
Lecture Outline

• PN Sequences and Maximal Linear Codes
• Synchronization
• RAKE Receivers
• Bandwidth Sharing in Multiuser Systems
• Multiuser Detection

1. Pseudorandom Sequences and Maximal Linear Codes
   • Generated using shift registers with feedback logic.
   • Autocorrelation property dictates multipath rejection.
   • Ideal autocorrelation is a delta function.
   • Maximal linear codes have the longest period for a shift register code ($2^n - 1$ for code of length $n$) and no DC component.
   • Autocorrelation approximately linear
   • Repeats every period. If period equals bit time get recorrelation at integer multiples of $T_b$ (multipath with this delay not rejected). If period greater than a bit time then must deal with partial correlations.

2. Synchronization
   • Synchronization adjusts delay of receiver spreading code to maximize peak of autocorrelation.
   • For synchronization long autocorrelation tails preferable (impossible to synchronize to a delta function).
   • Synchronization complicated by interference, noise, and multipath.
   • Offset in syncronization of $\Delta t$ reduces received signal power by $\rho(\Delta t)$.

3. RAKE Receivers
   • DSSS removes most of the energy from multipath and the received signal component typically experiences fading. For better performance the system should synchronize to the strongest multipath component.
   • A RAKE receiver has $N$ branches that synchronize to $N$ different multipath components.
   • These different multipath components can be combined using selection diversity (pick the strongest) or other forms of diversity (Equal gain or Maximal Ratio Combining). Analysis of spread spectrum system with RAKE same as previous diversity analysis.
4. Bandwidth Sharing in Multiuser Systems: Time and Frequency Division

- 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. Bandwidth Sharing in Multiuser Systems: Code and Space Division

- 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.
- 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.
- Space-division multiplexing (SDM) uses MIMO technology to assign different spatial dimensions to different users.

6. Multiuser Detection

- In CD systems with semi-orthogonal codes and in TD/FD/CD cellular systems, users interfere with each other.
- Interference is generally treated as noise, so systems required to meet a particular performance target become interference-limited (or SINR limited). Often uses complex mechanisms to minimize impact of interference (power control, smart antennas, etc.)
- Interference can be mitigated by Multiuser Detection (MUD, which exploits the fact that the structure of the interference is known and hence some/all of the interference can be removed.
• MUD structures generally trade performance for complexity.
• The optimal MUD is a maximum-likelihood detector which simultaneously detects all users. For \( N \) users, ML MUD is exponentially complex in \( N \).
• A common detector used in practice is successive interference cancellation, which sequentially subtracts out the strongest interferer. This technique is optimal from a Shannon capacity perspective, but in practice it suffers from error propagation.
• MUD is not used much in practice due to the added complexity of the signal processing and the requirements for a high dynamic range/precision in the A/D converters such that the weak user signals are not discarded by the A/D.

Main Points

• 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.
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• Maximal linear codes have good autocorrelation but poor cross correlation.
• Synchronization also depends on autocorrelation properties of the spreading code.
• RAKE receivers combine energy of all multipath components using standard diversity combining techniques.
• Multiple users can share the same spectrum via time/frequency/code/space division
• Multiuser detection mitigates interference through joint or successive detection