Discrete Multitone (DMT). OFDM Challenges. Spread Spectrum Systems.

Lecture Outline

- **Overlapping Subcarriers in MCM**
- **Fading across Subcarriers**
- **FFT Implementation of OFDM**
- **OFDM Challenges**
- **Overview of Spread Spectrum Modulation**
- **Direct Sequence Spread Spectrum (DSSS)**

1. **Overlapping Subcarriers**
   - MCM Mitigates ISI by dividing the transmit bit stream into N substreams, each modulated by a separate subcarrier with signal bandwidth $B/N < B_c$.
   - MCM can be implemented using frequency division multiplexing, but this requires sharp filtering and is not spectrally efficient. More bandwidth-efficient implementation (OFDM) overlaps the transmitted substreams such that they can be separated at the receiver.
   - For rectangular pulses, minimum required separation is B/N. Can be less if phases of subcarriers are aligned.

2. **Fading Across Subcarriers**
   - Frequency-selective fading leads to different gains (and BERs) on different carrier streams.
   - Can compensate using a frequency-domain equalizer, but leads to noise enhancement.
   - Precoding compensates for FS fading by inverting subcarrier fading at transmitter. Basically channel inversion: power inefficient. Also requires channel knowledge at transmitter.
   - Coding across subchannels sends each bit of a codeword on a different subcarrier. Takes advantage of frequency diversity.
   - Adaptive loading adapts power and rate on subcarriers relative to their gain. Optimization similar to that of adaptive modulation in time.

3. **FFT Implementation of OFDM: Discrete Multitone (DMT)**
   - Complexity of implementing N separate modulators/demodulators is prohibitive.
   - MCM effectively implemented using IFFT at transmitter and FFT at receiver.
   - The IFFT shifts modulated symbols to desired subcarriers.
   - A cyclic prefix is inserted in the data to remove ISI between blocks and make the linear convolution with the channel circular.
   - The received symbol is just a scaled version of the transmitted symbol.

4. **Challenges in OFDM**

   - OFDM/DMT consists of multiple sinusoids summed together, can have a large peak-to-average power ratio (PAR), which leads to amplifier inefficiencies.
   - PAR compensated through clipping or coding.
   - Timing and frequency offsets cause subchannels to interfere with each other.
   - Interference between subchannels mitigated by minimizing the number of subchannels and using pulse shapes robust to timing errors.

5. **Overview of Spread Spectrum Modulation**

   - Basic premise is to add additional modulation to the digitally-modulated signal that increases its bandwidth.
   - Spread spectrum techniques can mitigate or coherently combine ISI, mitigate narrowband interference and jamming, hide a signal below the noise floor or make it hard to track, or enable multiple users to share the same bandwidth (multiple access).
   - There are two main types of spread spectrum modulation: direct sequence (DSSS) and frequency hopping (FH).
   - Frequency hopping takes a narrowband signal and hops it across a wide range of frequencies.
   - Direct sequence multiplies the bit sequence by a faster chip sequence.

6. **Direct Sequence Spread Spectrum (DSSS)**

   - Bit sequence multiplied by faster pseudorandom chip sequence.
   - Spreads bandwidth of transmitted signal by large amount.
   - The bandwidth spreading allows for multipath and narrowband interference rejection. Also hides signal below noise.
   - *Not* spectrally efficient for one user, but DSSS also allows many users to share the same bandwidth (MAC technique).

7. **Multipath and Interference Rejection in DSSS**

   - Incoming signal multiplied by synchronized copy of spreading code
   - Ideally this removes the impact of spreading on desired signal
   - Narrowband interference is spread over wide bandwidth. Demodulation process effectively filters out most of its power.
   - Multipath that is delayed by τ is attenuated by the autocorrelation of the spreading code at time τ.

Main Points

- OFDM made more bandwidth efficient by overlapping subchannels.
- Fading across subchannels compensated by adaptive loading, precoding, or coding across subchannels.
- OFDM efficienctly implemented using FFTs and IFFTs.
- Challenges in OFDM include PAR and timing/frequency offsets.
- DSSS spreads signal over wide bandwidth to obtain multipath and interference rejection.