Digital Communication Systems Engineering with Software-Defined Radio

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Lecture 03

Engineering Trade-offs

- When designing wireless communication systems, decisions are required that adequately balance various system requirements
  - Transmit power, i.e., communication range, battery life
  - Data rate, i.e., bandwidth, throughput
  - Probability of bit error, i.e., error robustness
  - Interference
  - Cost
  - Form factor
- Some of these requirements can be conflicting
  - Transmit power *versus* probability of bit error
  - Interference *versus* data rate
  - Cost *versus* form factor
- Design decisions dependent on target wireless application

"Faster Than Real-time" Concept

- Rate at which discrete information is mapped to and from the analog domain dictated by *sampling rate*
  - Defined by the analog-to-digital converter (ADC) and digital-to-analog converter (DAC)
  - Bottleneck of any digital communication system
  - Digital processing rate could be orders of magnitude higher than ADC/DAC
- Within intra-sample time instants, numerous digital processing cycles can occur
  - Commit numerous digital processing cycles for each sample
  - Human operator unaware of any delay in transmitting/receiving samples
  - If sampling rate is in "real-time", then the digital processing between samples is "faster than real-time"
- Faster than real-time concept important since advanced processes and algorithms can be employed
  - Equalization and signal distortion compensation

Limited Battery Life

- Primary bottleneck on mobile wireless device performance is the *battery*
  - Limited supply of stored energy
  - Usually largest component of device $\rightarrow$ affects form factor and weight
  - Affected by temperature
- Unlike microprocessor industry, battery research and development has been relatively stagnant
- Only control that communication system engineers have in design process is to minimize power consumption
  - Minimize transmit power
  - Use power efficient digital processors
  - Reduce number of computations per operation
  - Lower transmission data rate
- Most wireless mobile devices have built-in power monitors

Interoperability

- Plethora of wireless standards
  - Depends on geographical location
    - City, state, country
  - Depends on wireless application
    - Cellular phone access, WLAN
  - Depends on organization
    - Fire fighters, police, national guard
- Standard differ significantly, preventing communications between users

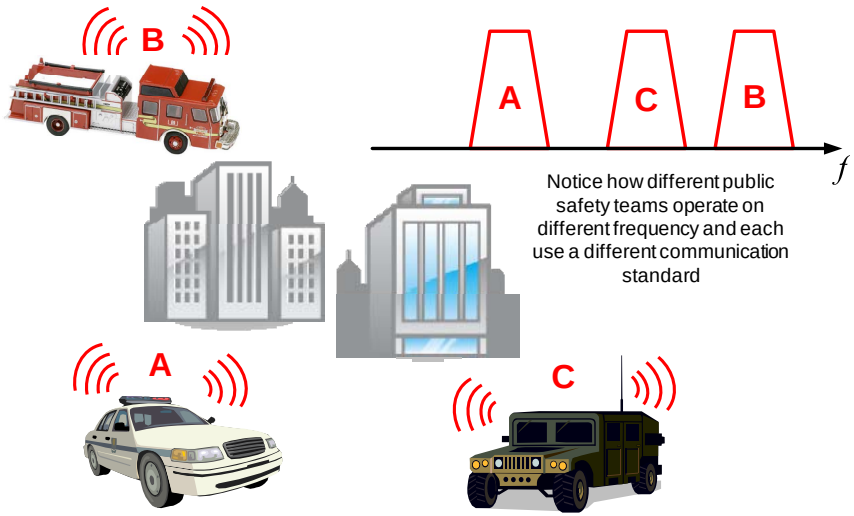

Figure : Example of Interoperability Issues in Emergency Scenarios (with Wireless Spectra Indicated).

Why Spectrum Regulations?

- When you have more than one transmitter, you have *electromagnetic interference*
  - In the frequency domain, signal spectra extend from $-\infty$ to $+\infty$
- Growing demand for access to frequency spectrum
  - Question: How many cell phone subscribers are their in the United States? Answer: 262 million subscribers in June 2008 (1.4 trillion minutes of talk time)
  - Need to accommodate as many users in a finite amount of spectrum
- Low frequencies are much preferred over higher frequencies
  - Prime spectral real estate ranges from DC to 3 GHz
  - Propagation characteristics are more favorable at lower frequencies

Who's Responsible?

- Electromagnetic spectrum is a *natural resource*
- Responsibility of national governments to monitor and regulation use of spectral resource
- International spectrum regulators
  - U.S. FCC & U.S. NTIA
  - Industry Canada
  - U.K. OfCom
  - Ireland ComReg

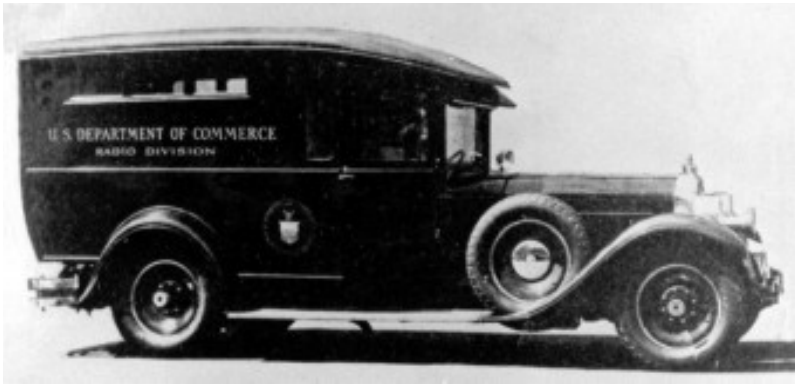

Figure : Radio Car - circa 1927 (photo courtesy of the Institute for Telecommunications Science (ITS), NTIA, U.S. Dept. of Commerce).

U.S. Spectrum Allocation Chart

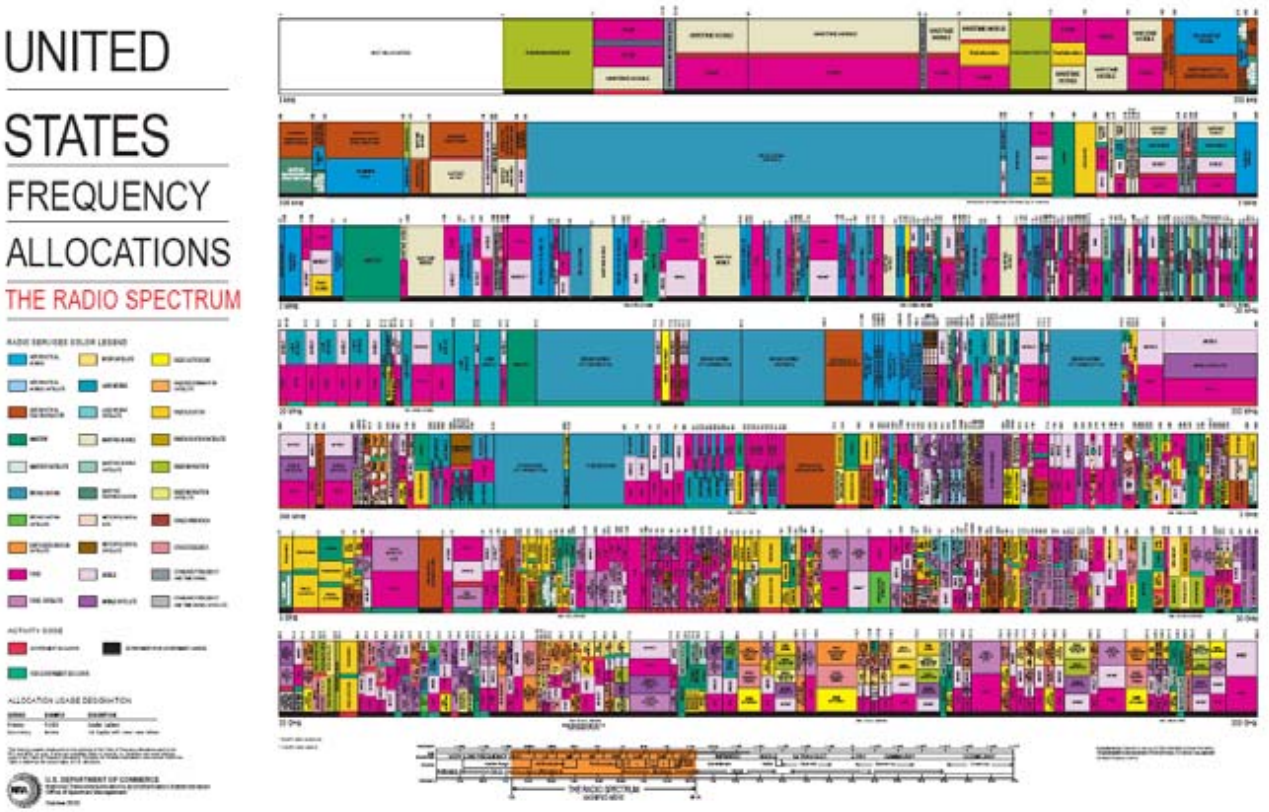

Figure : Frequency Allocation charts for the U.S. (courtesy of U.S. Dept. of Commerce, National Telecommunications and Information Administration, Office of Spectrum Management - Oct. 2003).

U.K. Spectrum Allocation Chart

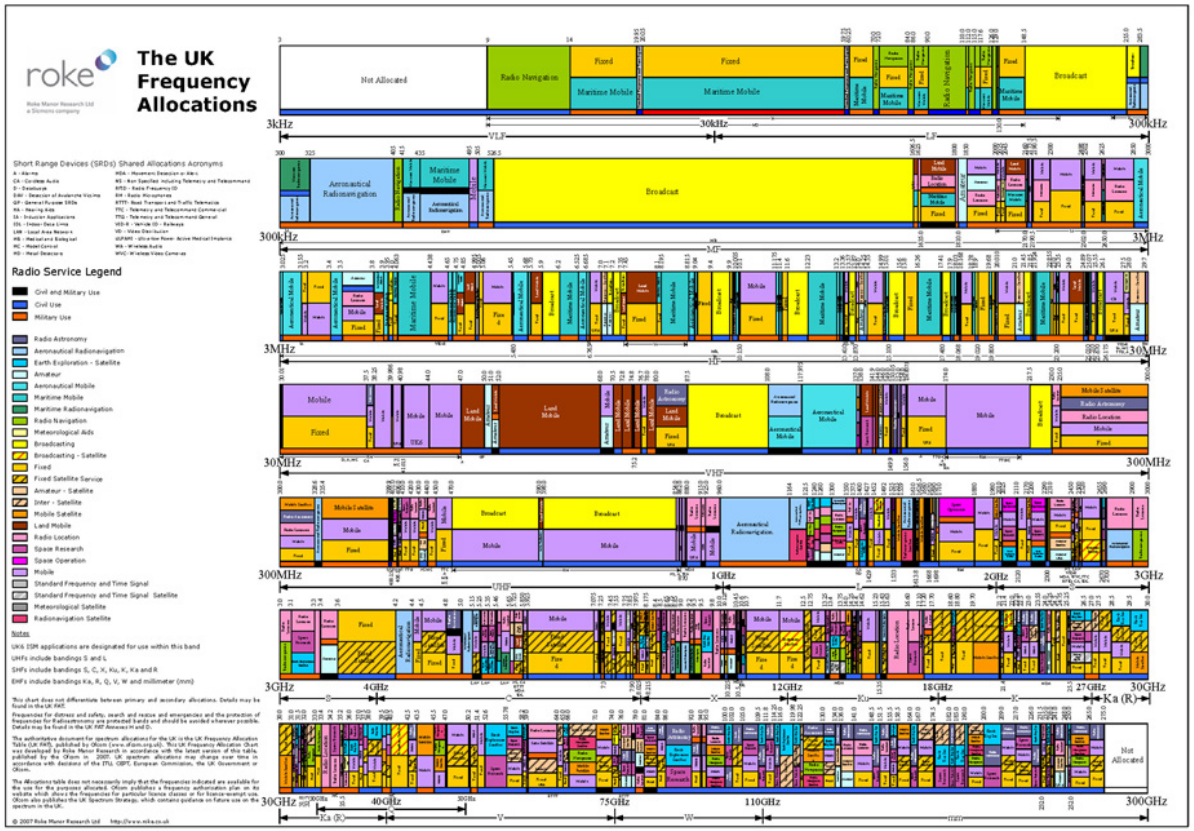

Figure : Frequency Allocation charts for the U.K. (courtesy of Roke Manor Research Ltd.).

Why Do We Need Spectrum Regulations?

- Many different wireless devices allocated same range of frequency spectrum
- Lack of centralized coordination between wireless devices employed in different applications
- Need to accommodate growing demand for wireless spectrum
- Without regulations, different wireless devices may unintentional interfere with each other
- Spectrum regulations dictate the following
  - Allowable transmit power levels
  - Frequency masks
  - Detection threshold for determining unoccupied spectrum

Out-of-band Emissions

- Out-of-band (OOB) emissions are a serious problem for any communication system
  - Interference issues with adjacent transmissions
- Transmit waveform determines amount of OOB emissions
- Signal processing techniques used to mitigate OOB interference

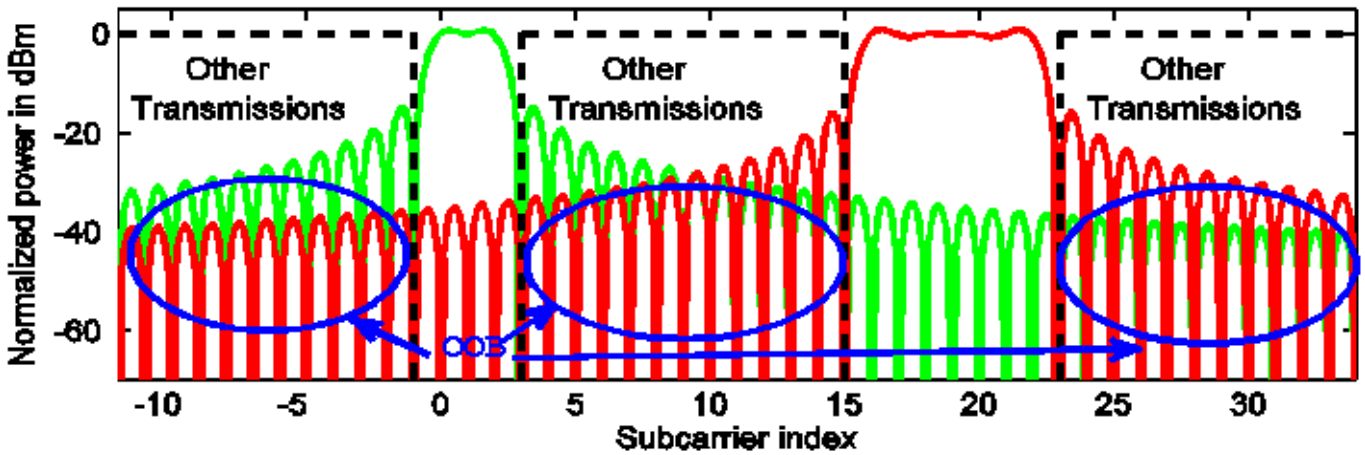

Figure : Illustration of OOB Emissions in the Frequency Domain.

Coexistence Between Different Signals

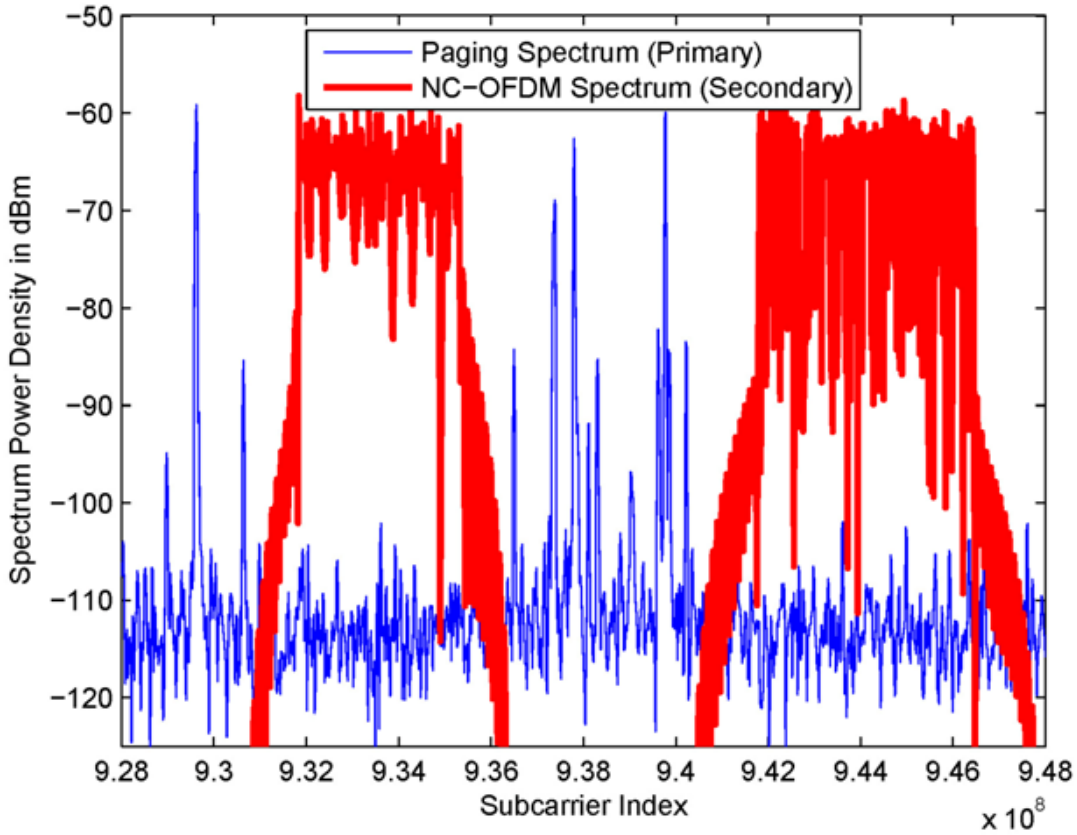

Figure : PSD of Paging Signals and NC-OFDM Signals Operating Across the 928 MHz-948 MHz Frequency Band.

"Hidden Node" Problem

- Multiple wireless communication networks *double booked* within same frequency spectrum
  - Different networks usually uncoordinated
  - Devices may or may not be designed to detect presence of other signals
  - Some devices can potentially be in receiver mode only
- Unintentional interference due to lack of spectral awareness
  - Devices not detected by other wireless systems within the vicinity called *hidden nodes*
- Difficult problem to solve $\rightarrow$ excellent graduate thesis topic!

"Hidden Node" Problem

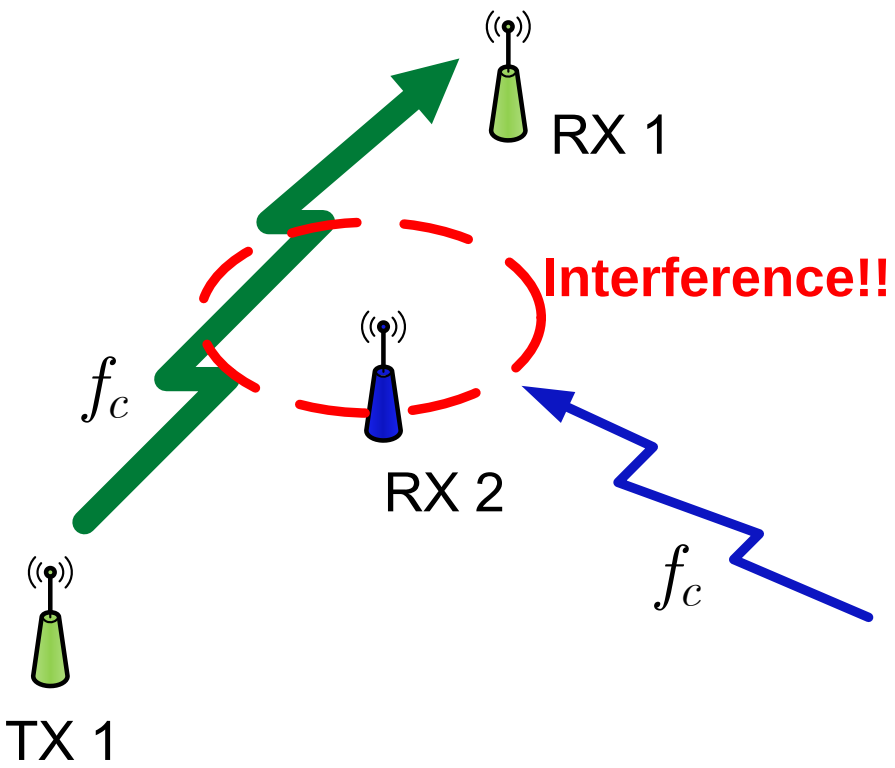

Figure : Illustration of the Hidden Node Problem, where **TX 1** Interferences with **RX 2** by Transmitting on the Same Frequency f_c.