



Spectrum Management

CYBR 4400 / 5400: Principles of Internet Policy, Lecture 4-2

Dr. David Reed, Technology, Cybersecurity, and Policy Program, CU Boulder

Today's Lecture

- ❖ ~~Canvas quiz~~
- ❖ Class planning
- ❖ Spectrum Management Lecture

Planning for Remote Course?

- ✿ If required to teach remotely, would like course to teach synchronously, with the class meeting “live” at the regular time for lectures
- ✿ Distance students remain asynchronous, though welcome to join any lecture
- ✿ Send me email if you have any problems with Internet access for this
- ✿ CHANGE STARTING TODAY:
 - ✿ Office hours by email, or appointment via Zoom
 - ✿ Any in-class students may attend class via Zoom

Spectrum Management

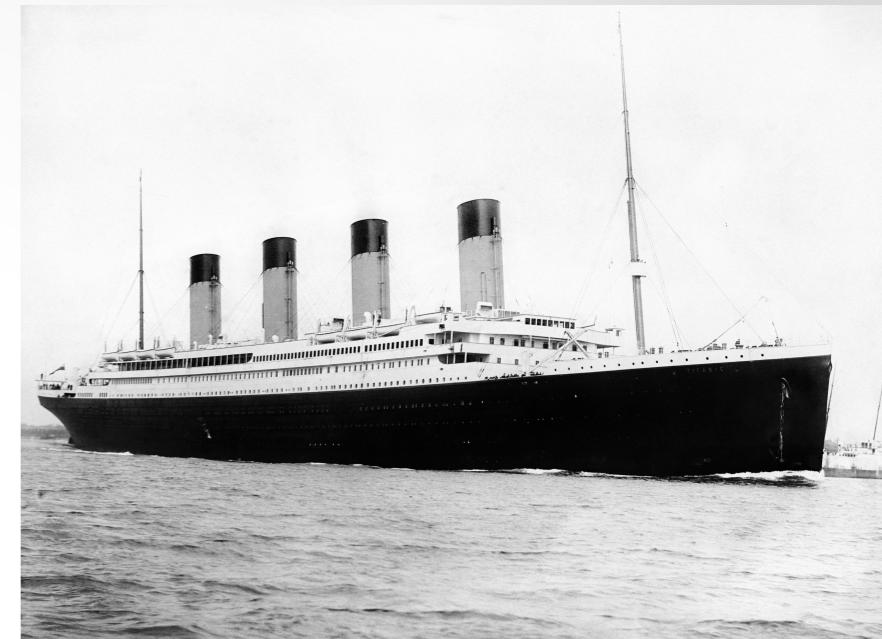


Basis of Spectrum Regulation

- ✿ No “ownership” of spectrum
 - ✿ A public resource
- ✿ Need to prevent “harmful” interference
- ✿ Spectrum is a “scarce” resource



Early Regulations



- ❖ Radio Act of 1912
 - ❖ Equipment using spectrum (e.g., for radio stations) must be licensed by the federal government
 - ❖ Seagoing vessels must monitor distress frequencies
- ❖ Herbert Hoover created market-based allocation system approving radio system transactions during the early 1920s as Secretary of Commerce
 - ❖ Stopped issuing licenses when market was full
- ❖ In 1926, court overturned Hoover's extralegal system in *Zenith* decision



Herbert Hoover

Early Regulations (cont'd)

- ❖ Radio Act of 1927
 - ❖ Established Federal Radio Commission
 - ❖ Regulate access to spectrum under “public interest, convenience, and necessity” standard
 - ❖ Public owns spectrum
- ❖ 1927 Act represented political equilibrium among regulators and industry
 - ❖ Restricted entry by only utilizing 5% of AM radio market capability
 - ❖ “Broadening of the band was disposed of with a finality which leaves little hope for the revival of that pernicious proposition...”

Rationales for Regulation of Spectrum

- ✿ Managing interference: a negative market externality (Khan Academy link)
- ✿ Rent Seeking
 - ✿ “Pirates” and “wave jumpers” after *Zenith* decision in 1926 that eliminated Hoover’s extralegal solution and created “breakdown” period
 - ✿ *Oak Leaves* decision: judge applied homesteading principle to find a common-law remedy to “tragedy of the commons” (Khan Academy link)
 - ✿ Established priority-in-use rule (property rights)

Interference: Negative Externality

- ❖ Managing interference
- ❖ Application of Coase Theorem: if trade of externality is possible, and there are sufficiently low transaction costs, bargaining will lead to an efficient outcome regardless of the initial allocation of property
- ❖ If FCC specifies property rights in spectrum licenses, parties should reach an efficient outcome



Other Rationales for Regulation of Spectrum

- ❖ Consumer preferences
 - ❖ Consumer's do not know what is in their own long-term interest (i.e., paternalism argument)
 - ❖ One person's consumption of broadcast content may affect another person's well-being (i.e., externality argument)
 - ❖ Negative externalities from violence on TV
 - ❖ Positive externalities from children's TV

Condensed Timeline

- ✿ Radio Act of 1912 authorized Secretary of Commerce to license users of equipment that communicated via spectrum
- ✿ Radio Act of 1927 established the Federal Radio Commission and that spectrum belongs to the public such that licensees have no property right to continue using it
- ✿ Communications Act of 1934 established the FCC and incorporated the Radio Act of 1927 into Title III

Spectrum Management

All activities associated with regulating the use of the radio spectrum. Basic elements:

- ✿ Allocation
 - ✿ Service Rules
 - ✿ Assignment
 - ✿ Enforcement
-
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Spectrum Allocation

- ✿ FCC only allocates for private, state, and local government uses
- ✿ National Telecommunications and Information Agency (NTIA) allocates for federal government and military
 - ✿ State Department coordinates with International Telecommunications Union (ITU)
- ✿ FCC decides license allotment
 - ✿ Amount of spectrum or bandwidth in license

Allocation Terminology – Three Possible Status Categories

- ❖ Primary allocations grant specific services priority in using the allocated spectrum
- ❖ Co-Primary allocations occur when there are multiple primary services within a frequency band
 - ❖ All have equal rights
 - ❖ Station is protected from any others that start operation at a later date
- ❖ Secondary allocations
 - ❖ Cannot cause harmful interference to stations of primary services in the band
 - ❖ Cannot claim protection from harmful interference from stations of primary service
 - ❖ Can claim protection from harmful interference from stations of the same or other secondary service(s) to which frequencies may be assigned at a later date

Service Rules

- ✿ Duration of the license
- ✿ Limits on transferability
- ✿ Maximum power levels
- ✿ Technical standard requirements
- ✿ Build-out obligations



Spectrum Assignment

- ✿ Comparative hearings (up to 1980s)
 - ✿ Meet public interest by selecting “most qualified” users
 - ✿ Slow, difficult process with high costs, delays, and arbitrary outcomes
- ✿ Lotteries to Qualified Users (late 1980s)
 - ✿ Delays in processing large number of applications and fairness concerns as most licenses were quickly “flipped”
- ✿ Auctions (early 1990s – present)



Spectrum Management Models

Command and Control
Exclusive Use
Commons

Key Elements of Spectrum Policy

- ❖ Maximizing *flexibility* of spectrum use to find highest valued use, subject only to interference limitations and reasonable opportunities for access by other users
 - ❖ Choice of use, technology, and right to transfer, lease, or subdivide spectrum rights
- ❖ Clear and exhaustive definition of spectrum rights and responsibilities
 - ❖ Designated frequency range and bandwidth
 - ❖ Geographic scope of right to operate
 - ❖ Maximum power output, both in-band and out-of-band
 - ❖ Interference protection (maximum level of noise/interference from other sources)
 - ❖ Note uncertainty defining “harmful interference”

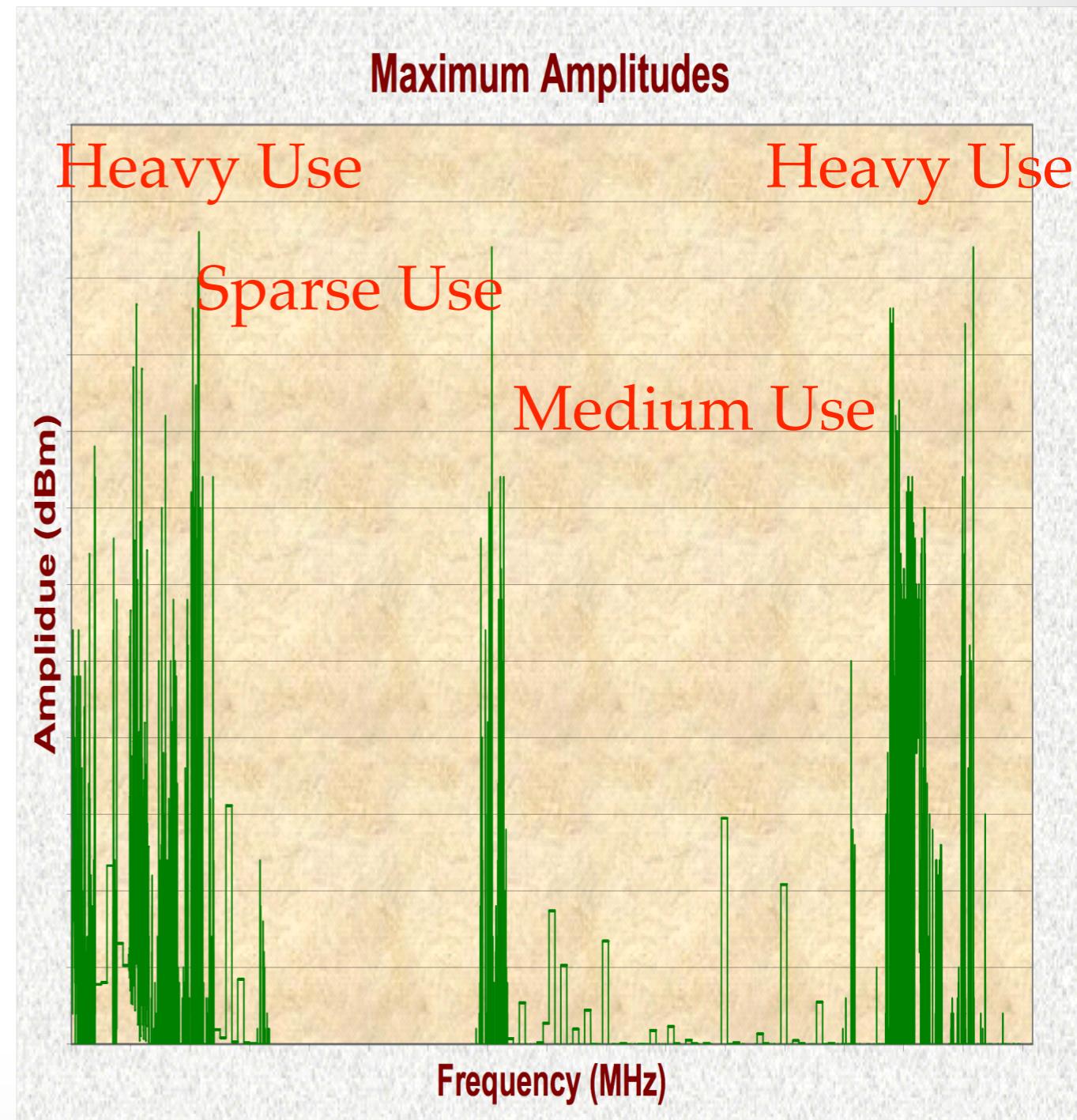
Traditional “Command and Control” Regulation

- ❖ After the Communications Act of 1934, FCC decided who and what was worthy of using spectrum
- ❖ Granted renewable licenses for specific government-defined uses
- ❖ Service rules define eligibility and service restrictions, power limits, and build-out requirements
- ❖ Users had no ownership right in spectrum
- ❖ Rules designed to prevent “harmful interference”



Criticisms of Command and Control Approach

- ❖ Rigid allocation, allotment, and assignment of spectrum
 - ❖ “Static” spectrum management results in spectrum going unused in the frequency, time and /or space dimensions
 - ❖ Under-utilization exacerbated by the use of “worst-case” interference models
 - ❖ Can “lock-in” existing uses at the expense of new, more socially-valuable uses



Exclusive Use of Licensed Spectrum Regulation

- ✿ Licensee has exclusive and transferable rights to use of specified spectrum in defined geographic area
- ✿ Flexible use rights with technical rules to protect other users against interference
- ✿ Exclusive rights resemble property rights
 - ✿ Coase's Theorem: with well-defined property rights, free market will allocate resources to their most efficient use
 - ✿ Owners, acting as “band managers,” can sell or lease spectrum
- ✿ Steps to date: auctions, license flexibility

Commons (aka Unlicensed) Model

- ❖ Allows unlimited numbers of unlicensed users to share frequencies
- ❖ Usage rights governed by technical standards that set power limits
- ❖ No right to protection from interference
- ❖ Examples to date: amateur radio, CB radio, Bluetooth, Wi-Fi



Commons Model — “Part 15” Rules

- ❖ FCC allows Part 15 devices to use certain unlicensed or licensed bands at very low power levels without prior authorization
- ❖ No protection from interference of others, cannot interfere with licensed users
- ❖ Devices must be certified by FCC as complying to technical standards

Examples of “Part 15” Bands

- ✿ 1989: Industrial, Scientific and Medical (ISM) — 900-928 MHz, 2,400-2,483.5 MHz, and 5,725-5,850 MHz
- ✿ 1995: 57-64 GHz (computer to computer)
- ✿ 1997: Unlicensed National Information Infrastructure (U-NII) devices — 5.15-5.35 GHz and 5.725-5.825 GHz
- ✿ 2002: Ultrawideband — 3.1-10.6 GHz
- ✿ 2003 U-NII devices — 5.47-5.725 GHz

Best Conditions for Applying Models (According to FCC Spectrum Task Force)

- ✿ Exclusive Use: when spectrum scarcity is *high* and transaction costs to moving to more efficient uses are *low* (e.g., bands below 5 GHz)
- ✿ Commons: when spectrum scarcity is *low* and transaction costs to moving to more efficient uses are *high* (e.g., bands above 5 GHz)
- ✿ Command and Control: Prescribing specific usage is necessary for the public interest (e.g., public safety)

Building Pressures on the Resource (more users, more uses, greater bandwidth)

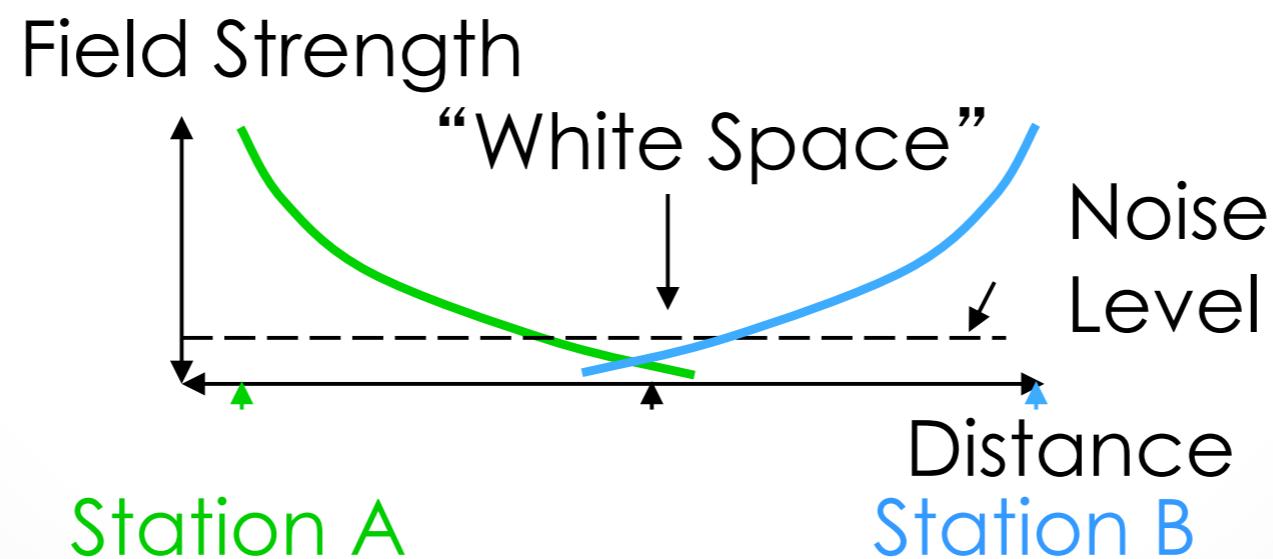
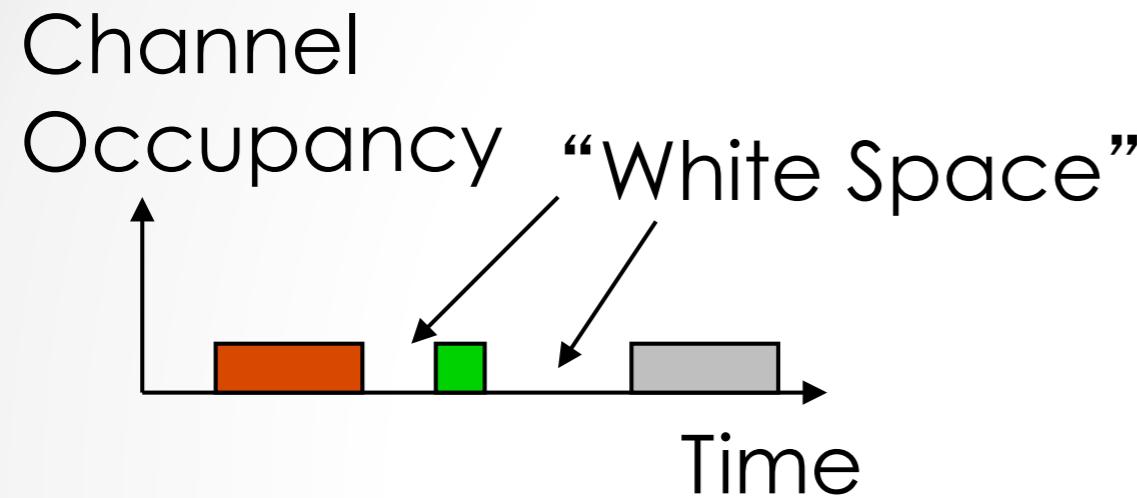
- ❖ Traditional solutions to spectrum congestion
 - ❖ Reallocation
 - ❖ Move higher in frequency
 - ❖ Increased sharing
 - ❖ Improved technology
 - ❖ More spectrally efficient technologies (bits/sec/Hertz)
 - ❖ More frequency reuse
 - ❖ Compression

Developing the Commons by Exploiting “White Space”

White spaces: unused portions of spectrum in terms of frequency, time, and space

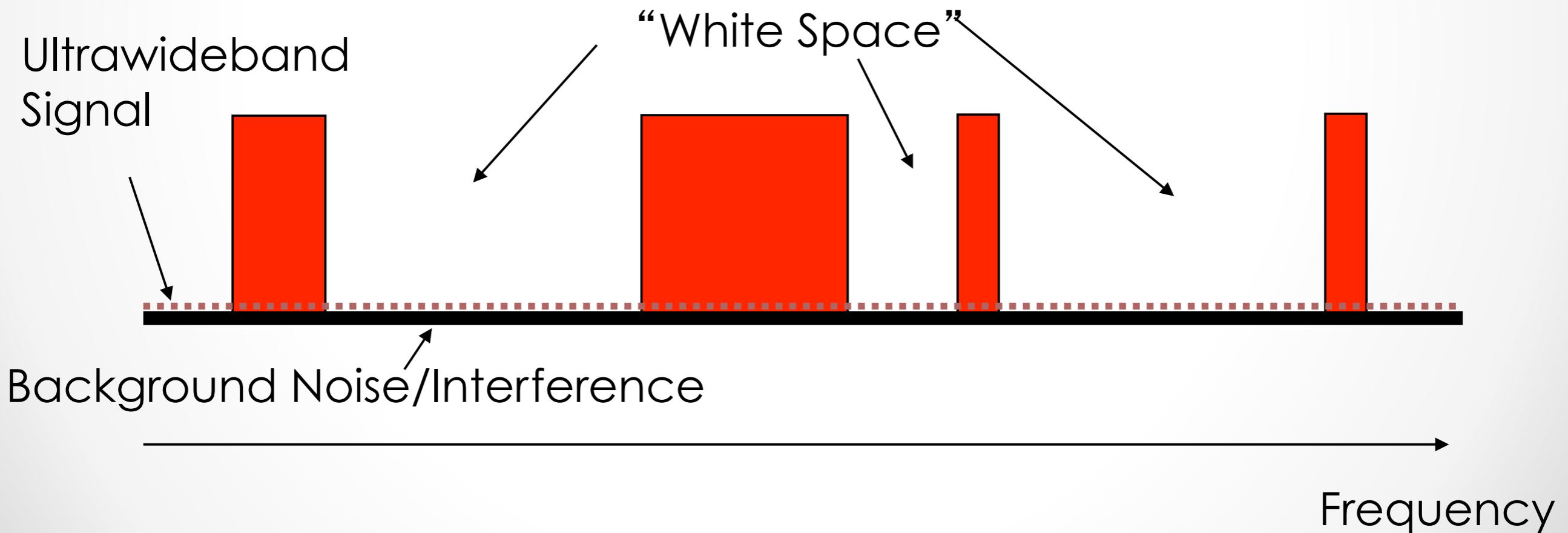
- ✿ Underlay technologies transmit at power levels below the electromagnetic noise floor (e.g., Ultrawideband)
- ✿ Overlay technologies detect and utilize unused spectrum
 - ✿ Dynamic Frequency Selection capability based on technologies such as GPS for location, beacons, and “listen-before-talk” protocols.

Exploiting “White Space”



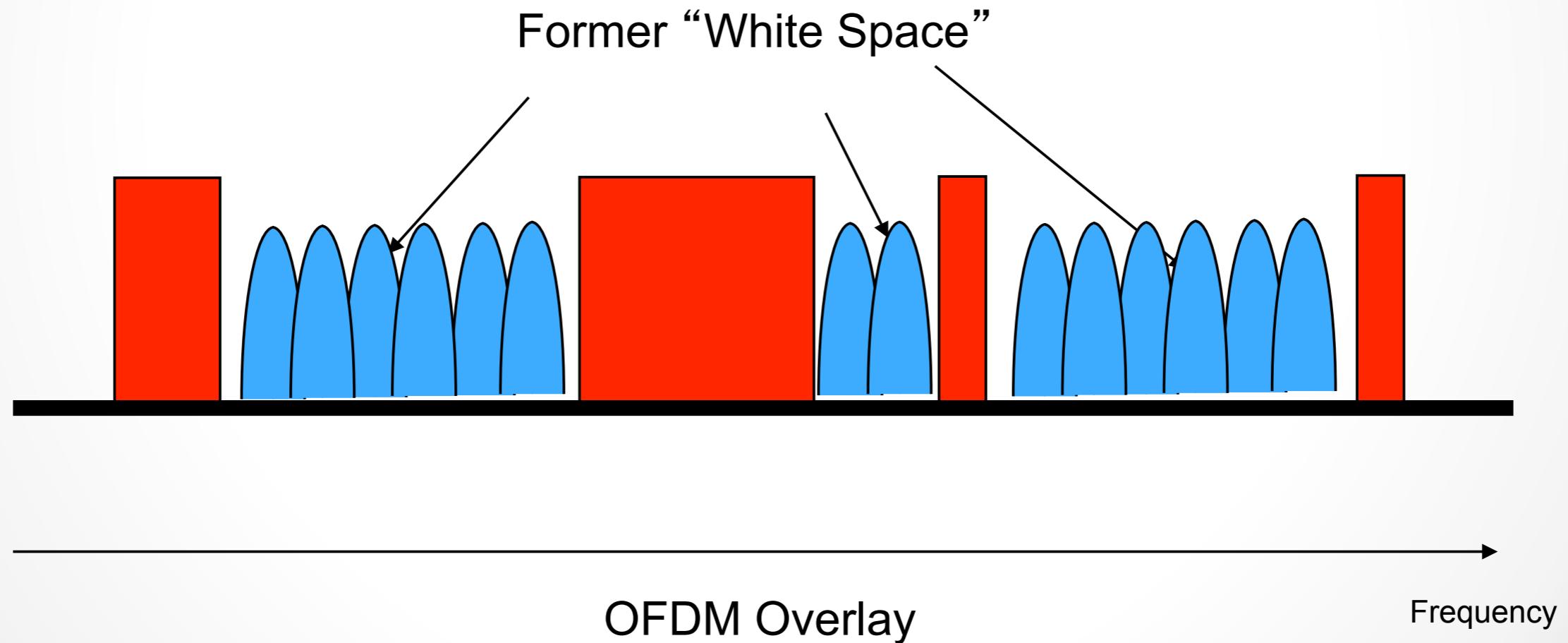
Exploiting “White Space”

Ultrawideband Underlay



Exploiting “White Space”

Orthogonal Frequency Division Multiplexing Overlay



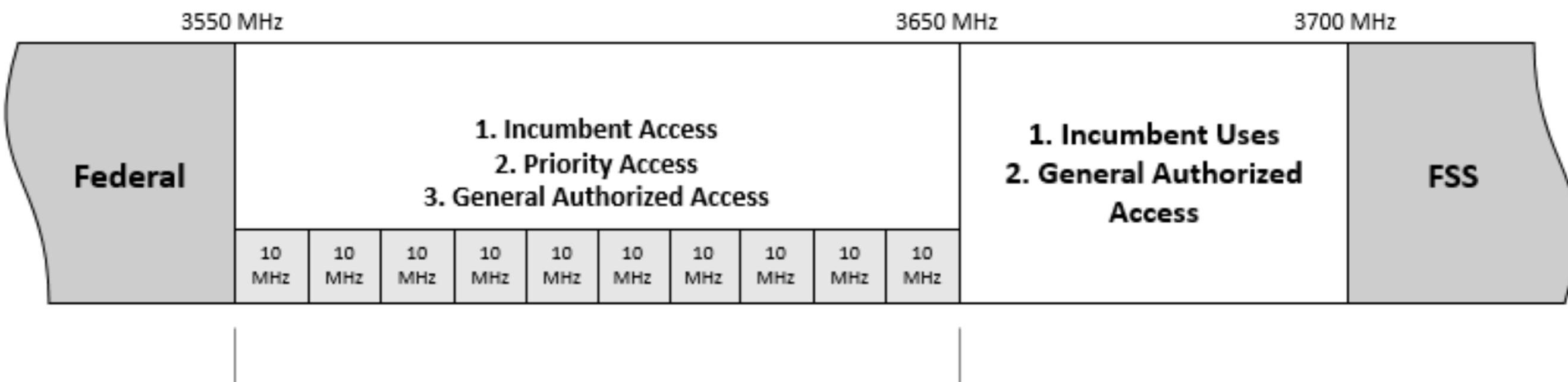
New Sharing Model: Citizens Broadband Radio Service (3550-3700 MHz)

- ❖ Tiered access and authorization framework to share federal/commercial use of 3.5 GHz band
- ❖ Spectrum Access System (SAS) manages access and operations (i.e., automated frequency coordinator based on actual transmissions in band)
 - ❖ Uses Environmental Sensing Capability (ESC) sensor network to detect transmissions from Dept. of Defense radar systems
 - ❖ SASs coordinate operations between and among users in three tiers
 - ❖ Incumbent Access (authorized federal users, Fixed Satellite Service (space-to-Earth) earth stations in 3600-3650 MHz band)
 - ❖ Priority Access (auction 10 MHz county Priority Access Licenses)
 - ❖ General Authorized Access (unlicensed)



New Sharing Model: Citizens Broadband Radio Service (3550-3700 MHz)

✿ Bandplan



Each PAL is a 10 MHz channel in the 3550-3650 MHz band.

No more than seven PALs will be issued in any county.

A licensee can aggregate up to four PALs channels in one county.