Digital Communication Systems Engineering with Software-Defined Radio

Di Pu, Alexander M. Wyglinski
Worcester Polytechnic Institute

Lecture 15

Repackaging Information

- Information can be transmitted using a variety of techniques
  - Manipulate dimensions of time, frequency, and space
- The choice of technique depends on the desired performance outcome of the communication system
  - If you want a data transmission scheme that possesses a low probability of interference, low probability of detection, and immunity to narrowband jamming → *Spread Spectrum*
  - If you want a data transmission scheme that possesses a high level of error robustness in dispersive environments and has high data rates → *Multicarrier Modulation*
- In most cases, the amount of information that can be transmitter remains constant given constraints on the total amount of available bandwidth and transmit power

Symbol Period Versus Bandwidth

- One of the key mathematical relationships in digital communications is between the symbol period T and the signal bandwidth B, defined as $B = \frac{1}{T}$
- Fundamental engineering trade-off between symbol period and signal bandwidth
  - If the number of bits of information are kept constant over one symbol period, then a shorter the symbol period will yield a higher overall data rate
  - If the symbol period is decreased in duration, then the transmission becomes increasingly susceptible to the effects of a dispersive channel
  - If the signal bandwidth is decreased, then we can accommodate more transmissions across the spectral band
  - If the signal bandwidth is decreased, then the cost of the digital communication equipment can be reduced (especially RF components)

"Divide-and-Conquer" Strategy

- Suppose we redistribute the information in our transmission as follows:
  - Demultiplex information into N parallel transmissions each with symbol period that is N times longer than the original
    - Greater resistance towards dispersive channel effects
    - Each transmission possesses a signal bandwidth that is N times smaller than the original
  - Modulate parallel transmissions to unique carrier frequencies
    - Total bandwidth of N parallel transmissions is equal to original transmission
    - Aggregate data rate of N parallel transmissions equivalent to original transmission
- Another advantage of "divide-and-conquer" is the tailoring of transmission parameters across parallel data streams
  - Tailoring based on prevailing channel conditions

Single Carrier Versus Multicarrier

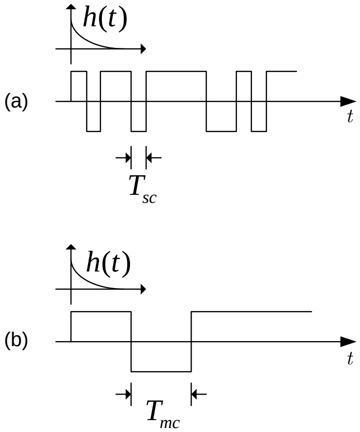

Figure : Time Domain Signal Representation.

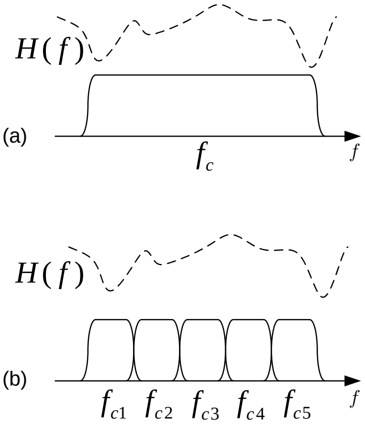

Figure : Frequency Domain Signal Representation.

Why Multicarrier Transmission?

- Multicarrier transmission not as severely affected by delay spread of channel
  - Due to longer symbol periods T_{mc}
  - Channel dispersion in single carrier transmissions much greater than T_{sc}
- Separate subbands of the multicarrier scheme can more readily handle frequency-selective fading using "divide-and-conquer" approach
  - Simple equalization techniques applied per transmission band
  - Single carrier schemes usually require very complex equalization techniques to undo effects of channel
- Multicarrier transmission suitable for high data rate communications due to its high robustness to error
  - Employed widely in numerous communication standards
  - Examples include: DSL modems, WiFi, WiMAX

Multicarrier Transmitter

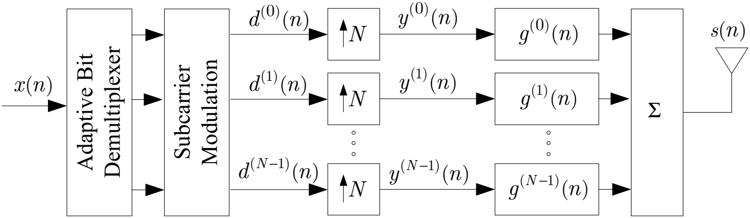

Figure : Schematic of a Generic Multicarrier Transmitter.

Multicarrier Receiver

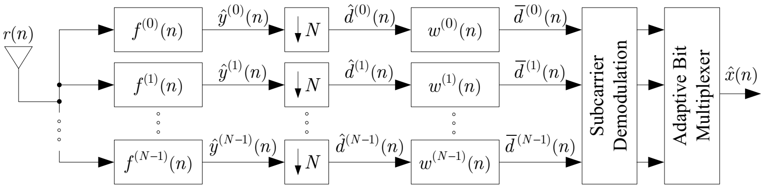

Figure : Schematic of a Generic Multicarrier Receiver.

Several Observations

- Data rate of $x(n)$ decreased by a factor of N when converting to N parallel subbands
- Upsampling is performed to compress the spectra by a factor of N, as well as generate replicas at periodic frequency intervals
- Each subband is filtered by a bandpass synthesis filter $g^{(i)}(n)$
  - Each synthesis filter located at a different center frequency
  - Filters out one of the replicas
- Receiver designed to extract individual subbands and place them into different parallel streams using analysis filters $f^{(i)}(n)$
- To compensate for the distortion, equalizer filters $w^{(i)}(n)$ are employed for each subband

Creating Multicarrier Subbands

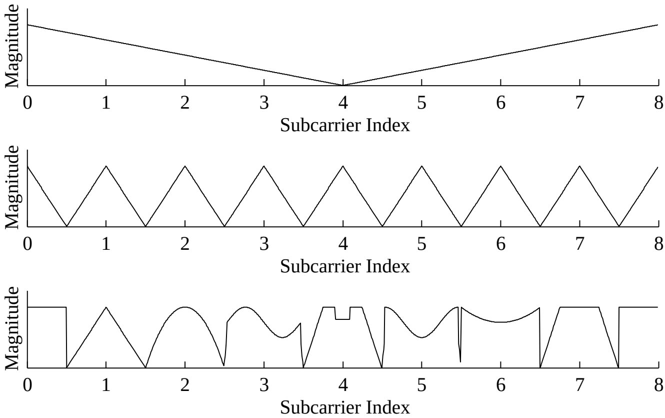

Figure : Generation of Frequency Parallel Subbands: (Top) Original Subband Transmission, (Middle) Upsampled Subband Transmission, (Bottom) Composite Subband Transmission.

Impact of Frequency Selective Fading

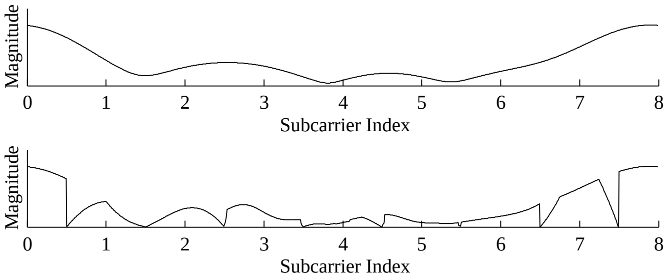

Figure : Impact of Frequency Selective Fading Channel: (Top) Frequency Selective Fading Channel, (Bottom) Subbands Experiencing Fading.