new memorandum regarding spectrum;**
- **State the policy of the U.S. government is to share underutilized Federal spectrum; and**
- **Identify immediately 1,000 MHz of Federal spectrum for sharing with the private sector.**

This would lead to creation of the first shared-use spectrum superhighways.

Recommended: New Federal Spectrum Access System

- Hierarchy of Users: Access to Unused Spectrum
  - Federal Primary Access (Incumbent)
  - Secondary Access (Quality of Service Applications)
  - General Authorized Access



Recommended: Immediate Actions to Get Started

- **Modify Rules to Allow "General Authorized Access" Devices to Operate in two bands** in the NTIA Fast Track List – specifically the 3550-3650 MHz (radar bands) and a second band to be determined

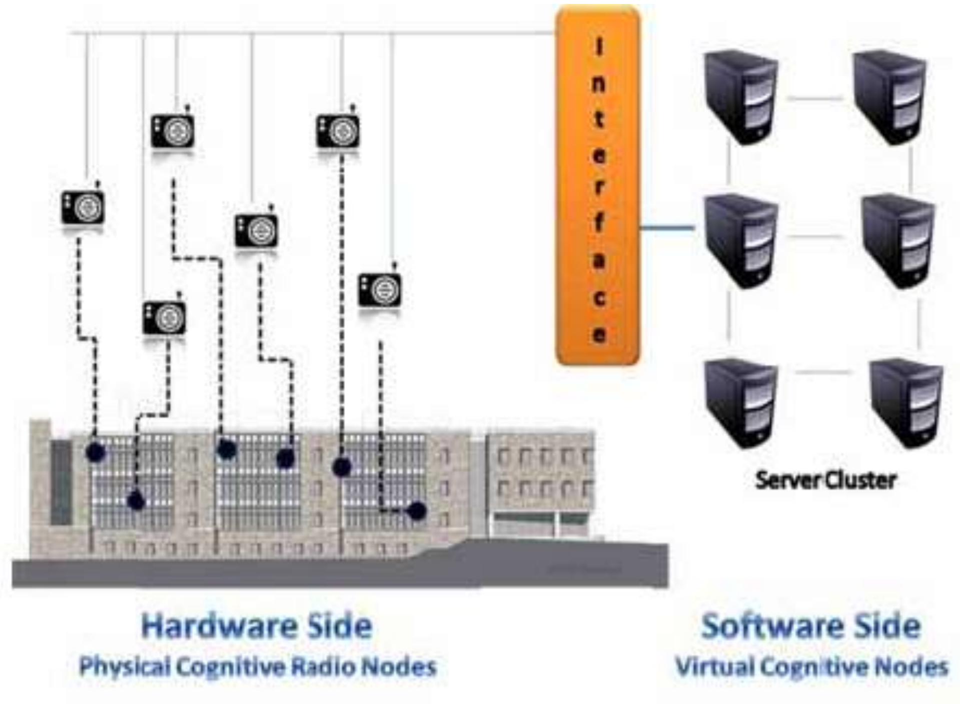
- Use Extended TV White Space System Already in Operation

3550-3650 MHz NTIA Exclusion Zones*

NTIA Fast-Track Report, Figure 5-3. Composite Depiction of Exclusion Zone Distances, Shipborne Radar Systems

Recommended: Immediate Actions to Get Started

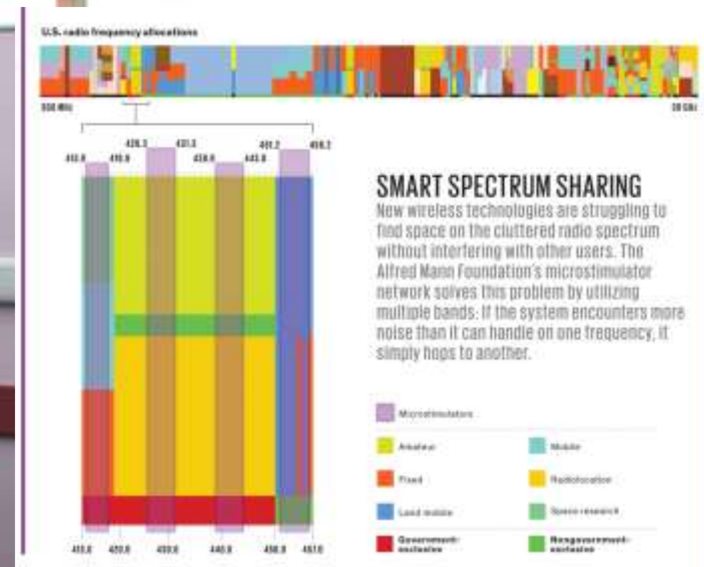
- **Establish Spectrum Sharing Partnership Steering Committee** - an Advisory Committee of Industry Representatives – to Advise on Federal Spectrum Sharing System Implementation



- **Provide Scalable Real-World Test Services** (a Test City and Mobile Test Service) to test Federal Bands and Public Safety

- **Release R&D Wireless Innovation Fund (WIN) -** Appropriated in 2012 Payroll Tax Agreement

Hospitals will have the Most Challenging Wireless Environment



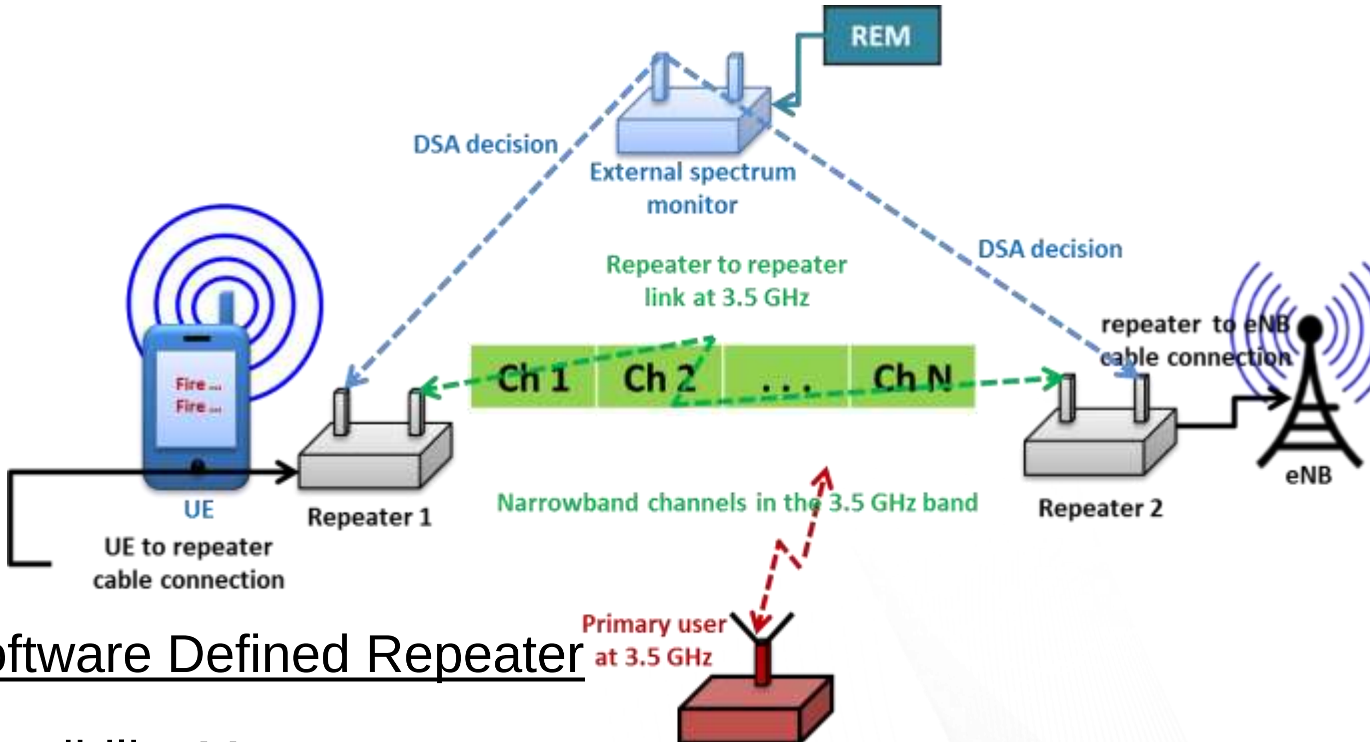
http://spectrum.ieee.org/telecom/wireless/peaceful-coexistence-on-the-radio-spectrum

Likely dozens of wireless devices in each room with a variety of different standards operating over many different bands.

A Presentation in Three Movements

On to the Finale

Software Defined <fill-in-the-blank>



<u>Projects Using this Software Defined Repeater</u>

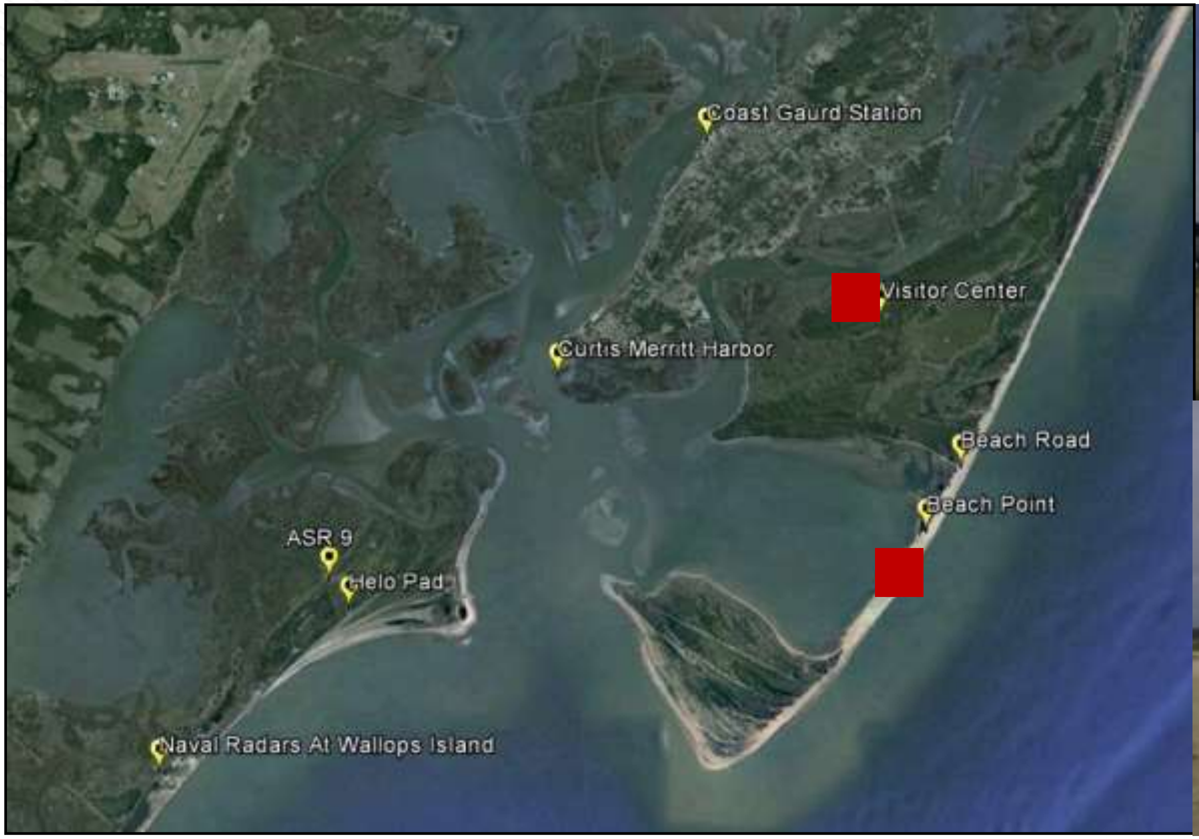
- LTE Radar Compatibility Measurements
- Public Safety Remote LTE Networks
- DSA-enabled LPE LTE

Preliminary LTE / Radar Testing

- LTE communication at 3550-3650 MHz in presence of Naval radar
- Location: Eastern Shore of VA
- Emphasis on proof-of-concept (existence proof)
- Used frequency repeater/translator, tablet UE, and CMW500 as eNodeB
- Horn antennas

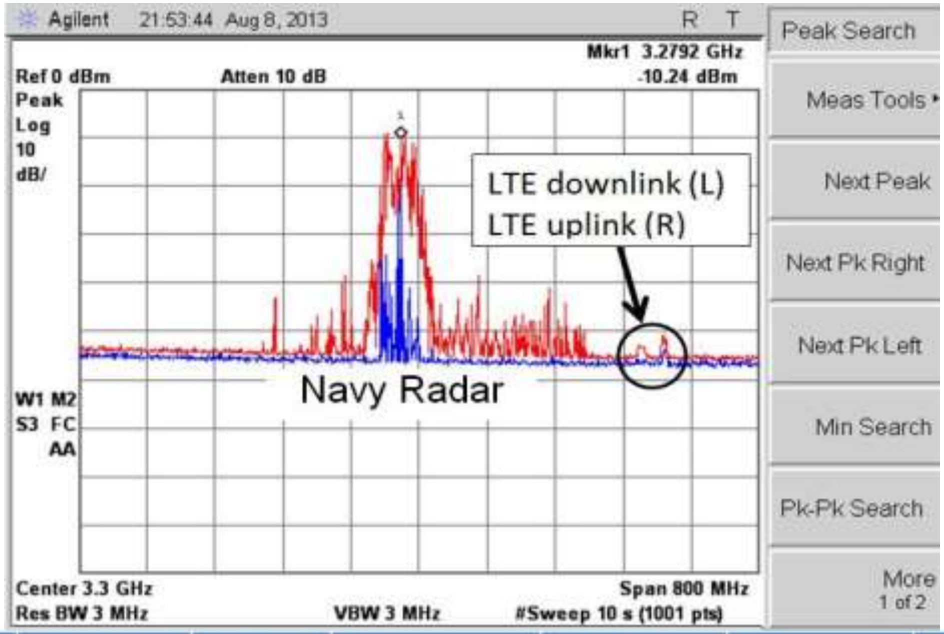
- **Equipment Used:**
- Rhode & Schwarz CMW500 as eNodeB
- Commercial LTE User Equipment
  - UE in shielded enclosure
  - Dipole affixed to UE as coupler
- Custom frequency translators
  - 700 MHz to/from 3550 MHz
- Broad-beam directional antennas
  - C-band TVRO feed horns
  - adjustable linear polarization

Measurement Locations



Beam width about 90 degrees, visitor's center had radar perpendicular to LTE path, on Beech radar was in the antenna 3dB BW and eNB pointed away from radar

LTE and Radar Spectra



Peak and instantaneous power displaced.

Location	LTE Path Distance	Path Loss est.	DL Resource Blocks	DL Mod.	UL Resource Blocks	UL Mod.
Visitor Center	25m	72 dB	16	QPSK	16	QPSK
Beach	45m	77 dB	16	QPSK	16	QPSK
Beach	45m	77 dB	50	64 QAM	16	16 QAM

Impact of Interference on TD-LTE System at 3.5 GHz

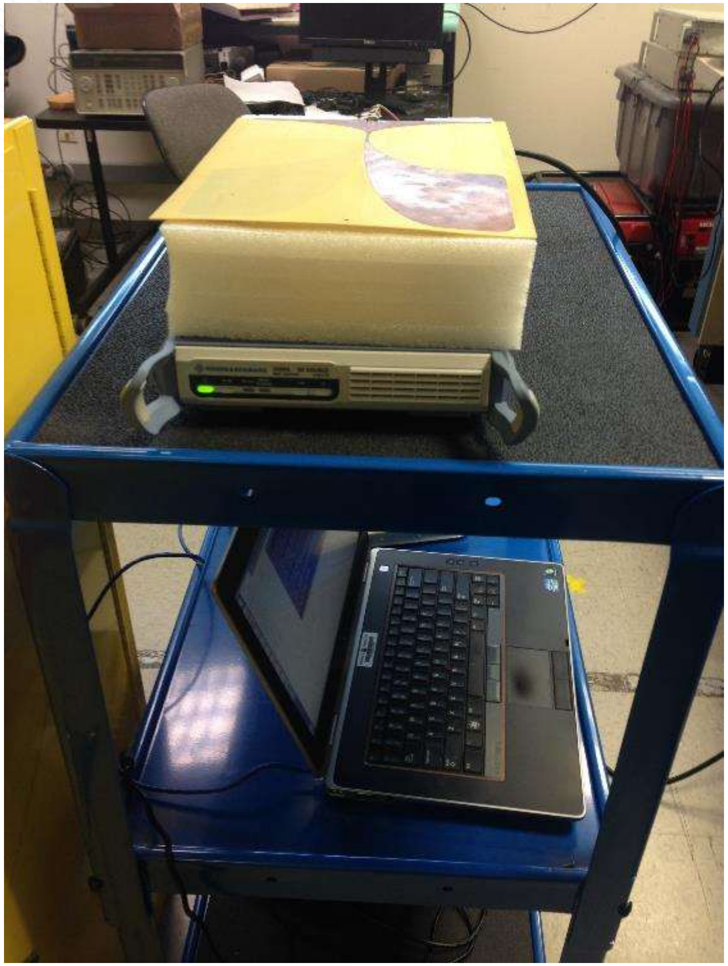
❑Objectives

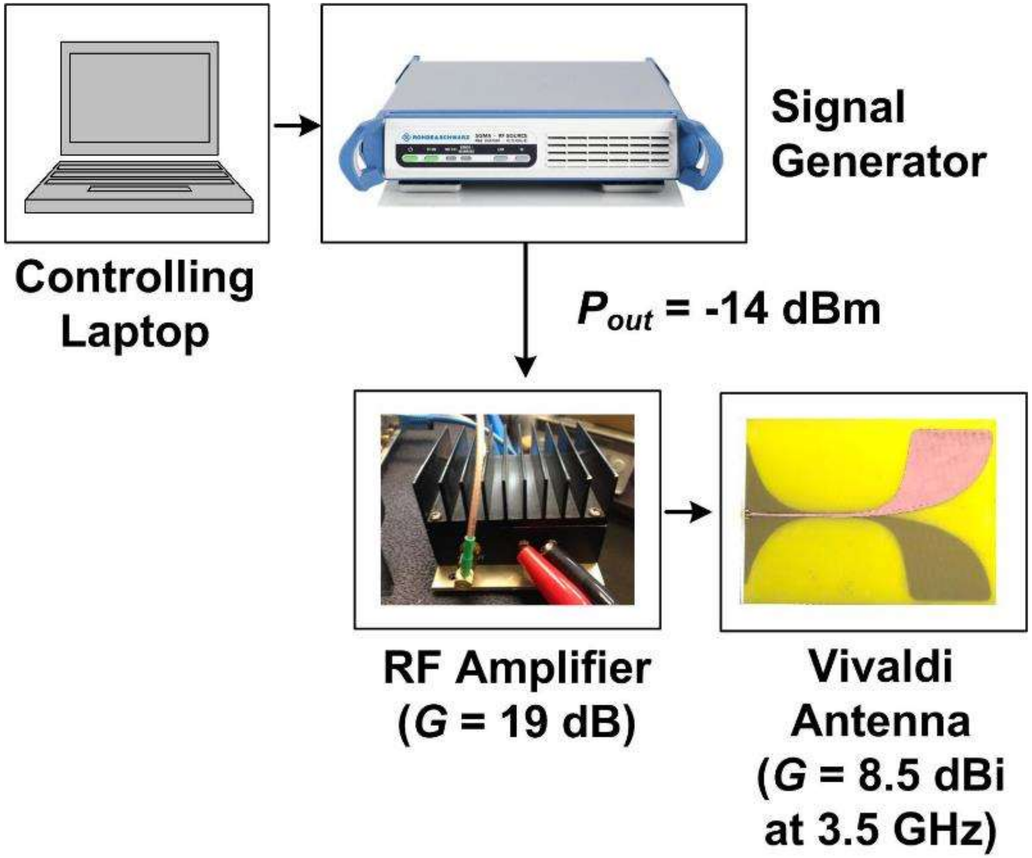
- Study the impact of radar-like interferences on the performance of a TD-LTE system operating at Band 42 (3.4 - 3.6 GHz)
- Identify appropriate performance metric to understand the required size of exclusive zone

❑Two Expedited Experiments

- **Continuous-wave interference** to observe the impact of a constant tone interferer on the TD-LTE system. The tone interference sweeps the entire bandwidth of the TD-LTE signal in steps of 1 MHz.
- **Pulsed interference** at a rate of 0.25 Hz (4 sec period) with a duty cycle of 1.1%

Experiment Setup: Interferer





➔ **EIRP: 13.5 dBm**

Experiment Setup: TD-LTE

❑User Equipment

- Huawei Repeater Bridge (CPE B593s-42)
- f_c = 3.5 GHz
- Support up to 20-MHz Cell BW
- 1 main + 1 diversity antennas

❑eNB

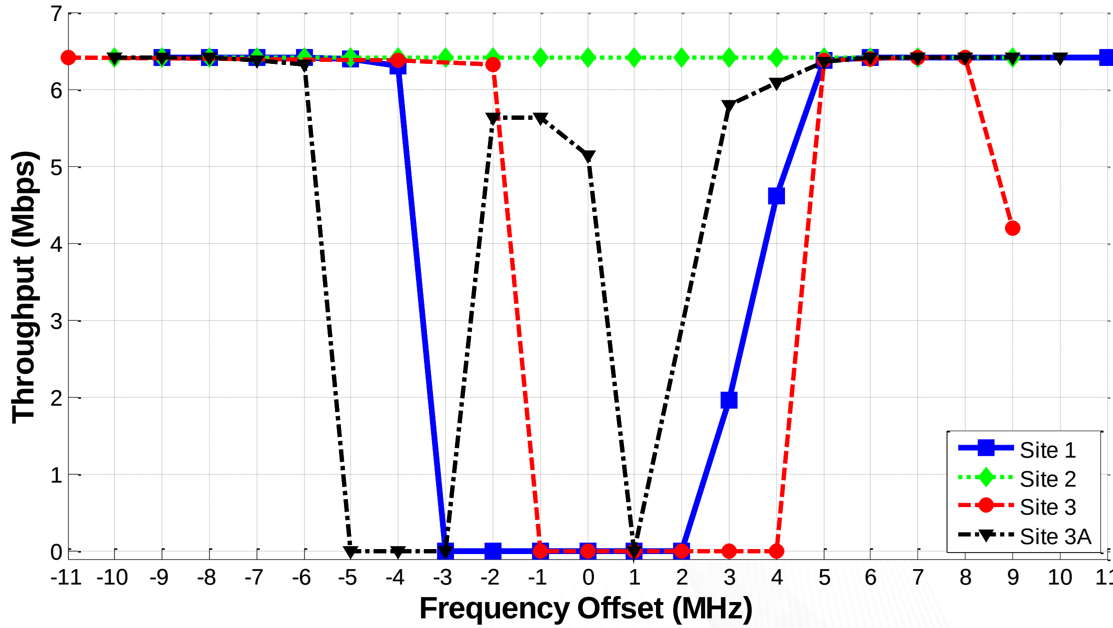
- R&S CMW500

❑Spectrum Analyzer

- Tektronix RSA3408A

Throughput Plots

Locations of Sites

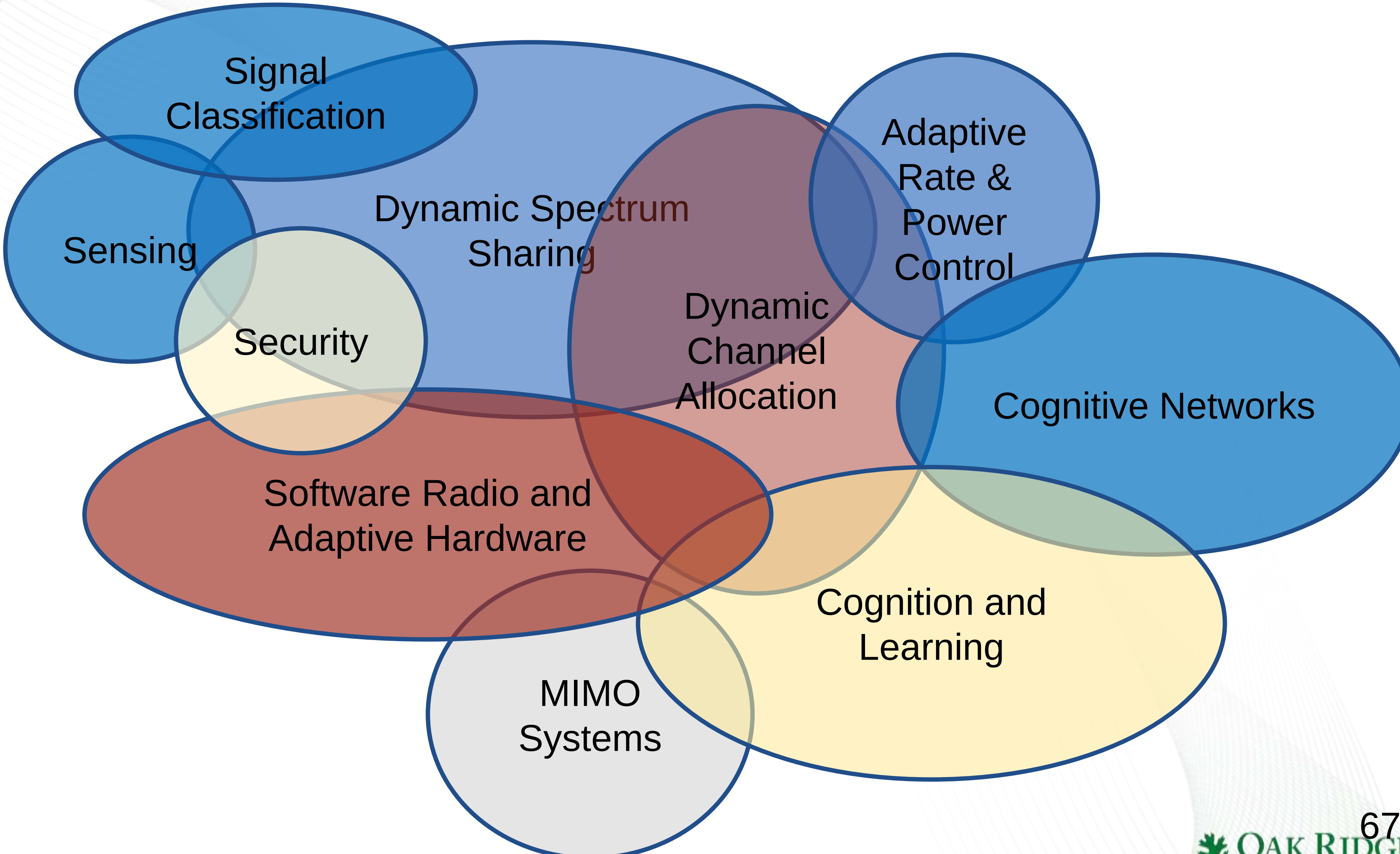


Oak Ridge National Laboratory

Summary of Testing

- Communication is possible in the presence of operating Naval radars under certain operating conditions
- Dynamic-spectrum-access-enabled LTE system can avoid the radar interference and operate close to the radar operation frequency with a small guard band
- From the perspective of the LTE system, little or no exclusion zone is required so long as the actual radar frequency is avoided

Cognitive Radio Research



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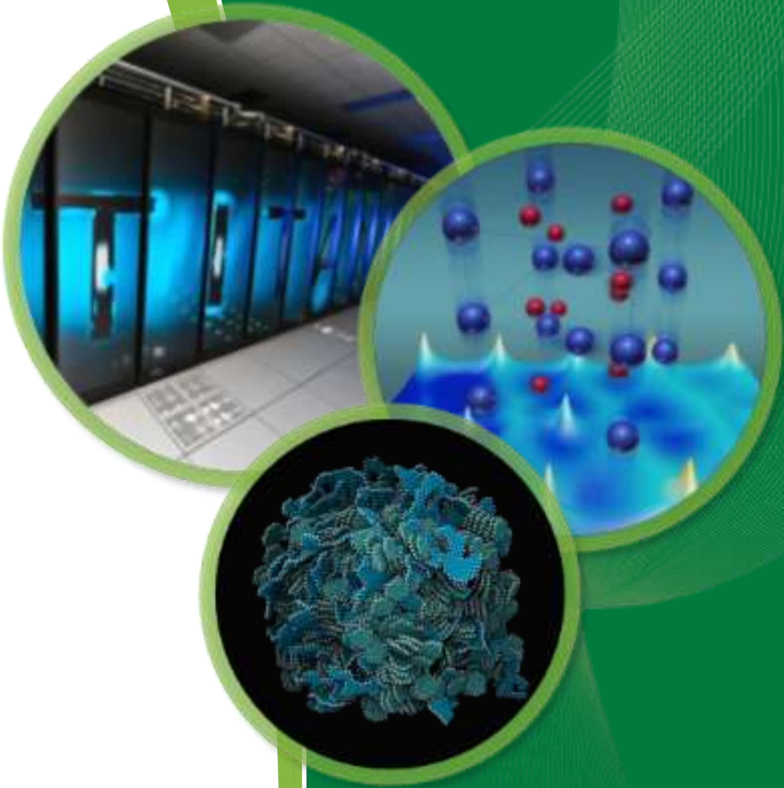
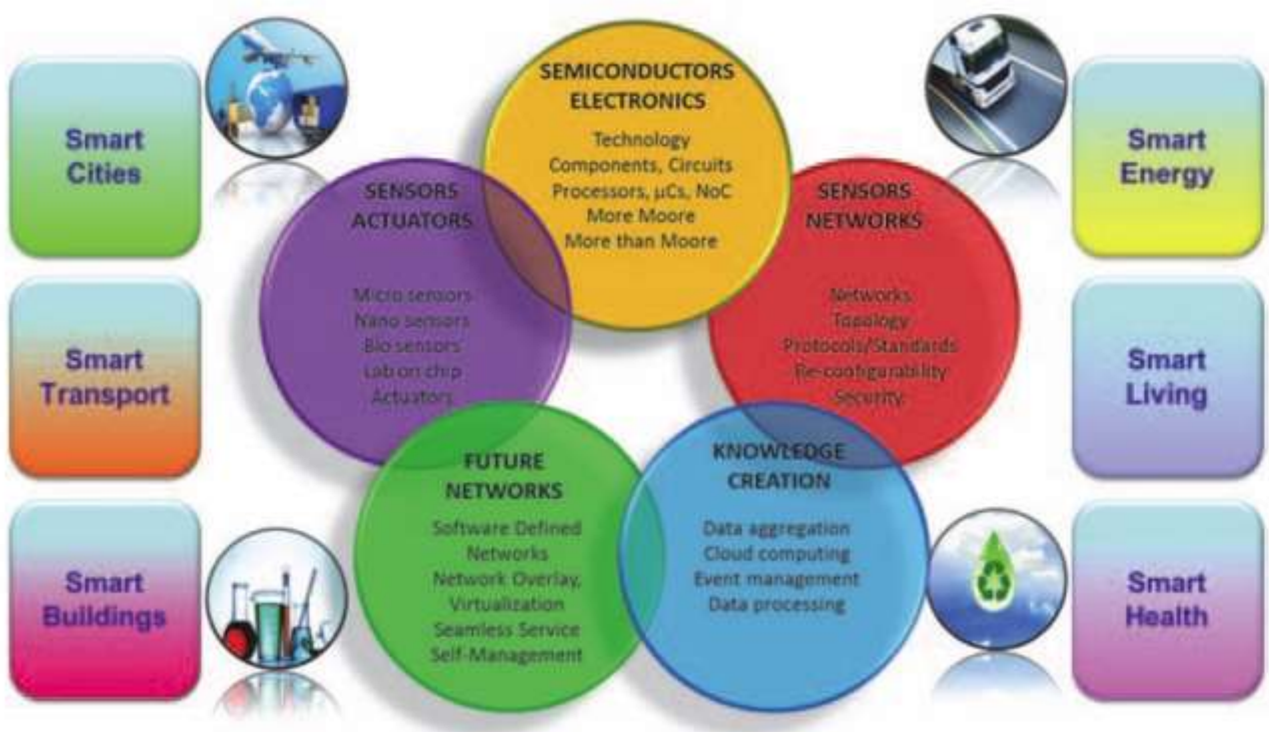
Research Challenges in IoT-SS

Opportunities



Challenges in IoT

- Major challenges to be addressed include:
  - –Complexity: deployment, interface, maintenance
  - –Privacy / Security
  - –Communications and Spectrum Scarcity



Internet of Things – Converging Technologies for Smart Environments and Integrated Systems, River Publishers, O. Vermesan and P. Friess, editors

IoT Challenges: Communications

- Integrated networks (probably a characteristic of 5G)
  - Machine-to-Machine Communications in later 4G
- Very long battery life
- Automated deployment and de-confliction
- Interoperability of standards
- Spectrum availability and uniformity across national boundaries

Challenges in Spectrum Sharing (1/2)

Spectrum Regulation

Policy Enforcement

Challenges in Spectrum Sharing

The Radio RF Front End

Metrics and Algorithms

Standardization

Challenges in Spectrum Sharing (2/2)

Spectrum Regulation
- Security
- Location specific mgmt of users
- Maximizing spectrum utilization
- Equipment Certification
- Regulate interference levels for various tiers

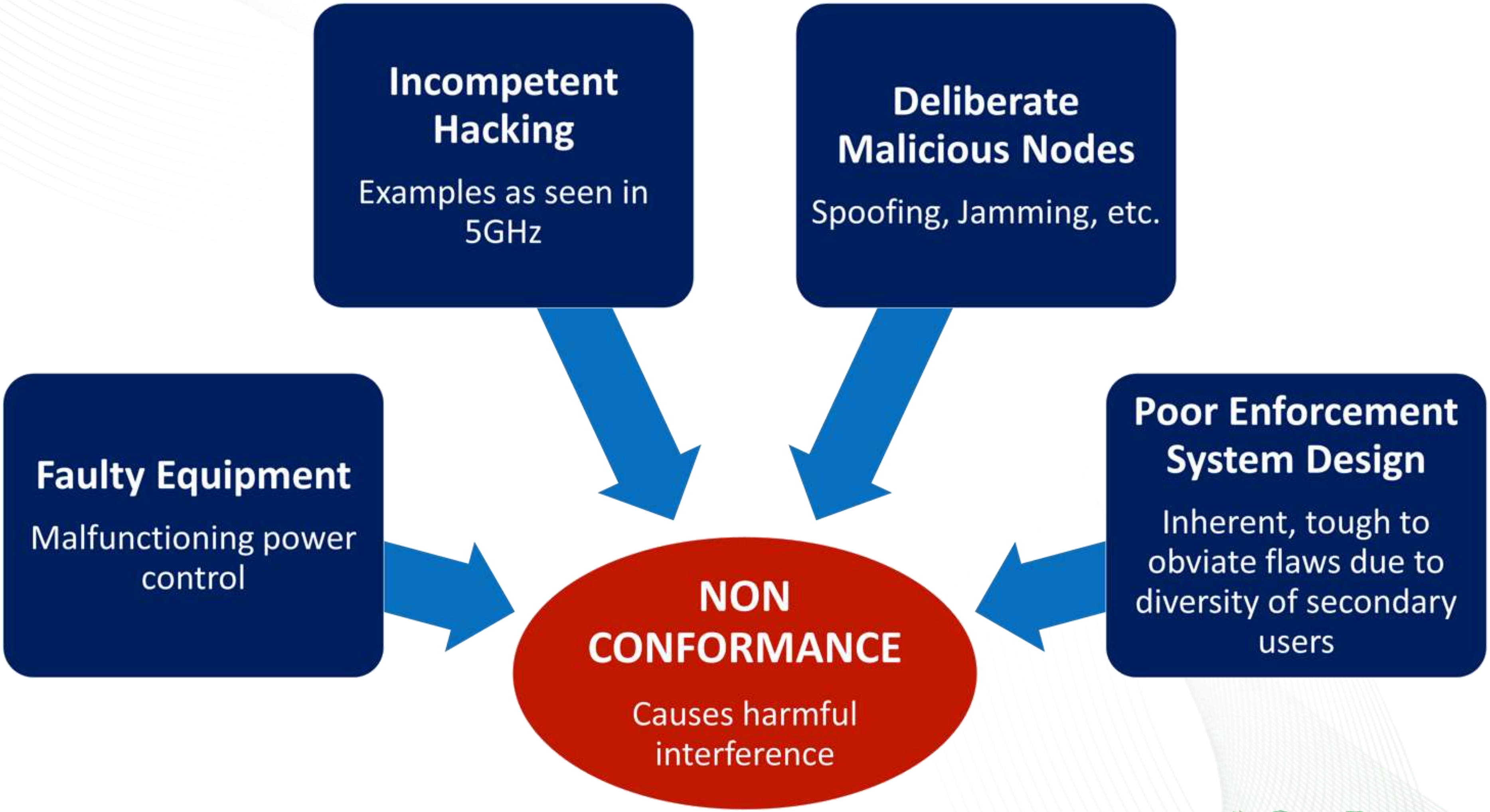
Policy Enforcement
- Enforcement of regulations imposed by spectrum manager (or SAS)
- Ensuring network safety given that a set of nodes are compromised (non-conforming)

Metrics and Algorithms
- Receiver Performance Metrics
- Spectrum Efficiency Metrics
- Interference Tolerance Metrics
- Time taken to vacate a band
- Localization accuracy
- Robust and intelligent algorithms for automated management

The Radio RF Front End
- Achieving Frequency Flexibility
- Wideband Antennas/ Selectivity
- Radio Cost

Standardization Efforts
- IEEE 1900 Standards Committee
- Standard should accommodate legacy services and devices

Spectrum Enforcement Issues



Security Issues for Cognitive Radio Networks

CR network security threats

Spectrum access-related security threats

Threats to incumbent coexistence mechanisms

- Spectral “honeypots”
- Sensory manipulation:
  - Primary user emulation
  - Geospatial manipulation
  - Chaff point attack
  - Spam point bias attack
- Obstruct synchronization of QPs

Threats to self-coexistence mechanisms

- Tx false/spurious inter-cell beacons (control messages)
- Exploit/obstruct inter-cell spectrum sharing processes

Radio software security threats

- Security threats to the software download process
  - Injection of false/forged policies
  - Injection of false/forged SW updates
  - Injection of malicious SW (viruses)
- Software IP theft
- Software tampering
  - Unauthorized policy changes
  - Tampering w/ CR reasoners (e.g., System Strategy Reasoner & Policy Reasoner)

Need for Propagation Models

- Good propagation and channel models critical to
  - Optimize for performance
  - Manage interference
- Vector channels for high frequencies (e.g. 3.5 GHz) neglected in existing literature
- Learning vs deterministic modeling– FCC can put constraints on the optimization
- Building penetration loss is critical for indoor small cell deployment – not completely understood in existing literature

Need for Interference Models

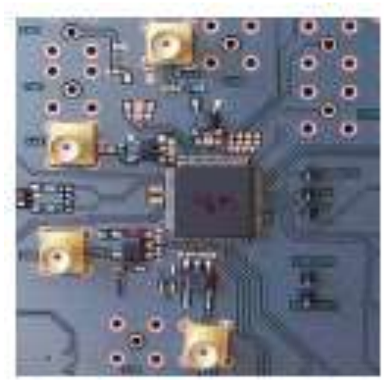
- Interaction between federal systems and LTE/WiFI
  - Signal dependent
  - Frontend requirements
- What constitutes harmful interference?
- Prediction of cumulative interference
- Fusion of data from multiple sources
- How do we handle airborne platforms?
- Impact of MIMIO

Software Challenges (same as usual)

- Better support for multicore DSPs and parallelism
- Scalability of solutions
- Security and Certification -- More to come.
- Co-design of SW/HW
- Reprogramming of hardware in real time
- Dynamic software architecture
- Cross-platform compatibility
- Validation of software and general testing
- Structured and common APIs
- Integration of heterogeneous systems FPGAs, GPUs, DSP, GPPs

Hardware Challenges

- Very high performance RF and ADCs
  - High dynamic range
    - Interference unpredictable
    - Mitigate hidden nodes
    - Especially needed with radar co-existence
    - Better characterization of RF performance
  - Wide bandwidth
    - Need to find available spectrum
    - Need to determine contingent spectrum
    - Antenna performance
    - Duplexer issues
  - High performance computing and memory
    - Optimization requirements
    - Low Latency
    - Low Power



Spectrum Regulation and Management: Multidimensional Optimization Strategy

- Spatial Management :
  - Interference limits decided by the receiver performance of the Priority Access or GAA user
  - Power control and Propagation maps (Regional dependent)
- Temporal Management:
  - Time for which a device can remain in a frequency
  - Swift agility can provide better optimization
- Frequency Management:
  - Adjacent channel interference effects on receivers
  - Allocation of Bandwidth and hence power

Real issues of intermods, reverse intermods, AGC capture impact performance and depends on the device.

Where's the money coming from– New Spectrum Bill

- Congress passed legislation that authorizes the FCC to hold voluntary incentive spectrum auctions.
- Expands the U-NII program at 5 GHz to include the 5350 MHz to 5470 MHz band.
- Gives 10MHz block of spectrum -- the so-called D block in the 700 MHz band -- to public safety agencies for use in a nationwide mobile broadband network for public safety
- Provides an estimated $7 billion from the proceeds of incentive auctions to build the nationwide network.   Up to $300 M in R&D funding

Where's the money coming from
…FCC Auction

Federal Communications Commission

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Since 1994, the Federal Communications Commission (FCC) has conducted auctions of licenses for electromagnetic spectrum. These auctions are open to any eligible company or individual that submits an application and upfront payment, and is found to be a qualified bidder by the Commission (More About Auctions...)

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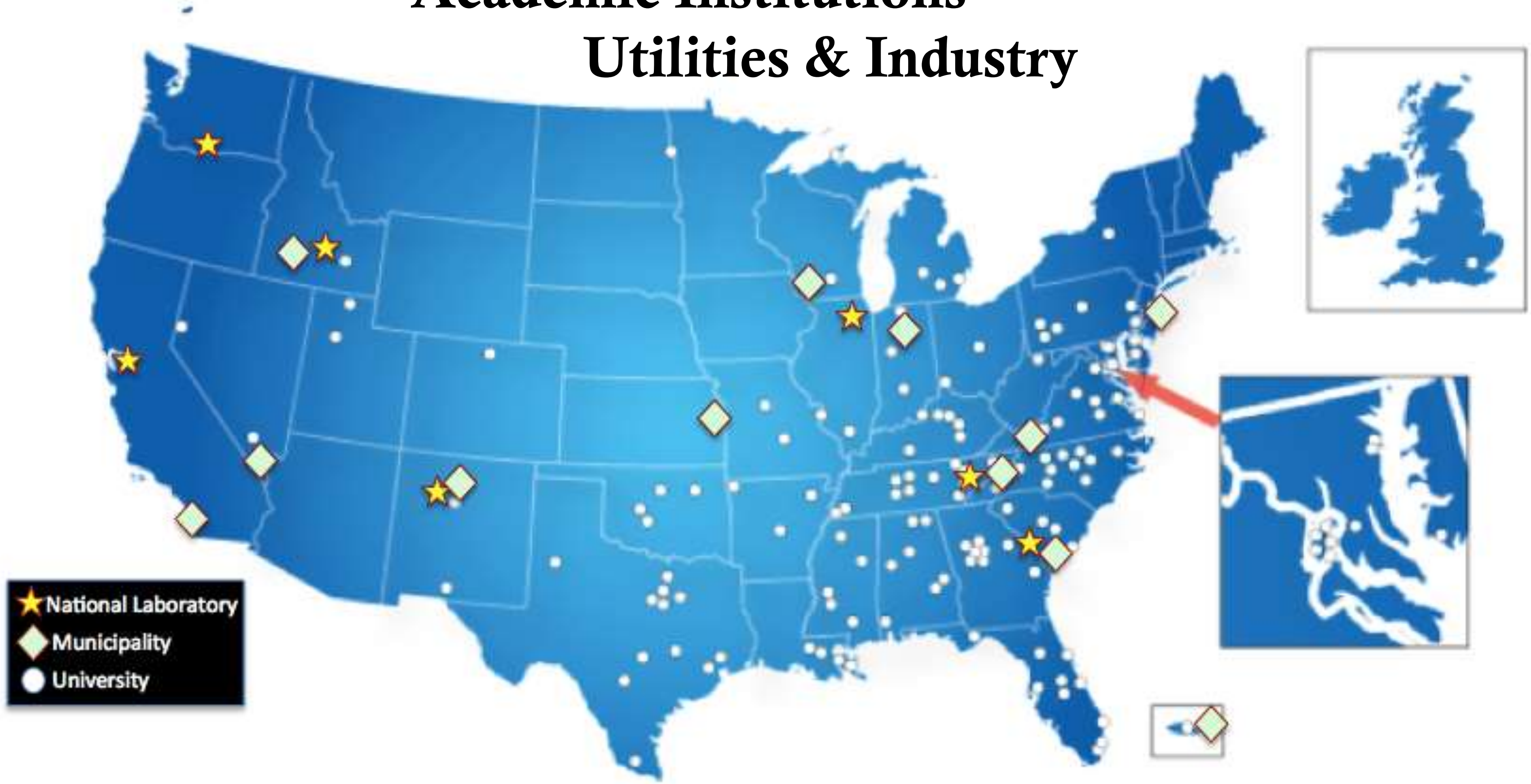
7/23/2014
PUBLIC NOTICE (DA 14-1018)
Auction 97
Auction of Advanced Wireless Services (AWS-3) Licenses Scheduled for November 13, 2014; Notice and Filing Requirements, Reserve Prices, Minimum Opening Bids, Upfront Payments and other Procedures for Auction 97
pdf - Word
Attachment A: pdf - xls

7/18/2014
PUBLIC NOTICE (DA 14-1012)
Auction 902
Tribal Mobility Fund Phase I Support; Authorized For One Winning Bid
pdf - Word
Attachment A: pdf

7/18/2014
PUBLIC NOTICE (DA 14-1023)
Auction 97
The Federal Communications Commission and the National Telecommunications and Information Administration: Coordination Procedures in the 1695-1710 MHz and 1755-1780 MHz Bands
pdf - Word

Workshop Goals:
* Develop IoT Science Strategy to address gaps through partnerships with: academic, corporate and laboratory worlds.

National Laboratories
Municipalities
Academic Institutions
Utilities & Industry

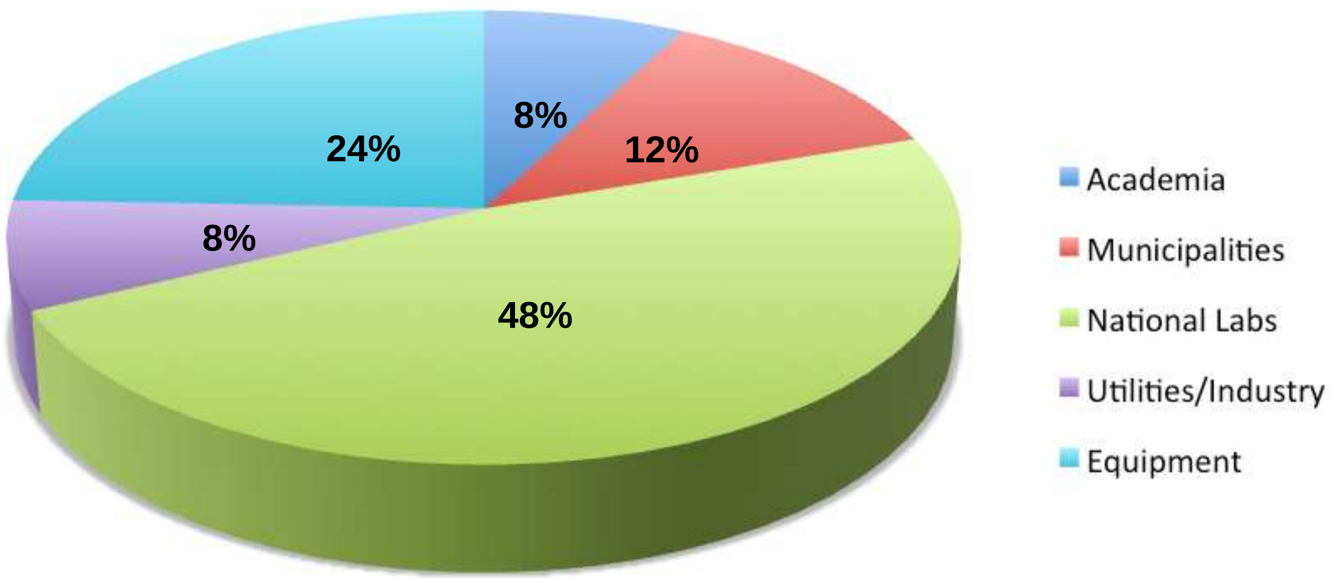


Affiliated Organizations

Standards development
Piloting initiatives using innovative contracting methodologies
Utility/Industry/Municipality end user engagement
Liaison & advocate activities
Planners

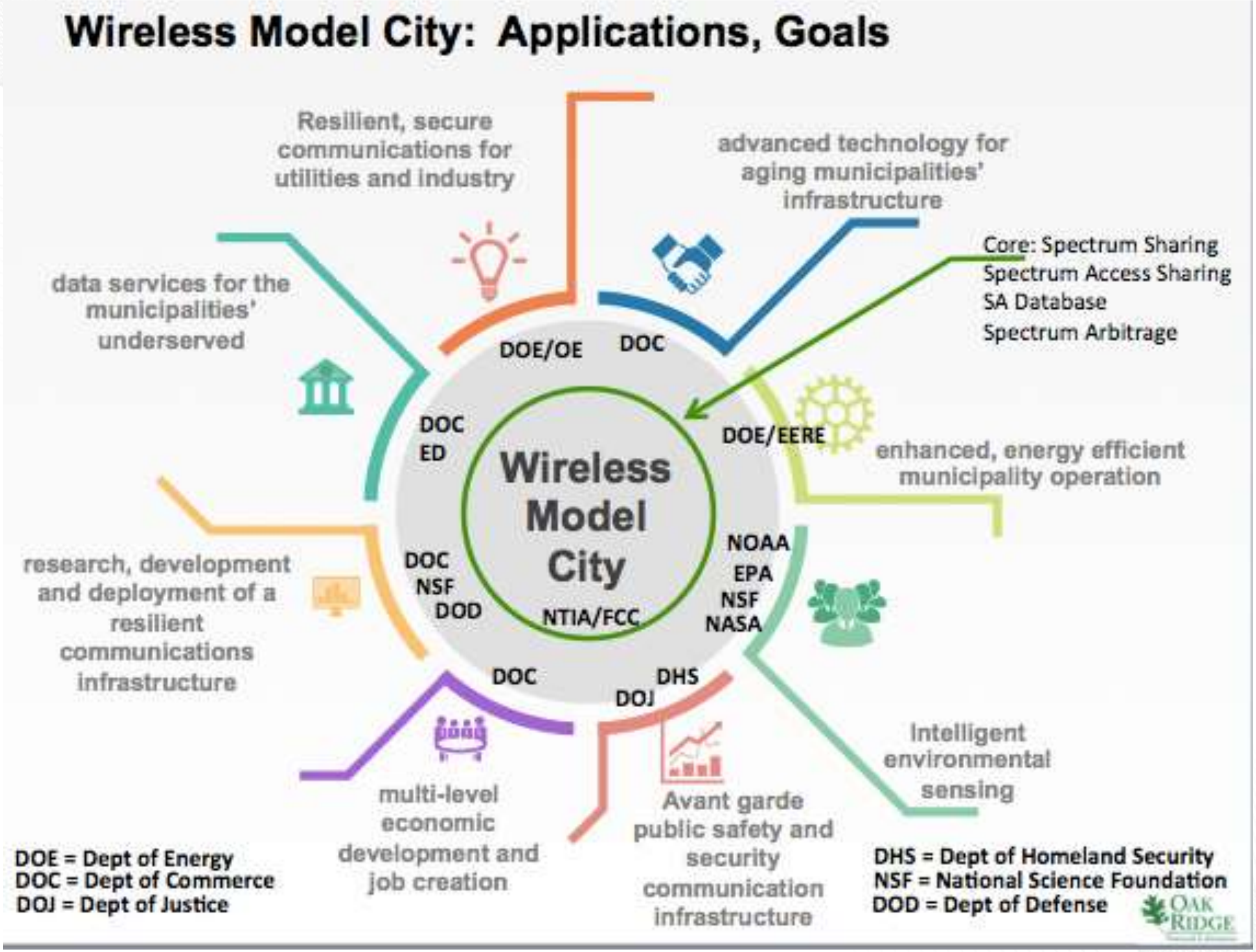
www.ieee-ims.org
www.isa.org
www.nationalspectrumconsortium.org
www.wina.org
www.aceee.org
www.planning.org/aicp/

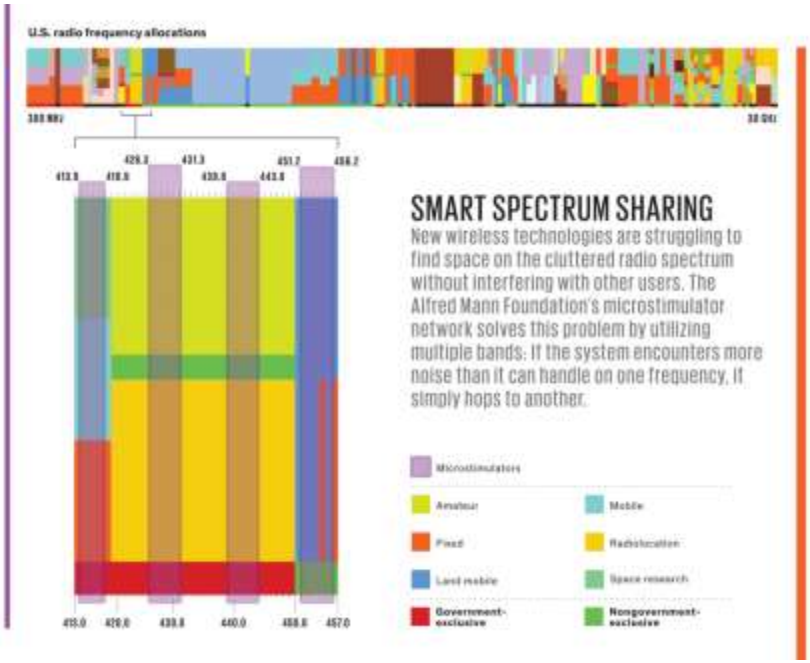
Estimated Budget
5 Years



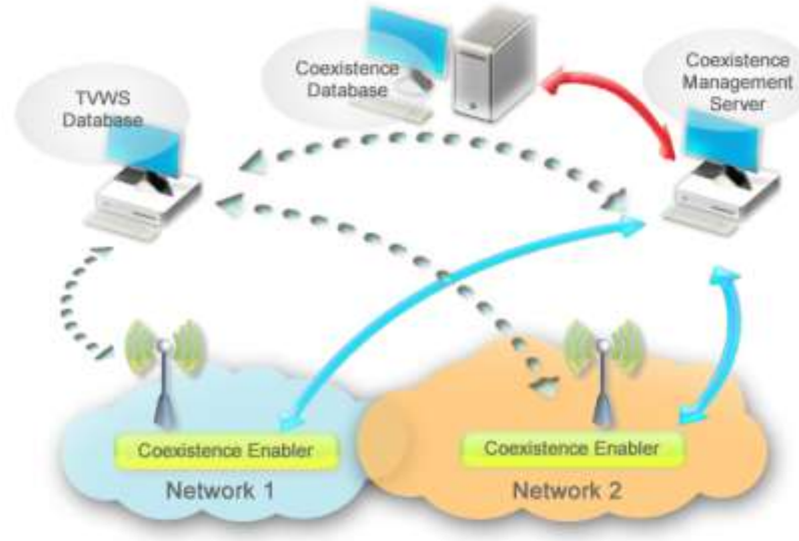
Total: ~$29M/year

Applications and StakeHolders

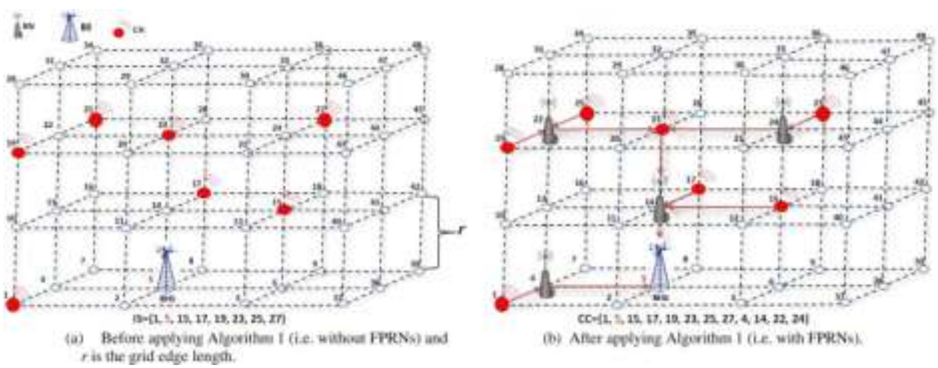




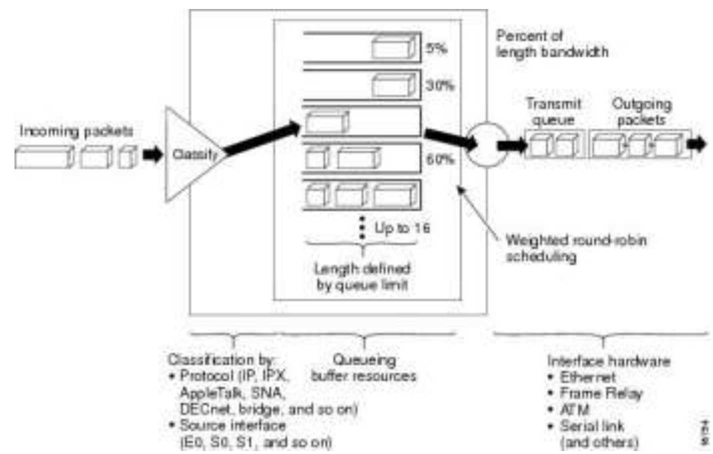
See article in IEEE Spectrum, 20MAR13



Orchestrated databases for coexistence management



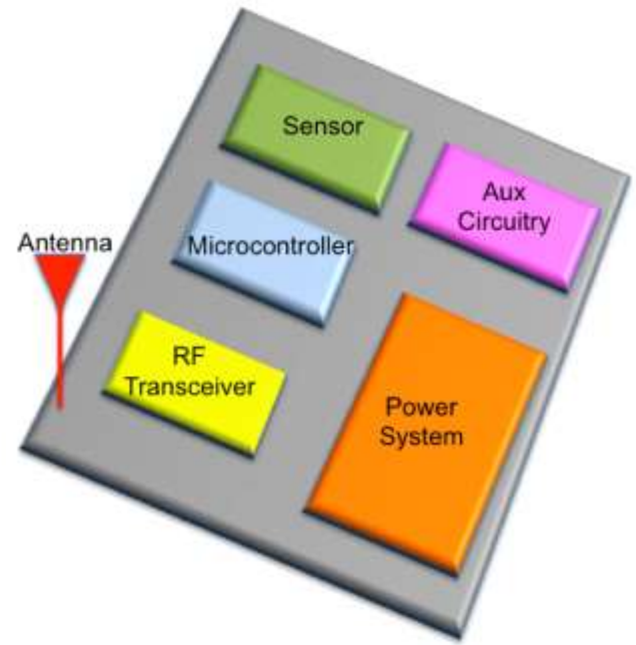
Enhanced deployment strategies



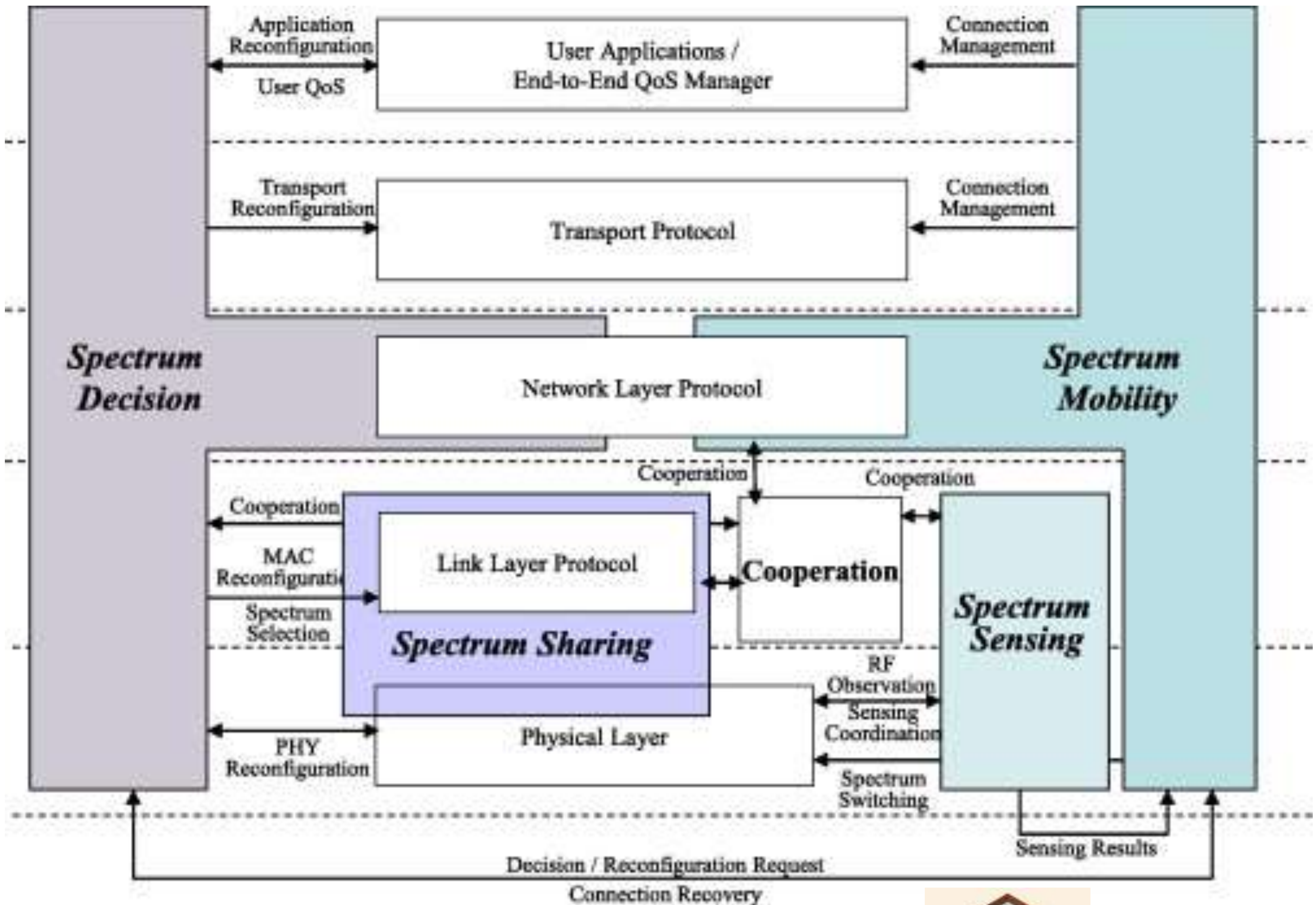
HW with optimal congestion management algorithms

Devices will probably look the same…

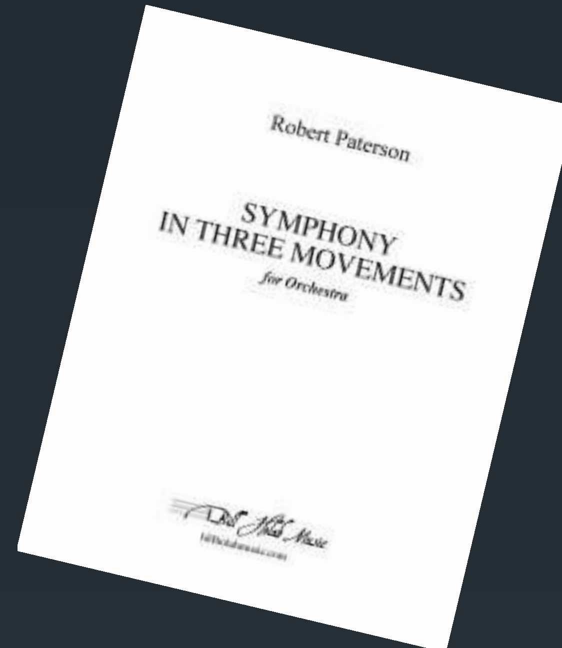
With the same internal architecture



…with a much better architecture…



…and…



FIN

A Presentation in Three Movements

FIN

A Report that (IMHO) you should examine…

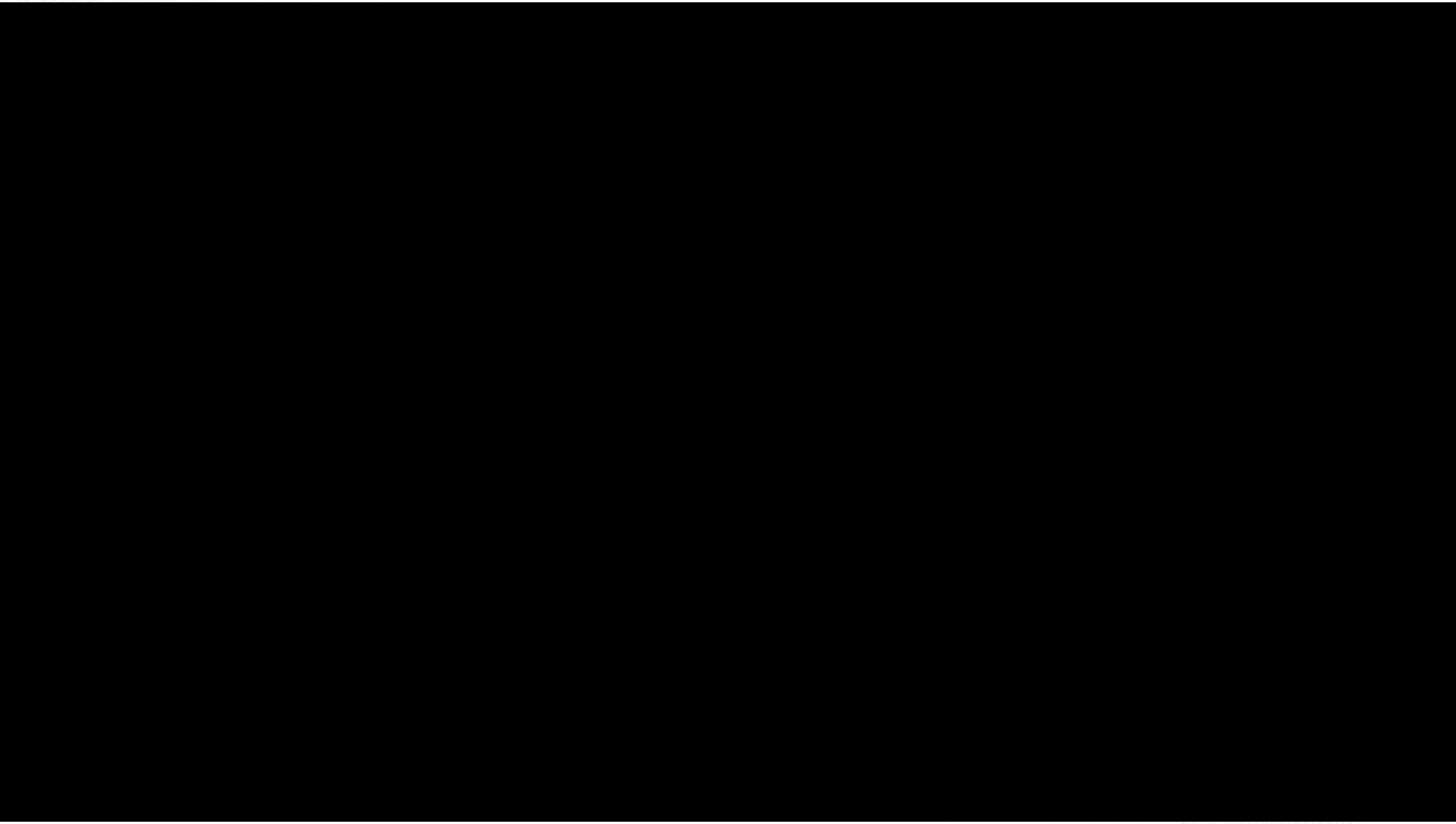
INTERNET TRENDS 2015 – CODE CONFERENCE

Mary Meeker
May 27, 2015

kpcb.com/InternetTrends

KPCB | KLEINER PERKINS CAUFIELD BYERS

This sums it up… (play the video)



Drones need spectrum too…

For more information…fuhrpl@ornl.gov