Workshop on Research Recommendations for the Broadband Task Force

A Radio Perspective

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November 23, 2009

Wireless @ Virginia Tech

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Virginia Tech Invent the Future

I gratefully acknowledge contributions to this presentation by
- Scott Midkiff
- Thomas Rondeau
- Feng Ge
- Preston Marshall

The ideas I will present about spectrum efficiency and cross-layer optimization in wireless networks are Dr. Marshall's, and, with his permission, I have reproduced text and graphics from his dissertation: *A Generalized Method for Quantification of Cognitive Radio Benefits within Wireless Systems,* University of Dublin, Trinity College, Department of Electronic & Electrical Engineering.

2) What are the shortcomings of the current research funding process as it relates to broadband?
a. Is there anything that might be done to enhance the productivity or quality of research in the US?
b. Are there areas where additional research funding could have a substantial impact?
c. What are impediments to research, particularly groundbreaking research such as the research programs that led to the Internet?

Lack of Integration !

Exploit inherent capabilities of wireless networks: cognitive radio techniques in spectrum re-use, bandwidth control, routing.

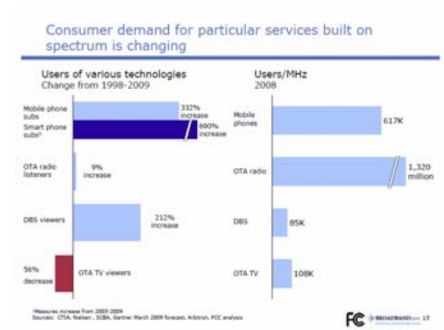
Lack of opportunities for large-scale experimentation

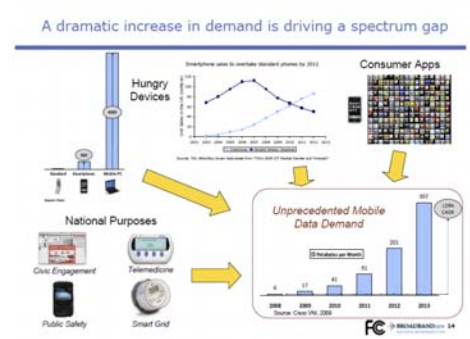
Integration!
Dynamic Spectrum Access -> Robust Wireless Networking -> Mobile Applications
Basic Research -> Large-scale Experimentation

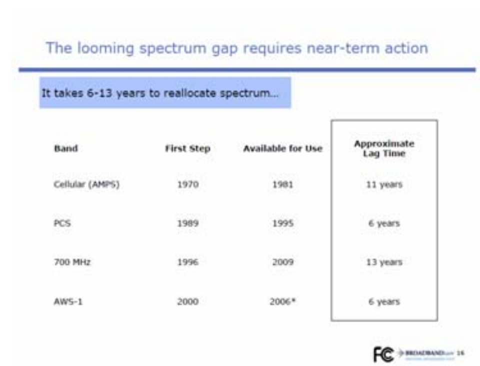
A near-term research recommendation: spectrum re-use

Lack of access to spectrum in a desirable frequency range is a key problem restricting potential new services and service providers and thus limiting competition.

- Demand for a changing mix of services
- Unprecedented mobile data demand
- Difficulty of reallocating spectrum






The looming spectrum gap requires near-term action

It takes 6-13 years to reallocate spectrum...

Band	First Step	Available for Use	Approximate Lag Time
Cellular (AMPS)	1970	1981	11 years
PCS	1989	1995	6 years
700 MHz	1996	2009	13 years
AWS-1	2000	2006*	6 years

FCC November 18, 2009, *Broadband Gaps* document (DOC-294708A1).

Solution lies in using the spectrum more efficiently. Dynamic Spectrum Access (DSA) draws a lot of academic interest, but

Finding and using "vacant" spectrum is impractical. It is like opening a business on a vacant lot without knowing who owns it.

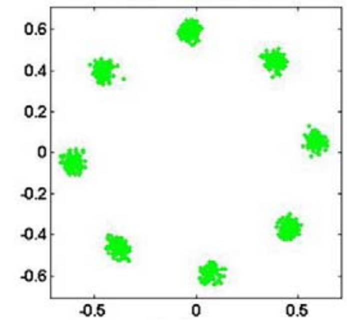
- Somebody owns it and paid real money for it.
- "Vacancy" is subjective and transient.

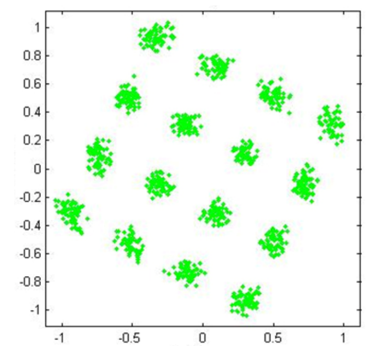
- Making more spectrum accessible equates to using the spectrum more efficiently – adopting technology and policies that make more spectrum **reusable**.
- Current white space approach is based on ***no interference*** to primary users. Understandable for TV band, but restrictive and difficult to implement in large scale deployment.
- A better approach would be based on **managed interference**, considering all occupants of the spectrum whose global use of the spectrum is optimized.

Traditional approach to spectrum efficiency and digital radio optimization: minimize spectrum used by individual radios by maximizing bits/Hz

BPSK->QPSK->64 QAM

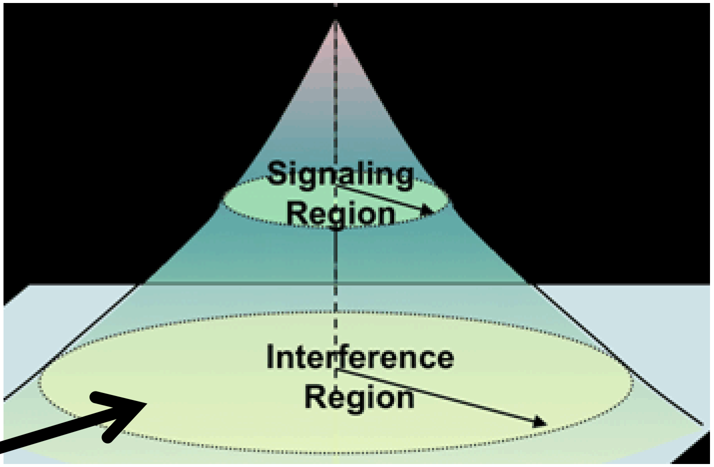
Consequences: Increasing bits/Hz increases required energy per bit at receiver (E_b/N_0) and the required transmitter power. It increases the area over which the signal propagates as a significant interference contributor.





Measure efficiency of spectrum use by normalizing it to the area over which the reuse of that portion of the spectrum by other devices is prohibited.

Moves up with
TX Power
Modulation Index
E_b/N_0



Spectrum re-use efficiency = (bits/Hz)/(area in which only one user can occupy the channel at a time)

Area value depends on path loss. Model as r^{Alpha}

Alpha = 2 line-of-sight; Alpha = 4 beyond line-of sight

Modulation index for most efficient spectral re-use efficiency depends on alpha. Taking advantage of it creates a lot more usable and re-usable spectrum.

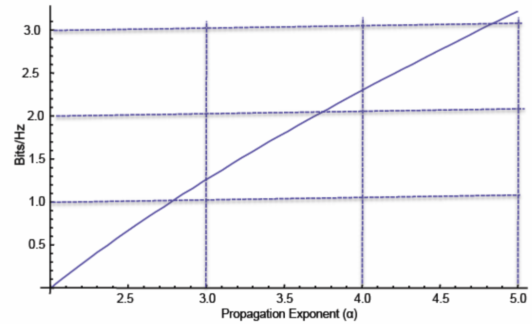
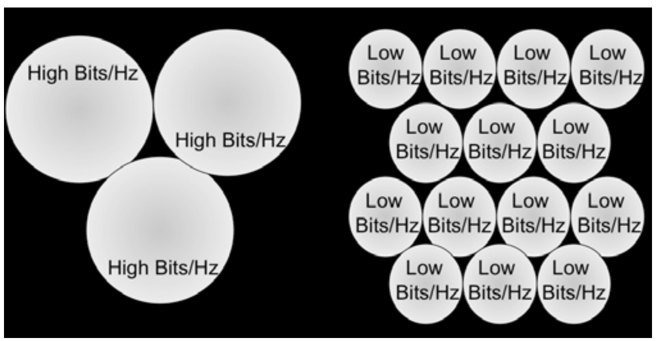


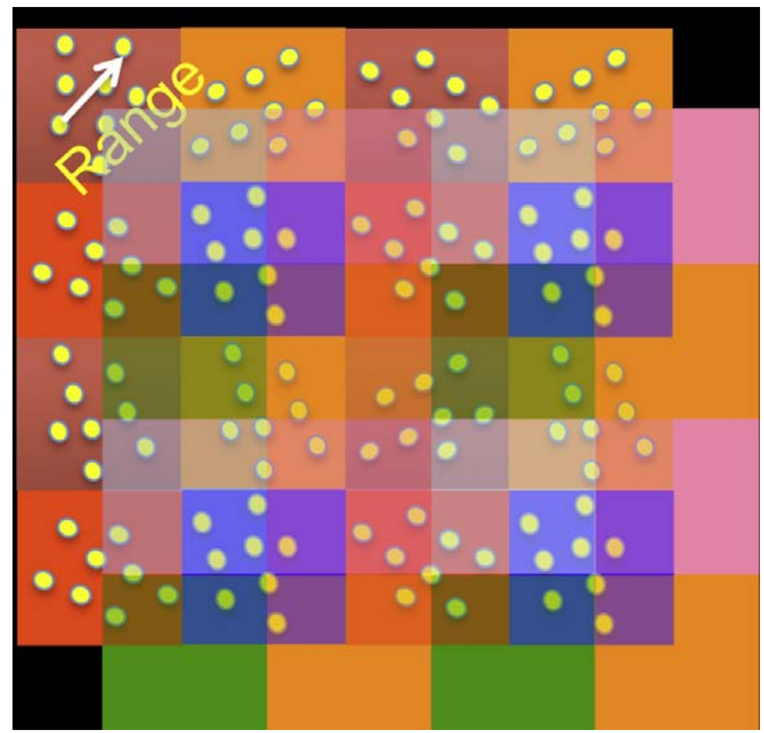
Figure 7-5 Optimal Values of Bits per Hertz for a Range of Propagation Values

Do this

Not this



8 frequencies used for 32 independent subnetworks



Long-term research recommendation - Exploit the inherent advantages of wireless networks. Don't limit wireless networks to what wired networks can do. **Allow cross-layer interaction and wireless networks can:**

- determine the routing that is needed, and use DSA to create a topology to implement it. Implement demand responsive topologies based on traffic and spectrum conditions
- balance spectrum and throughput bandwidth in response to traffic dynamics
- autonomously select frequency and bandwidth for each link
- Implement disruption tolerant networking to cache content, defer address resolution, maintain connectivity in disrupted environments

These lead to orders of magnitude improvement in network performance

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