Multiplexing

CSE370
What is multiplexing?

• Multiple users share a medium with minimum or no interference.
• Example of interference: two people talking at the same time.
Use different frequency band

• If two signals are transmitted at the same time but the two signals have different frequency.

• By using Fourier transform, we can single out the signals within certain frequency band. ➔ filter out the other signals (noises).
Time-Domain v.s. Frequency-Domain

- Fourier transform

- Inverse Fourier transform

Bandpass filter
Time-Domain v.s. Frequency-Domain

- Fourier transform

- Inverse Fourier transform
Frequency division multiplexing

- Frequency division multiplexing (FDM)
  - Frequency spectrum is divided into several non-overlapping frequency bands.
  - Each user uses a unique band.

- Radio stations
  - Each radio station has its own frequency.

- Receiver:
  - Tune in to the specific sender.
Frequency division multiplexing
Frequency division multiplexing

• Advantage:
  – The senders can send signals continuously.
  – Works for analog signals too.
  – no dynamic coordination necessary

• Disadvantage:
  – Frequency is scarce resources.
  – Radio broadcasts 24 hours a day, but mobile communication only takes place for a few minutes.
  – A separate frequency for each possible communication scenario is a tremendous waste of frequency resources.
  – Inflexible: one channel idle and the other one busy.
Time division multiplexing

- All senders use the same frequency but at different points in time.
- A channel gets the whole spectrum for a certain amount of time: one guy talks at a time.
- Precise synchronization is needed.
  - All senders have precise clocks and scheduling.
  - Or, there has to a way to distribute synchronization signals.
  - Receivers have to listen to the right frequency at exactly the right points in time.
  - Flexible, adaptive to users with different loads.
Time division multiplexing
Time and frequency multiplex

- Combination of both methods
- A channel gets a certain frequency band for a certain amount of time.
- Example: GSM
  - (Global System for Mobile Communications), one of the leading cellular systems.
  - GSM was introduced in 1991.
  - As of the end of 1997, GSM service was available in more than 100 countries and has become the de facto standard in Europe and Asia.
Time and frequency multiplex
Time and frequency multiplex

• Advantages:
  – better protection against tapping
  – protection against frequency selective interference (e.g., interference in a certain small frequency band)
  – higher data rates compared to code multiplex (we’ll talk later)

• but: precise coordination required
  – Two senders will interfere if they choose the same frequency at the same time.
Code division multiplexing

- Each channel has a unique code
- All channels use the same spectrum at the same time
- First used in military applications due to its inherent security features.
- Now used in many civil applications due to low processing power.
- Basic intuition: people talk different languages in a party.
Code division multiplexing
Code division multiplexing

- If the listener doesn’t know the language, the signals are received but useless.
- In military applications, it is preferred to have the signals look like random noise, so as to stay undetected.
- But with a special code, the receiver can “decode” the signal.
- Good protection against tapping and interference.
- Code space is also a lot larger than frequency space.
- We can assign individual code to individual sender.
Code division multiplexing

- **Disadvantages:**
  - High complexity of the receiver – decoding cost.
  - A receiver has to know the code so as to separate the useful signal from the rest signals and the background noise.
  - A receiver must be precisely synchronized with the transmitter to apply the decoding correctly.
  - All the signals received by the receiver should have equal strength, otherwise some signals drain others.

- It is realized by using **Spread Spectrum**.
Spread spectrum

• A signal with a narrow frequency band is now spread to a wide frequency band.
• Sounds stupid…
• Reason: protection against narrowband interference.

\[
\frac{dP}{df}
\]

![Diagram showing frequency spectrum](image)
Spread spectrum

- Against narrowband interference
Spread spectrum for several channels

- Narrowband channels
  - Narrow band signal
  - Guard space

- Spread spectrum channels
Spread spectrum

• The narrowband signal is turned into a broadband signal with the same total energy.
• The power of the broadband signal is much lower → as low as the background noise.
• Appealing for military application: stay undetected! & no interference.
Spread spectrum

- More and more appealing to everyday applications: frequencies are scarce resources.
- We just add in a low-power broadband signal on top of current narrow band applications.
- Used in US cellular phone systems.
- Drawbacks:
  - Increased complexity of receivers. (less a problem due to cheaper processors)
  - Need a large frequency band.
  - It still increases the background noise level.
DSSS (Direct Sequence Spread Spectrum)

- XOR of the signal with pseudo-random number (chipping sequence)
  - many chips per bit (e.g., 128) result in higher bandwidth of the signal
  - Chip sequence looks like random noise.
- Spreading factor: $s = \frac{t_b}{t_c}$ → the bandwidth of the resulting signal.

$t_b$: bit period
$t_c$: chip period

user data

XOR

chipping sequence

resulting signal

0 1 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 0 1 1 0 0 1 0 1 1 0 1 0 1 0 0 1 0 1 1 0 1 0
DSSS (Direct Sequence Spread Spectrum)

- Civil applications use spreading factors between 10 and 100, military applications use factors up to 10,000.
- Wireless LANs (IEEE 802.11) use 10110111000, called Barker code.
DSSS (Direct Sequence Spread Spectrum)

• Advantages
  – reduces frequency selective fading
  – in cellular networks
    • base stations can use the same frequency range
    • several base stations can detect and recover the signal
    • soft handover

• Disadvantages
  – precise power control necessary

\[ \text{XOR} \]

\[ \begin{array}{c}
0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 \\
\end{array} \]

\[ 0 \ 1 \ 0 \ 1 \ 0 \ 1 \ 0 \ 1 \ 0 \ 0 \ 1 \ 0 \ 1 \ 0 \]

\[ t_b: \text{bit period} \]
\[ t_c: \text{chip period} \]
DSSS (Direct Sequence Spread Spectrum)

**Transmitter**

- User data
- Chipping sequence
- Radio carrier
- Spread spectrum signal
- Modulator
- Transmit signal

**Receiver**

- Received signal
- Radio carrier
- Chipping sequence
- Correlator
- Lowpass filtered signal
- Products
- Sampled sums
- Integrator
- Decision
- Data
DSSS (Direct Sequence Spread Spectrum)

- At the receiver side, basically reverse all operations.
- If there is noise, some bits might be flipped.
- Input data: 01
- XOR with Barker code 10110111000.
- We get 1011011100001001000111
- Receiver XOR with Barker code
- Get 0000000000011111111111
- Add up each 11 bits, get 0 (11) → 01
DSSS (Direct Sequence Spread Spectrum)

- At the receiver side, basically reverse all operations.
- If there is noise, some bits might be flipped.
- Input data: 01
- XOR with Barker code 10110111000.
- We get 10100110100001001100111.
- Receiver XOR with Barker code
- Get 0001001000111110111111
- Add up each 11 bits, get 2 (10) ➔ 01
DSSS (Direct Sequence Spread Spectrum)

• Synchronization is important!
• Multi-path fading causes a problem.
  – The receiving signal is shifted and added up on itself!
  – Rake receiver: detect the strongest correlation.
FHSS (Frequency Hopping Spread Spectrum)

- Total bandwidth is split into many channels of smaller bandwidths.
- Transmitters and receivers stay on one of these channels for a certain time and then hop to another channel.
- Implements FDM and TDM.
- The pattern of channel usage is called hopping sequence.
- The time spend on a channel with a certain frequency is called dwell time.
FHSS (Frequency Hopping Spread Spectrum)

• Slow hopping:
  – Transmitter uses one frequency for several bits periods.

• Fast hopping:
  – Transmitter changes the frequency several times during the transmission of a single bit.
FHSS (Frequency Hopping Spread Spectrum)

- Slow hopping (3 bits/hop)
- Fast hopping (3 hops/bit)

$t_b$: bit period  
$t_d$: dwell time
FHSS (Frequency Hopping Spread Spectrum)

- **Slow hopping:**
  - Cheaper, with relaxed tolerances.
  - Not as immune to narrowband interference as fast hopping

- **Fast hopping:**
  - More complex
  - Overcome narrowband interference as they only stick to one frequency for a very short time.
FHSS (Frequency Hopping Spread Spectrum)

- Bluetooth uses FHSS.
- Advantages
  - frequency selective fading and interference limited to short period
  - simple implementation
  - uses only small portion of spectrum at any time
- Disadvantages
  - not as robust as DSSS
  - simpler to detect
FHSS (Frequency Hopping Spread Spectrum)

user data → modulator → modulator → frequency synthesizer → spreading signal → transmitter

Analog signal → frequency synthesizer

received signal → demodulator → demodulator → data → receiver

hopping sequence → frequency synthesizer → narrowband signal ∴
Summary

• Multiplexing
• Frequency division multiplexing
• Time division multiplexing
• Time and frequency multiplex
• Code division multiplexing
• Spread spectrum
• Direct Sequence Spread Spectrum
• Frequency Hopping Spread Spectrum