Technical Underpinnings of Spectrum Management

Presentation by

Dale N. Hatfield

Adjunct Professor, University of Colorado

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Conference On

Spectrum Policy: From the Foundations to the Future

Washington, DC

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Introduction

Outline

- Background
  - What is Spectrum?
  - Basic Radio Communications System
  - Nature of the Spectrum Resource
  - Characteristics of Different Frequencies
  - Spectrum Diagram and Characteristics
  - Propagation Impairments
  - Notions of Bandwidth and Capacity
  - Dimensions of the Resource
  - Definition of Spectrum Management
  - Interference Considerations

Introduction

- Outline (Cont'd)
  - Spectrum Sharing/Interference
    - Geographic dimension
    - Frequency dimension
    - Time and other dimensions
  - Architectural Aspects of Spectrum Usage

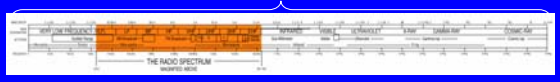
Background

- What Is Spectrum?
  - "Spectrum" is a conceptual tool used to organize and map a set of physical phenomena
  - Electric and magnetic fields produce (electromagnetic) waves that move through space at different frequencies
  - The set of all possible frequencies is called the "electromagnetic spectrum"

Background

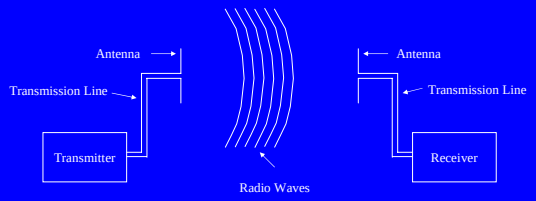
- What Is Spectrum?
  - The subset of frequencies between 3,000 Hz and 300 GHz is known as the "radio spectrum"
  - Note that radio waves do not require a medium *per se*, that is, radio waves can travel through a vacuum (e.g., outer space)

Electromagnetic Spectrum



Background

- Basic Radio Communication System



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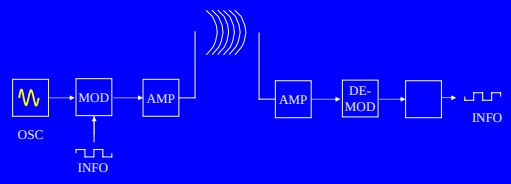


Transmitter Receiver

Background

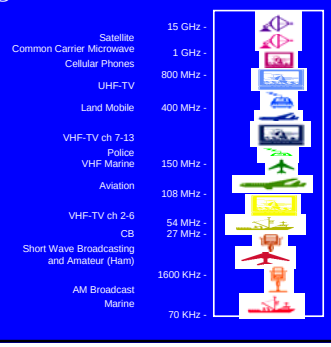
- Nature of the Spectrum Resource
  - A Unique Natural Resource
  - A National and International Resource
  - Infinitely Renewable
  - Like Air or Water It Can Be Polluted
  - Scarcity of the Resource – Economic Value

Background

- Characteristics of Different Frequencies
  - Some Factors Vary with Frequency
    - How fast the wave weakens with distance
    - Size of efficient antennas
    - Ability of the waves to penetrate buildings
    - Ability of the waves to penetrate through trees and other vegetation
    - Reflectivity of various objects to the waves

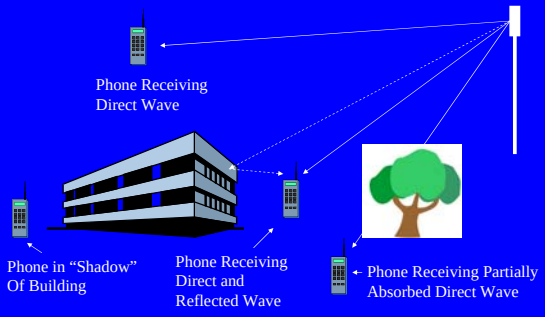
Background

- Spectrum Diagrams



Background

- Propagation Impairments



Background

- Concept of Bandwidth
  - The term bandwidth is an analog concept that is used in two (related) ways:
    - To mean the range of signal frequencies that a circuit (channel) will pass
    - To mean the range of signal frequencies that are occupied or utilized by a particular type of signal (e.g., an ordinary voice or an NTSC television signal)

Background

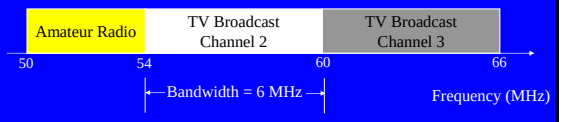
- Concept of Bandwidth (Cont'd)
  - The term bandwidth has been carried over into the digital world
  - In the digital world, bandwidth is just a measure of how fast information can be transmitted
  - In the digital world, bandwidth is measured in bits per second
  - Analogous measures: vehicles per hour or gallons per minute

Background

- Concept of Bandwidth (Cont'd)
  - Digital bandwidth (capacity) is related to analog bandwidth (capacity) by Shannon's Law
  - Shannon's Law states that the maximum amount of information that a circuit or channel can carry per unit of time (as measured in bits per second) depends upon its bandwidth and the strength of the desired signal relative to the strength of the noise in the channel

Background

- Concept of Bandwidth (Cont'd)



Note that in the "real world" radio systems achieve capacities of between less than 1 bps/Hz to 7 bps/Hz depending upon the quality of the channel (e.g., the signal-to-noise/interference ratio); stated another way, higher spectral efficiencies (bps/Hz) require higher signal-to-noise/interference for a fixed amount of analog bandwidth

Background

- Bandwidth Requirements of Different Signals
  - Voice requires only narrow bandwidths
    - Tens of kilobits/second (narrowband)
  - Still images require wide bandwidths
    - Hundreds of kilobits/second (wideband)
  - Video requires broad bandwidths
    - Several megabits/second (broadband)

*For transmission of the image in a reasonable amount of time

Background

- Dimensions of the Spectrum Resource (Eight):
  - Location (latitude, longitude, elevation)
  - Frequency
  - Time
  - Direction of Arrival (azimuth and elevation angle)
  - Polarization

Background

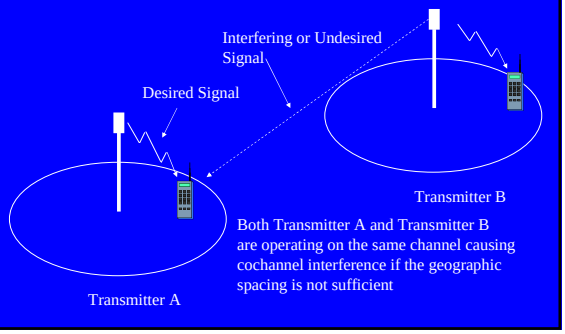
- Definition of Spectrum Management
  - All activities associated with regulating the use of the radio spectrum; it includes the structure and processes for allocating, allotting, assigning, and licensing the scarce resource as well as enforcing the associated rules and regulations

Background

- Interference Considerations
  - Some interference ("spillover") in each spectrum dimension is unavoidable in a practical sense
  - Interference occurs in the receiver (i.e., radio waves traveling through space do not "collide" with each other in a destructive fashion)
  - Managing interference (through regulation or market forces) is a key element of spectrum management
    - Overly restrictive interference regimes may lead to higher than necessary system costs and under-utilized spectrum ("white spaces")
    - Overly lenient interference regimes may lead to poor system performance, uneconomic mitigation techniques and hazards to systems that are critical to the safety of life and property/

Spectrum Sharing/Interference

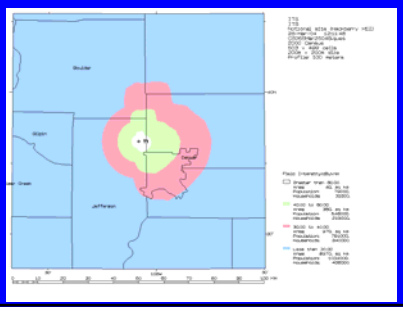
- Geographic Dimensions - Cochannel Interference



Both Transmitter A and Transmitter B are operating on the same channel causing cochannel interference if the geographic spacing is not sufficient

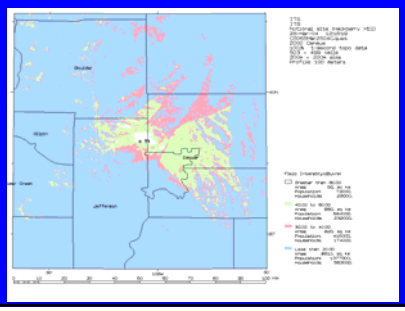
Spectrum Sharing/Interference

- Practical Radio Propagation Models
  - Site General Model



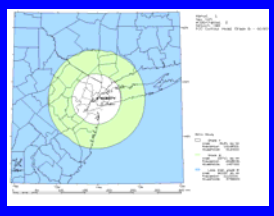
Spectrum Sharing/Interference

- Practical Radio Propagation Models
  - Site Specific Model

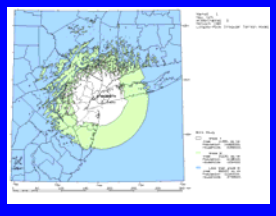


Spectrum Sharing/Interference

- Practical Radio Propagation Models



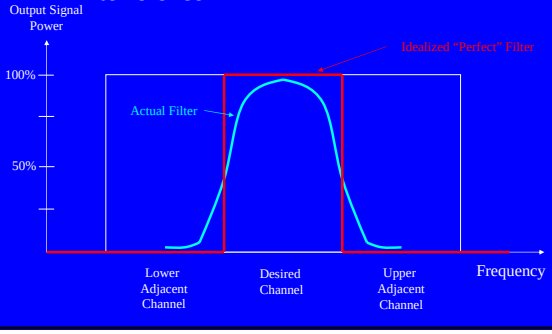
FCC Model (Carey)



ITS (Longley-Rice) Model

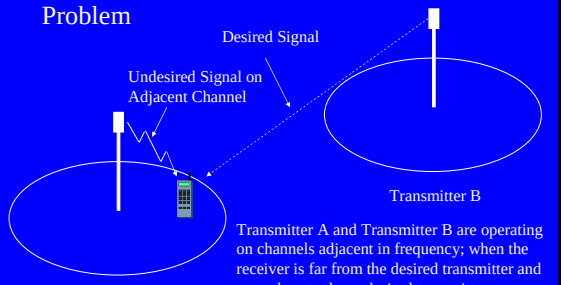
Spectrum Sharing/Interference

- Frequency Dimension - Adjacent Channel Interference



Spectrum Sharing/Interference

- Adjacent Channel Interference – "Near-Far" Problem

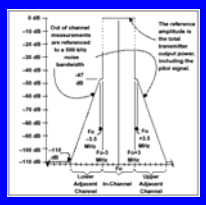


Transmitter A and Transmitter B are operating on channels adjacent in frequency; when the receiver is far from the desired transmitter and very close to the undesired transmitter, adjacent channel interference is exacerbated

Spectrum Sharing/Interference

- Transmitter Emission and Receiver Selectivity Characteristics

Sample Transmitter Emission Mask



Note that the FCC does not regulate receiver characteristics even though in some sense it is the receivers that "consume" spectrum; poor receiver front end selectivity, adjacent channel selectivity, intermodulation performance etc. can produce very inefficient use of the resource (See NOI in ET Docket No. 03-65, In the Matter of Interference Immunity Performance Specifications for Radio Receivers, Rel. 3/24/03)

Spectrum Sharing/Interference

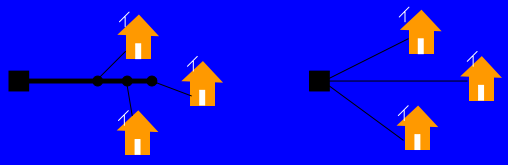
- Time Dimension
  - Transmitters cannot turn on and off instantaneously
  - Multipath
- Other Dimensions
  - Direction of Arrival
    - Transmitting/receiving antennas are not perfectly directive – beamwidths and sidelobes
  - Polarization
    - Imperfections due to atmospheric effects and reflections

Architectural Aspects

- Communications Types
  - One-to-many (e.g., broadcast -- communicating identical information to multiple users/devices simultaneously)
  - One-to-one (e.g., telephony or internet session – communicating different information between individual users/devices)
  - Many-to-one (e.g., telemetry – communicating different information from multiple users/devices)

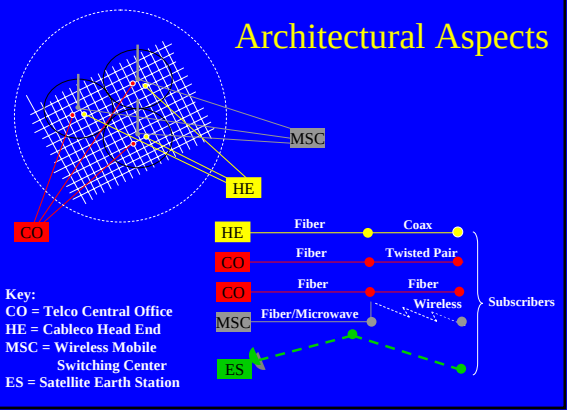
Architectural Aspects

- Network Types



Buss/Broadcast Star

Architectural Aspects



Conclusions

- Recent Paper Available At:
  - Weiser, Phil and Hatfield, Dale N., "Spectrum Policy Reform and the Next Frontier of Property Rights" . George Mason Law Review, Vol. 60, No. 3, 2008 Available at SSRN: http://ssrn.com/abstract=1097391
  - Response by Prof. Hazlett

Contact Information

Dale N. Hatfield
Adjunct Professor
Interdisciplinary Telecommunications Program
University of Colorado at Boulder
Engineering Center - ECOT-317
Campus Box 530
Boulder, CO 80309-0530
Main Tel: 303-492-8916
Direct Dial: 303-492-6648
Fax: 303-589-4546
Email: dale.hatfield@ieee.org
or hatfield@spot.colorado.edu