Digital Communication Systems Engineering with Software-Defined Radio

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Lecture 19

Recall U.S. Spectrum Allocation Chart

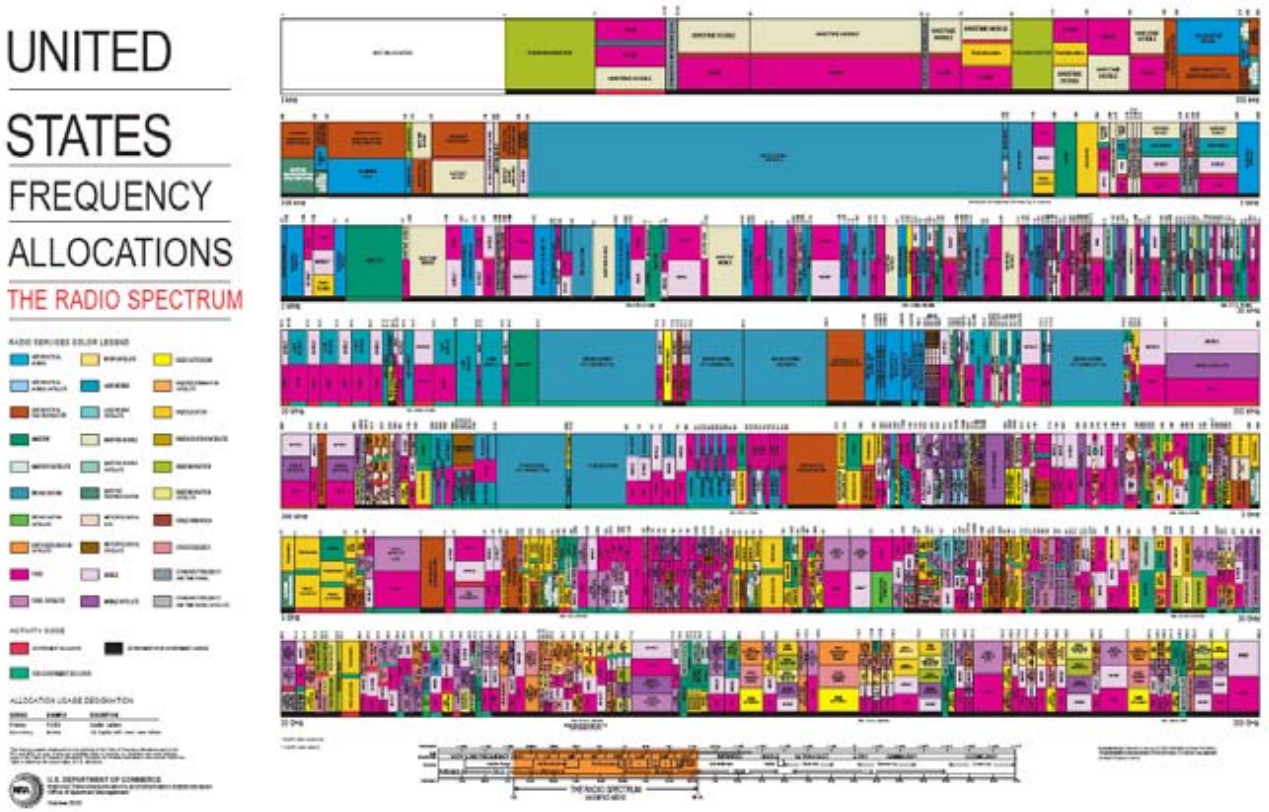

Figure : Frequency Allocation Charts for the U.S. (Courtesy of U.S. Dept. of Commerce, National Telecommunications and Information Administration, Office of Spectrum Management - Oct. 2003).

Need for 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

Electrospace Concept

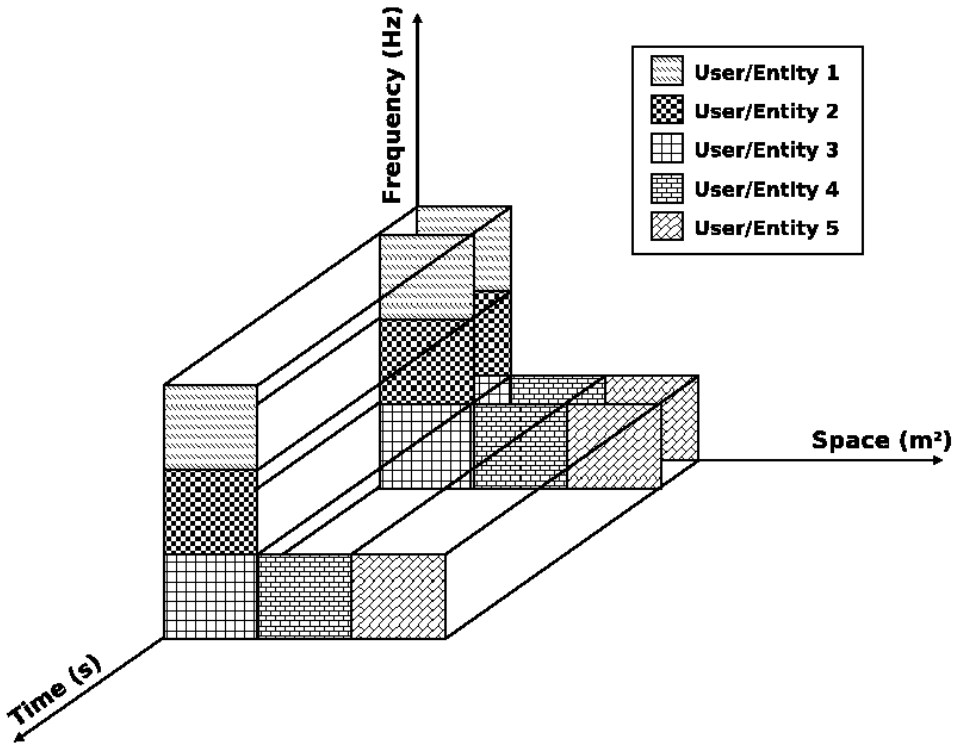

Figure : Schematic of the Electrospace Concept.

A. Attar, O. Holland, H. Aghvami. "Spectrum Access and Sharing." in *Cognitive Radio Communications and Networks: Principles and Practice* (A. M. Wyglinski, M. Nekovee, Y. T. Hou (eds.)), Academic Press, 2009.

Determining Unoccupied Spectrum

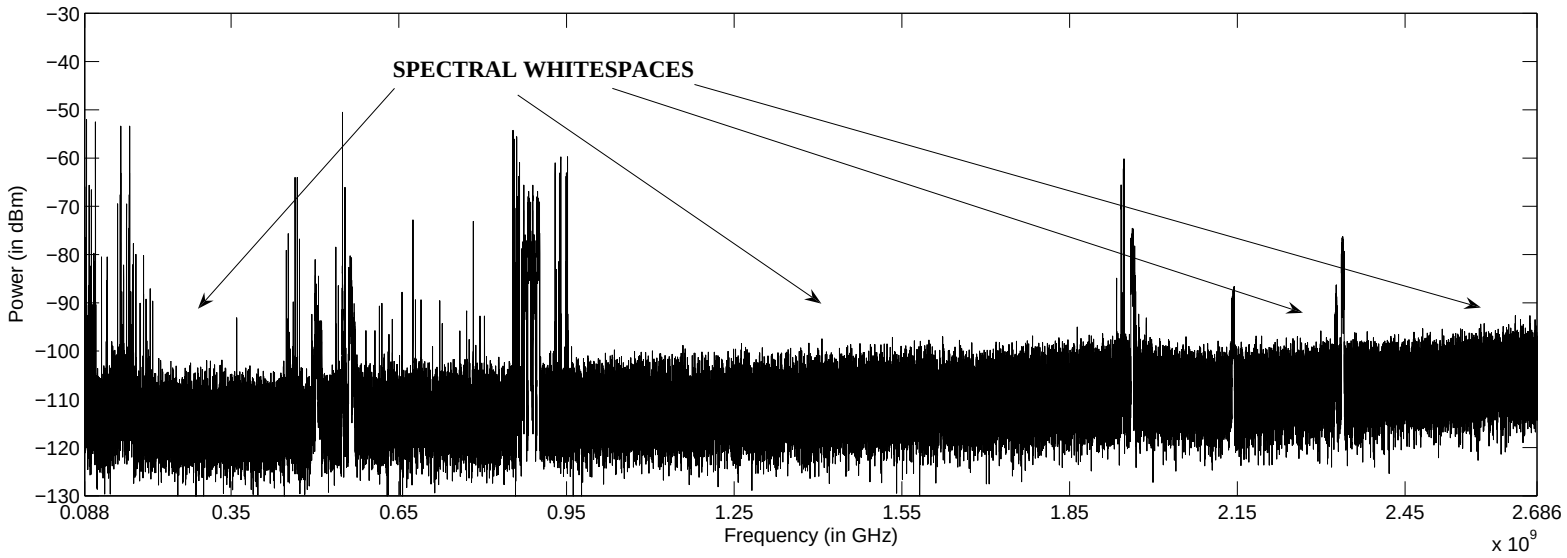

Figure : Spectrum Snapshot from 88 MHz to 2686 MHz Measured on July 11, 2008 in Worcester, MA, USA ($N42°16.36602$, $W71°48.46548$).

S. Pagadarai, R. Rajbanshi, G. J. Minden, A. M. Wyglinski. "Agile Transmission Techniques." in *Cognitive Radio Communications and Networks: Principles and Practice* (A. M. Wyglinski, M. Nekovee, Y. T. Hou (eds.)), Academic Press, 2009.

Spectrum Sensing

- To assess the occupancy of specific frequency band, there exists three commonly used techniques for sensing spectrum:
  - **Matched Filtering**: Optimal approach to detecting presence of specific signals due to SNR maximization, but effectively requires demodulation of the received signal
  - **Energy Detection**: Simple implementation based on averaging the frequency bins of an FFT and applying an energy threshold to the result, but possesses substantial probabilities of missed detection and false alarm
  - **Cyclostationary Detection**: Exploits redundancy and statistical characteristics of an intercepted signal, but at the cost of high computational complexity

Conventional Spectrum Access

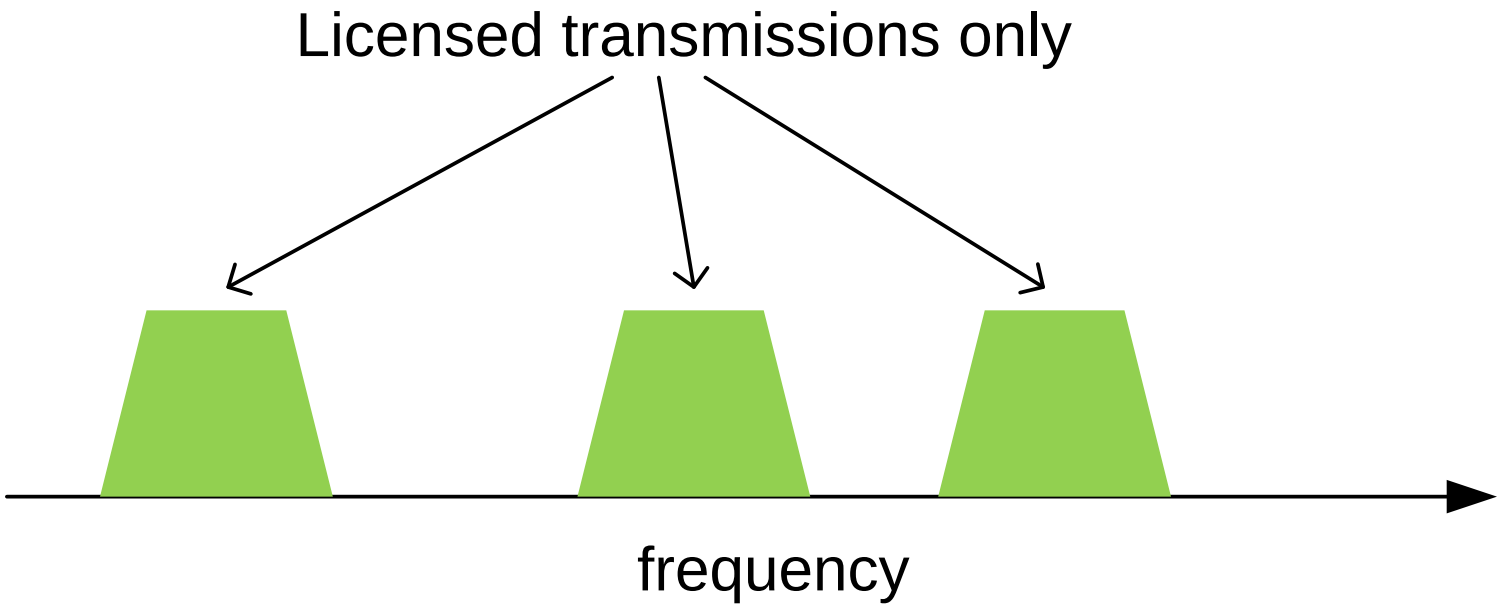

Figure : An Example of Conventional Spectrum Allocation. Notice the Absence of Secondary Transmissions in the Licensed Frequency Band.

Dynamic Spectrum Access Paradigm

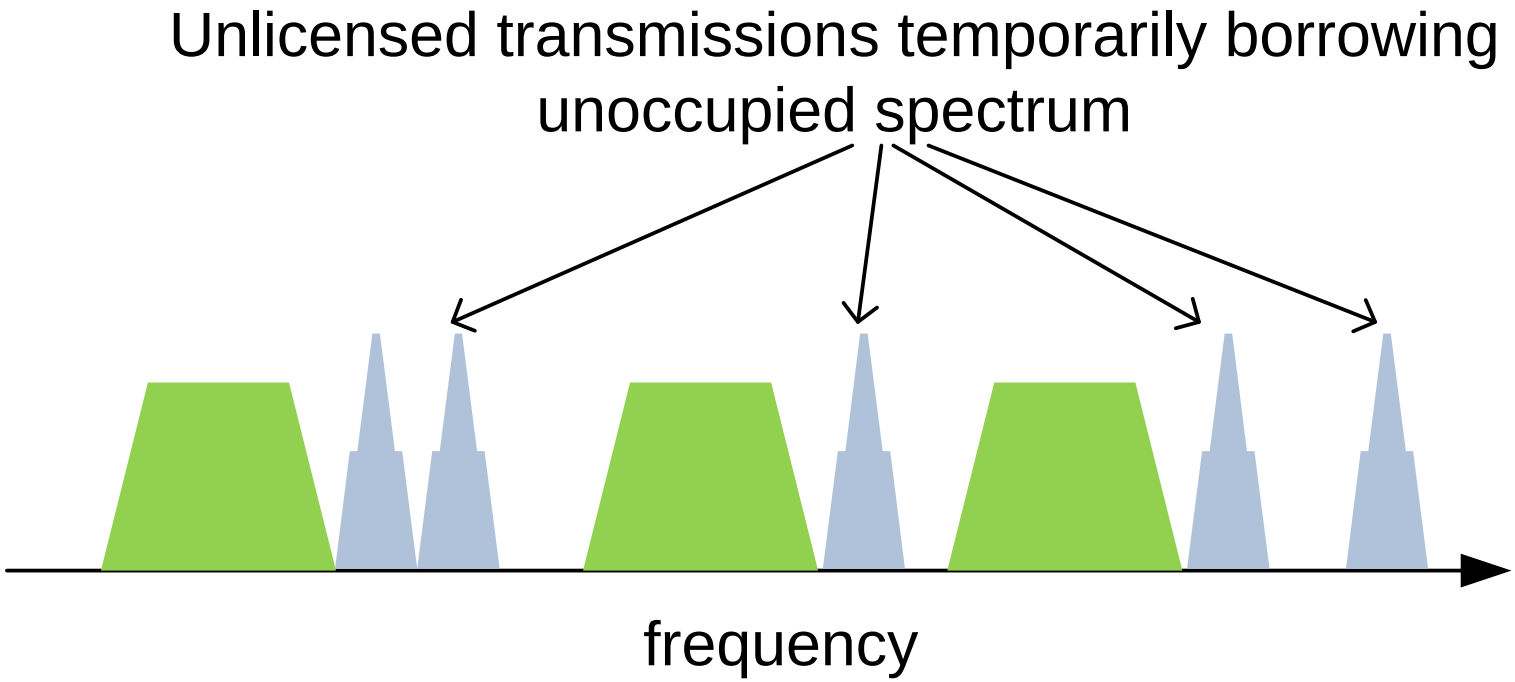

Figure : An Example of Dynamic Spectrum Access.

Must Avoid Spectral Collisions!

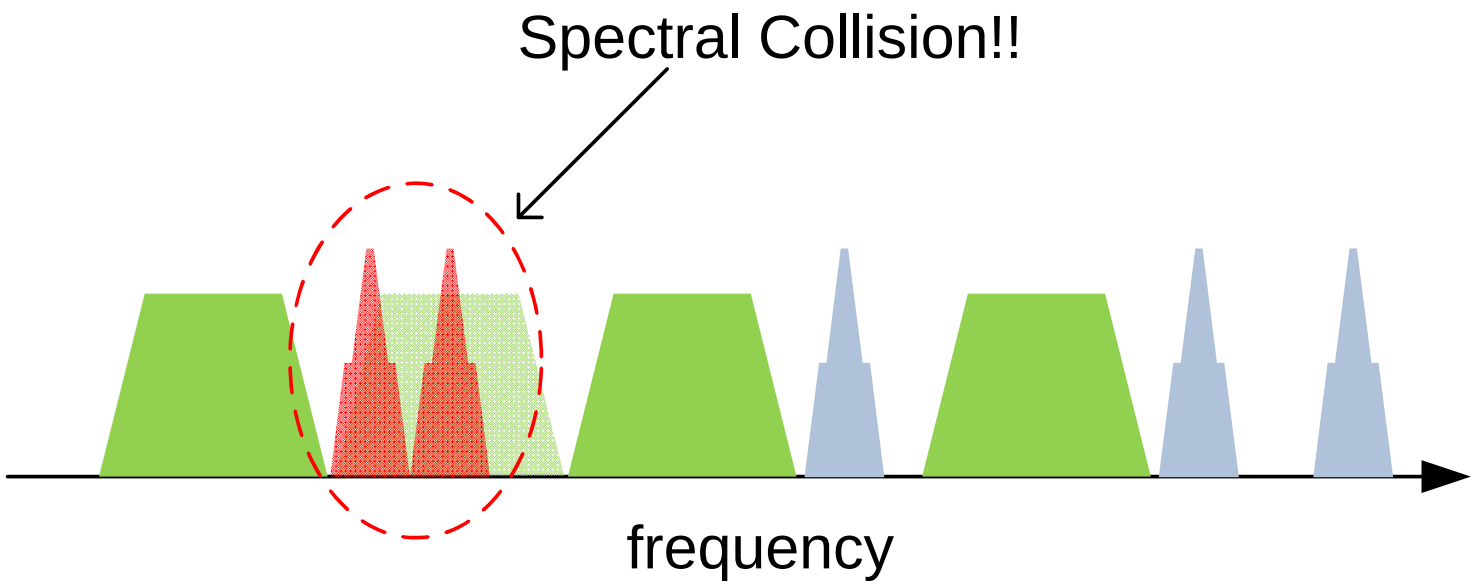

Figure : An Example of Spectral Collision between Primary and Secondary Transmissions.

Wireless Interoperability

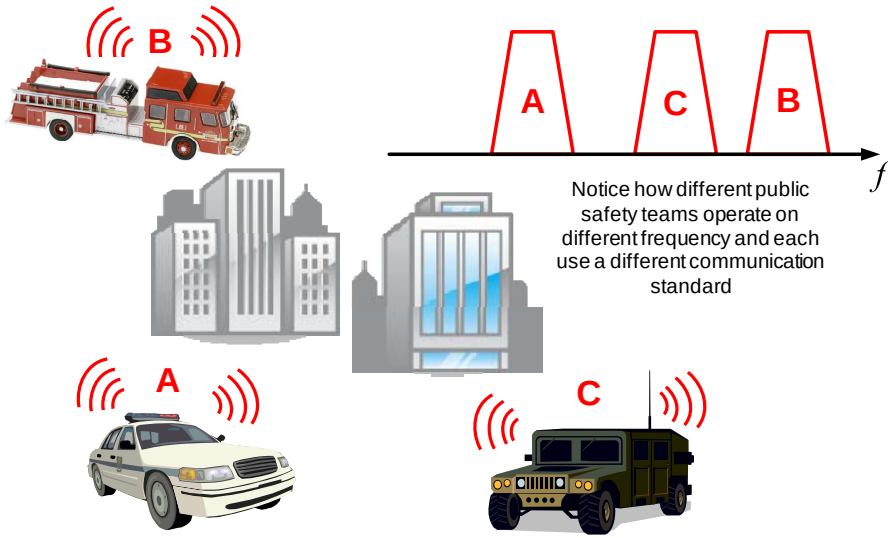

Figure : Example of Interoperability Issues in Emergency Scenarios (with Wireless Spectra Indicated).

A. M. Wyglinski, M. Nekovee, Y. T. Hou. "When Radio Meets Software." in *Cognitive Radio Communications and Networks: Principles and Practice* (A. M. Wyglinski, M. Nekovee, Y. T. Hou (eds.)), Academic Press, 2009.

Practical Spectrum Sensing Considerations

- There are several consideration that must be accounted for when conducting a spectrum measurement:
  - **Sweep Time**: The amount of time necessary to acquire spectrum measurement data over a specific frequency range and resolution is finite
  - **Resolution Bandwidth**: Being able to accurately characterize the spectrum requires numerous sample points
  - **Sweep Averaging**: Wireless transmissions are a time-varying phenomena whose spectral characteristics may significantly differ at two separate time instants, thus an averaging of several spectrum sweeps is necessary

Spectrum Occupancy Decision Making

- *Hypothesis testing* can be used in making decisions about whether a specific frequency is occupied or not by a signal
- The following hypothesis test can be employed in this process:

$$\begin{aligned} \mathcal{H}_0: &\quad y(k) = w(k) \rightarrow \text{Idle} \\ \mathcal{H}_1: &\quad y(k) = s(k) + w(k) \rightarrow \text{Occupied} \end{aligned}$$

where $w(k)$ is the noise signal sample and $s(k)$ is a transmitted signal sample