# An Introduction to Spectrum Engineering

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**Note: The views expressed in this presentation are those of the author and may not necessarily represent the views of the Federal Communications Commission**

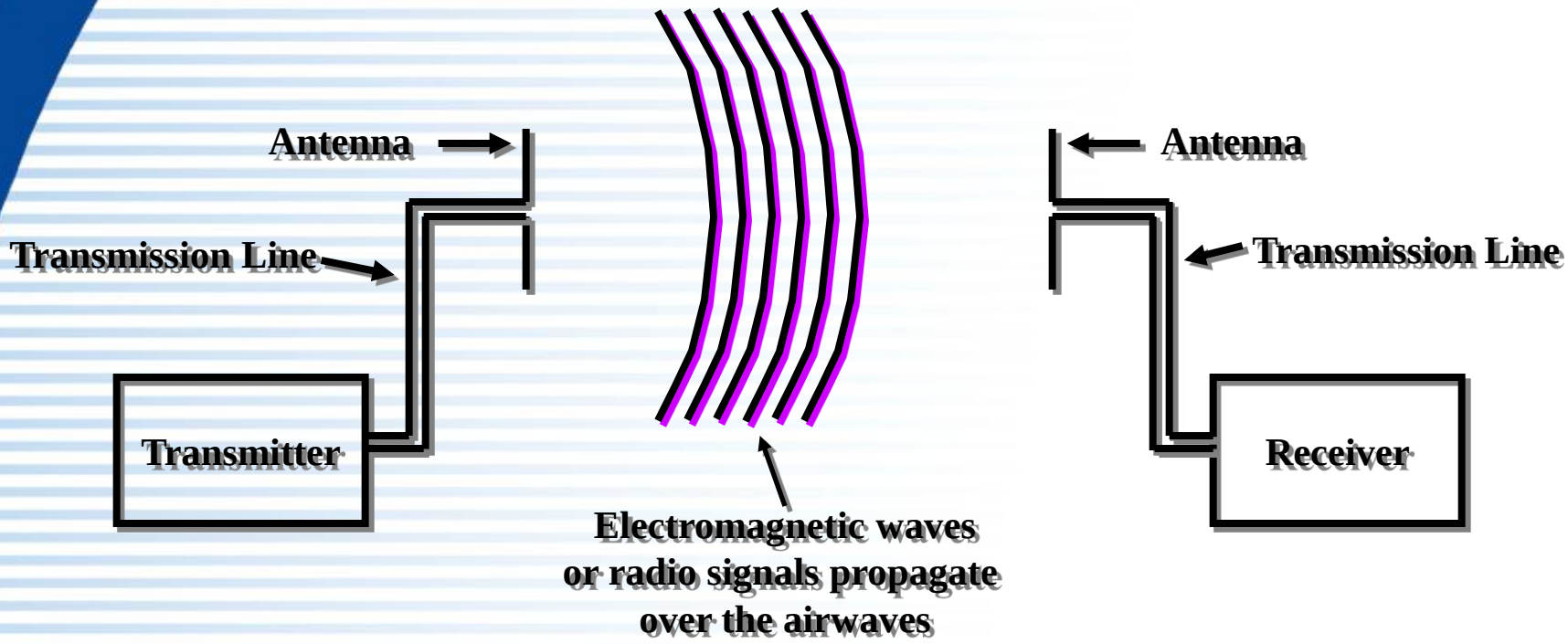
# Why We Are Here: Utility Wireless Applications Use Spectrum

- Voice
- Dispatcher to Crews
- Crew to Crew
- Emergency Call
- “Talk Around”
- Interconnect
- Trunked Operation
- Mutual Aid/Interoperability
- Data: System Monitoring and Control, Reports and Status Messaging
- Telemetry, Protective Relaying
- SCADA (Supervisory Control and Data Acquisition)
- Automated Meter Reading
- Home Automation
- Security
- Mobile/Personal Data Computer/Terminal Applications
- Wireless LAN/WAN Connectivity
- Remote Device Monitoring
- Robotics support
- Commercial Services
- Status Messaging
- Wide Band Data and Static Imaging
- Video

**Source: Utilities Telecom Council 2009 report:**
**The Utility Spectrum Crisis – A Critical Need to Enable Smart Grids**

# Basic Concepts of Radio Technology

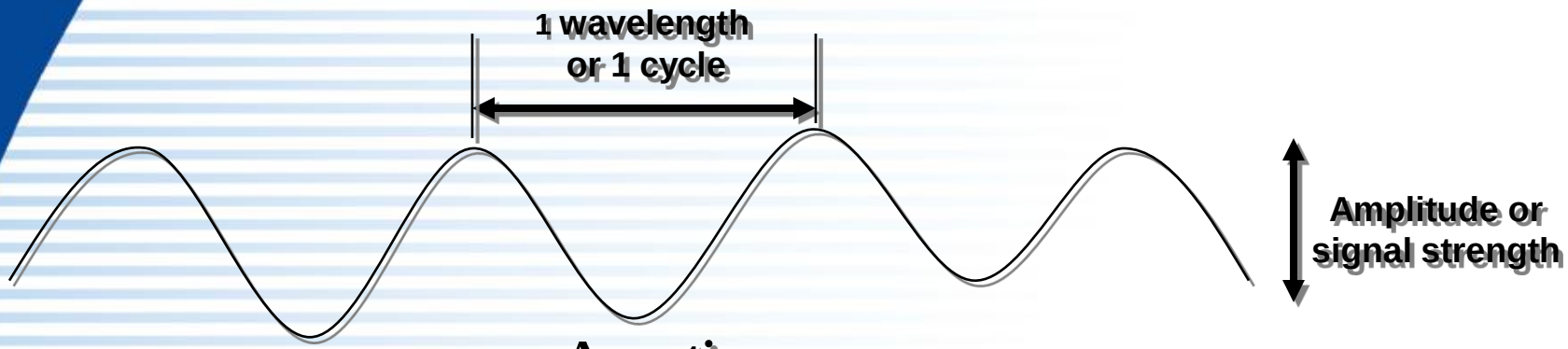
# A Basic Radio System




The transmitter generates an electrical signal and feeds it to an antenna by a transmission line.

An antenna picks up the signal from the airwaves and passes it via a transmission line to the receiver.

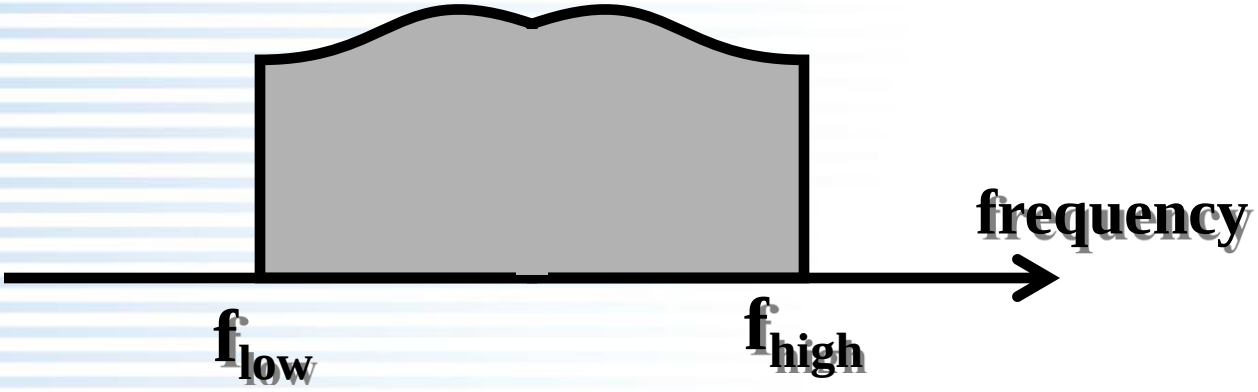
# Radio Signal Characteristics




**A continuous wave**
**or (CW) carrier wave (signal)**

- Frequency = number of cycles per second
  - Hertz (Hz) = 1 cycle per second
  - Kilohertz (kHz) = 1 thousand cycles per second
  - Megahertz (MHz) = 1 million cycles per second
  - Gigahertz (GHz) = 1 billion cycles per second
- Wavelength = (speed of light) / (frequency)
- Amplitude = Signal strength or power

# Bandwidth




**Bandwidth = the amount of the radio frequency spectrum occupied by an RF signal**

$$BW = f_{high} - f_{low}$$

# Conveying Information

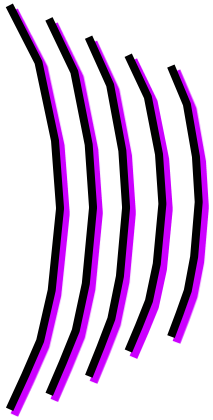
## Modulation

- **The information (voice, video, or data) is converted to an electrical signal that "modulates" a radio signal at the transmitter and is "demodulated" at the receiver.**
- **Modulation is the systematic variation of the characteristics of one signal (radio frequency carrier) in accordance with the characteristics of another signal (information).**
- **Examples: AM, FM, OFDM, etc.**

# Radio Propagation

- **Signals lose energy as they travel over the airwaves or other medium**

- **Like the ripples from a rock thrown in a pond - - waves decrease in size with distance**



- **Different propagation models used:**
  - **Free space – line of sight**
  - **Statistical models for urban, suburban, etc.**
  - **As frequency increases, radio signals behave like light; more loss**

# Overview of Spectrum Management

# Spectrum Management

- “Radio Spectrum” is the range of frequencies from 3 kHz to 400 GHz
- The spectrum resource is finite, but is never “exhausted”
- Spectrum Management: All activities associated with managing this resource
- Allocating & assigning the spectrum; managing interference; enforcement

# Frequency Allocations

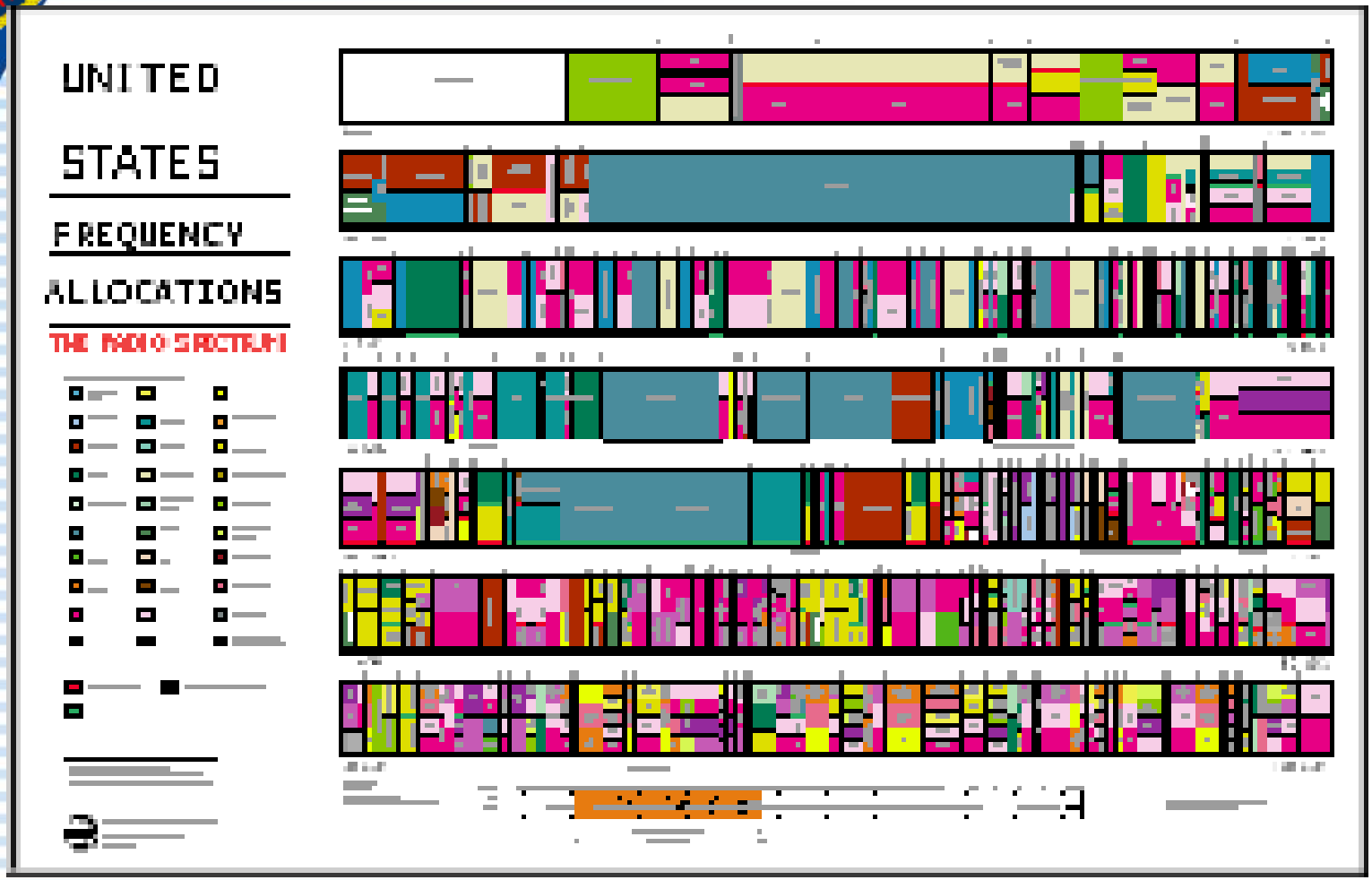
- "Master Zoning Map" - The entire range of usable spectrum is divided into blocks or bands of frequencies that are "allocated" for particular radio services: Mobile; Fixed; Broadcasting; Satellite; etc.

- Int'l Table of Frequency Allocations:
  - Radio signals do not recognize boundaries
  - World/Table is divided into three Regions

- U.S. Table of Frequency Allocations:
  - Government exclusive bands (NTIA)
  - Non-Government exclusive bands
  - Shared bands

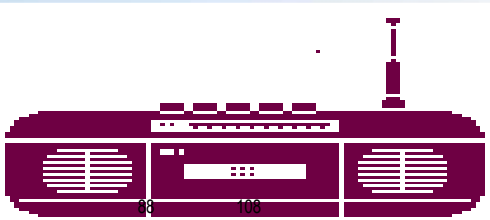
- Interference Protection Status:
  - Primary - Fully protected
  - Co-Primary - First-in is protected
  - Secondary - Must protect primary
  - Footnotes to the table (S, US, G, NG)

# U.S. Table of Frequency Allocations




Available at: http://www.ntia.doc.gov/osmhome/allochrt.html

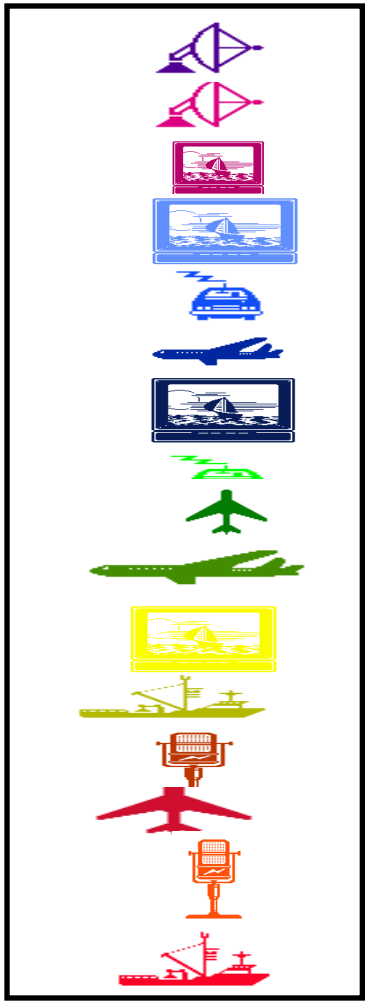
# A Simplified Spectrum Chart




FM Broadcast (88-108 MHz)

Satellite
Common Carrier Microwave
Cellular Phones
UHF-TV
Land Mobile
Coast Guard/Harbor
VHF-TV ch 7-13
Police
VHF Marine
Civil Air Patrol
Aviation
VHF-TV ch 2-6
CB
Amateur (Ham)
Search & Rescue (SAR)
AM Broadcast
Marine

15 GHz -
1 GHz -
800 MHz -
400 MHz -
150 MHz -
108 MHz -
54 MHz -
27 MHz -
1600 KHz -
70 KHz -



# All Spectrum Is Not Created Equal

| Frequency | Wavelength | Interesting Properties | Typical Uses |
|---|---|---|---|
| 10 kHz | 30 km (20 miles) | Waves penetrate significant distance into water | Communication with submarines |
| 100 kHz | 3 km (2 miles) | | Navigation |
| 1000 kHz (1 MHz) | 300 meters (1,000 feet) | | AM broadcasting |
| 10 MHz | 30 meters (100 feet) | Ionospheric reflection | CB radio, HF broadcasting |
| 100 MHz | 3 meters (10 feet) | | FM broadcasting TV broadcasting |
| 1000 MHz (1 GHz) | 30 cm (1 foot) | | Cellular radio, top of UHF TV band |
| 10 GHz | 3 cm (1 inch) | Higher ranges affected by intense rain | Satellite TV, point-to-point communications, radars |

# FCC's Table of Frequency Allocations 47 C.F.R. §2.106 (Sample)

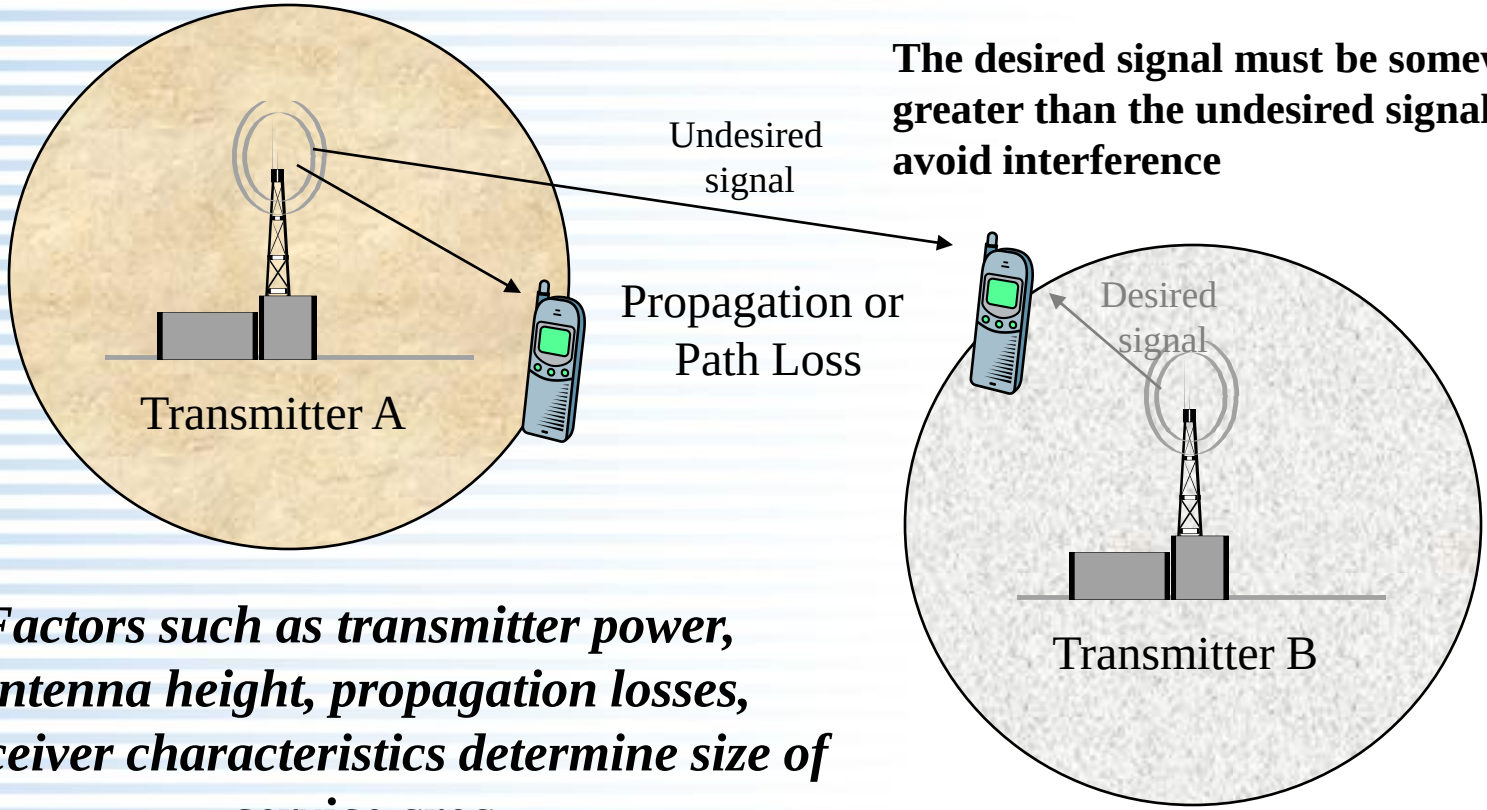
941-1429 MHz (UHF) Page 41

| International Table | | | United States Table | | FCC Rule Part(s) |
|---|---|---|---|---|---|
| Region 1 | Region 2 | Region 3 | Federal Government | Non-Federal Government | |
| See previous page for 890-942 MHz | See previous page for 928-942 MHz | See previous page for 890-942 MHz | 941-944<br>FIXED | 941-944<br>FIXED | Public Mobile (22)<br>Fixed Microwave (101) |
| 942-960<br>FIXED<br>MOBILE except aeronautical mobile<br>BROADCASTING S5.322 | 942-960<br>FIXED<br>MOBILE | 942-960<br>FIXED<br>MOBILE<br>BROADCASTING | US268 US301 US302 G2 | US268 US301 US302 NG120 | |
| | | | 944-960 | 944-960<br>FIXED | Public Mobile (22)<br>International Fixed (23)<br>Auxiliary Broadcast. (74) |
| S5.323 | | S5.320 | | NG120 | Fixed Microwave (101) |
| 960-1215<br>AERONAUTICAL RADIONAVIGATION<br><br>S5.328 | | | 960-1215<br>AERONAUTICAL RADIONAVIGATION<br><br>S5.328 US224 | | Aviation (87) |

Complete Table Available at: http://www.fcc.gov/oet/spectrum/

# Controlling Interference

***Transmitters operating on the same frequency need to be separated by some distance to avoid "harmful interference".***

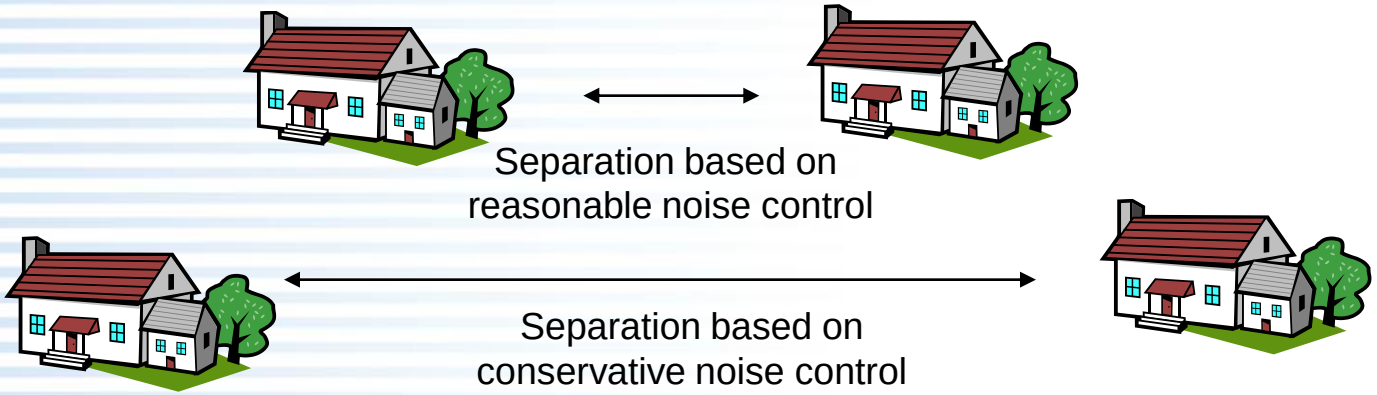



**The desired signal must be somewhat greater than the undesired signal to avoid interference**

***Factors such as transmitter power, Antenna height, propagation losses, & receiver characteristics determine size of service area***

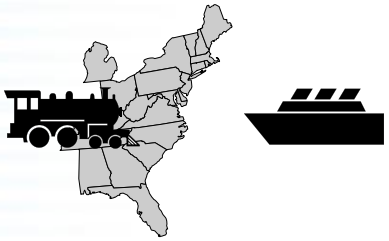
# Defining “Harmful Interference” And Why it Matters

- *Harmful Interference.* Interference which endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radio communication service operating in accordance with [the ITU] Radio Regulations
- Incumbents and newcomers often have different view of “harmful”
- Why it matters - - determines viability of spectrum access
- if radio were “audio” and were a basis for separation between homes - -

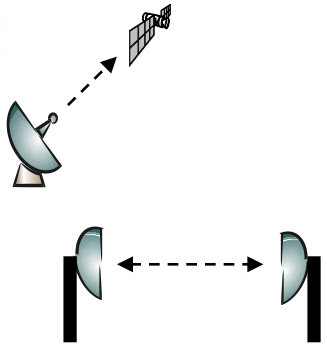


# Finding Spectrum for New Services

- Improve efficiency – pack more service in same space
  - Technical rules
  - Secondary markets
- Sharing:
  - Geographic separation
  - Frequency coordination
  - Overlays
  - Time of use
- Reallocation:
  - Remove or reduce allocation w/ no compensation
  - Reallocate and new licensee pays for relocation
  - Reallocate & pay for relocation w/ auction proceeds



Re-use Frequencies Through Geographic Separation

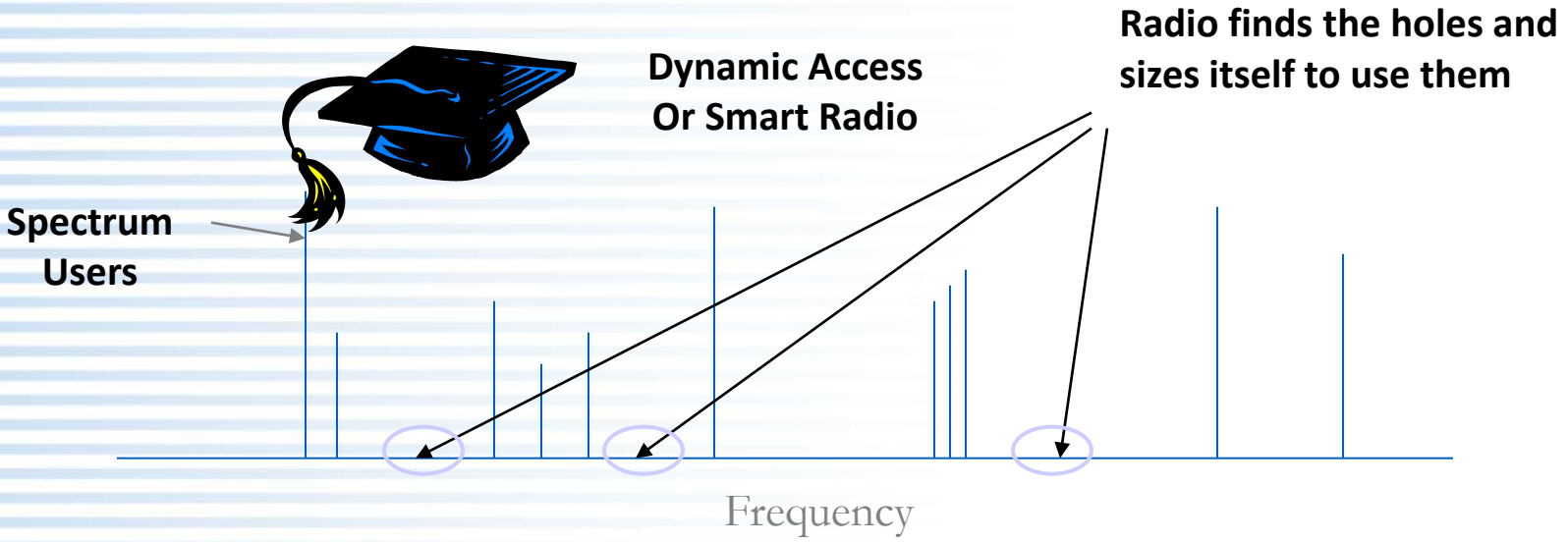


Earth Stations (Uplinks) and Fixed Microwave Links Can Use the Same Frequencies Through Antenna Discrimination

**Examples of Sharing**

# New Models: Dynamic Spectrum Access

- At any given location/time, much of the spectrum is “unused”
- Dynamic spectrum access or opportunistic use could potentially identify the “unused” spectrum and radio can adapt itself to operate without causing harmful interference
- FCC Notice of Inquiry adopted November 30



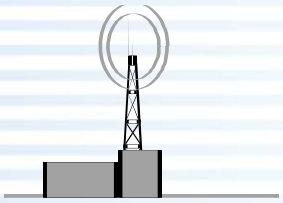
# Overview of FCC Rules

# FCC Jurisdiction

- FCC manages non-federal spectrum
- National Telecommunications & Information Administration (NTIA) manages federal spectrum
  - Advised by Interdepartmental Radio Advisory Committee (IRAC)
  - Federal Agencies participate in IRAC: DoE, DoD, DoT, NASA, State Dept., etc.
- FCC works closely with federal agencies on a wide variety of issues

# Licensed Radio Services

- Broadcasting

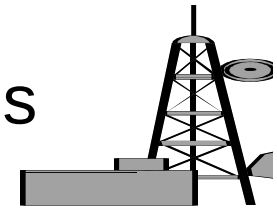


- Satellite

- Private Wireless
  - Public Safety
  - Industrial
  - Aviation
  - Marine
  - Amateur

- Commercial Mobile
  - Cellular
  - Personal Communications
  - Advanced Wireless
  - 700 MHz
  - Broadband Radio Service

- Fixed Wireless
  - Private
  - Common Carrier



# Standards For Licensed Radio Services

- Primarily focus on interference control
  - Frequency
  - Power Output
  - Bandwidth/Channels
  - Spurious Emissions
- Other:
  - RF Exposure
  - Hearing aid compatibility
  - E-911
- Rules strive to be technology neutral
- FCC *generally* has not regulated:
  - Protocols (i.e. LTE, WiMAX)
  - Performance
  - Reliability
  - Compatibility

# Unlicensed Devices: Part 15

- Part 15 provides for operation of low power unlicensed radio transmitters

- Operating conditions:
  - May not cause harmful interference
  - Must accept any interference received

- Part 15 minimizes likelihood of interference by:
  - Identifying permissible frequencies
  - Limiting power very low levels
  - Requiring equipment authorization

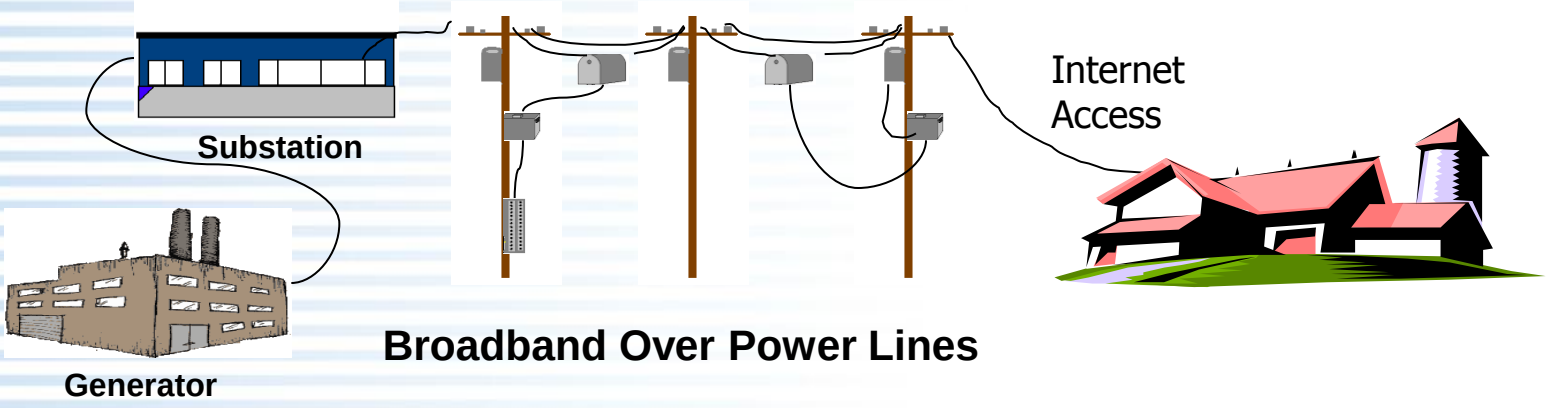
# Unlicensed Devices

**Part 15** provides for unlicensed devices: May not cause harmful interference and must accept any interference that may be received.


**Business & home networking**

**Metropolitan & Community Networks – WISPs**


**Devices for Consumer And Business Applications**




**Broadband Over Power Lines**

# Technical Standards for Unlicensed Devices

- Primarily focus is on interference control
- Operating frequencies/restricted bands
- Power/signal strength
- Out-of-band and spurious emissions
- Industry has developed protocol standards within the framework of the rules: Wi-Fi, Bluetooth; Zigbee; Homeplug, etc.

# TV White Spaces (TVWS)

- TV channels are "allotted" to cities to serve the local area
- Other licensed and unlicensed services also operate in the TV bands
- "White Spaces" are the channels that are "unused" at any given location by licensed devices

New York City Full Power TV Stations

2 | Low Power TV | 4 | Non-Broadcast spectrum | 5 | White Space | 7 | Wireless Microphones | 9 | Etc.

*Only for illustrative purposes*

Philadelphia Full Power TV Stations

White Space | 3 | Low Power TV | Non-Broadcast spectrum | White Space | 6 | White Space | 8 | Wireless Microphones | 10 | Etc.

# Overview of TVWS Rules

- Fixed and personal/portable devices allowed to operate in the TV white spaces on an unlicensed basis
- To identify channels available for use, devices must:
  - 1) include a geolocation capability and
  - 2) provide their location to a database of protected radio services at sends back a list of available channels at that location
- Database will be established and administered by a third party operators
- Rules also provide for devices that use spectrum sensing to identify available channels; separate rules and authorization path

# TVWS: Facilities to Be Protected

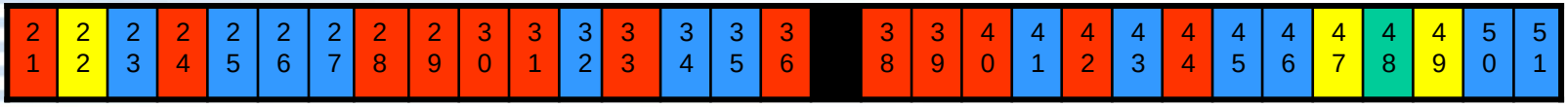
- Full power, low power, translator and Class A TV stations (also Canadian and Mexican stations in border areas)
- Low power broadcast auxiliary (mostly wireless mikes)
- Land mobile/CMRS (13 markets; public safety)
- Fixed broadcast auxiliary links
- Offshore radio telephone service (Gulf region)
- Certain radio astronomy sites

- Also must protect:
  - Unlicensed wireless mikes used at event venues
  - MVPD and low power TV receive sites

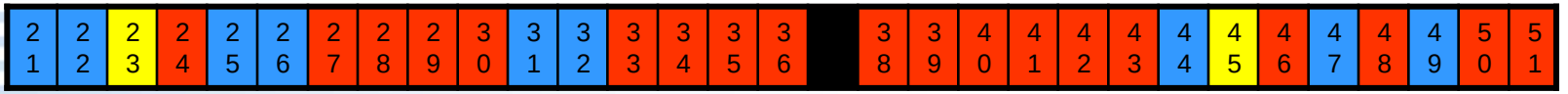
# TVWS Spectrum Availability

- Available spectrum varies by location
- In rural areas many channels are available
- In big cities only a few channels may be available
- Examples of availability in UHF channels 21 – 51 (**Illustrative**):

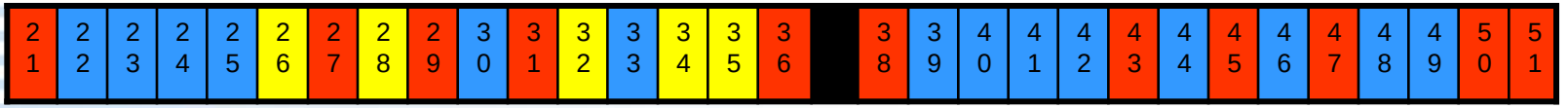
**New York**




**Washington, DC**




**Chicago**




Full Service DTV Station

Low Power TV Station

Channel Open/ Adjacent to TV

Channel Open/ Not Adjacent to TV

# Equipment Authorization

- Multi-tiered equipment authorization program - - many devices self-declared
- Most transmitters must be certificated by FCC or telecommunications certification body
- Equipment may not be imported or marketed until certificated
- Check label for FCC ID
- Grants of certification available on FCC web site

**Equipment Authorization (EA)**

*Office of Engineering and Technology (OET)*

*See http://www.fcc.gov/oet/ea/*

*FCC Id: XXXYYYY*

FC

# The National Broadband Plan

# Congress's charge in the Recovery Act led to the creation of the National Broadband Plan

**Congress said that the plan should:**

- "Ensure that all people of the United States have access to broadband capability and establish benchmarks for meeting that goal."
- "[I]nclude . . . a detailed strategy for achieving affordability . . . and maximum utilization of broadband infrastructure and service"
- "[I]nclude . . . an evaluation of the status of deployment of broadband service"
- "[I]nclude . . . a plan for use of broadband . . . in advancing consumer welfare, civic participation, public safety and homeland security, community development, health care delivery, energy independence and efficiency, education, worker training, private sector investment, entrepreneurial activity, job creation and economic growth, and other national purposes."

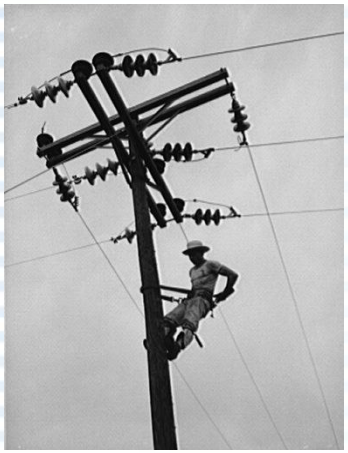
CONNECTING AMERICA: THE NATIONAL BROADBAND PLAN

**Published March 16, 2010**

# Why a National Broadband Plan?

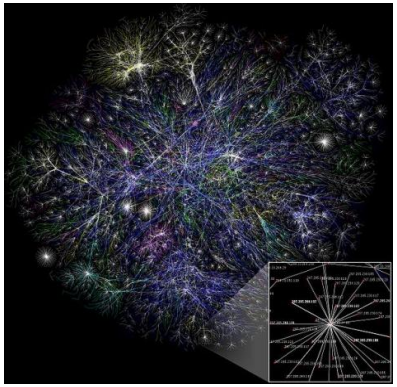
**Because broadband is the great infrastructure challenge of the early 21st century**


Transcontinental railroad (1860s)



Rural electrification (1930s)


Interstate highways (1950s)



**Broadband**

# Gaps in the broadband ecosystem today

**Availability gap**

- Fourteen million Americans do not have access to broadband infrastructure that can support today's and tomorrow's applications

**Adoption gap**

- 93 million Americans do not have broadband at home

**Digital skills gap**

- Many Americans lack digital skills, even as many job openings are posted exclusively online

**National purposes gap**

- The U.S. ranks in the bottom half of comparable countries on nearly every metric used to measure the adoption of health information technology

- Most of the U.S. electric grid is not connected to broadband

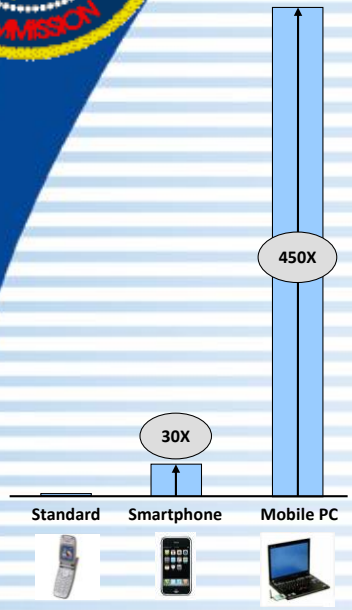
# Goals of the National Broadband Plan

- **Goal No. 1:** At least 100 million U.S. homes should have affordable access to actual download speeds of at least 100 megabits per second and actual upload speeds of at least 50 megabits per second.
- **Goal No. 2:** The United States should lead the world in mobile innovation, with the fastest and most extensive wireless networks of any nation.
- **Goal No. 3:** Every American should have affordable access to robust broadband service and the means and skills to subscribe if they so choose.
- **Goal No. 4:** Every American community should have affordable access to service of at least 1 gigabit per second to anchor institutions such as schools, hospitals and government buildings.
- **Goal No. 5:** To ensure the safety of the American people, every first responder should have access to a nationwide, wireless, interoperable broadband public safety network.
- **Goal No. 6:** To ensure that America leads in the clean energy economy, every American should be able to use broadband to track and manage their real-time energy consumption by 2020.

# Spectrum

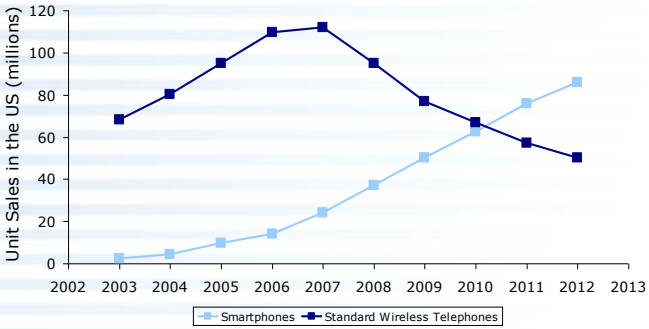
# Spectrum is the "oxygen" that wireless broadband needs to thrive

## Hungry Devices



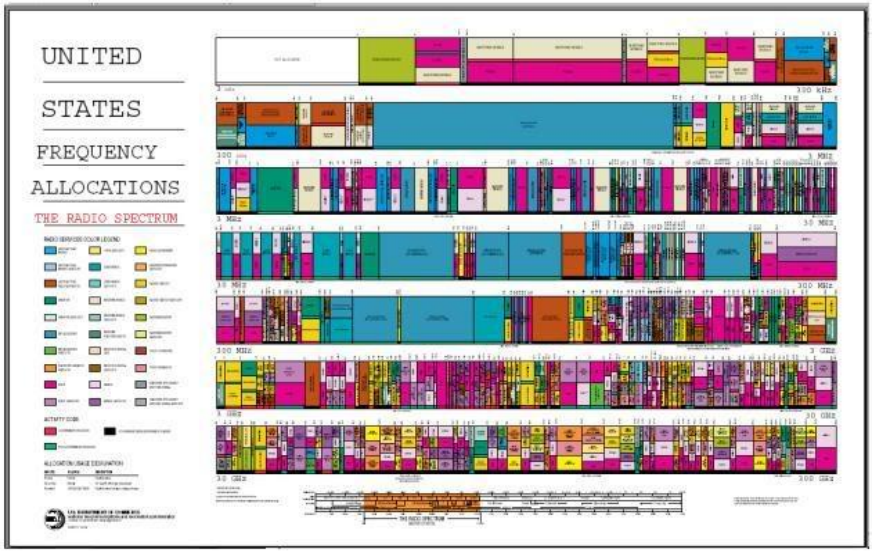

Source: Cisco

Smartphone sales to overtake standard phones by 2011




Source: TIA, Wilkofsky Gruen Associates from "TIA's 2009 ICT Market Review and Forecast".

## Consumer Apps




## National Purposes


*Civic Engagement*

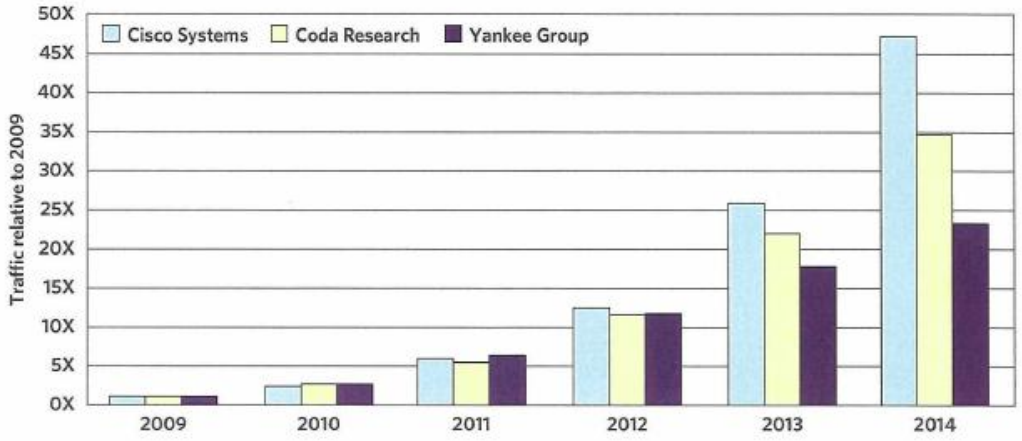
*Telemedicine*

*Public Safety*

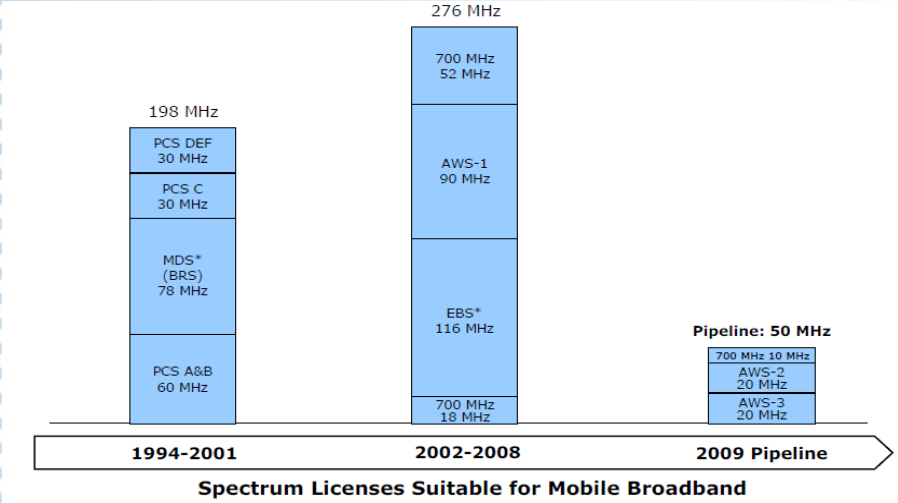
*Smart Grid*

# Trends in demand and supply suggest a looming spectrum gap

**Forecasted mobile data traffic in North America**




**Mobile broadband spectrum pipeline**




*In 2004 MDS/ITFS was rebanded to create the EBS/BRS band

**Need to transform spectrum policy to meet wireless broadband demands**

# Policy changes needed for a range of issues

| *Gaps* | *Issues* |
| --- | --- |
| **Lack of transparency in allocation and utilization** | • Current allocation and utilization data is largely unattainable and often esoteric |
| **Few spectrum reallocation tools** | • FCC needs at its disposal multiple tools for reallocating underutilized spectrum to next-generation users |
| **Insufficient capacity for broadband** | • Wireless broadband growth is causing network strain that will intensify with next-generation technologies<br>• Spectrum can take years to reclaim |
| **Suboptimal backhaul deployment** | • Growing need for expensive backhaul services, including microwave<br>• Access lacking in terms of capacity, flexibility and affordability |
| **Access models limited** | • Opportunistic access to spectrum is limited to certain bands<br>• Demand for unlicensed spectrum among key stakeholders |
| **Policy scope too bounded** | • There is no framework for identifying future spectrum bands and needs<br>• Coordination of multiple domestic and international stakeholders |

# Framework for recommendations

## 1 Ensure greater transparency in allocation and utilization

- Spectrum dashboard

## 2 Expand incentives and mechanisms available to reallocate or repurpose spectrum

- Incentive auctions
- Spectrum fees

## 3 Make more spectrum available

- Within 10 years, 500 megahertz total
- Bands under consideration include Broadcast TV, MSS, WCS and AWS

## 4 Facilitate deployment of spectrum for wireless backhaul

- More flexible rules

## 5 Expand opportunities for innovative spectrum access models

- New unlicensed allocation
- Opportunistic use
- R&D

## 6 Increase comprehensiveness of spectrum policy

- Work with NTIA
- Tribes
- International

# Unleash More Spectrum for Mobile Broadband

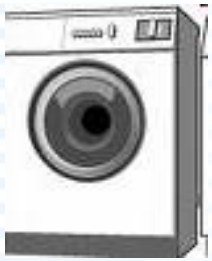
**The Plan recommends that the FCC make 500 MHz newly available for broadband use within the next ten years, of which 300 MHz of high-value spectrum between 225 MHz and 3.7 gigahertz (GHz) should be made newly available for mobile use within five years.**

| Band | Key Actions and Timing | Megahertz Made Available for Terrestrial Broadband |
|---|---|---|
| WCS | 2010—Order | 20 |
| AWS 2/3[2] | 2010—Order<br>2011—Auction | 60 |
| D Block | 2010—Order<br>2011—Auction | 10 |
| Mobile Satellite Services (MSS) | 2010—NPRM<br>2010—L-Band and Big LEO Orders<br>2011—S-Band Order | 90 |
| Broadcast TV[3] | 2010—NPRM<br>2011—Order<br>2012/13—Auction<br>2015—Band transition | 120 |
| Total | | 300 |

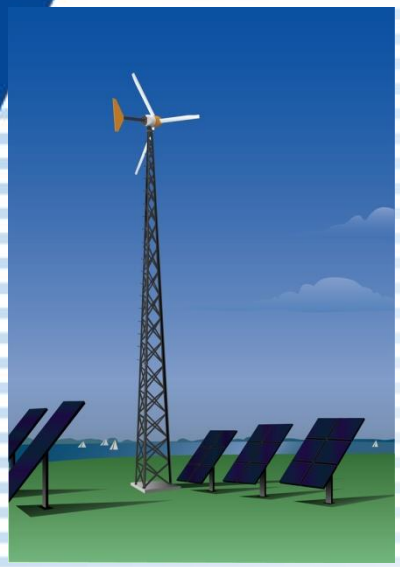
# Energy and the Environment

# As a platform for innovation, broadband helps consumers understand and manage their energy use





# Smart Grid Applications



HVAC Control

Appliance Control

Lighting

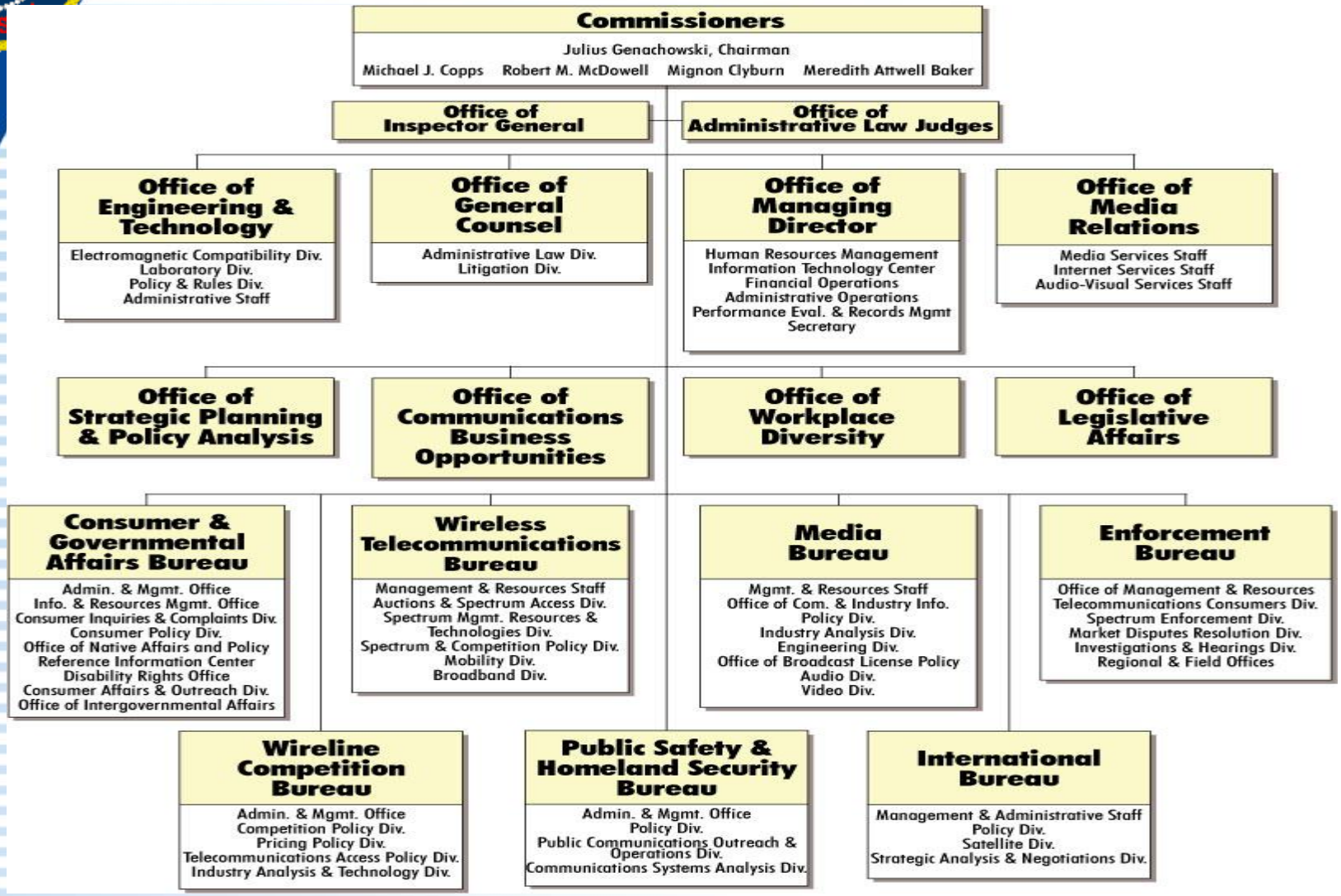
Meter Reading

Manage the Grid: Control Generation, Distribution and Storage of Energy

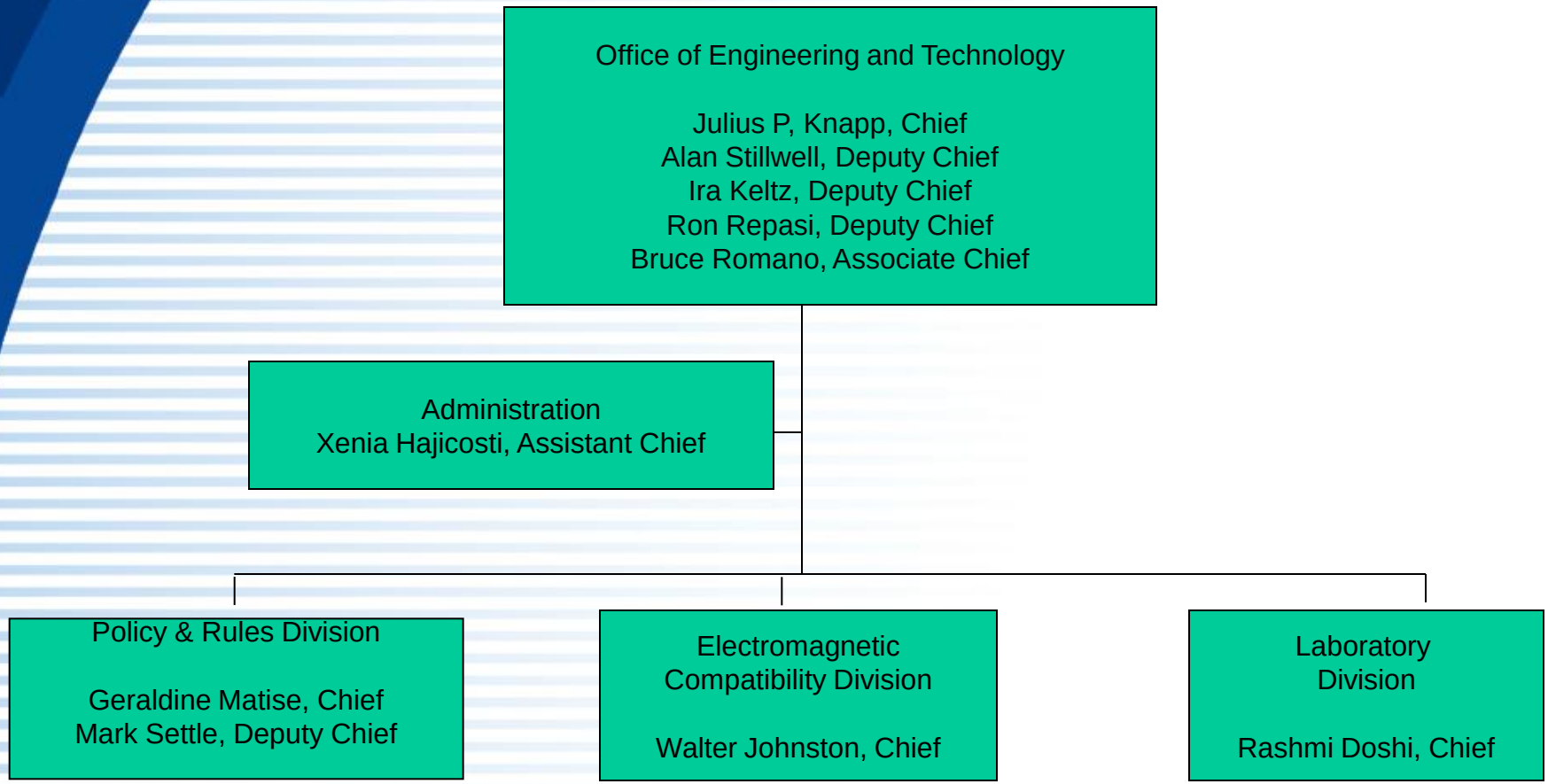
Manage Dynamically Efficient Use of Energy by Homes and Businesses

**A wide assortment of technologies - - wired, licensed and unlicensed - - are available for these and other Smart Grid applications**

# FCC Organization



# OET Organization Chart



# OET's Core Responsibilities

- **Provide independent technical analysis and advice to the Chairman, Commissioners, Bureaus and Offices**
- **Spectrum Management**
  - **Manage the Table of Spectrum Allocations**
  - **Develop & coordinate technical rules**
- **Responsibility for:**
  - **Part 2: Frequency Allocations and Radio Treaty Matters; General Rules and Regulations (particularly equipment authorization & marketing rules)**
  - **Part 5: Experimental Radio Service (Other Than Broadcast)**
  - **Part 15: Radio Frequency Devices**
  - **Part 18: Industrial, Scientific & Medical Equipment**
- **Authorization of Service**
  - **Equipment Authorization Program**
  - **Experimental Radio Licensing**
- **Technical Research and Analysis**

# Conclusion

Questions and Answers