Chapter 12 Spread Spectrum Techniques

- Introduction

- Comparison of multiple access/multiplexing techniques
  - i) FDMA: frequency division multiple access
  - ii) TDMA: time division multiple access
  - iii) CDMA: code division multiple access

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12.1 Spread spectrum

- Implementations:
  i) DS-CDMA
  ii) FH-CDMA

- Applications:
  i) Security in military usage
  ii) Anti-jamming/ noise: military, wireless LAN
  iii) Multiple access: high capacity in mobile phones

- What's spread spectrum?
  use a transmission bandwidth which is much greater than the minimum information bandwidth
System block diagram

- Channel coding
- Baseband modulation
- Passband modulation
- Multiple access

Channel decoding
- Baseband demod.
- Passband demod.

Spreading
- Despreading
12.1.1 Some properties

- Why SS ca has anti-jamming capability?
  i) Jamming: intentional interference, noise
  ii) Jamming usually has fixed energy, limited bandwidth (narrowband)
  iii) Narrowband jamming becomes has low power density after spreaded
  iv) Narrowband jamming can be filtered out

- SS ca has high security with low probability of interception:
  i) signal energy are distributed to a wider bandwidth
  ii) power density becomes low.

- SS ca has fine time resolution, for position location

- Good for multiple access.
12.1.3 DS-CDMA model.

- Use a pseudo-noise sequence to spread signal

PN sequence:
  i) Appear random (flat-like autocorrelation)
  ii) Deterministic: be able to generate independently at the receiver

![Diagram showing the process of spreading and de-spreading]

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12.2 Pseudo-noise sequences

- A sequence of "1" and "0" with noise-like auto-correlation and zero cross-correlation
- PN sequences have zero cross correlation

- Generator: linear feedback shift register
  e.g.: \[ C_0 \xrightarrow{T} C_1 \xrightarrow{T} C_2 \xrightarrow{T} C_3 \xrightarrow{+} \text{output} \]

  at \( t=0 \), \[ [C_0 \ C_1 \ C_2 \ C_3] \] output (\( C_3 \))
  \[ 1 \ 1 \ 0 \ 0 \ 0 \]
  \( t=1 \), \[ 1 \ 1 \ 1 \ 0 \ 0 \ 0 \]
  \[ \vdots \]
  \( t=7 \), \[ 1 \ 1 \ 0 \ 0 \ 0 \ 0 \]

  output sequence:
  \[ 0 \ 0 \ 1 \ 1 \ 0 \ 1 \ \ldots \]
- **m-sequence**: maximum-length shift register sequence
  - length: $L = 2^n - 1$,
  - shift register constraint length $n$
  - sequence period: $L$

- Auto correlation:
  \[
  R_x(\tau) = \sum_i c_i c_{i+\tau}
  = \begin{cases} L, & \text{if } \tau = 0 \\ -1, & \text{if } 1 \leq \tau \leq L-1 \end{cases}
  \]

- **Example**:

- Cross-correlation:
  - almost zero: Gold sequence
  - zero: Walsh code
12.3 DSSS (or DS-CDMA)

- BPSK modulator

\[ x(t) \rightarrow S(t) \rightarrow \Phi(t) \rightarrow \sqrt{\frac{2}{T}} \cos(2\pi f_c t) \rightarrow s(t) \]

- Bit rate: \( R_b \)
- Bit interval: \( T_b \)
- Chip rate: \( R_c \)
- Chip interval: \( T_c \)

- Processing gain: \( L_c = \frac{R_c}{R_b} = \frac{T_b}{T_c} \)
  - (# of PN chips per bit)
  - (Anti-jamming capability)
  - (# of users for multiple access)

\[ s(t) = \sqrt{\frac{2}{T}} \cos(2\pi f_c t) \times \Phi(t) \times x(t) \]

(89)
Demodulator (BPSK)

1) \[ r(t) \rightarrow h(t) \rightarrow S \times (t) \rightarrow x(t) \]

\[ \sqrt{\frac{2}{T}} \cos(2\pi ft) \]

BPSK Demodulator despread

2) \[ r(t) \rightarrow h(t) \rightarrow \sqrt{\frac{2}{T}} \cos(2\pi ft) \rightarrow x(t) \]

despread          BPSK demodulator

Let \( r(t) = S \times (t) = \sqrt{\frac{2}{T}} \cos(2\pi ft) \times (t) \).

\[ y(t) = r(t) \times (t) \]
\[ = \sqrt{\frac{2}{T}} \cos(2\pi ft) \times (t) \times (t) \times (t) \]
\[ = \sqrt{\frac{2}{T}} \cos(2\pi ft) \times (t) \]

(90)
Processing gain and anti-jamming

i) Narrowband interference \( i(t) \),
Wideband SS signal \( s(t) \).
Received signal \( r(t) = s(t) + i(t) \)
\[
= \sqrt{\frac{2}{T}} x(t) g(t) \cos(\pi f_c t) + i(t)
\]

ii) Despreading:
\[
g(t) = r(t) g(t) = \sqrt{\frac{2}{T}} x(t) \cos(\pi f_c t) + i(t) g(t)
\]

iii) Demodulation:
\[
\left[ g(t) \sqrt{\frac{2}{T}} \cos(\pi f_c t) \right]_{4p} = x(t) + \left[ i(t) g(t) \sqrt{\frac{2}{T}} \cos(\pi f_c t) \right]_{4p}
\]

\[\begin{array}{c}
 I(f) \\
 S(f) \\
 \downarrow \quad \downarrow \\
 \frac{R_b}{R_c} \\
 \end{array}\quad \begin{array}{c}
 x(f) \\
 \text{despreaded} \\
 I(f) \\
 \end{array}\]

iv) Assume \( i(t) \) has fixed power \( P_J \),
then power density is \( J_0 = \frac{P_J}{R_c} \)
Jammer power in the signal bandwidth \( P_J R_b \) is:
\[
N_J = J_0 R_b = \frac{P_J}{R_c} R_b = \frac{P_J}{\frac{R_c}{L}}
\]

SIR enhancement:
\[
\frac{P_s}{P_J} \quad \text{input} \quad \rightarrow \quad \frac{P_s}{P_J} \quad \text{output}
\]

\[ (91) \]
• Conclusion:
  
  i) Interference power reduced by $L$ times

  ii) SIR increased by $L$ times.

  ($L$: processing gain)

• Example: in wireless LAN IEEE 802.11b, 11-bit Barker sequence is used, what is the processing gain?

• Example:

  If the required SIR = 10 dB, however, the received SIR is only -20 dB, how much should the processing gain be?
12.7 Commercial applications

- CDMA: Users share the same channel each one with a unique spreading code

- IS-75 CDMA Digital Cellular System:
  - Channel: 1.25 MHz bandwidth
  - Chip rate: $R_c = 1.2288$ Mc/s
  - Data rate: $R_b = 9.6$ kbps
  - Processing gain: $L = ?$
  - Modulator: QPSK
  - Channel coding: convolutional + interleaver