

Let the Spectrum Games Begin

New wireless businesses will emerge
from adaptive radio technology and
monetized spectrum

Lloyd Nirenberg, Ph.D.

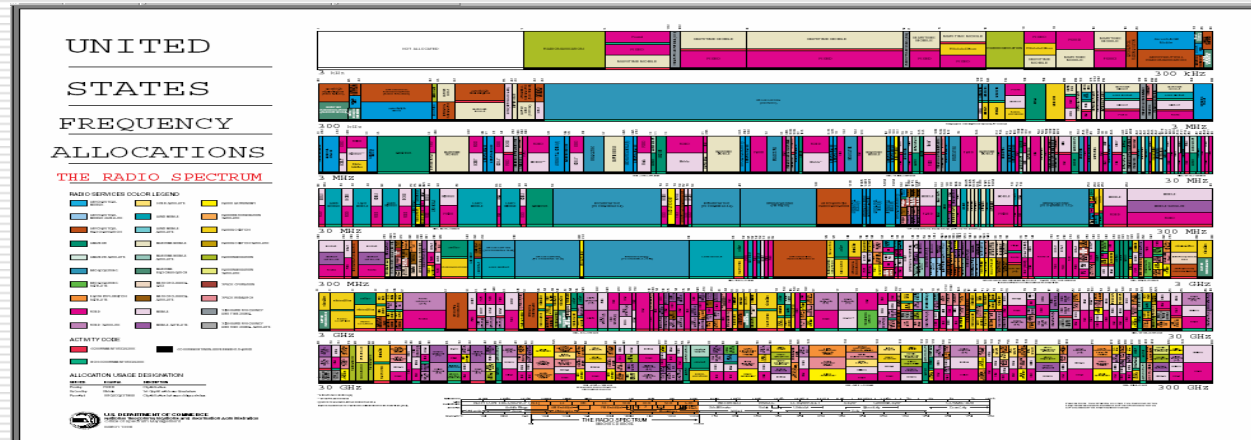
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Wireless Communications Alliance

Silicon Valley

The Spectrum's Open Secret

- All spectrum now allocated

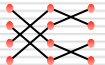


- < < "20%" in use at any given moment
- Measurements show a large quantity of long duration, large bandwidth spectrum holes

Sources: NTIA; FCC Cognitive Radio Workshop, 5/19/03; DARPA; B. Fette, General Dynamics, 2003; FCC Spectrum Policy Task Force, 2002; Berkeley Wireless Research Center

...Leads to a Paradox

- Even as the spectrum is under utilized, more interference degrades what is used, especially in Unlicensed bands



...and a Witch's Brew

Monetized
Spectrum

Advances in
Adaptive Radio
Technologies

FCC Regime
Change

- What's "Fair"?
- What's efficient?
- Who pays?
- How do we do it?



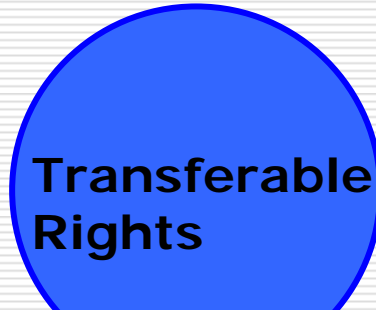
Regime Change at FCC

"C & C"



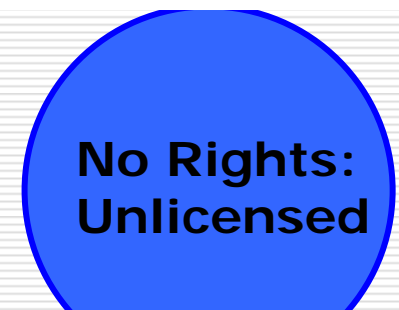
Broadcast TV

"Exclusive use"



PCS, SMR, LMDS, ...

"Private Commons"

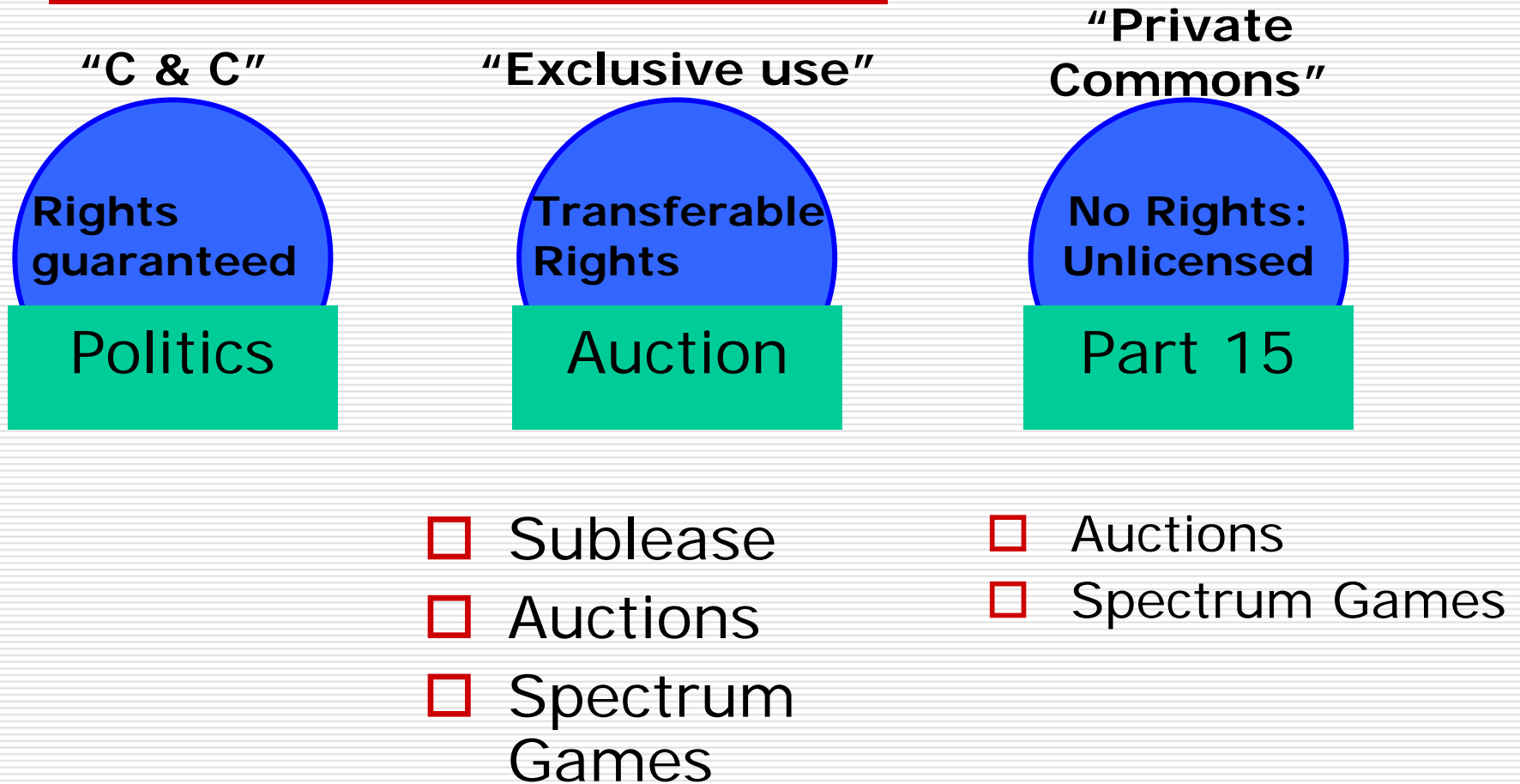


WiFi

- 2nd Report & Order, 2004
- Report and Order, Docket 05-57, 10 MAR 05
- May 15, 2003, by Report and Order and NOPR (FCC 03-113)

- SubLeasor may use spectrum and not licensee's architecture
- Use economic principles of competition and allocation
- Legal Requirements for SDR set
- Use "Cognitive Radio (CR) technologies

How Regimes Allocate and Share Spectrum



What are Spectrum Games?

- Game theory is all about competitively allocating resources
- Players → A bunch of radios compete for QoS from the channel
- Rules of engagement set by FCC and technology
- Available Strategies
- Each Player's Goal: Maximize QoS = "Utility"
- Solve for "Best" Strategy
 - Get improved spectrum allocation, utilization, fairness



Power Control Game for Uplink CDMA Data Traffic (1)

- ❑ All players transmit power levels from a finite set of choices
- ❑ More power for me hurts you
- ❑ A player's chosen power is its "strategy"
- ❑ What is best strategy to max QoS?



Power Control Game for Uplink CDMA Traffic (2)

$QoS_j = \text{utility}_j$

$= E[\text{Number correct bits}]/\text{Joule} - \text{Energy_cost}/\text{Joule}$

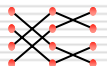
$= (K/p_j) * \Pr[\text{Correct bits} \mid \text{SINR}(v_j)] - c_j * p_j$

- “Price” here is money or simply a power control signal
- C_j is determined and broadcast by base station

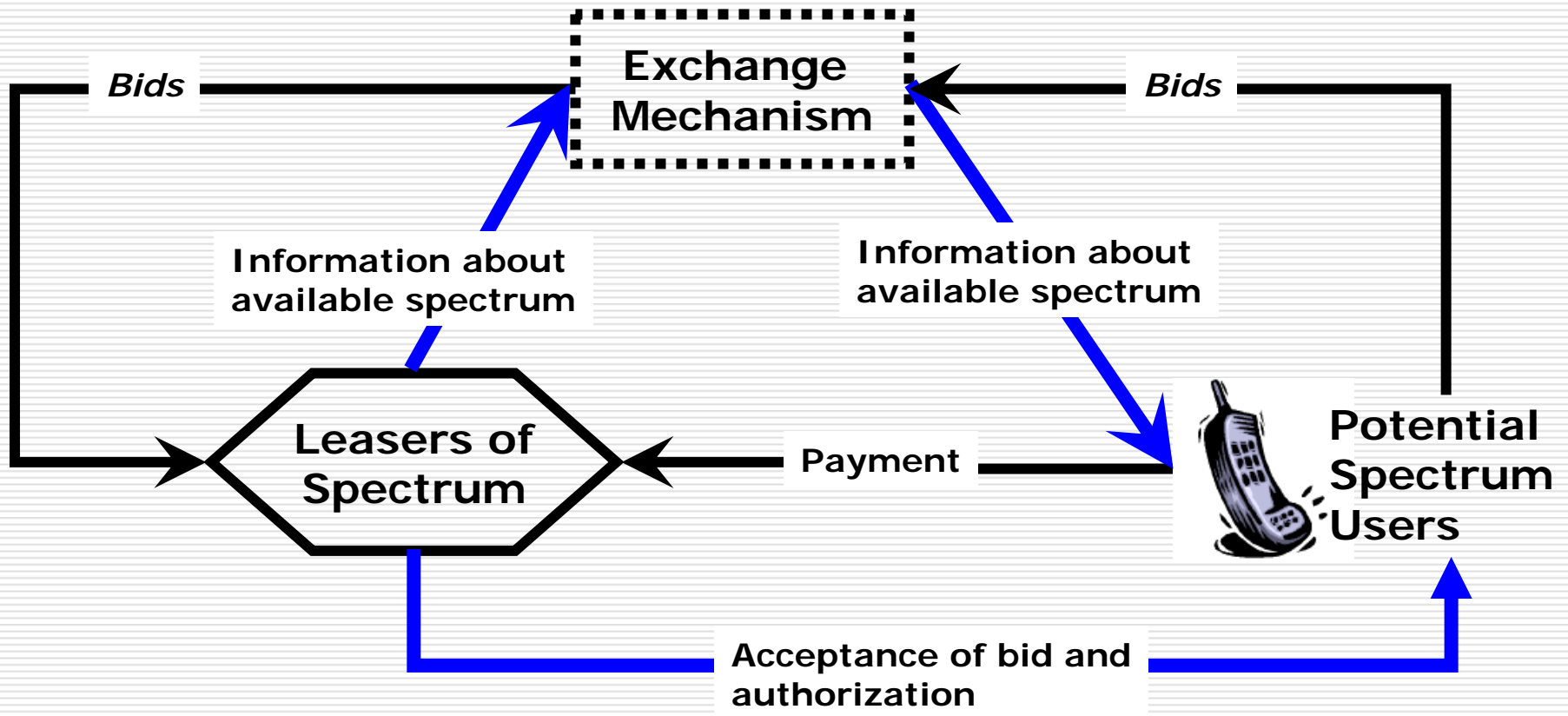
Power Control Game: Results

- Equilibrium in unpriced game ($c_j = 0$):
all received powers are identical (and thus the same SINR)
- Pricing
 - Reduces everyone's required power
 - Reduces everyone's SINR
 - Improves everyone's QoS

C. Saraydar, N. Mandayam, D. Goodman, "Efficient Power Control via Pricing in Wireless Data Networks," *IEEE Transactions on Communications*, vol.50, No.2, Feb 2002



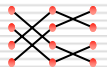
Real-Time Auction Games



Spectrum Monetization

- ❑ FCC and Game Theory set the stage
- ❑ Systems need to be designed and built
 - Continuously match supply and demand
 - Pay for spectrum resources
- ❑ Payment occurs in a Spectrum Game
- ❑ Spectrum Resources get most effectively allocated

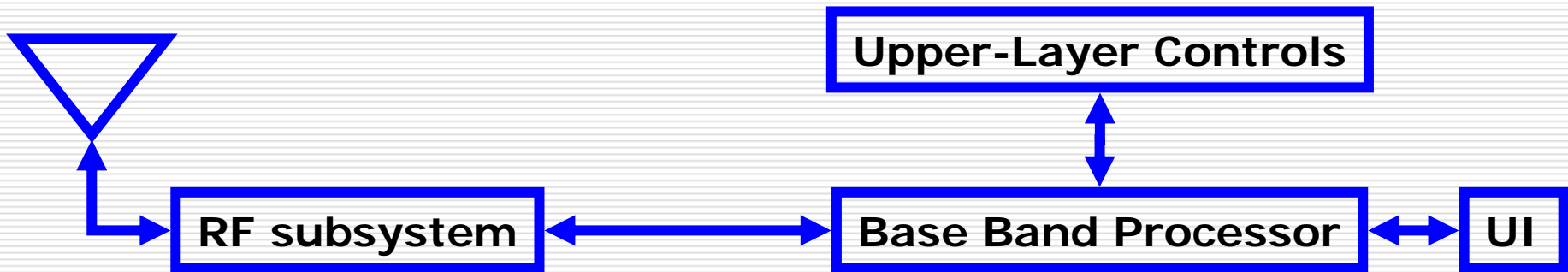
Who will Bell the Cat?



Adaptive Radio Provides Opportunity Awareness

- Sensing
 - Determine channel occupancy and parameters
 - ID + classify signal structures
 - Measure emitter power, bandwidth
 - Identify, measure and locate emitters
- Disseminate + Coordinate
- Find spectral “holes” and fill ‘em
- Implement spectrum games
- ELINT/SIGINT/COMINT

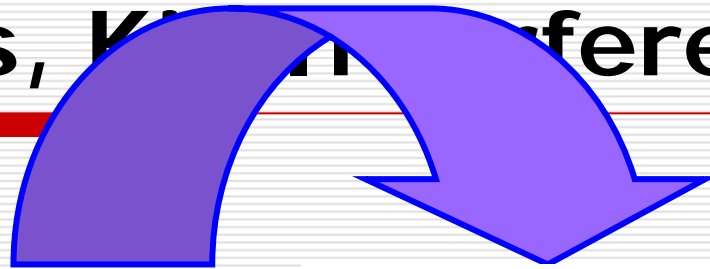
Adaptive, Cognitive, Software-Defined Radios (AR, CR, SDR)



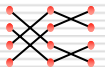
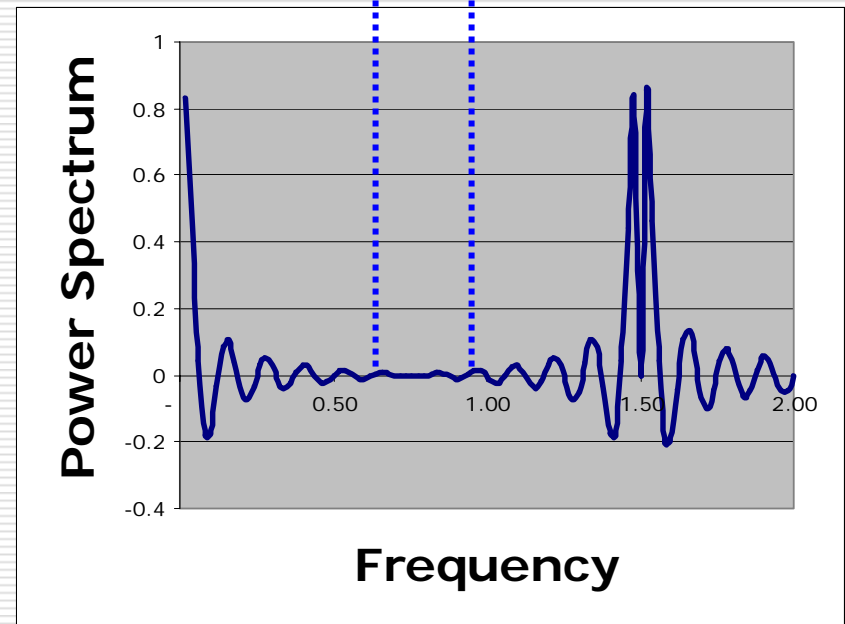
- Dynamic frequency selection
- Transmit power control
- Measure emitter power and location
- Beam forming
- Programmable filters
- Changes its internal signal processing based on embedded or external programs

Find+Fill Holes, Kill Interferers

- Heteromorphic Waveforms
- Transform Domain Comm Systems allow interference avoidance by Tx (vs mitigation by Rx)
 - OFDM
 - MC-CDMA
- MUD => Successive Interference Cancellation

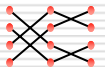


Create and insert adaptive signal here



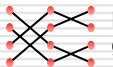
Adaptive Radio Lives in WiFi

- Multiband and Multimode
- “Smart” antennas
- Adaptive techniques for
 - Channel identification,
 - Dynamic frequency selection
 - Selecting Modulation and Data Rate
- AP Load Balancing through power control
- Distributed Coordination Function



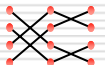
Business Opportunity Points

- Sub-Leasing for fees
 - Access and reversion mechanisms
 - Handshaking protocols
 - Sub-threshold operation
 - Overlays; interference temperature
 - Technical Example: IEEE 802.22 WRAN
- Personal Infrastructure
- Proprietary Locations



Personal Infrastructure

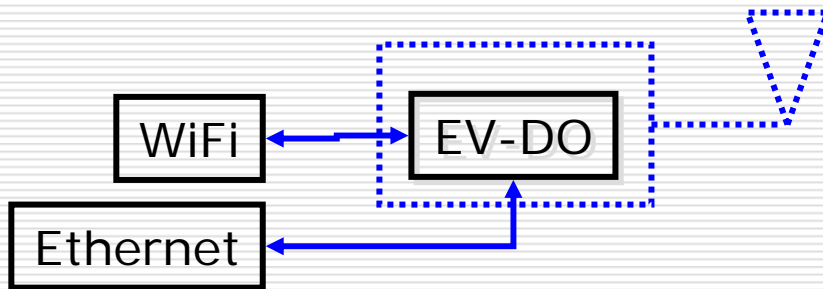
- Users create their own payment/revenue plans- not just Wireless Carriers
- Self-Organizing networks
 - Adds coverage or capacity as needed
 - Potential for “convenience” revenues
- Third Party Software Vendors
 - FCC Compliance for SDR
 - Implement Spectrum Games
 - Viral Coordination software



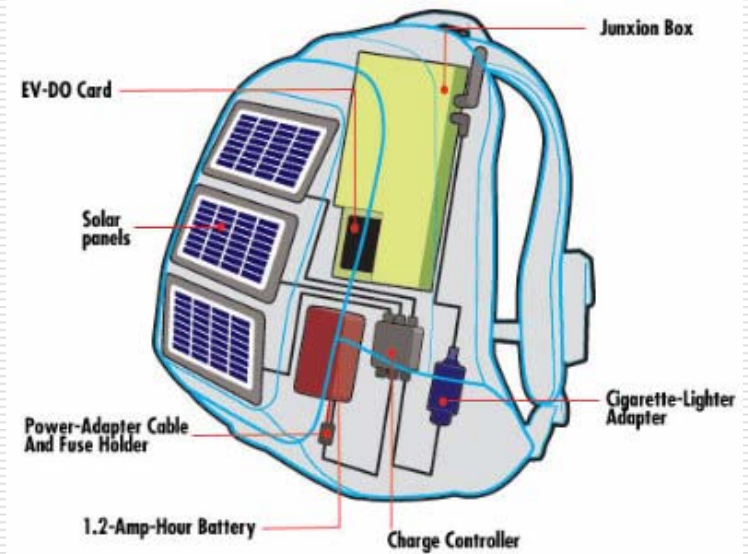
Proprietary Locations

- ❑ Anyone can rent a "spectrum rooftop"
- ❑ Incremental Enterprise WLAN Access
- ❑ Convenience use for your neighbor

- ❑ Backpack based wireless access point
- ❑ Solar powered



<http://www.junxionbox.com>



The Whole Story

- ❑ Spectrum is vastly under utilized in face of rising demand
- ❑ FCC seeks market-based solutions to spectrum utilization and allocation
- ❑ Spectrum Games are ready to monetize Spectrum in real time
- ❑ RF and baseband technologies are almost ready to support economic access
- ❑ New business models will emerge

What will *you* do?

