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
Cyber – in today’s world...
A Presentation in Three Movements
KEEP CALM AND BUCKLE UP

‘cause here we go!
“non Carpet-land” Wireless
\[ E(t) = A(t) e^{j\omega t + \phi(t)} \]

This is Industrial Wireless

Multiple Protocols

DSSS

FHSS

The Seven Layers of OSI

Transmit Data
- Physical layer
- Data link layer
- Network layer
- Internet layer
- Session layer
- Presentation layer
- Application layer

Receive Data

Antennas

Canyons of Metal
Industri Wireless operates here

So does Bluetooth, Wi-Fi, other stuff
Industrial Wireless

![Diagram of IEEE 802.11 frequency bands](image)

14 x IEEE802.11 fixed 22 MHz wide Channels, 2.4 GHz, DSSS

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

<table>
<thead>
<tr>
<th>Microcontrollers</th>
<th>RFID</th>
<th>Energy harvesting technologies</th>
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</table>

**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.
What language (protocol) does an IoT device speak?

- 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
- Guarani
- 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
Open Interconnect Consortium Members

Diamond
- Cisco
- Intel
- MediaTek
- Samsung

Platinum
- ADT
- Atmel
- HP
- Dell
- Eyeball Networks

Gold
- Acer
- ActnerLAB
- Allion
- AEPONa
- cryptosoft
- laplink
- Exu
- ENEA
- GCR
- gluu
- Infocus
- JIOT
- laplink
- OSS
- Nokia
- McAfee
- NewAer
- nitergo
- Silego
- SDC 2014
- McAfee
- NewAer
- nitergo
- Silego
- SDC 2014
- McAfee
- NewAer
- nitergo
- Silego
- SDC 2014
- McAfee
- NewAer
- nitergo
- Silego
- SDC 2014

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www.samsungdevcon.com
What language/protocol?

HyperCat (UK centric)
Allseen Alliance

Qualcomm - Allseen Alliance: +60 Members

Summer '14

What language/protocol?
Industrial Internet Consortium

What language/protocol?
What language/protocol?

The Big List

Handbook: Internet of Things Alliances and Consortia

Technology Architecture Focused

Link / Comms

IEEE, ZigBee Alliance, Wi-Fi Alliance, Bluetooth Special Interest Group, Wi-SUN Alliance

Core / Session / Transport / Messaging / Semantic

IETF, ISO, IEC, ISA, OGC, W3C, OASIS, OMG, UPnP, OMA, HYPER/CAT

Multilayer

Vertical Focused

Connected Body, Connected Home, Connected City / Buildings, Transportation, Industrial IoT

Protocol

HealthKit, ZigBee Alliance, HomePlug, enOcean Alliance, HomeKit

Industry

Wireless Life Sciences Alliance, Thread Group, Continua, Open Automotive Alliance, Industrial Internet Consortium

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IoT Companies

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,
  - 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
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…. 
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

Carriers Warn of Crisis in Mobile Spectrum

Why the government needs to free up more spectrum for wireless companies
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 on the Horizon?

Spectrum Need Fuels Tension Between Wireless Industry, FCC

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

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<tbody>
<tr>
<td>Data</td>
<td>174,942</td>
<td>329,841</td>
<td>549,559</td>
<td>864,122</td>
<td>1,349,825</td>
<td>2,165,174</td>
<td>65%</td>
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<tr>
<td>File sharing</td>
<td>76,764</td>
<td>114,503</td>
<td>154,601</td>
<td>204,617</td>
<td>261,235</td>
<td>361,559</td>
<td>36%</td>
</tr>
<tr>
<td>Video</td>
<td>307,869</td>
<td>736,792</td>
<td>1,545,713</td>
<td>2,917,659</td>
<td>4,882,198</td>
<td>7,615,443</td>
<td>90%</td>
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<tr>
<td>VoIP</td>
<td>7,724</td>
<td>10,327</td>
<td>12,491</td>
<td>15,485</td>
<td>22,976</td>
<td>35,792</td>
<td>36%</td>
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<td>Gaming</td>
<td>6,957</td>
<td>13,831</td>
<td>24,388</td>
<td>40,644</td>
<td>77,568</td>
<td>118,330</td>
<td>76%</td>
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<tr>
<td>M2M</td>
<td>23,009</td>
<td>47,144</td>
<td>92,150</td>
<td>172,719</td>
<td>302,279</td>
<td>508,022</td>
<td>86%</td>
</tr>
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<tbody>
<tr>
<td>Nonsmartphones</td>
<td>22,686</td>
<td>55,813</td>
<td>108,750</td>
<td>196,262</td>
<td>357,797</td>
<td>615,879</td>
<td>94%</td>
</tr>
<tr>
<td>Smartphones</td>
<td>104,759</td>
<td>364,550</td>
<td>933,373</td>
<td>1,915,173</td>
<td>3,257,030</td>
<td>5,221,497</td>
<td>119%</td>
</tr>
<tr>
<td>Laptops and netbooks</td>
<td>373,831</td>
<td>612,217</td>
<td>917,486</td>
<td>1,340,062</td>
<td>1,963,950</td>
<td>2,617,770</td>
<td>48%</td>
</tr>
<tr>
<td>Tablets</td>
<td>17,393</td>
<td>63,181</td>
<td>141,153</td>
<td>300,519</td>
<td>554,326</td>
<td>1,083,895</td>
<td>129%</td>
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<tr>
<td>Home gateways</td>
<td>55,064</td>
<td>108,073</td>
<td>180,562</td>
<td>267,545</td>
<td>376,494</td>
<td>514,777</td>
<td>56%</td>
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<tr>
<td>M2M</td>
<td>23,009</td>
<td>47,144</td>
<td>92,150</td>
<td>172,719</td>
<td>302,279</td>
<td>508,022</td>
<td>86%</td>
</tr>
<tr>
<td>Other portable devices</td>
<td>525</td>
<td>1,460</td>
<td>5,429</td>
<td>22,966</td>
<td>84,204</td>
<td>242,681</td>
<td>241%</td>
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<tbody>
<tr>
<td>North America</td>
<td>118,972</td>
<td>259,283</td>
<td>493,323</td>
<td>844,416</td>
<td>1,304,870</td>
<td>1,964,477</td>
<td>75%</td>
</tr>
<tr>
<td>Western Europe</td>
<td>180,370</td>
<td>365,722</td>
<td>683,843</td>
<td>1,160,571</td>
<td>1,704,598</td>
<td>2,437,922</td>
<td>68%</td>
</tr>
<tr>
<td>Asia Pacific</td>
<td>205,624</td>
<td>437,601</td>
<td>831,616</td>
<td>1,502,748</td>
<td>2,614,055</td>
<td>4,322,879</td>
<td>84%</td>
</tr>
<tr>
<td>Latin America</td>
<td>40,171</td>
<td>77,242</td>
<td>145,794</td>
<td>267,327</td>
<td>455,463</td>
<td>737,808</td>
<td>79%</td>
</tr>
<tr>
<td>Central and Eastern Europe</td>
<td>34,317</td>
<td>67,722</td>
<td>133,716</td>
<td>252,930</td>
<td>439,143</td>
<td>706,469</td>
<td>83%</td>
</tr>
<tr>
<td>Middle East and Africa</td>
<td>17,810</td>
<td>44,868</td>
<td>90,610</td>
<td>187,254</td>
<td>377,953</td>
<td>634,765</td>
<td>104%</td>
</tr>
</tbody>
</table>

| Total (TB per Month)                  | 597,266| 1,252,438| 2,378,903| 4,215,246| 6,896,080| 10,804,321| 78%            |

Source: Cisco, 2012

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

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.
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.
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
Current Spectral Situation:
Trending Shows That Despite Increasing Efficiency, Energy/User in Network is Rising

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

[Graphs showing power per user (W) over years for different categories: Fixed Access, WDM, Mobile, Routing & Sw.}

[Graphs showing power per user (W) over years for BAU and Optimistic Improvements.]
Greentouch…

Traffic is growing

While Innovation is slowing

Total Backbone

Internet Video

Wireless Data

Wireless Voice

Traffic (Tb/s)

Year

Traffic (Tb/s)

2010 2015 2020

2.5 dB/year

(78%/year)

0.5 dB/year

(12%/year)

Fiber Transmission Research Records

System capacity (Tb/s)


Single channel

Multiple channels

1

0.1

0.01

0.01

WDM channels

P2P

Wireless Data

Wireless Voice

10^1

10^2

10^3

10^-1

10^-2
Subcommittee on Networking and Information Technology Research & Development (NITRD)

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

June 2011
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<th>Department of Defense</th>
<th>Department of Energy</th>
<th>Department of Homeland Security</th>
<th>Department of Justice</th>
<th>Federal Aviation Administration</th>
<th>Federal Communications Com.</th>
<th>National Aeronautics and Space Administration</th>
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An assessment of national resources was conducted by NITRD

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<td>Agency</td>
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<td>U. S. Naval Research Laboratory</td>
<td>Coit2/UCSD</td>
<td>NSF</td>
<td>Department of Commerce of the National Institute of Standards and Technology (NIST)</td>
<td>Department of Energy</td>
<td>Idaho Falls, ID 83415</td>
<td>Fort Huachuca, AZ; White Sands Missile Range, NM; Yuma Proving Ground, AZ; Aberdeen Proving Ground, MD; Redstone Arsenal, AL</td>
<td>US Army Research Facility; Stockbridge Research Facility; Vlone Research Site</td>
<td>Approximately 48 university and industry sites across the continental U.S. and Alaska</td>
<td>Virginia Tech</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Washington, DC</td>
<td>Washington, DC</td>
<td>La Jolla, CA</td>
<td>Boulder, CO</td>
<td>Oaki Ridge, Tennessee</td>
<td>Fort Huachuca, AZ; White Sands Missile Range, NM; Yuma Proving Ground, AZ; Aberdeen Proving Ground, MD; Redstone Arsenal, AL</td>
<td>US Army Research Facility; Stockbridge Research Facility; Vlone Research Site</td>
<td>Approximately 48 university and industry sites across the continental U.S. and Alaska</td>
<td>Virginia Tech</td>
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<tr>
<td>Name of facility</td>
<td>NREL Cognitive Radio Test Laboratory</td>
<td>NREL Tactical Edge Network Testbed</td>
<td>Coit2 Wireless System Lab</td>
<td>ORBIT</td>
<td>institute for Telecommunication Sciences</td>
<td>ORNL Communications Test Bed</td>
<td>INL Wireless Test bed</td>
<td>US Army Test Ranges including Electronic Proving Ground, White Sands Missile Range, Aberdeen Test Center, Yuma Test Center, and Redstone Test Center</td>
<td>US Army Research Facility; Stockbridge Research Facility; Vlone Research Site</td>
<td>Approximately 48 university and industry sites across the continental U.S. and Alaska</td>
<td>Virginia Tech</td>
<td></td>
</tr>
<tr>
<td>Operator of facility</td>
<td>U. S. Naval Research Laboratory</td>
<td>U. S. Naval Research Laboratory</td>
<td>Coit2</td>
<td>WINLAB, Rutgers University</td>
<td>National Telecommunication and Information Administration and NIST</td>
<td>UT-Battelle, LLC</td>
<td>Battelle Energy Alliance (BEA)</td>
<td>US Army Developmental Test Command (BDC), which reports to the United States Army Test and Evaluation Command (ATTC)</td>
<td>US Army Communications-Electronics Research, Development and Engineering Center (ERDEC)</td>
<td>Raytheon BBN Technologies/GENI Project Office</td>
<td>Virginia Tech</td>
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<tr>
<td>Available to industry</td>
<td>Yes, with cooperative research agreements</td>
<td>Yes, with cooperative research agreements</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, via Cooperative Research and Development Agreement (CRADA) under the Technology Transfer Act of 1986</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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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

Normalized % of Types of Internet Traffic vs. Time

A. Gothard, “Managing Femtocells and the Evolved Packet Core”

Global Mobile Data Traffic

A. Gothard, “Managing Femtocells and the Evolved Packet Core”

http://www.chetansharma.com/usmarketupdateq12010.htm
A New Paradigm is Required for Granting Spectrum Access and Use Rights

Increasing delays in making harmonized spectrum available for mobile broadband

<table>
<thead>
<tr>
<th>Spectrum band</th>
<th>6 years</th>
<th>8 years</th>
<th>10 years</th>
<th>more</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 MHz</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2.1 GHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2.5/2.6 GHz</td>
<td></td>
<td></td>
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<tr>
<td>2.3 GHz</td>
<td></td>
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</table>

* 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
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

3550-3650 MHz NTIA Exclusion Zones*

- **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**

*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

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

http://spectrum.ieee.org/telecom/wireless/peaceful-coexistence-on-the-radio-spectrum
A Presentation in Three Movements

On to the Finale
Software Defined <fill-in-the-blank>

Projects Using this Software Defined Repeater

- 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
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
Peak and instantaneous power displaced.
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
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

- Dynamic Spectrum Sharing
- Adaptive Rate & Power Control
- Cognitive Networks
- Cognition and Learning
- MIMO Systems
- Software Radio and Adaptive Hardware
- Security
- Sensing
- Signal Classification
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
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
- The Radio RF Front End
- Standardization
- Policy Enforcement
- Metrics and Algorithms
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

- Incompetent Hacking
  Examples as seen in 5GHz

- Deliberate Malicious Nodes
  Spoofing, Jamming, etc.

- Faulty Equipment
  Malfunctioning power control

- Poor Enforcement System Design
  Inherent, tough to obviate flaws due to diversity of secondary users

NON CONFORMANCE
Causes harmful interference
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

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Where’s the money coming from
...FCC Auction

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...)

Recent Releases

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.
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

Wireless Model City: Applications, Goals

- Resilient, secure communications for utilities and industry
- Advanced technology for aging municipalities' infrastructure
- Data services for the municipalities' underserved
- Research, development and deployment of a resilient communications infrastructure
- Multi-level economic development and job creation
- Avant garde public safety and security communication infrastructure
- Enhanced, energy efficient municipality operation
- Intelligent environmental sensing
- DOE = Dept of Energy
- DOC = Dept of Commerce
- DOJ = Dept of Justice
- DOE/OE
- DOC
- DOC ED
- DOE/EEERE
- NOAA
- EPA
- NSF
- NASA
- Core: Spectrum Sharing
  - Spectrum Access Sharing
  - SA Database
  - Spectrum Arbitrage
  - DHS = Dept of Homeland Security
  - NSF = National Science Foundation
  - DOD = Dept of Defense

DOE/OE
DOC
DOE/EEERE
NOAA
EPA
NSF
NASA
DHS
DOJ
ED
NTIA/FCC
Orchestrated databases for coexistence management

See article in IEEE Spectrum, 20MAR13

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...
A Presentation in Three Movements
A Report that (IMHO) you should examine...

INTERNET TRENDS 2015 – CODE CONFERENCE

Mary Meeker
May 27, 2015

kpcb.com/InternetTrends
This sums it up… (play the video)

Drones need spectrum too…
For more information…fuhrpl@ornl.gov