Lecture 18 - EE 359: Wireless Communications - Winter 2020

Spread Spectrum. Multiuser Systems

Lecture Outline

- **Overview of Spread Spectrum Modulation**
- **Direct Sequence Spread Spectrum**
- **ISI and Interference Rejection in DSSS**
- **Multiple Access in Multiuser Systems: Time/Frequency/Code/Space Division**
- **Random Access**

1. **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.

2. **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).

3. **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.
   - A RAKE receiver has taps at integer multiples of the chip time. This allows each tap to demodulate the multipath associated with that delay while attentuating all other multipath components. All multipath components can then be coherently combined from each tap via the diversity techniques discussed earlier in the course.

4. **Multiple Access: Bandwidth Sharing in Multiuser Systems (TD and FD)**

   - Multiple users can share the same spectrum via time division, frequency division, code division, space division, or hybrid combinations of these techniques.
   - Time-division (TD) allocates each user a non-overlapping timeslot occupying the entire signal bandwidth. For N users, this reduces the per-user rate by a factor of N relative to a single-user system. ISI can cause interference between timeslots, which is often mitigated by guard bands in time.
   - Frequency-division (FD) allocates each user an overlapping (for OFDM) or non-overlapping frequency band to be utilized over all time. For N users and non-overlapping bands this reduces the per-user rate by approximately N, since the data rate is typically proportional to the signal bandwidth.
   - Since filters are imperfect, FD systems typically use guard bands in frequency to avoid interference between users in the frequency domain.
   - OFDMA is a form of FD coupled with OFDM that assigns different subcarriers in the OFDM system to different users.

5. **Multiple Access: Bandwidth Sharing in Multiuser Systems (CD and SD)**

   - Code-division (CD): In CD orthogonal or semi-orthogonal codes are used to modulate each user's signal.
   - The code properties allow the users to be separated at the receiver, either completely (orthogonal codes) or with some residual interference between users (semi-orthogonal codes).
   - The orthogonality of codes is compromised by flat and frequency-selective fading such that orthogonal CD operating in typical wireless channels may not be able to completely separate out the users at the receiver.
   - In the uplink of CD with semi-orthogonal codes, users close to the receiver are received at a much higher power than those farther away, leading to the "near-far" problem whereby far away users experience significant interference. This can be mitigated through power control that inverts the channel gain.
   - Space-division multiplexing (SD) uses MIMO technology to assign different spatial dimensions to different users.
   - TD, FD, and orthogonal CD chop up the time/frequency/code resources in an orthogonal manner and hence support the same number of users in a given bandwidth.
   - Practical considerations which dictate the size of the time (in TD) or frequency (in FD) guard bands, or reduce the number of users in CD due to channel impairments impacting orthogonality, determine how many users each of these schemes can support in practice.
   - TD and FD multiple access schemes can also overlap channels. This is referred to as non-orthogonal multiple access (NOMA). NOMA increases spectral efficiency, particularly for short-packet communications, but increases interference.
   - Multiuser detection techniques can be used to reduce interference in non-orthogonal TD, FD, and CD multiple access techniques.

6. **Multiple Access vs. Random Access**

   - Multiple access requires a dedicated controller and control channel to assign channels. This entails system overhead.

- Dedicated channel assignment can be inefficient for short and/or infrequent data transmission.
- In random access there is no dedicated channel assigned to each user. Rather users access the channel randomly whenever they have data to send.
- The most common forms of random access are Aloha and Random Aloha.
- In both cases, the data is packetized with a certain packet length/time duration
- In Pure Aloha, a packet is sent whenever available. A collision occurs if more than one user sends packets that overlap over any fractional packet duration at the receiver. Packets received in error are retransmitted after a random delay.
- Efficiency is improved over Aloha through slotted Aloha, which synchronizes packet transmissions at the receiver through packet slotting. Packets are only sent during pre-defined timeslots. A collision occurs when packets overlap but there is no partial overlap of packets. Packets received in error are retransmitted after a random delay.
- For L the rate of new and backlogged packets, assuming Poisson arrivals, throughput under Pure Aloha is $T = Le^{-2L}$ and under Slotted Aloha is $T = Le^{-L}$

Main Points

- DSSS spreads signal over wide bandwidth to obtain multipath and interference rejection.
- DSSS rejects narrowband interference power by roughly the spreading gain and multipath by the spreading code autocorrelation evaluated at the multipath delay. So this autocorrelation is the key to multipath rejection.
- Multiple users can share the same spectrum via time/frequency/code/space division. A central controller allocated channels in these multiple access schemes.
- Multiple access schemes can be orthogonal or non-orthogonal. Non-orthogonal schemes are more efficient, but induce interference.
- Random access is a better mechanism to allocate channels when users have short or infrequent data to transmit, but is inefficient compared to multiple access.