Digital Communication Systems Engineering with Software-Defined Radio

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Lecture 23

Inefficient Spectrum Utilization

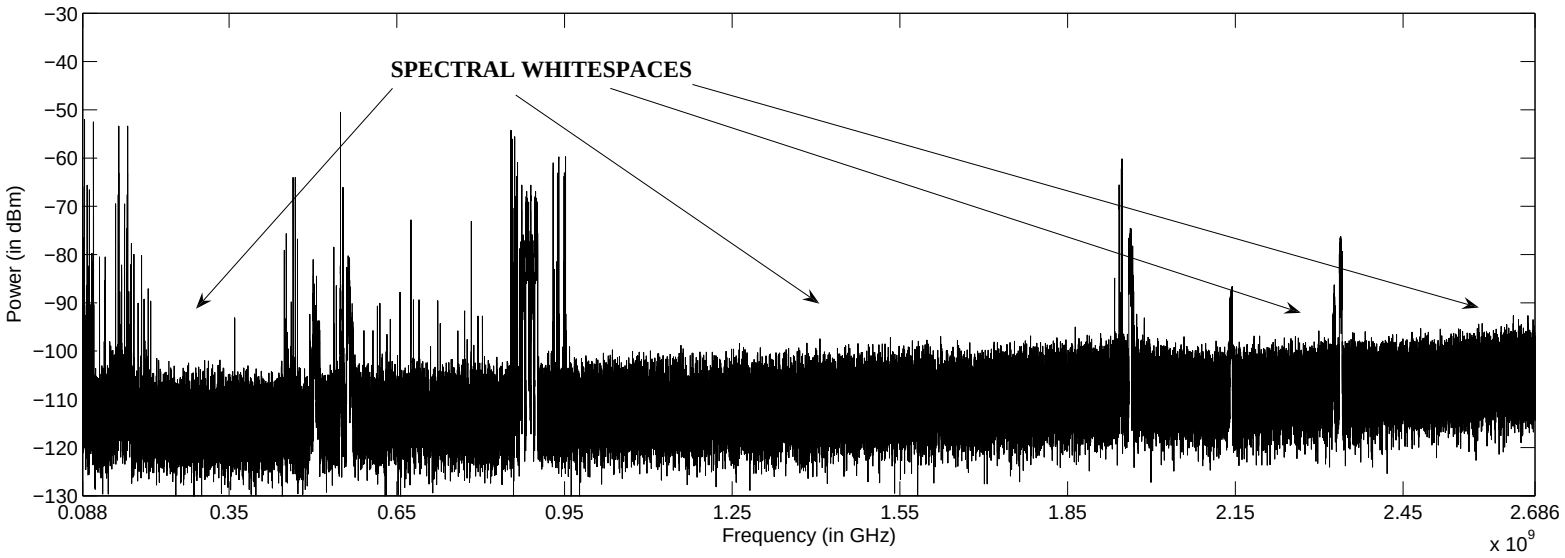

Figure : Spectrum Snapshot from 88 MHz to 2686 MHz Measured on July 11, 2008 in Worcester, MA, USA ($N42°16.36602$, $W71°48.46548$).

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.

Waveform Agility Needed

- The utilization efficiency of "prime" wireless spectrum has been shown to be poor
- In order to better utilize wireless spectrum, detection of white spaces in licensed bands and hardware reconfigurability are crucial
- A variant of OFDM named *non-contiguous OFDM* (NC-OFDM) meets the above requirements and supports high data-rates while maintaining acceptable levels of error robustness

Spectral "Divide-and-Conquer"

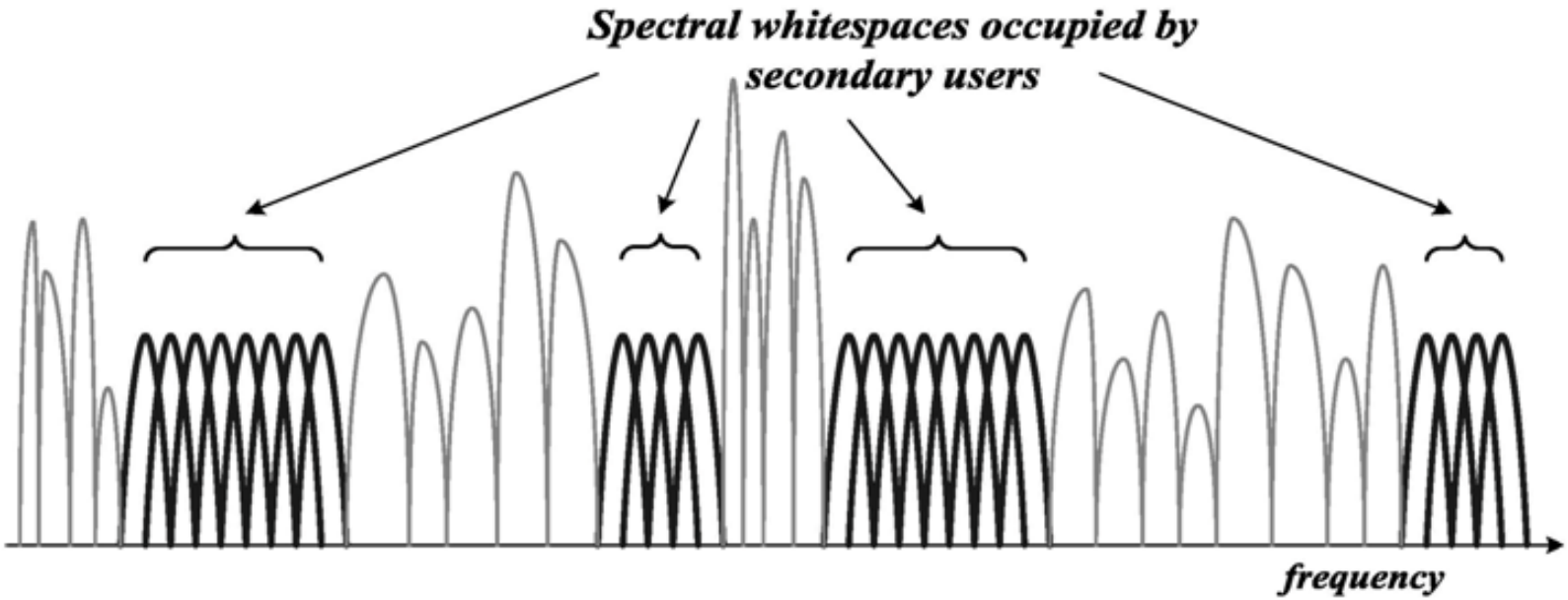

Figure : An Illustration Showing Utilization of Non-contiguous Regions of Spectrum for Wireless Transmission.

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Existing Dynamic Spectrum Access Approaches

- *Spectrum Pooling*: Create a common inventory of spectral resources from licensed users
- Cooperative versus non-cooperative transmission
  - *Cooperative Transmission*: Exchange of information between users, centralized or non-centralized control, etc.
  - *Non-cooperative Transmission*: Minimum or no exchange of information, poor spectrum utilization efficiency, nodes act in a greedy fashion
- Underlay versus overlay transmission

Underlay Transmission Approach

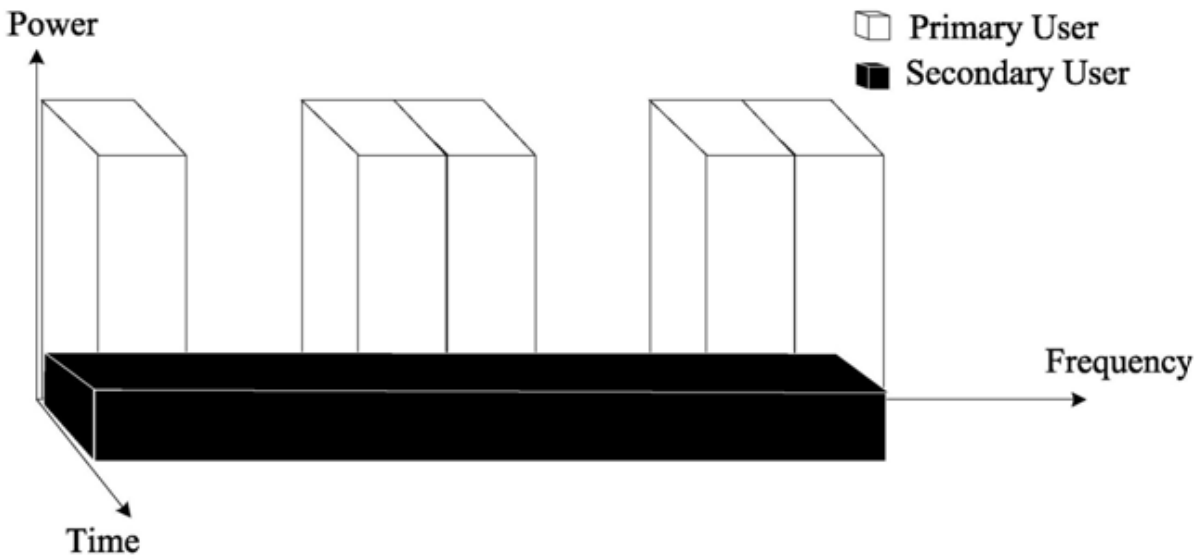

Figure : Underlay Spectrum Sharing.

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Overlay Transmission Approach

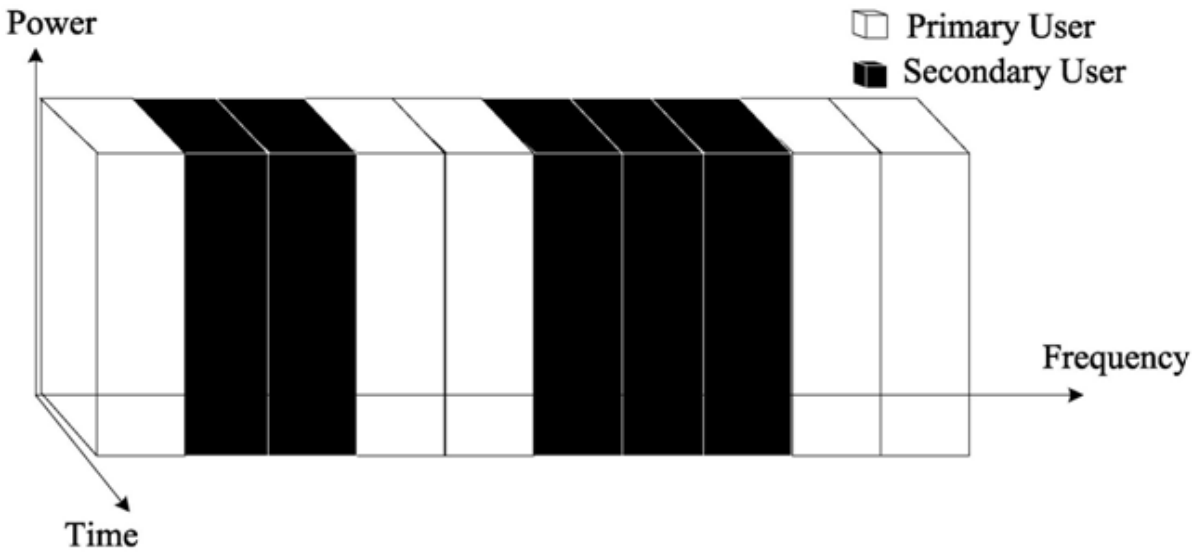

Figure : Overlay Spectrum Sharing.

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Challenges

- What are the design issues that arise during secondary utilization of a licensed band?
  - Minimum interference to licensed transmissions
  - Maximum exploitation of the gaps in the time-frequency domain

NC-OFDM Transmitter

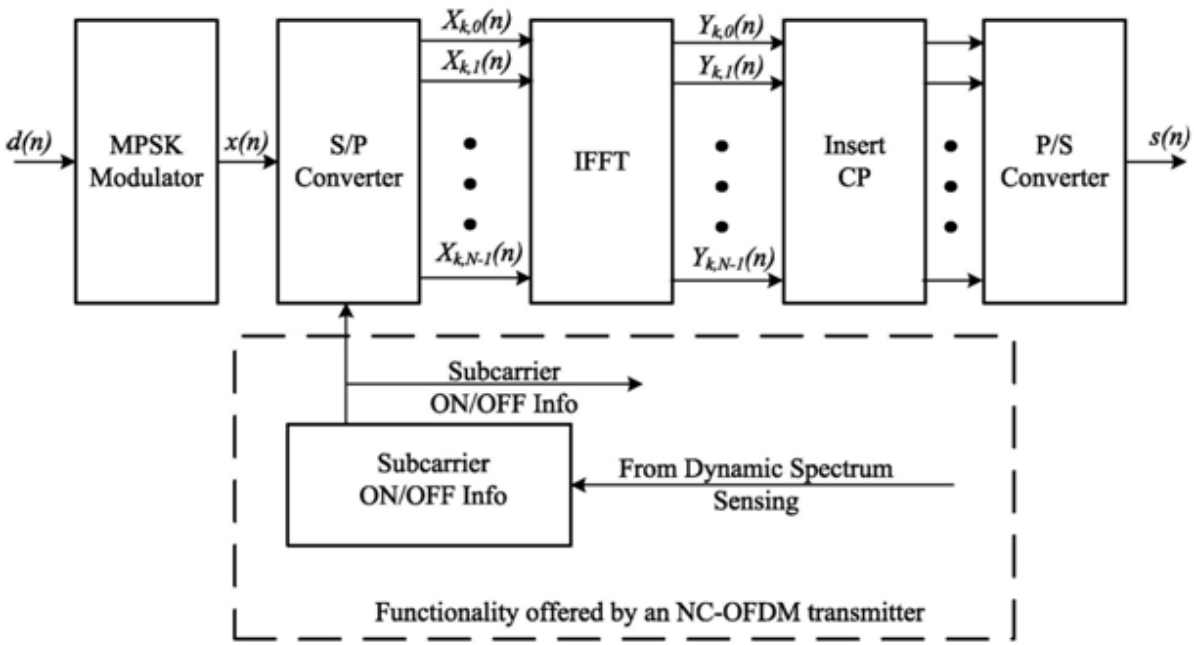

Figure : Non-contiguous OFDM Transmitter.

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NC-OFDM Receiver

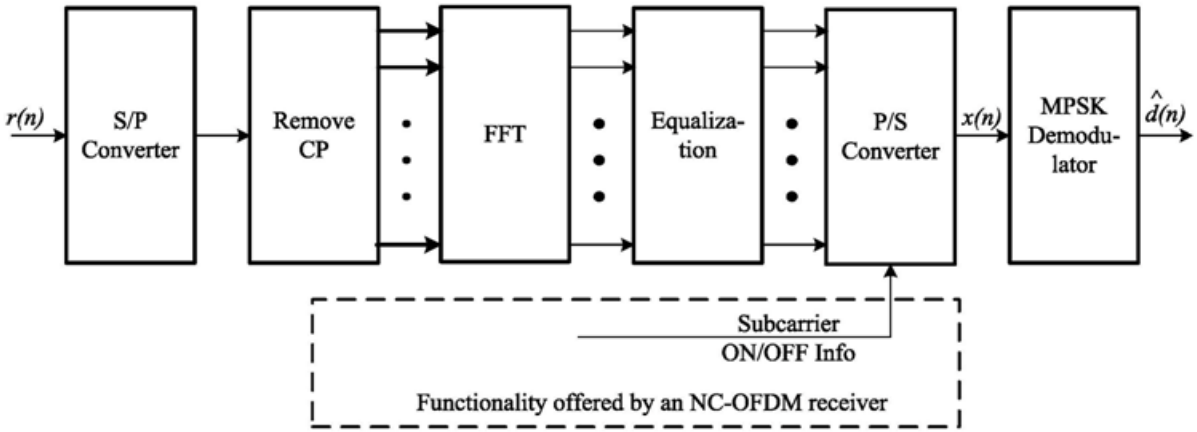

Figure : Non-contiguous OFDM Receiver.

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OOB Interference Issue

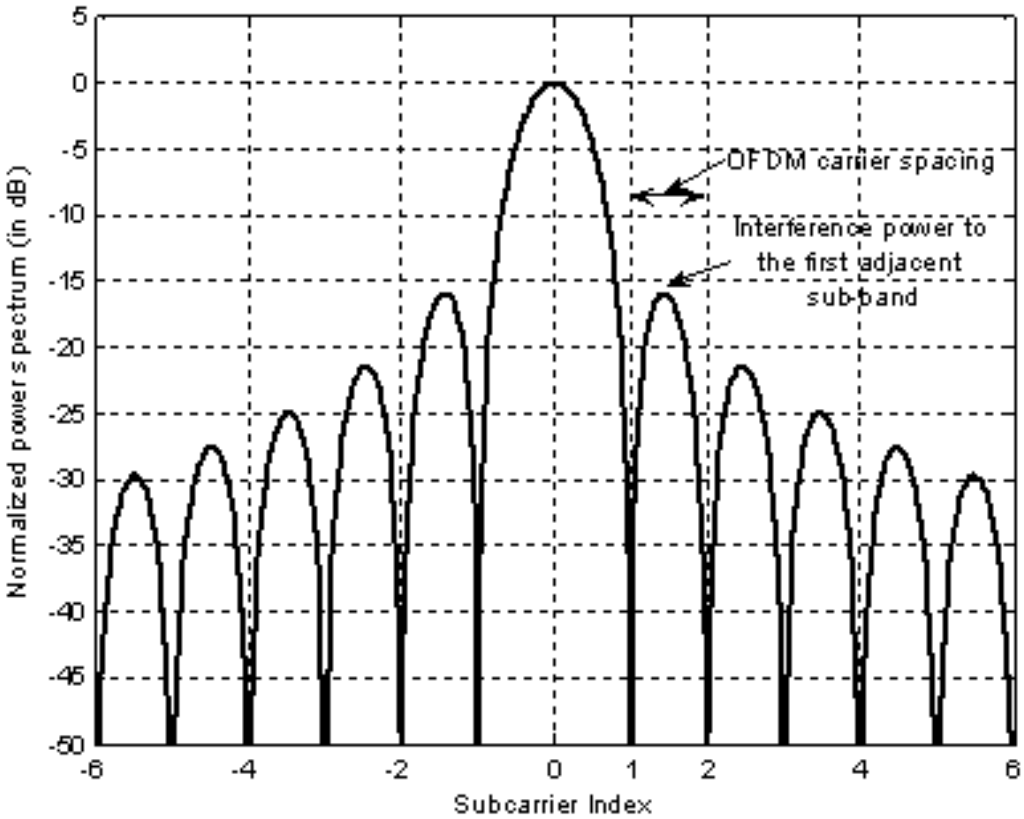

Figure : An Illustration of the Interference Due to One OFDM-modulated Carrier.

OFDM Interference

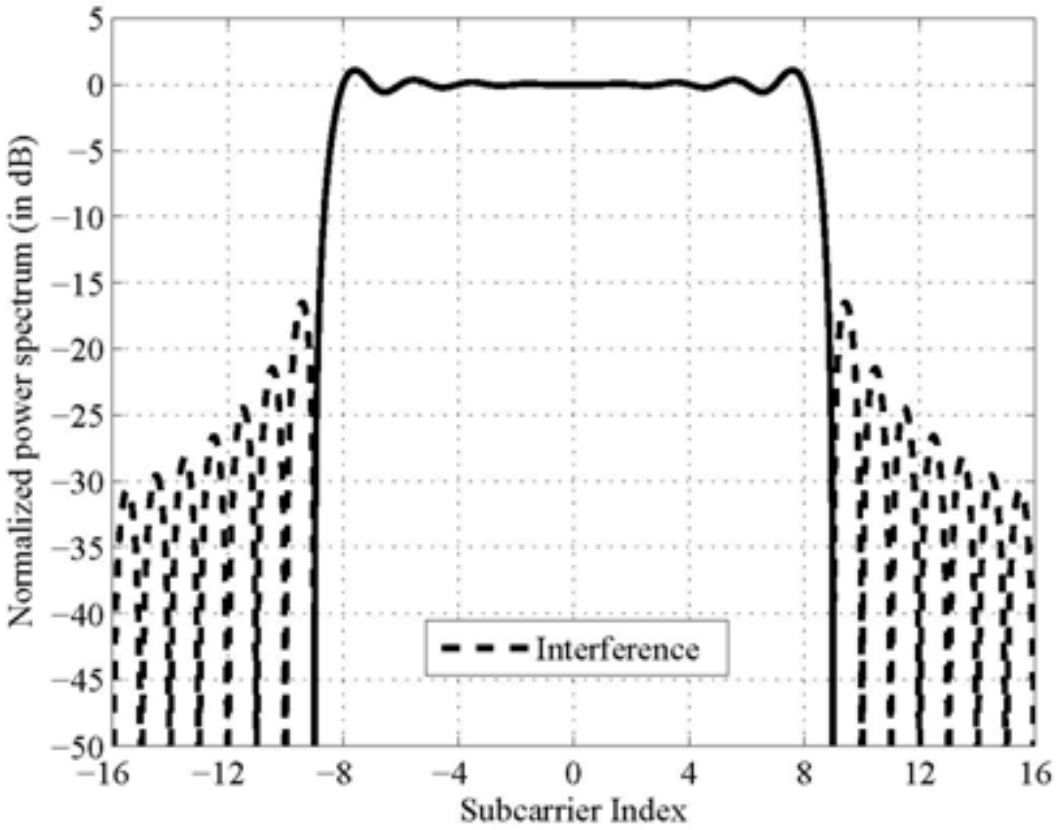

Figure : An Illustration of the Interference in a BPSK-OFDM System with 16 Subcarriers.

Interference Solution 1: Windowing

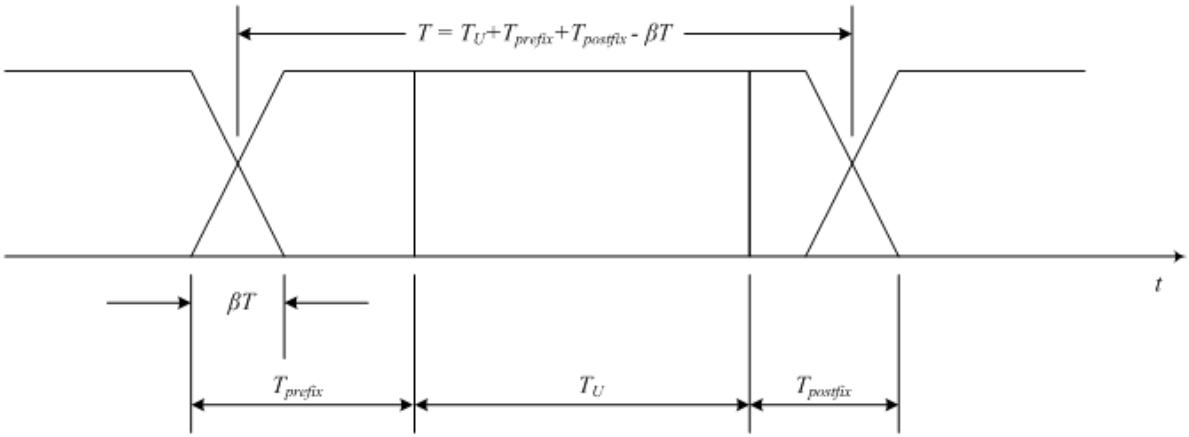

Figure : Structure of the Temporal OFDM Signal Using a Raised Cosine Window.

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Interference Solution 1: Windowing

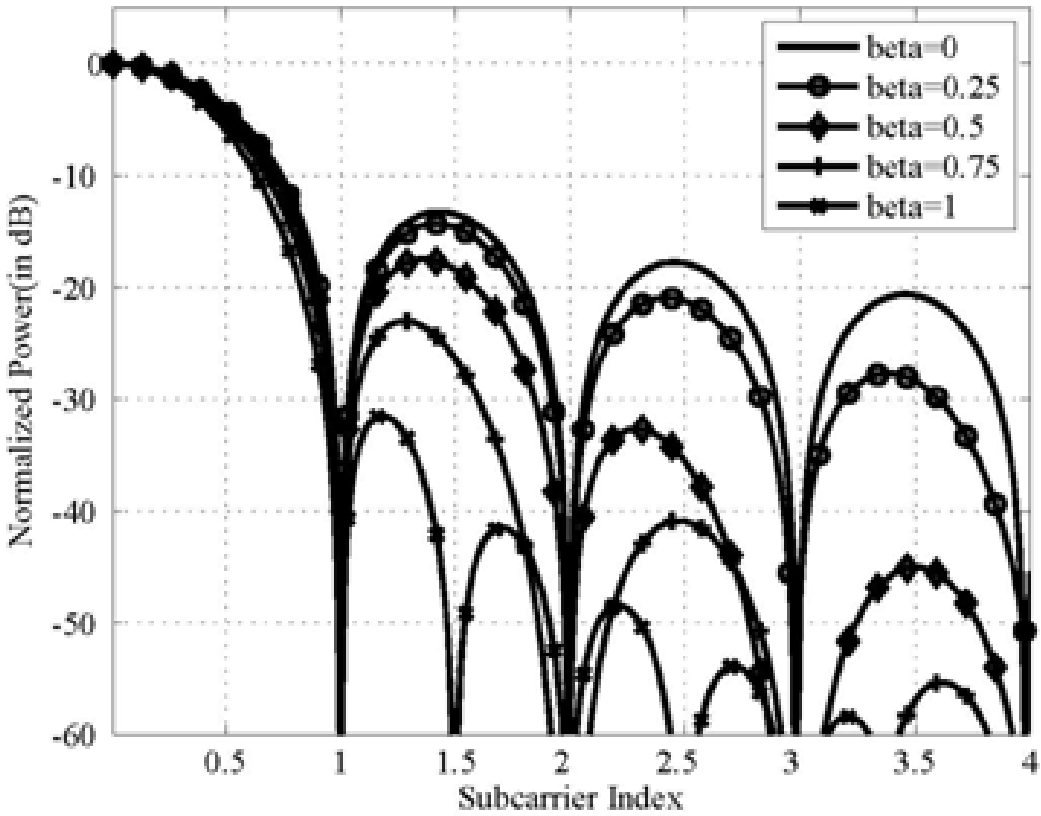

Figure : Impact of Roll-off Factor on the PSD.

Interference Solution 2: Cancellation Subcarriers

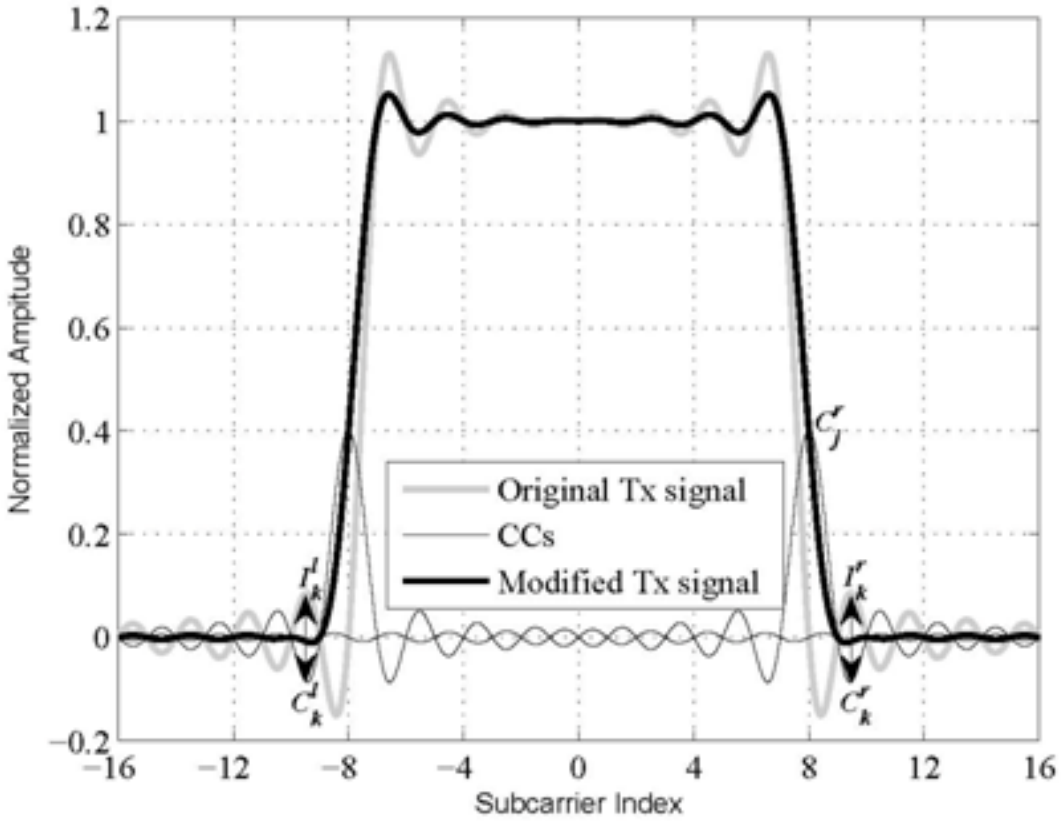

Figure : Illustration of Sidelobe Power Reduction with Cancellation Subcarriers.

Interference Solution 3: Constellation Expansion

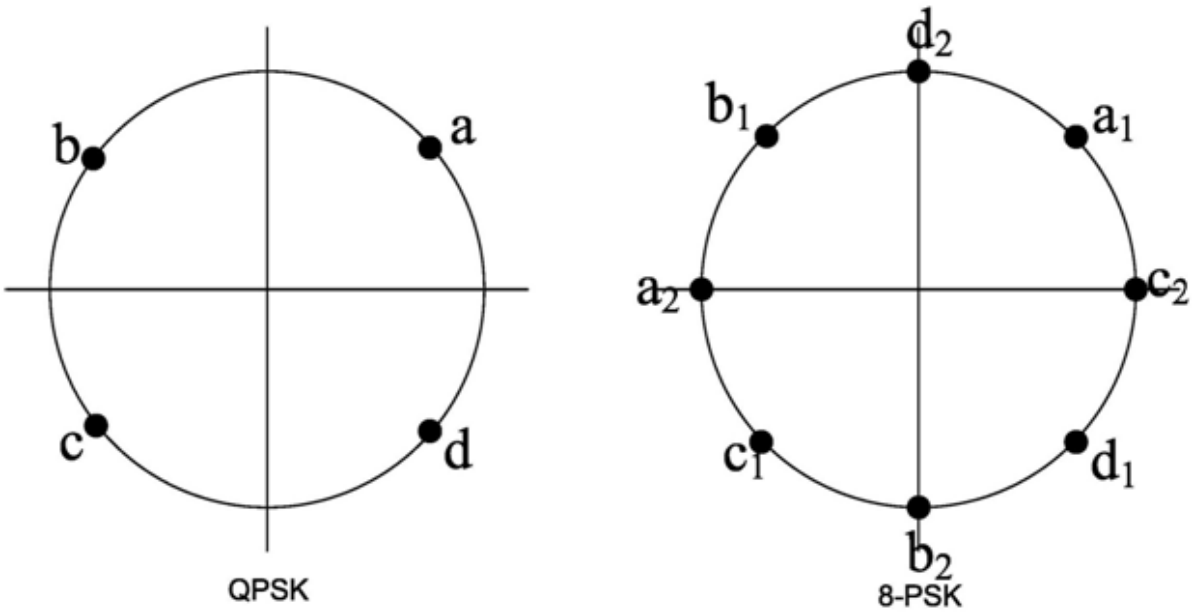

Figure : A Mapping of Symbols from QPSK Constellation to an Expanded Constellation Space.

Interference Solution 3: Constellation Expansion

- Map symbols from the original constellation space to an expanded one
  - Multiple symbols from the expanded constellation are associated with each symbol from the original constellation
- Exploit the randomness in choosing the symbols and consequently, their combination which leads to a lower sidelobe level compared to the original case

Non-contiguous Transmission Implementation

- In an NC-OFDM scenario, several OFDM subcarriers are turned OFF in order to avoid interfering with an incumbent user
- If the available spectrum is sparse, the number of zero-valued inputs to the FFT lead to an inefficient use of hardware

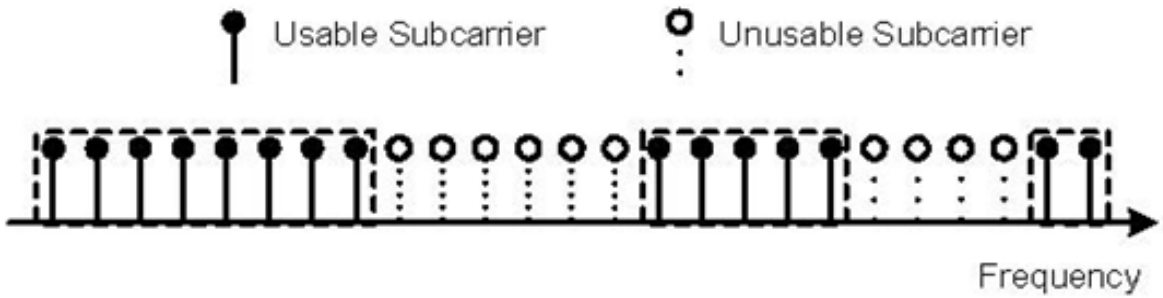

Figure : Subcarrier Distribution over Wideband Spectrum.

FFT Pruning

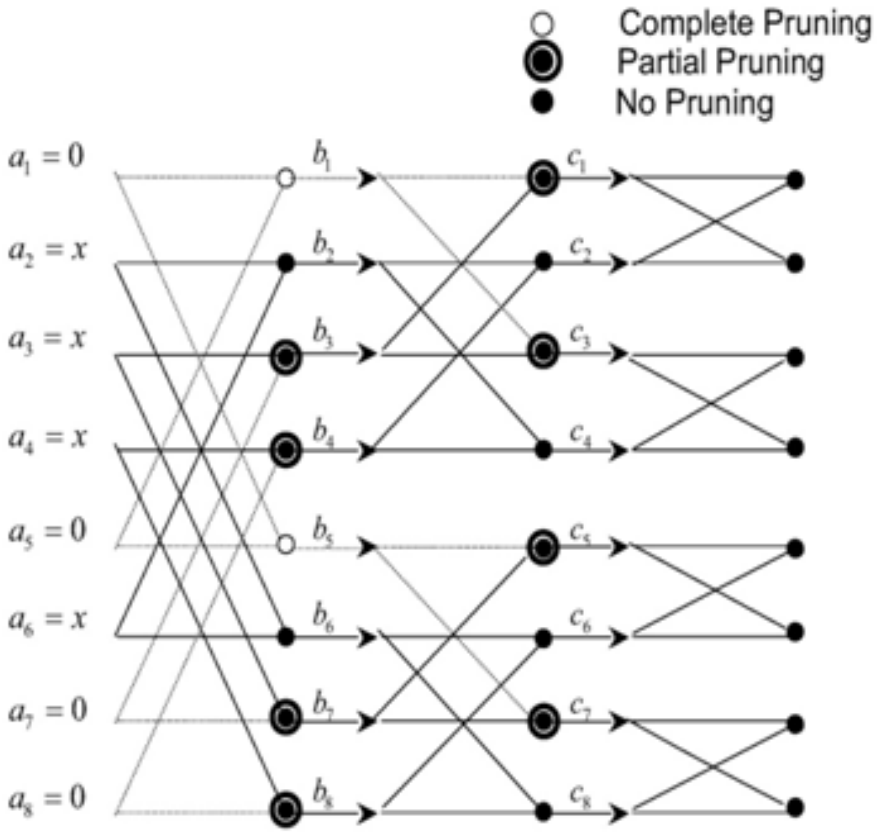

Figure : An 8point DIF FFT Butterfly Structure for a Sparse Input.