EE 359: DISCUSSION SESSION 9

Agenda:

* OFDM
* Spread spectrum
* Multimode systems

Recap

Multi-carrier modulation

* ISI avoidance: divide signal bandwidth into narrow chunks ($\frac{B}{N} < B_c$)

* Guard bands / buffer - reduces spectral efficiency
  (but) less sensitive to time / frequency offset

* Orthogonal subcarriers -> implement as separate modulators or DFT
OFDM through DFT.

\[ x[0], x[1], \ldots, x[N-1] \]

\[ X[k] = \sum_{n=0}^{N-1} x[n] e^{-j \frac{2\pi nk}{N}} \]

\[ (Q_w)_{ij} = w^{ki} \]

\[ X = Q_w x \]

\[ \text{Typically} \rightarrow O(N^2) \]

\[ \text{FFT} \rightarrow O(N\log N) \]

Multi-carriers.

\[ \times 2\pi f_1 t \]

\[ \times 2\pi f_2 t \]

\[ \times 2\pi f_3 t \]

\[ \sum \]

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OFDM

$X[n]$ → $\frac{s}{T} \rightarrow X[1] \rightarrow \cdots \rightarrow X[N-1]$

OFDM symbol

$T \times$

$X[n] \rightarrow D/A$

$\cos 2\pi f_c t$

$X[n] = \sum X[k] e^{j \frac{2\pi nk}{N}}$

RX

$\cos 2\pi f_c t$

$X[n] \rightarrow \frac{s}{T} \rightarrow FFT$

Cyclic Prefix

\[ y[n] = h \ast x[n] + u[n] \]

Linear convolution not multiplication under DFT.
\[ F_y = F_h \cdot F_x \quad J \rightarrow DFT \]

\[ y[n] = \sum_{l=1}^{\mu} h[l] x[-l] \]

\[ x[n] \]

\[ y[n] = h \otimes x[n] + \nu \]

\[ y[n] = H[k] x[n] \]

OFDM symbol, length \( N \)

CP \( \rightarrow \mu \) in a computationally cheap manner

CP \( \rightarrow + \) removes ISI (but) loss of spectral efficiency

What we transmit length \( N + \mu \)

representation
Matrix representation

\[ Y = Hx + \nu \]

Touplitz

\[ Y = \tilde{H}x + \nu \]

Circulant

\[ \tilde{H} = \Omega_w^{-1} \sum \Omega_w \]

diagonal matrix

\[ \text{diag}(\mathbf{F} h) \]

OFDM

Efficient implementation of multi-carriers

(187 removal !)
\[ PAPR = \frac{\max_n |x[n]|^2}{E_n [1 + |x[n]|^2]} \]

Amplifier gain

\[ x_0, \ldots, x_{n-1} \]

\[ x_{n-m}, \ldots, x_0, \ldots, x_{n-1} \]

- Spread spectrum

Spread narrowband signal over a wider band

\[ \text{indistinguishable from noise floor} \] (covert communication)
Signal processing and communication systems involve the allocation of wireless resources and interference rejection. This can be achieved through various means, such as wideband receivers.

**FHSS (Frequency Hopping Spread Spectrum)**

- Bluetooth uses frequency hopping spread spectrum (FHSS).

**DSSS (Direct Sequence Spread Spectrum)**

- Direct sequence spread spectrum (DSSS) uses spreading codes (chip sequence) \( s_c(t) \).

For narrowband signals, the spreading code is given by:

\[
\text{Narrowband signal: } g(t) \quad [T_s, \quad B_s = \frac{1}{T_s}]
\]

For transmit signals:

\[
T_X \rightarrow \quad g(t) \cdot s_c(t) = r(t)
\]

For receive signals:

\[
R_X \rightarrow \quad \tilde{g}(t) = \frac{1}{T_s} \int_{t=0}^{T_s} r(t) \cdot s_c(t) \, dt
\]
Multipath rejection:

\[ R_x = \frac{1}{T_s} \int g(t) s_c(t - 2T) s_c(t) \, dt \approx 0 \]

Interference rejection:

\[ s_c(t - 2T) s_c(t) \, dt = \delta(t) \]

\[ \int s_c^2(t) s_c(t) \, dt \approx 0 \]

Narrowband interference rejection:

\[ h(t) = s_c(t) - g(t) \]

Rake Receivers

- we can resolve multipath components
- Rake receivers gather energy from all multipath components
  - different branch, different component
  - $s_c, w_c$
Multimedia design considerations.

Q 6)

\[ G \]

C DMA

\[ G \]

\[ \text{SINR} = \frac{G \, P}{(k-1) \, P} \]

\[ \text{SINR} = \frac{G \, P}{(k-1) \, P + C \, N_0} \]

Q 7)

\[ \sum \sum I_{\text{user i transmits}} \left[ \begin{array}{l} \text{successfully in slot j} \\ \text{in slot j} \end{array} \right] = \]

FDMA