CSEP 561 – Multiplexing

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Topic

• How do we share a wireless channel between users?

• The physical/link layers:
  1. Static allocation methods

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Wireless Channel Issues

• We know the signal strength (SNR) will vary widely depending on location of the sender/receiver
  – Can use different bit rates (modulations) at different times

• Other problems we have to handle:
  1. Interference. Can divide (multiplex) the channel so that each sender has their own time/freq./space channel to use.
  2. Fading. Can send over independently faded channels and use modulations that are robust to fading (CDMA, OFDM)
Time Division Multiplexing (TDM)

Time division multiplexing shares a channel over time:
- Users take turns on a fixed schedule; this is not packet switching or STDM (Statistical TDM)
- Widely used in telephone / cellular systems
Frequency Division Multiplexing

FDM (Frequency Division Multiplexing) shares the channel by placing users on different frequencies:

Overall FDM channel
Code Division Multiple Access (CDMA)

This is “direct sequence spread spectrum” CDMA

Each user has their own code signal as follows:

• Codes signal are orthogonal; they multiply to zero
• To send a “1”, send code, to send “0” inverse code
• At receiver, correlate with code signal to get bits

Effect of overall signal:

• Up to N codes, overall signal has N times bandwidth
• Each user signal is spread out over the entire band
• All users can send at the same time
• Less vulnerable to narrowband interference/fading
(Synchronous) CDMA example

CDMA shares the channel by giving each user a code

- Codes signal are orthogonal; they multiply to zero
- To send a “1”, send code, to send “0” inverse code
- At receiver, correlate with code signal to get bits

*Sender Codes*

\[
\begin{align*}
A &= \begin{array}{c}
+1 \\
-1
\end{array} + \begin{array}{c}
+1 \\
-1
\end{array} \\
B &= \begin{array}{c}
+1 \\
-1
\end{array} + \begin{array}{c}
+1 \\
-1
\end{array} \\
C &= \begin{array}{c}
+1 \\
-1
\end{array} + \begin{array}{c}
+1 \\
-1
\end{array}
\end{align*}
\]
(Synchronous) CDMA example

Receive signal is superimposition of transmissions

Send Codes

\[ \begin{align*}
A &= +1 \quad +1 \\
   & \quad -1 \quad -1
\end{align*} \]

\[ \begin{align*}
B &= +1 +1 \\
   & -1 -1
\end{align*} \]

\[ \begin{align*}
C &= +1 \\
   & -1 -1
\end{align*} \]

Transmitted Signal

\[ S = +A -B \]
(Synchronous) CDMA example

To decode, correlate (multiply, sum) rx signal with codes
- Do this for each user code to get message from that user
- Positive = 1, negative = 0, zero = nothing sent

Sender Codes

A = \begin{pmatrix} +1 & +1 \\ -1 & -1 \end{pmatrix}

B = \begin{pmatrix} +1 & +1 \\ -1 & -1 \end{pmatrix}

C = \begin{pmatrix} +1 & +1 \\ -1 & -1 \end{pmatrix}

Transmitted Signal

S = \begin{pmatrix} +2 \\ -2 \end{pmatrix}

S = +A -B

Receiver Decoding

S x A = \begin{pmatrix} +2+2 \\ 0 \end{pmatrix}

Sum = 4
A sent “1”

S x B = \begin{pmatrix} -2-2 \\ 0 \end{pmatrix}

Sum = -4
B sent “0”

S x C = \begin{pmatrix} +2 \\ 0 \end{pmatrix}

Sum = 0
C didn’t send
CDMA and fading

Sending an N-chip code for each bit “spreads” the signal in the frequency domain by a factor of N.

This means overall signal is robust to narrowband fading – a small part of it is lost, but we will be OK.
CDMA decoding – Rake receiver

Multipath causes signal to be received as copies at different time offsets; might have a few main copies.

Can correlate for a code at different time offsets to find main copies, then add them together; rest is orthogonal.
Asynchronous CDMA

Widely used in 3G (“WCDMA”) systems based on CDMA

Uses asynchronous version of CDMA

• Codes are also approx. orthogonal to delayed copies
  – Gold codes rather than Walsh codes
• Lets mobiles send without careful synchronization
• Otherwise the idea is the same
FDM revisited

Multipath spreads the signal out in time – makes it desirable to signal at a slow rate so one symbol doesn’t get spread into adjacent ones very much.

Could divide a fast, large band into many slow, small bands with FDM, but classic FDM needs guard bands:

Orthogonal FDM divides the large band efficiently.
Orthogonal Frequency Division Multiplexing

OFDM widely used for 802.11, 4G cellular, digital TV, cable, etc.

- Many slower channels used in parallel vs. one fast channel
- Channels are coordinated subcarriers (set of 64, 128… 2048)
- Subcarrier $f$ and $\Delta f$ are $k / \text{symbol-time}$ so that correlation of subcarrier freq. responses is zero; can pack them efficiently

![Diagram of OFDM subcarriers](image)
OFDM overview

Conceptually, just many parallel channels:

- Start with $R$ bps overall channel
- Split into $N$ parallel channels of $R/N$ bps
- Each channel is passband at freq $f + i/symbol\text{-}time$, $i=0$ to $N-1$
- For each channel, map bits to I/Q symbols
- Use I/Q to modulate each subcarrier (as before)
- Then add all subcarrier signals to get transmitted signal
- Reverse steps at receiver
- See tutorials, e.g., complextoreal.com

But $N$ parallel modulators/demodulators is expensive! Instead, there is an efficient implementation based on Fourier transforms.
OFDM implementation

Efficient transmitter uses IDFT (Inverse Discrete Fourier Transform) to modulate all subcarriers at once

• IDFT maps freq. components into time signal
• Wrinkle: a “cyclic prefix” helps with delay spread
OFDM implementation cont.

Similarly, efficient receiver uses DFT (Discrete Fourier Transform) to decode all subcarriers at once

- DFT maps time signal into freq. components
Some subcarriers will be received well, others faded
• Errors are likely, so add redundant (coded) data
• \( \rightarrow \) error-correcting coding tolerates errors [next]

![Graph showing carrier amplitude before and after fading](image)
Recap

We can divide a channel at a location by time, freq. or codes; one sender can use portion w/o interference

Multipath fading can be tolerated with modulations:
• CDMA is robust to narrowband interference
• OFDM will lose some subcarriers so code bits [next]

We will want to support multiple users too [later]
• E.g., how to support 802.11 users?