Communicating in White Space:

Lessons Learned in the Regulatory Wars

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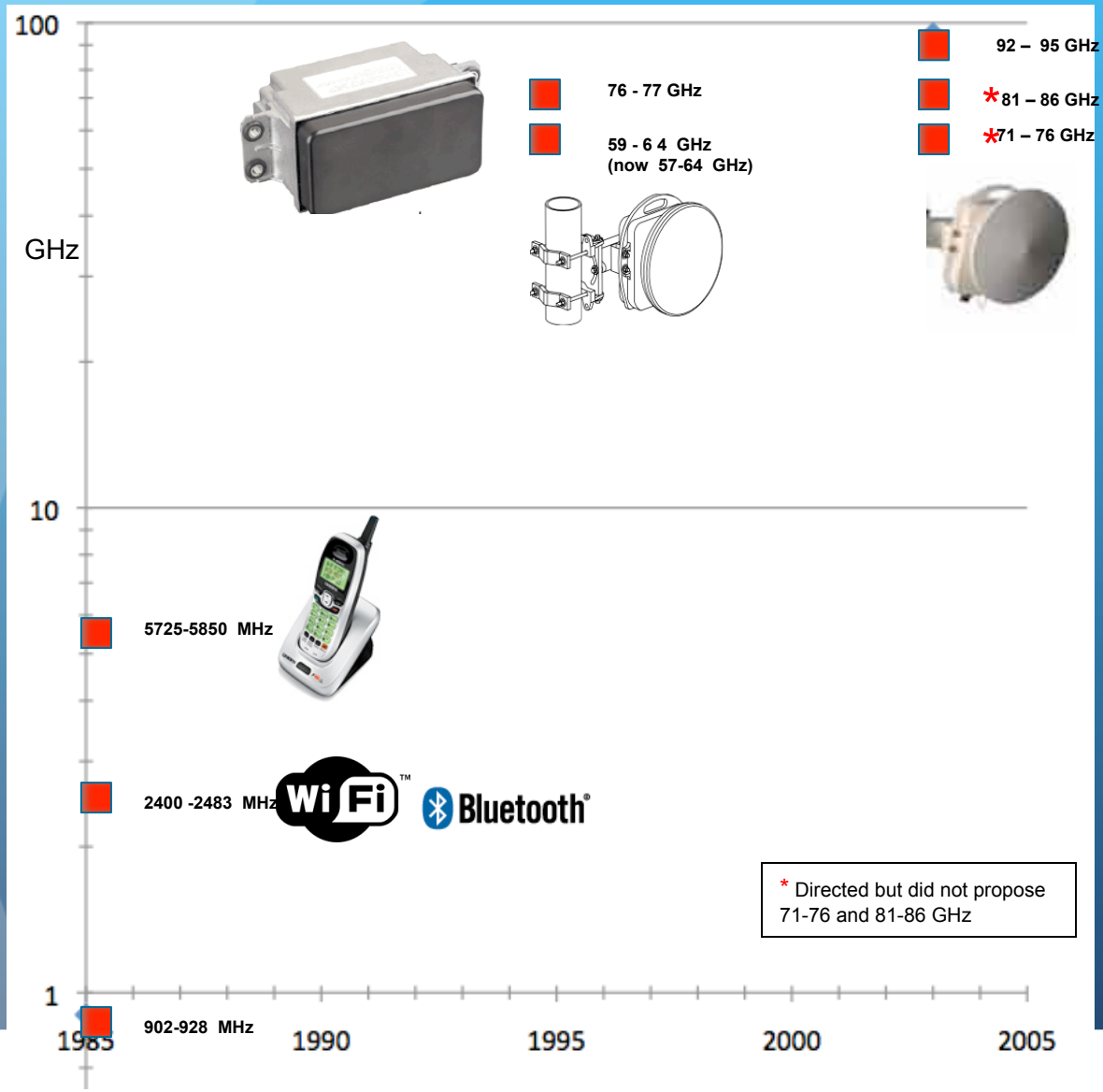
My Career @ FCC

Spectrum Openings I Proposed* & Directed



Macroeconomics of Telecom

- Telecom is a large industry in its own right ~ 10^{11} US$
- Telecom is a basic commodity in today's economies

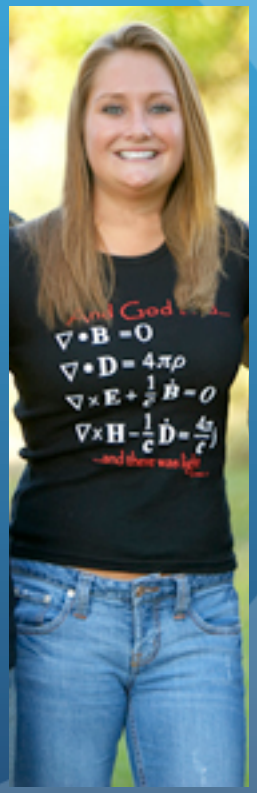
ICT also contributes macro-economically to productivity growth and increased competitiveness of the European economy as a whole, and thus is a factor in growth and job creation. -- COM(2006) 334

- New telecom services can <u>both</u> enable whole new nontelecom industries and improve efficiency of existing ones
  - Example 15/10/06 *Washington Post* article describes economic impact of cell phones on fisherman and farmers in rural India as a result of better access to market pricing. http://letters.washingtonpost.com/W9RH02534803A09CEF27F33AE5DD00

Wireless is Different!

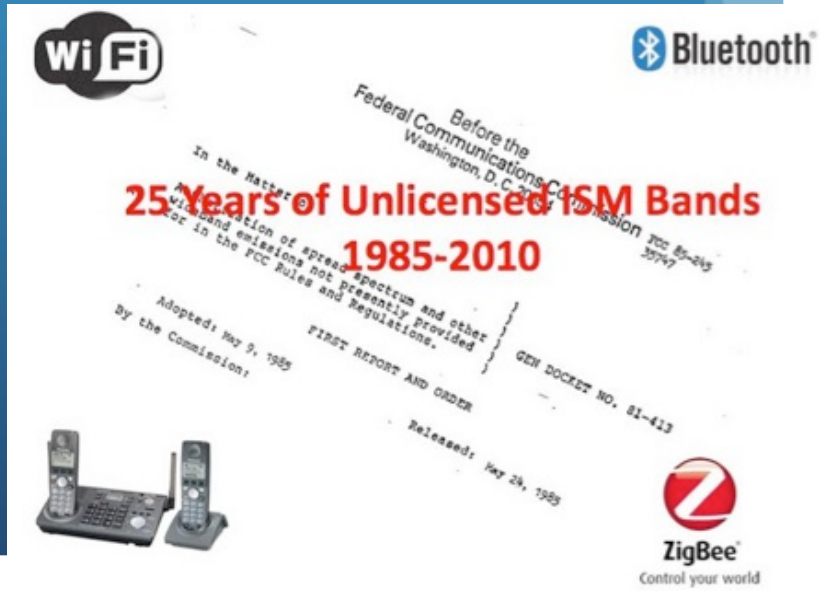
- Around the world - for better or for worse - wireless is more regulated than most other technologies

In wireless, regulations are just as *real* as Maxwell's equations!



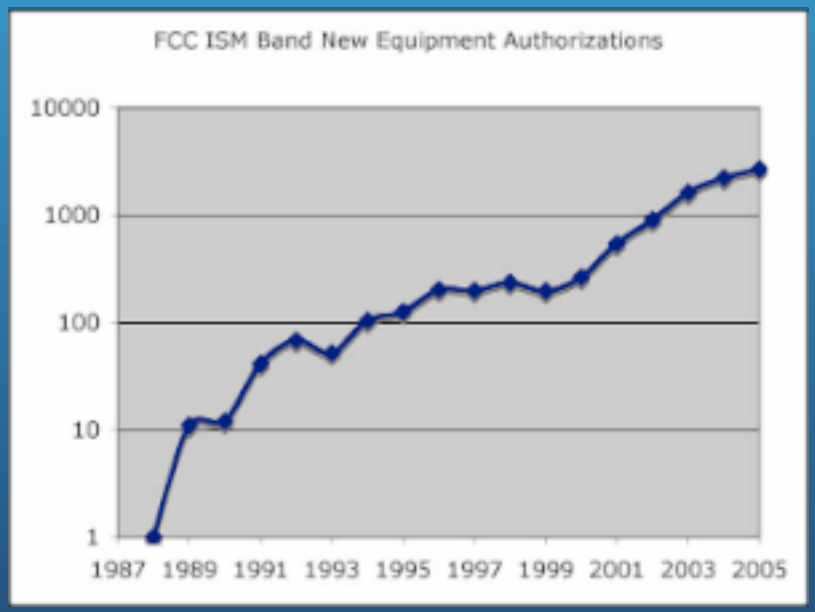
CTW 1983 & Wi-Fi/Bluetooth

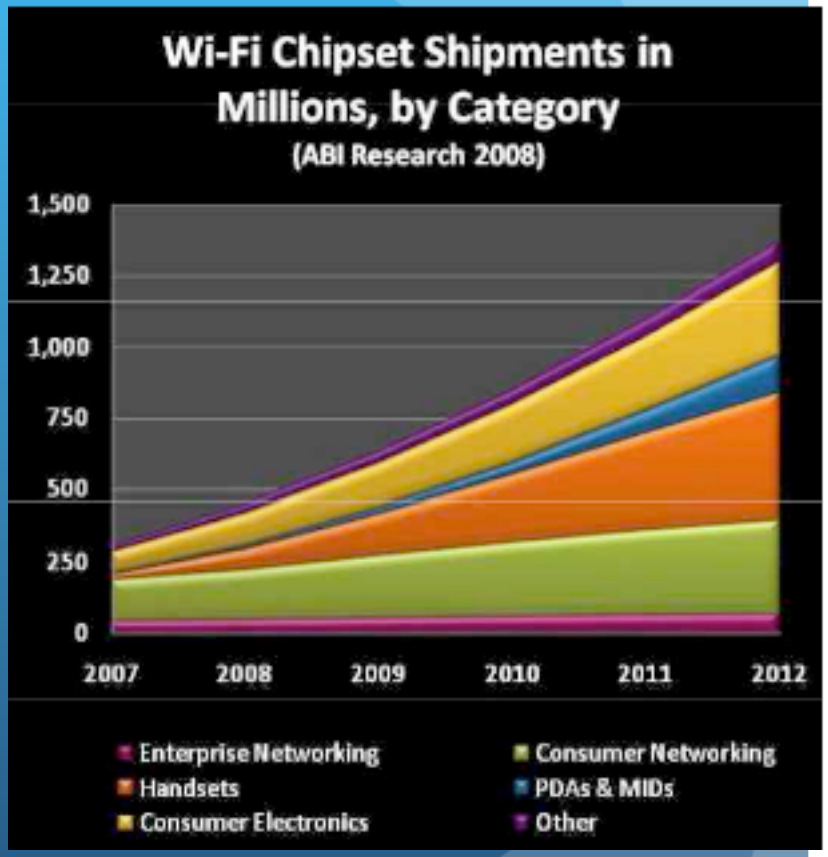
- In a parallel session at 1983 CTW, commercial uses of spread spectrum was discussed
- Your speaker challenged audience to get involved in policy deliberations to get technology from pages of IEEE journals into marketplace
  - Ray Pickholtz, Don Schilling, & Larry Millstein drafted IEEE comments
- Resulting input was useful in FCC deliberations that resulted in Wi-Fi & Bluetooth foundations



CTW 1983 & Wi-Fi/Bluetooth

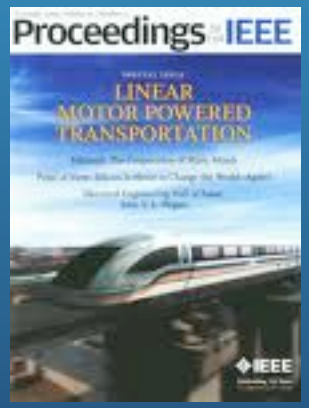
From the Arizona dude ranch CTW, Wi-Fi and Bluetooth have truly changed our world!





Today …

- Helping to move technology from IEEE journal pages to the marketplace continues to be challenging & fun
  - Also vital for the economy
  - Often financially profitable



Why whitespace? The honne and tatemae of spectrum

- While most spectrum is allocated and assigned …

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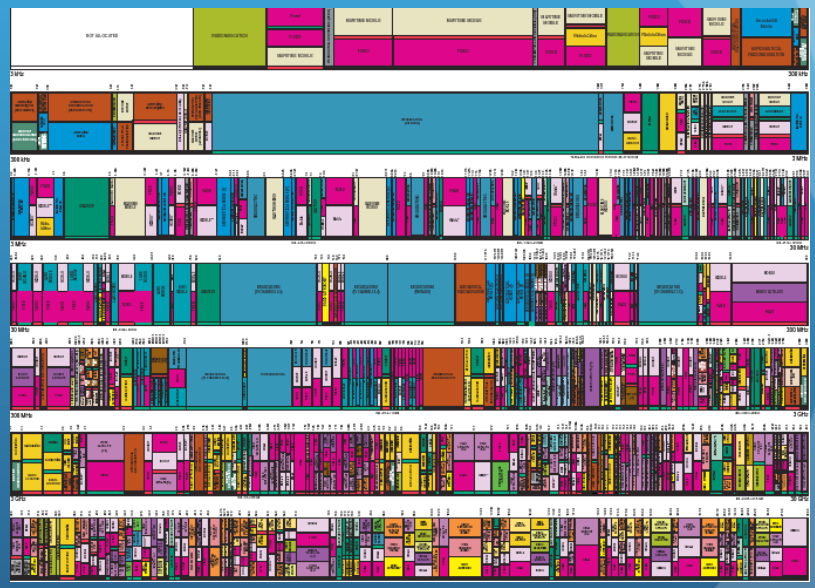
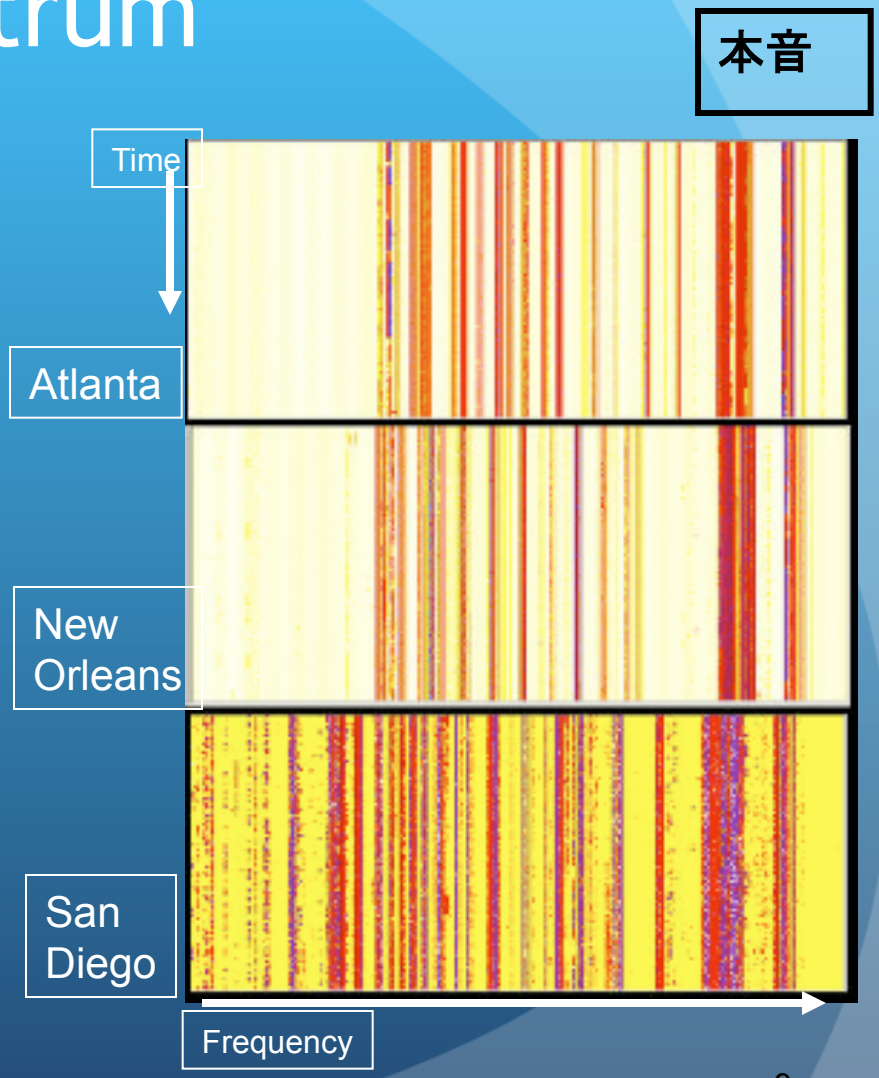
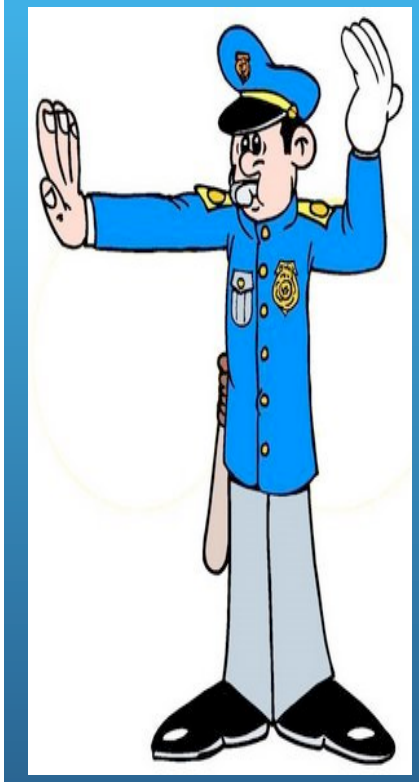


The honne and tatemae of spectrum

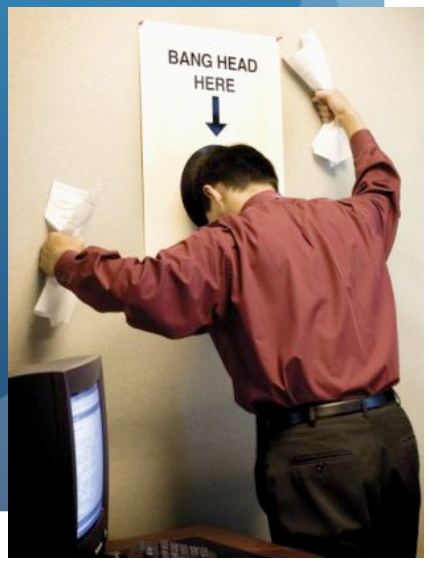
- In practice, at a given time and place there is lots of unused spectrum
- Results from:
  - Uneven population density
  - Uneven terrain
  - Allocations and assignments based on peak needs



CR & Regulation



- CR is a promising technique to improve the efficiency of wireless spectrum use
- But the reality of wireless technology is that it is subject to a level of regulation not seen in other fields by national spectrum regulators/ "administrations" (ITU jargon)
- How have CR proposals fared before such administrations?
  - Not well
- What can we learn from that?



CR & Regulation

- 2 case studies
  - 5 GHz DFS (ITU)
  - TV whitespace (FCC)

- Alternative paths to CR benefits that might fare better with administrations to pave the way for broader CR use

5 GHz DFS

(U-NII in US jargon)

- WRC-03 approved DFS as a cognitive radio access mechanism for the bands 5250-5350 MHz and 5470-5725 MHz
  - Band is shared with a variety of radar systems for air traffic control, military use, and other applications
  - RLAN use is unlicensed and secondary to radars
- Use subject to terms of ITU-R Recommendation M.1652:
  - "The DFS mechanism should be able to detect interference signals above a minimum DFS detection threshold of –62 dBm for devices with a maximum e.i.r.p. of < 200 mW …averaged over 1 μs.
  - "A channel that has been flagged as containing a radar signal, either by a channel availability check or in-service monitoring, is subject to a 30 min period (non-occupancy period) where it cannot be used by the WAS device in order to protect scanning radars. The non-occupancy period should start at the time when the radar signal is detected.

5 GHz DFS

- So,

  1 μs detection of a power > –62 dBm results in inability to use a channel for the next 30 minutes ***and***

- This is implemented in an ITU Radio Regulation provision which has treaty status!
  - The result of hard negotiations between proponents seeking new spectrum access and incumbents who had the upper hand in administrations
    - Conference date added time pressure
  - Ignores classic detection theory relationship between FAR and Pr {d}

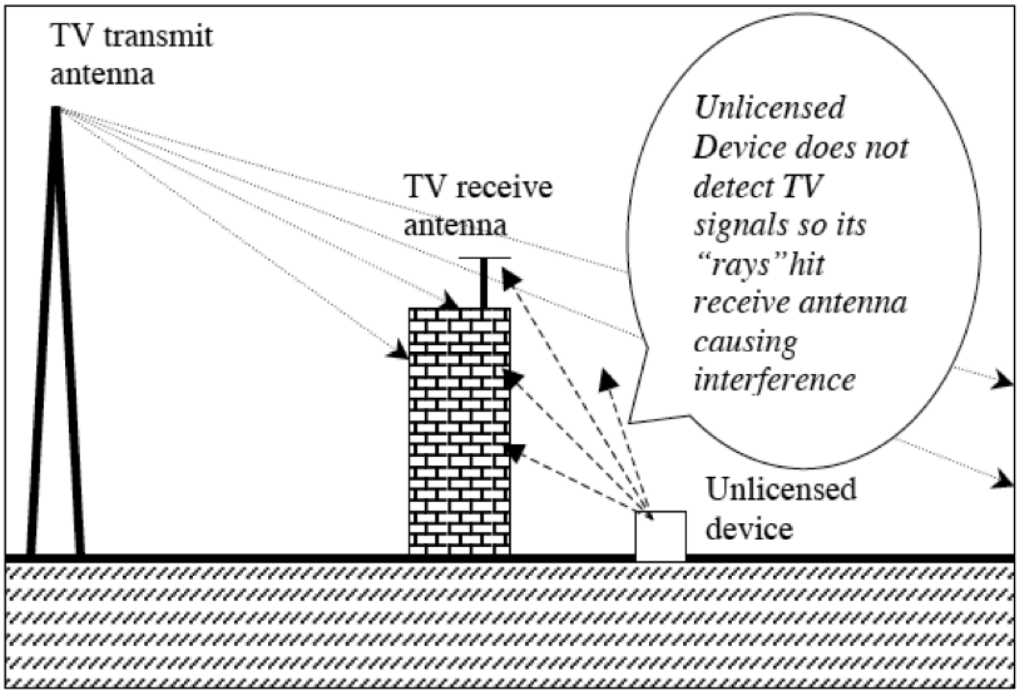
- Fortunately "liberal" interpretations of testing needs has permitted practical use of this band

FCC TV Whitespace Rules

- On November 4, 2008 FCC adopted cognitive radio rules for "TV Band Devices"
  - Rules were adopted after 4 years of contentious deliberations and testing
  - Permit unlicensed use of vacant TV channels in a given area based on equipment that both:
    - Uses LBT algorithm to detect presence of signals ***and***
    - Uses geolocation to verify it is not within theoretical TV coverage area
  - Described by FCC leaders as "belt and suspenders" approach
  - Further complicated by sensing requirement for wireless microphones that requires below ambient noise detection of wideband FM

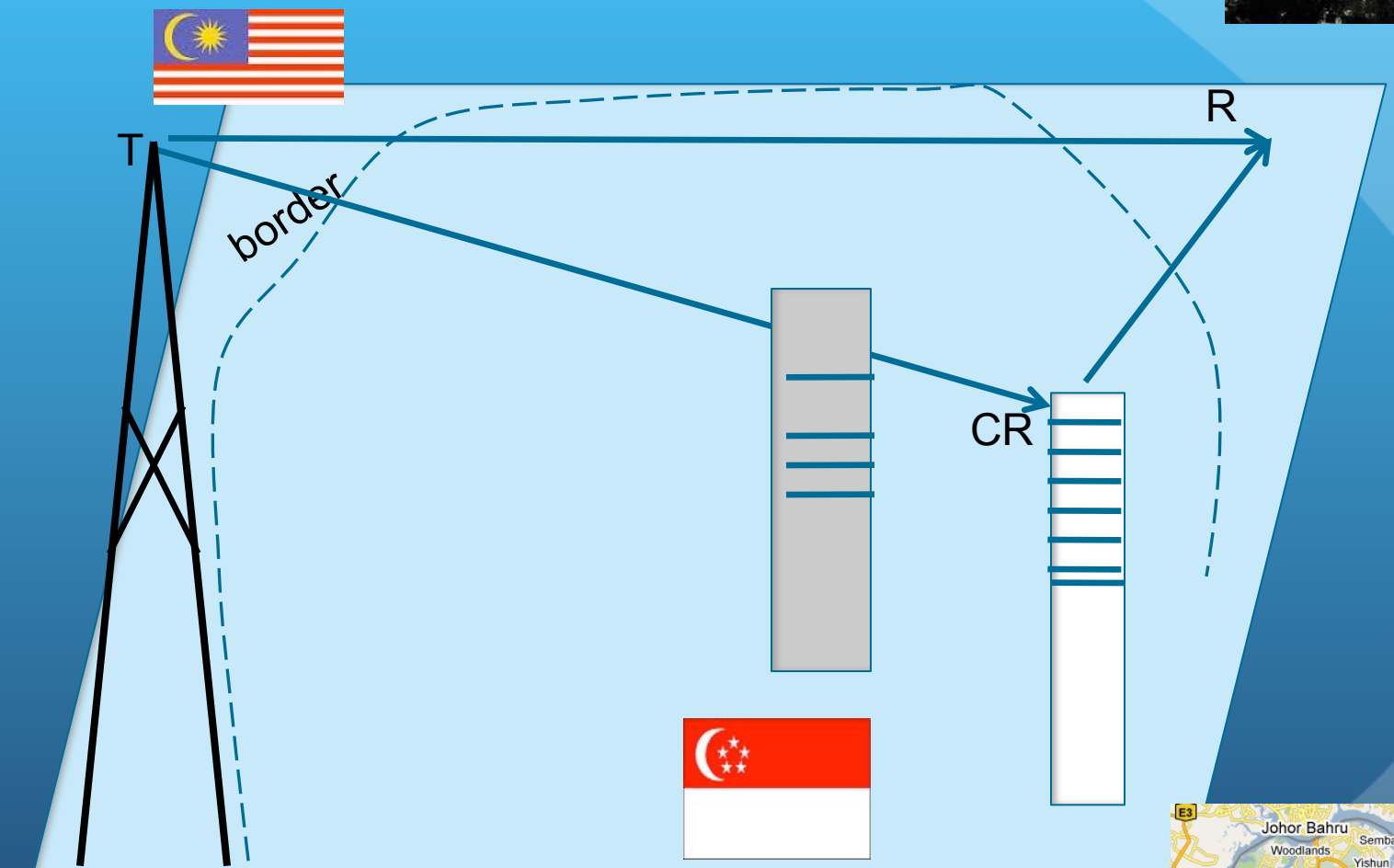
Controversy

- Focused on the LBT case and “hidden node problem”

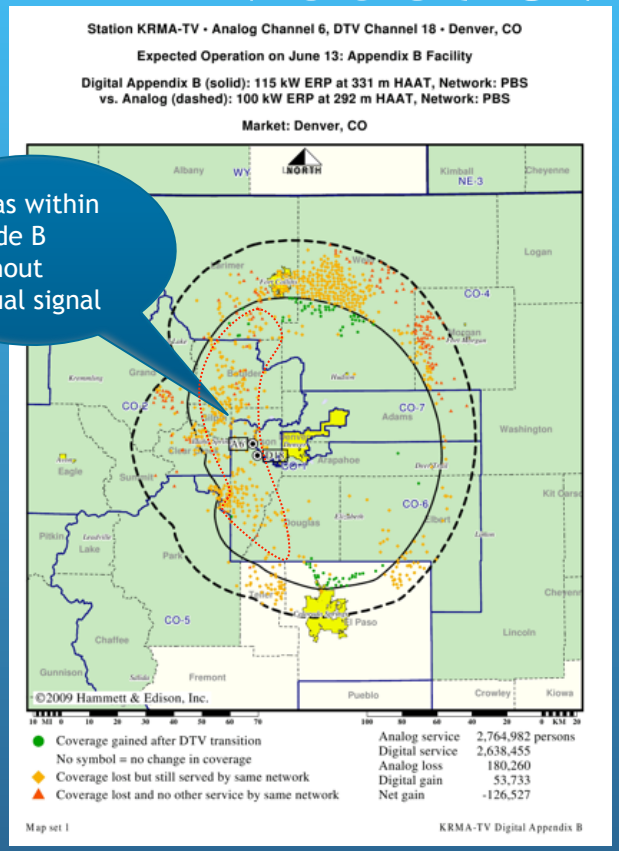


Singapore Variant

Most housing is high rises

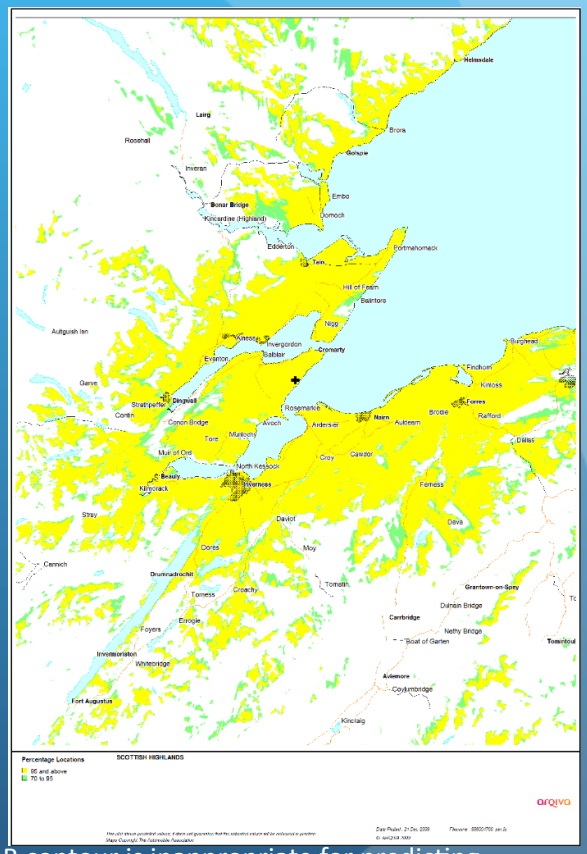


FCC Use of Unrealistic Propagation Model Overly Restricts TVBDs



http://www.fcc.gov/mb/engineering/maps/images/callsigns/KRMA.gif

Ofcom/Arqiva coverage prediction for white space



"the Commission's traditional predictive methodology for determining a Grade B contour is inappropriate for predicting signal strength at individual locations…The traditional methodology does not accurately reflect all the topographic differences in a station's transmission area, and explicitly does not account for interference from other signals. These omissions make it an imperfect methodology for predicting whether an individual household can receive an adequate signal."
R&O, Docket 98-201 (February 2, 1999) at para. 67

How Many More "Victories" Like These Does CR Community Need?

- Worldwide, "administrations" often have "Stockholm syndrome" relationships with incumbent spectrum users
  - Regulators and incumbents have spent many stressful periods together at ITU meetings
  - Government spectrum users generally have "inside track" status with administrations
- "Monetization" of spectrum though spectrum auctions has made incumbents very protective
- Incumbents are a "tough audience" for CR proposals

Research topic suggestion

LBT CR Risks

- Listen-before-talk "LBT" CR systems pose novel hidden node problem issues which are not answered by standard radio propagation models
  - Answer depends **critically** on cross correlations of path losses

  - Not addressed in standard models
- Better understanding of CR capability depends on realistic test beds and propagation measurements that focus on crosscorrelations in local areas

Need for Objective Definitive Testing

e.g. Ft. A. P. Hill DARPA XG Test (8/06)

http://www.sharedspectrum.com/press/pdf/2007-02_SSC_Description_Demonstrations_Ft_AP_Hill.pdf

- Test of multiple mobile CR units in an area with conventional radios and simulated traffic on multiple frequencies (and a few jammers too!)
- Measured **both** CR throughput **and** impact on conventional systems

Figure 8. AN/PSC-5 instrumented with BER test equipment.

Need for Objective Definitive Testing

Research topic suggestion

- An objective testbed would be very helpful to demonstrate ability of CR to share with incumbents on an acceptable basis
- While FCC and NTIA nominally have “testbeds”, they probably are illusionary
- NSF is beginning an enhanced program in CR
  - Hopefully a testbed will be integral part
  - How can existing testbeds at Rutgers and Va Tech be used to validate CR concepts?

FCC TV White Space Tests:

A Poor Precedent

http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-08-2243A3.pdf

- All testing was static
  - Most was on bench
  - Bench tests used recorded DTV signals
- Focused on detection threshold –something that will no doubt improve with time
- Never tested devices in fully automatic mode to check for interference

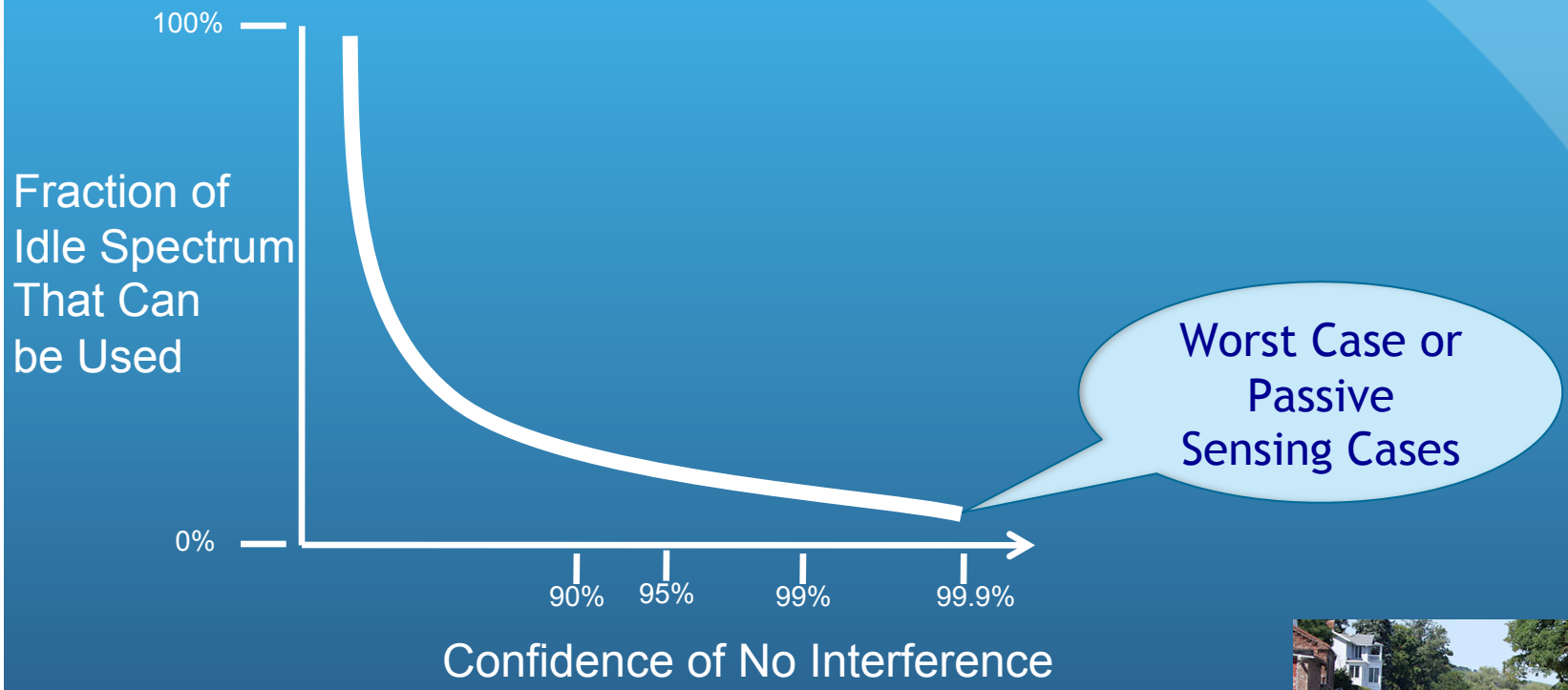
"… full of sound and fury,
Signifying nothing"

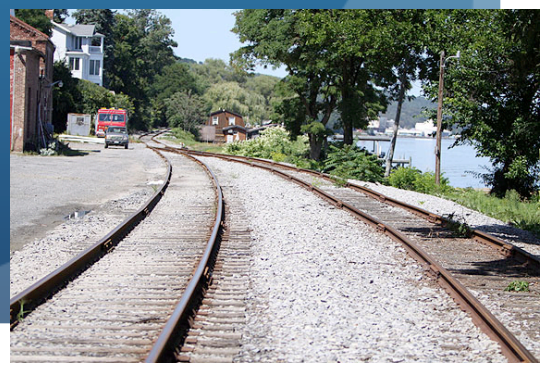
Let's Consider 2 Parallel Tracks to Improving Spectrum Use Through CR

- Basic concept of CR is using spectrum based on knowledge of nearby uses
- Concepts that had difficulties with incumbents and administrations have been ones that
  - Were based on purely passive sensing
  - Tried to share spectrum with incumbent systems that were not originally designed for sharing
  - Offered no benefit at all to incumbent - only the risk of problems
  - **LBT is a means to an end – not an end in itself**

Basic Hypothesis of This Presentation

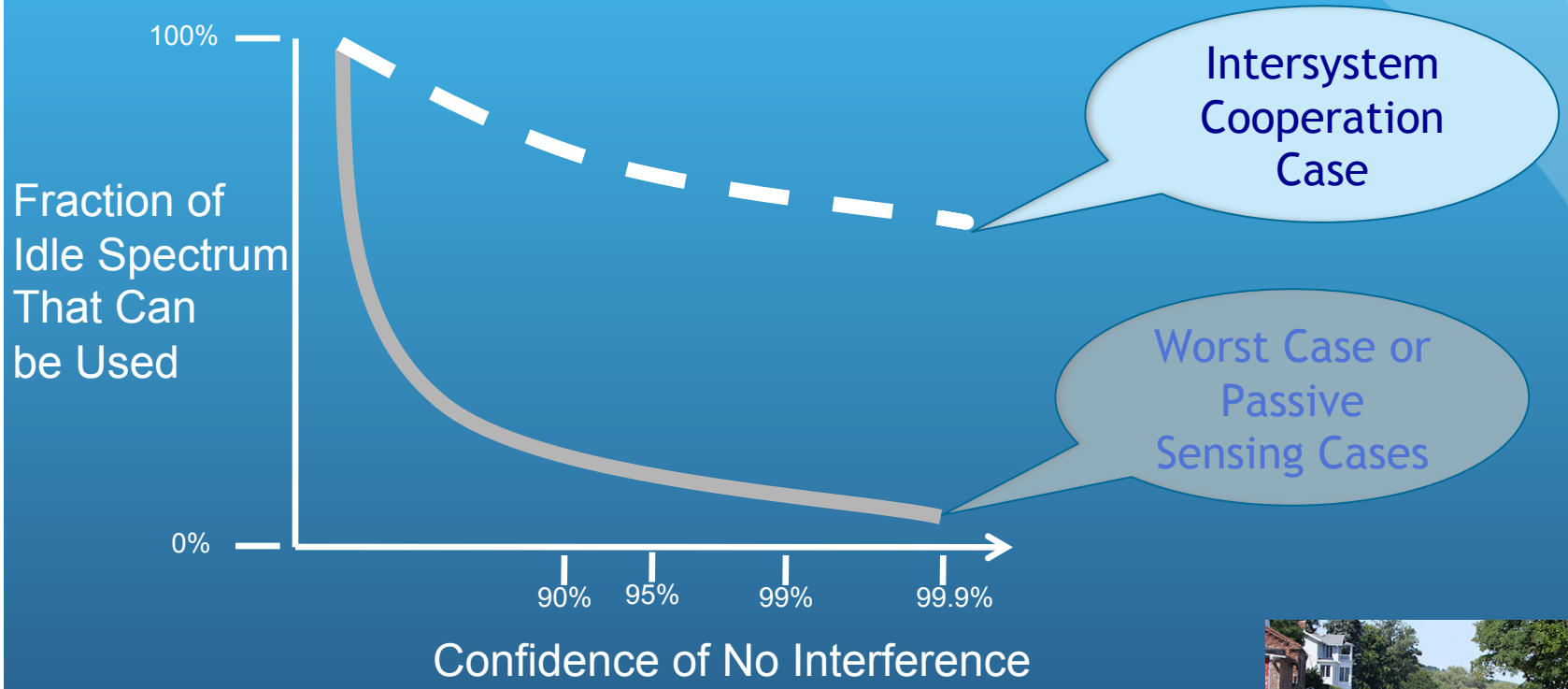
Research topic suggestion

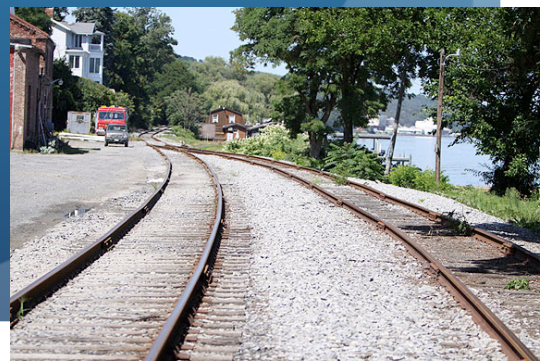




Basic Hypothesis of This Presentation

Research topic suggestion



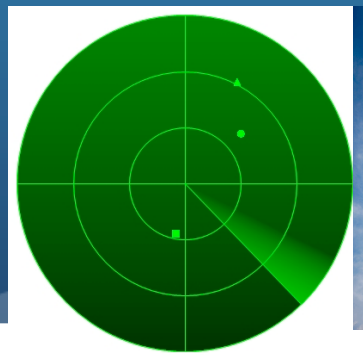


Trends That Facilitate Novel Sharing

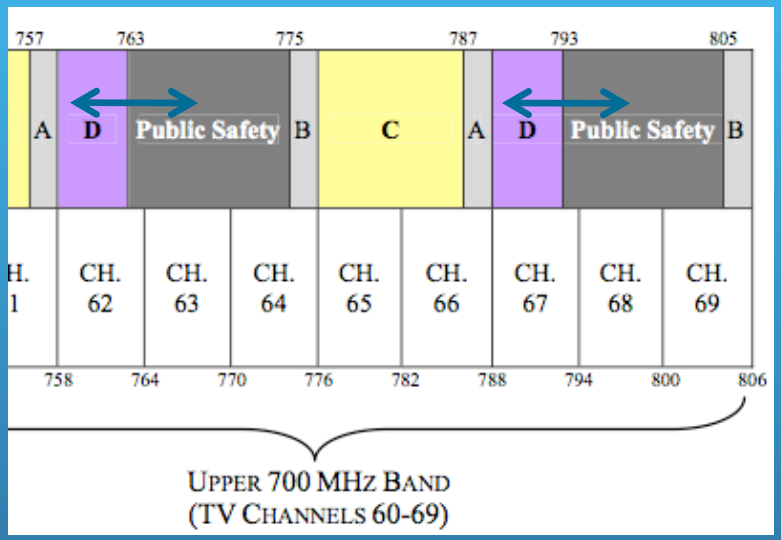
- Traditionally most nonbroadcast spectrum use was full duplex paired spectrum and such spectrum was the most valued
  - Hence cellular industry asked that 3G spectrum be symmetric paired spectrum in anticipation of services that *never came*
- Major carriers now buy service from Qualcomm's MediaFLO and seek unpaired AWS-3 spectrum to meet growing demands for asymmetric services
- Intermittent access to spectrum can be used to provide the packetized asymmetric services that are have growing demand
  - *e.g.* Sirius/XM uses packetized intermittent channel to provide an apparent continuous service

Two Areas for Real Time Coordinated Spectrum Sharing

- Land mobile channels
  - Spectrum normally sized for peak loads
  - Electric utilities try to manage peaks, wireless community doesn't
  - Clever designs can approximate "unrealizable systems"
- Radar systems – a major use of government spectrum
  - Radar use has unique space-time characteristics
  - At a given time, interference free low power use is possible in most azimuths for most systems



700 MHz D Block
An Innovative Sharing Example



FCC proposed that 700 MHz D block have dynamic sharing with adjacent public safety block

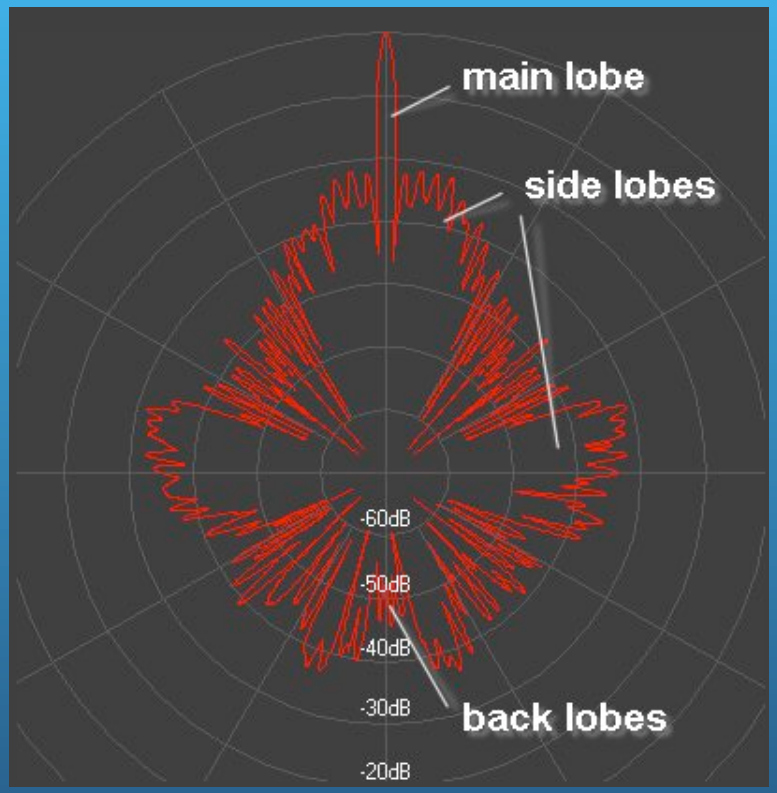
- Public safety can use D block at times of surging demand
- Commercial operator can use PS block when PS traffic is light

- Initial auction was unsuccessful due to naïve FCC rules that pandered excessively to PS

Radar Sharing with Cooperative Systems

- GPS technology provides time and frequency references in addition to position
- Except for some critical early warning systems, radars could use
  - Published locations
  - Published rotation phasing synched to GPS
  - Use better sidelobe/backlobe suppression than presently needed or used to facilitate sharing

Radar Sharing with Cooperative Systems



- Any cooperative sharing is limited by radar antenna patterns and inevitable sidelobes and backlobes.
- While these can not be eliminated for finite size antennas, then can be reduced to facilitate sharing *at a increase in cost*
  - Size of antenna will also generally increase

Radar Sharing with Cooperative Systems

- Spectrum sharers could
  - Geolocate and determine radars within interference potential range
  - Synch to rotation via GPS
  - Avoid transmitting during part of rotation that is interference prone
    - Weather radars with irregular rotations could cue sharing partners about azimuth of beam

LM Sharing with Cooperative Systems

- D block-like technology remains an option
  - Common system for PS and other users with preemption for PS
- Trunking systems with cooperative cuing to sharing systems
  - Passive sensing can *at best* determine what is happening now – although hidden node problem limits performance
  - Controllers of trunking base stations have perfect information about present *and limited information about the future*
    - Is traffic increasing or decreasing?
    - What channel will be used next if one is needed?
    - Such information can be used to implement a system that is "nonrealizable" if it is shared with sharing users

LM Sharing with Cooperative Systems

- D block-like option would require common technology for both systems
- Cuing option would allow divergent technologies
  - Avoid limitation of sensing LBT technology
  - Would allow significantly more intense use of idle spectrum for a given required confidence limit

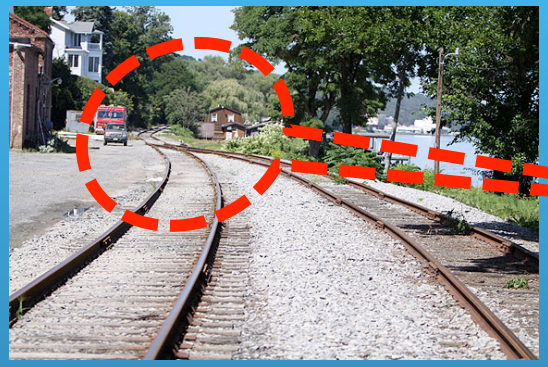
Financial Issues

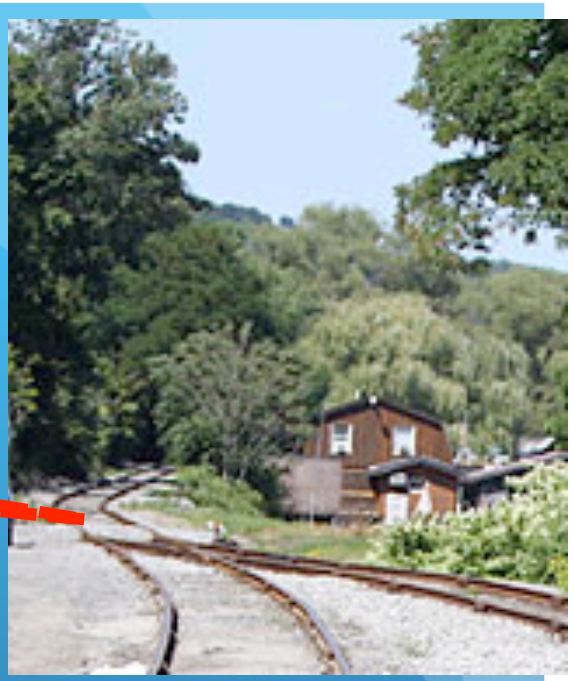
- In many countries, spectrum has been effectively monetized through the use of auctions
- Except in UK, national government spectrum users do not pay for spectrum and have no financial incentive to economize on usage
- Government users have legitimate concerns about marginal costs of sharing-friendly design features in typical budget environment
- New types of sharing may require legislation that assures that government users are compensated and need mechanisms that move the funds from new sharers to government users at the time needed for new system acquisition
  - Possibly a “spectrum bank” to help cash flow

Conclusions

- Cognitive radio applications where primary system design did not anticipate it **and** where primary user can dictate terms will always have limited access to idle spectrum
- Cooperative system designs can lead to much higher use of idle spectrum and provide reliability for primary users
- While in the past full duplex symmetric spectrum was most valued, in today's market asymmetric applications and packetized systems are key

The 2 Tracks Can Converge!





- Cooperative CR may complement passive sensing CR and increase its acceptance
- The end goals remains improving spectrum utilization by improved use based on actual conditions

Research Topics (Mostly) Unrelated to Cognitive Radio

1 – Relationship between CR processing gain, propagation uncertainty, & probability of interference

2 – Stealth bomber-like interdisciplinary design of cellular base stations antenna system to get new designs that are both functional and have less impact on neighborhood

Research Topics (Mostly) Unrelated to Cognitive Radio

3 – Filters

a – “Moore’s Law” for historic filter improvement

b – Impact of transmitter and receiver filters performance on spectrum efficiency

4 – Impact of cosecant squared (uniform pfd ground illumination) antenna design on spectrum efficiency

- Surf over to web site for more information
- Thanks for the opportunity

Questions?