Lectures on *Wireless Networks & Mobile Computing*

Dynamic Spectrum Access & Spectrum Markets

CS 439

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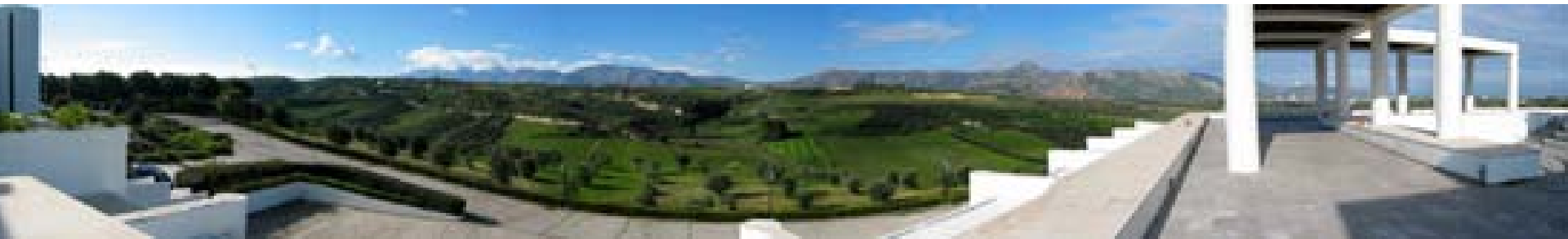


References & Acknowledgement

The slides of this lecture are heavily based on the

- talks given @ IEEE DySPAN'11
- IEEE DySPAN'11, Tutorial 5, given by Randall Berry & Michael Honig, EECS, Northwester University

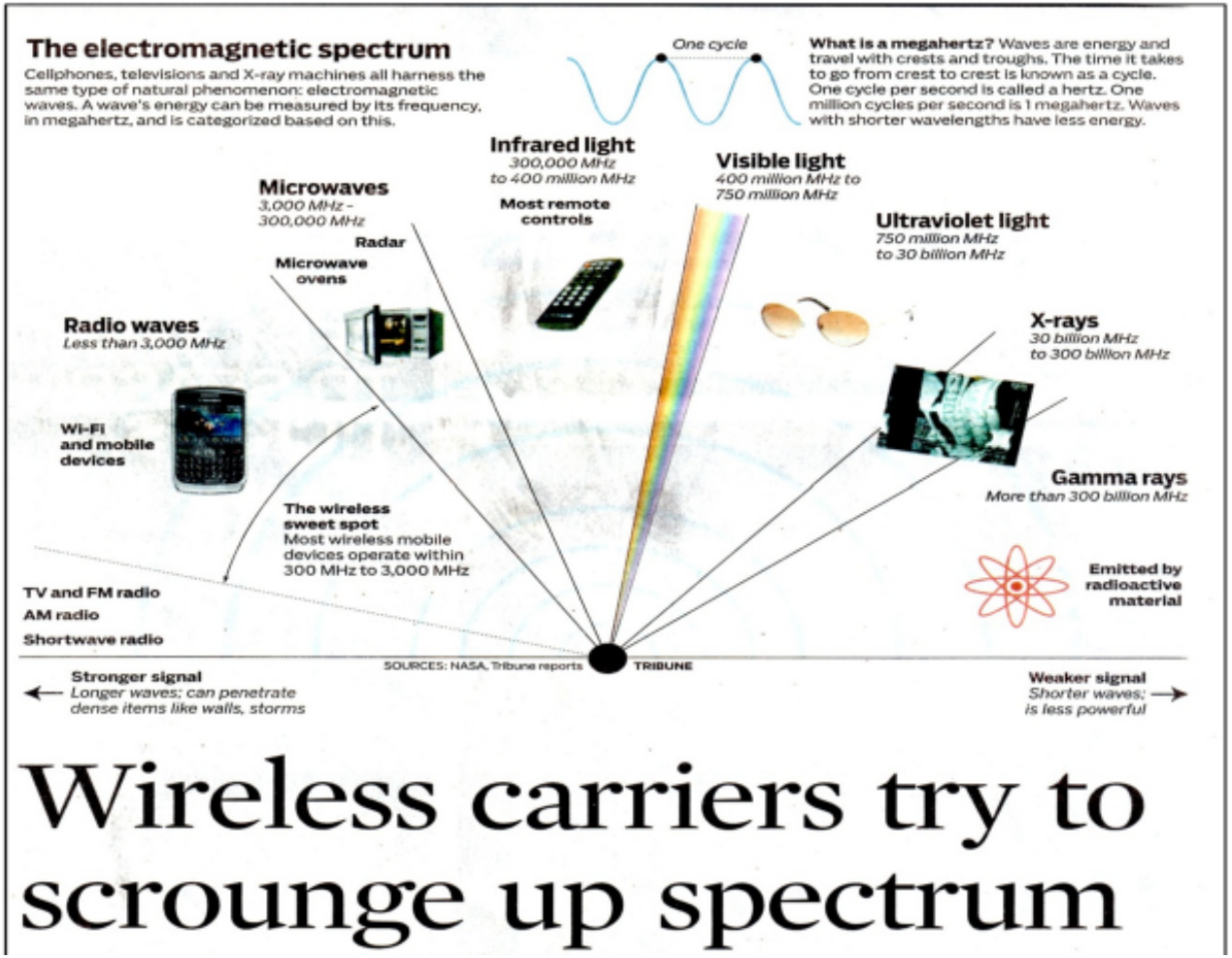
Spectrum and Cognitive Radios Markets

Policy

Economics

Communications Engineering

Dialogue between network operators, manufacturers, federal states & municipalities, and researchers



Wireless carriers try to scrounge up spectrum

Chicago Tribune
April 15, 2011

Broadband & Spectrum Markets

Broadband connections 2001-2010

- The competition among providers has increased substantially
- Interoperability among different types of devices is an important aspect
- Harmonization of CPC frequency allocations in Europe
- Specification of access products relevant to mass markets
- Conjecture "Cooper's Law": spectrum use is doubling every 30 months
  - Spectrum use: amount of traffic put in the spectrum

Advances on Spectrum

- More spectrum x 25
- Thinner slides x 5
- Modulation technology x 5
- Architecture x 1600

Challenges in cognitive radio evolution:

- Complexity of the existing use of spectrum **(legacy systems)**

Spectrum Markets

- Different bands of the spectrum have different value in the market
  Large variations in spectrum value in $/MHz/population
  Germany ~2Ghz : 0.01 < UK 3G < US 700MHz : 10
  Two orders of magnitude difference

- **Directives on how CR devices can access certified or authorized databases**
- Cognitive Pilot Channel (CPC)
- Support activities for cognitive radios:
  - CEPT (SE'43, WGFM), ETSI (e.g., TC-RRS), TCAM, WRC-12, ITU-R
- Support corresponding standardization
  - ETSI TC-RRS: harmonized standards
  - CEPT: identify possible candidate band and develop sharing conditions
  - CEPT ECC Report 159
    - Sensing, geo-location and beacon

Spectrum Markets

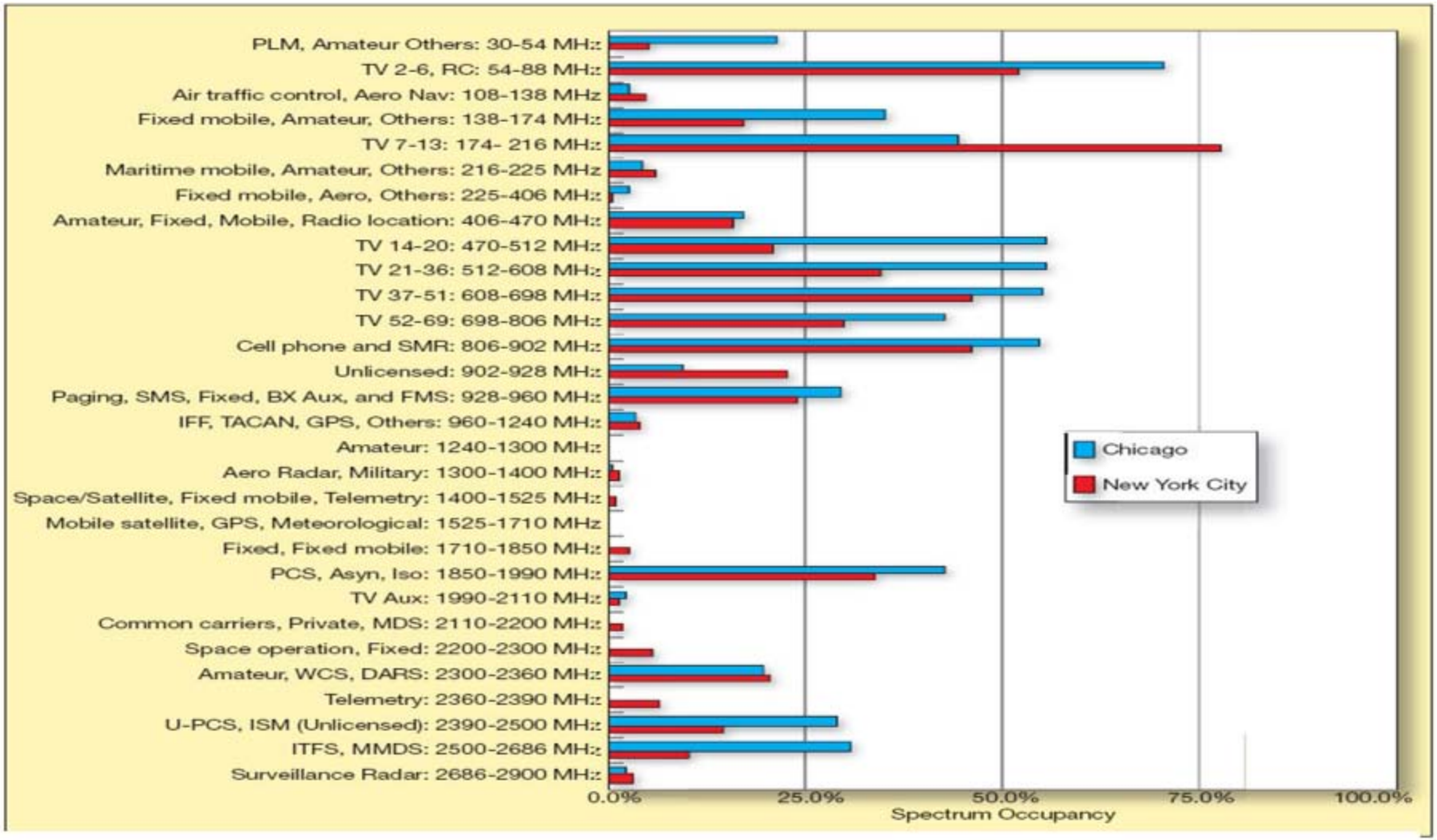
- Business impact of secondary spectrum sharing:
  - still unclear
  - Lots of discussions in the industrial, regulation, policy making, research & technology sectors
- Multi-parameter and utility-based assessment of spectrum value
- Consideration of network operators to form “coalitions” for sharing parts a network infrastructure
- Deployment of Femtocells: catalytic of innovation
- Lack of transparency in allocation and utilization
- Incentive to reallocate spectrum
- TV spectrum – utilization of white space in TV spectrum
  - Easier to start with
  - 2 or more stations can combine their

FemtoCell

- A small cellular base station
- Typically for use in a home or small business
- Connects to the service provider's network via broadband (e.g., DSL or cable)
- Supports 2 to 4 active mobile phones in a residential setting, and 8 to 16 active mobile phones in enterprise settings
- Extends coverage indoors, especially where access would otherwise be limited or unavailable
- Can use WCDMA, GSM, CDMA2000, TD-SCDMA, WiMAX ,LTE
- Broadband backhaul introduces issues of network jitter

Spectrum Paradox:

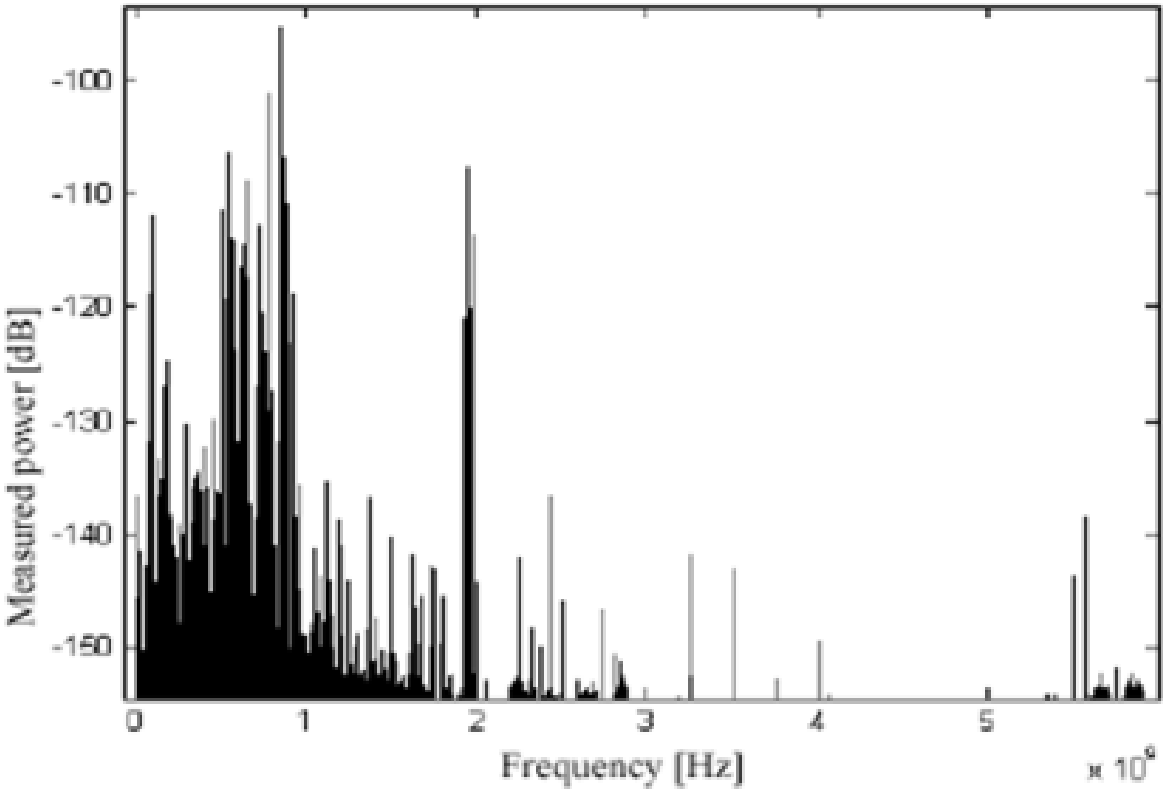
- The spectrum is a scarce resource
- The spectrum is underutilized!



Spectrum measurements in New York City and Chicago conducted by Shared Spectrum Co.

Dynamic Spectrum Access: Motivation

Percentage of spectral utilization is relatively low
→ Need for flexible multiband operation!



In 0,03-6 GHz band approximately 10% of spectrum resources are utilized in average time.

D. Cabric et.al. "CORVUS: A Cognitive Radio Approach for Usage of Virtual Unlicensed Spectrum Access", 2004

Two Views on Spectrum Access

- Broadcast spectrum is a public good; regulation needed to avoid a tragedy of the commons, and police content.

- Efforts to privatize spectrum derailed due to rent-seeking by incumbents, special interests, and desire to control content [Hazlett, `90]

Regulation since 1927: "Command and Control"

- Federal Radio Commission (FRC) established in 1927.

- Federal Communications Commission (FCC) established in 1934.

FCC

- Maintains authority to
  - Grant / renew / deny licenses for spectrum use.
  - Assign applications to particular frequencies.
  - Police content and use

- An economist's critique:
  - Requires excessive information overhead
  - Difficult to estimate value (utility) of a frequency assignmen
  - Encourages rent-seeking and facilitates entry barriers
- An engineer's critique:
  - Demand for different applications varies over time and geographic locations.
  - Static assignments cannot exploit statistical multiplexing.
  - New technologies can facilitate more efficient spectrum sharing.

Europe vs. US spectrum markets

- Population density

  52 persons/km2 in Europe, 32 persons/km2 in US

- Europe:

many administrators, many borders => need for bilateral agreements

Cognitive Radios

- Add intelligence to mobile devices
  - Frequency agility
  - Wideband sensing
  - Interference avoidance
  - Adaptive quality of service (context aware)
- Enables spectrum scavenging

Spectrum Sharing Models

- Exclusive Use
- Commons
- Hierarchical
- Hybrid

Exclusive Use

- Spectrum owned by government
  - Licensed to particular application, service provider
  - Rigid use rules
- Spectrum is private property
  - Applications, technical constraints decided by markets

"Liberal" licenses

- Spectrum publicly owned, but licenses can be transferred, liberal use rules
- Secondary markets (2003)

Spectrum Commons

- Unlicensed
- Requires etiquette rules for sharing

- State-regulated
  - Spectrum owned by government
  - Etiquette rules part of industry standard (802.11)
- Privately owned
  - Owner sets rules, polices band
  - Revenue from selling approved equipment

Hierarchical

- Primary and secondary users
- Secondary users must not disrupt primary users
- Relies on cognitive radio

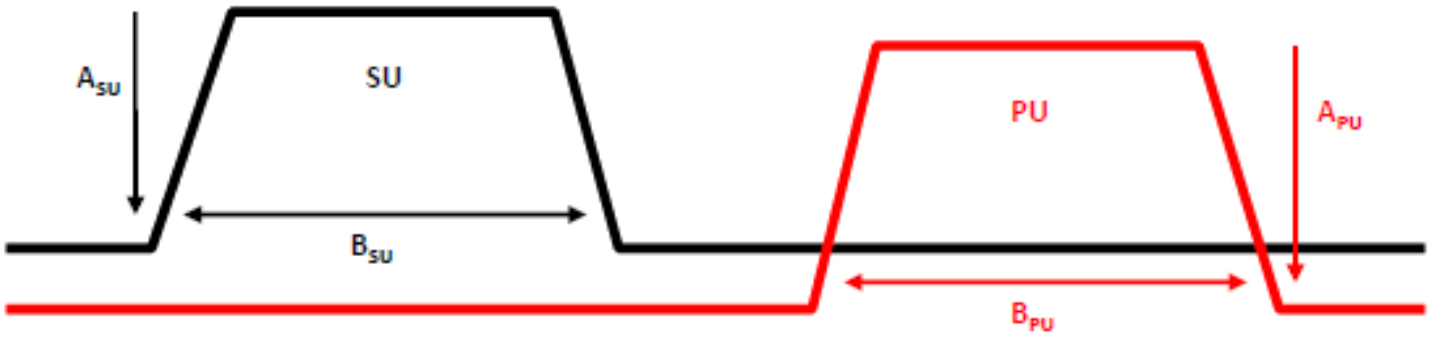
State-regulated

- Spectrum owned by government
- Use rules for secondary users part of standard (802.22)

Private contracts with "spectrum scavengers"

- Interference levels/payments set by mutual agreement

Primary & Secondary Users



Simplified spectrum diagram for evaluation of interference caused by the SU (black line) to the PU (red line). SU transmission mask is presented, while for PU it is the equivalent reception filter characteristic.

- How do we protect the PU transmission from interference?
- How do we aggregate the available fragmented spectrum?
- How do we assure the SU's desired transmission performance at reasonable complexity and power in a dynamically varying operating environment?

- Spectrum designated for exclusive use could be operated as a commons and/or with secondary users.
- Underlay/overlay can be used to facilitate further sharing.
- Spectrum scavenging can increase utilization.

Hybrid Access Models

- Mix of:
  - restricted use bands (e.g., broadcast TV)
  - liberalized licenses (cellular)
  - state-regulated commons (WiFi)
- Active trading of liberalized licenses among commercial service providers
  - About 10 billion MHz-pops annually since 2003 [Mayo & Wallsten `10]
- US Policy trends have favored assignments of unlicensed spectrum over liberalized licenses
  - 955 MHz unlicensed vs 422 MHz licensed in the US (2008)

Are secondary markets selling?

- Service providers are not issuing short-term leases.
- Companies with spectrum (e.g., Boeing) are not reselling.

But…

- There are active markets for:
  - transferring large blocks of spectrum among service providers,
  - "wholesale" use of spectrum and infrastructure (e.g., Kindle)

Current State of Affairs

- Large parts of the useful spectrum remain underutilized.
- Restricted supply of spectrum with liberalized licenses.
  - Cellular spectrum is extremely expensive.
  - Service providers encouraged to build out national footprint.
  - Fosters the development of expensive (spectrally efficient) systems.
- Unlicensed spectrum is increasing.

- Designing a *dynamic* market for spectrum.
  - "Short-term" allocations done in "real-time"
  - "Small" spatial-scale

- Consider one entity responsible for leasing/selling spectrum to multiple agents.

Companies, such as Microsoft, Google, and British Telecom, express interest in the idea of a geo-database spectrum leasing service