Part 2: Wireless Communication

• Section 1: Wireless Transmission
• Section 2: Digital modulation

• Section 3: Multiplexing/Medium Access Control

Introduction to Multiple Access

• Multiple access schemes are used to allow many mobile users to share simultaneously a finite amount of radio spectrum without severe degradation in the performance of the system.

• 5 different methods:
  3.1- TDMA Time Division Multiple Access
  3.2- FDMA Frequency Division Multiple Access
  3.3- SSMA Spread Spectrum Multiple Access
  3.4- SDMA Space Division Multiple Access
  3.5- PR Packet Radio

• These methods can be combined
  eg: SDMA/FDMA/TDMA in GSM

3.1- TDMA (Time Division Multiple Access)

• The radio spectrum is divided into time frames that are divided into time slots
• One user is allowed to either transmit or receive on specific time slots

<table>
<thead>
<tr>
<th>Frame 1</th>
<th>Frame 2</th>
<th>Frame 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slot 1</td>
<td>Slot 2</td>
<td>Slot 3</td>
</tr>
</tbody>
</table>

• TDMA transmit data in a buffer-and-burst method, thus the transmission is non-continuous:
  - this results in low battery consumption since the subscriber transmitter can be turned off when not in use
  - handoff process is much simpler for a mobile unit, since it is able to listen for other base stations during idle time slots.

3.2- FDMA (Frequency Division Multiple Access)

• The radio spectrum is divided into narrowband (~30 kHz) frequency channels
• Each user is allocated a unique channel

<table>
<thead>
<tr>
<th>Channel 1</th>
<th>Channel 2</th>
<th>Channel 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>960 kHz</td>
<td>960.2 kHz</td>
<td>960 kHz</td>
</tr>
</tbody>
</table>

• FDMA channel carries only one connection at a time: if the channel is not used, because the mobile does not have any data to send or receive, the capacity is lost (note: this is also the case with TDMA).

3.3- SSMA (Spread Spectrum Multiple Access)

• Also known as CDMA (Code Division Multiple Access)

• Principle
  - each user is assigned a unique code sequence (spreading code)
  - the various codes are orthogonal to each other (code1.code2 = 0)
  - the data signal is encoded using this code
  - all encoded signals share the same frequency band and therefore interfere
  - yet a receiver knowing the sender’s code can decode the signal and recover data

Spread Spectrum Techniques

There are two basic spread spectrum techniques:

• Direct Sequence Spread Spectrum (DSSS):
  - the signal is multiplied by a spreading code in the time domain
  - the spreading code is a pseudo random sequence that looks like noise

• Frequency Hopping Spread Spectrum (FHSS)
  - the signal changes of carrier frequency
  - sequence of frequency changes is determined via a pseudo random sequence
The initial application of spread-spectrum (SS) techniques was for military applications. SS investigation was motivated primarily by the desire to achieve highly jam-resistant communication systems. It is now used in civil applications:
- Multiple Access (e.g., CDMA) / Modulation
- Coordinated systems coexistence (e.g., SS UMTS)
- Uncoordinated systems coexistence (ISM bands)

A system is defined to be a SS system if the signal occupies a bandwidth much in excess compared to the minimum bandwidth necessary to send the information.

**DSSS Technology**

**DSSS Technology (3)**

- The spreading signal is controlled by a pseudo-random sequence (called PN) or pseudo-random code
  - A PN sequence is a random binary sequence
  - Nearly equal number of 0s or 1s
  - Very low correlation with shifted versions of the sequence

- Principle:
  - Multiplication by the PN code once spreads the signal bandwidth
  - Multiplication by the PN code twice, recovers the original signal
  - At a receiver, the desired signal gets multiplied twice, but the interference signal (if any) gets multiplied only once...

Once spread, a signal looks like noise...

**Spread spectrum Benefits (1)**

*interference suppression*

- No interference filtering
- Source 1 (SS with code 1)
- Source 2 (SS with code 2)
- Source 1 is the desired signal
- Source 2 is the interference

- Despreading at the receiver:
  - With code 1
  - With code 2

**Spread spectrum Benefits (2)**

*multi access capability*

- Source 1
- Source 2
- Source 3

- Signal Despreading at the receiver:
  - With code 1
  - With code 2

**Spread spectrum Benefits (3)**

*Other benefits*

- Improved confidentiality
  - A receiver that doesn’t know the code only sees white noise

- Anti-jamming capability
  - Jamming deliberately injected in the system is filtered just like interferences are
  - Especially true with narrow-band jamming

- Low probability of interception
  - Because of its low power density the signal is difficult to detect and intercept by a hostile listener

**DSSS: interference filtering**

- Assume a signal $x(t)$ and a spreading code $g(t)$
  - $x(t)$ is narrowband compared to $g(t)$

- The spread signal is generated by:
  - $s(t) = x(t)g(t) \rightarrow X(w)G(w)$
  - If the $x(t)$ is narrowband compared to $g(t)$, $s(t)$ will have approximately the bandwidth of the spreading signal.

- $Y(t) = s(t) + n(t)$ is transmitted on the channel, where $n(t)$ is the noise or interference

- At the receiver, $y(t)$ is multiplied by the spreading code $g(t)$:
  - $y(t)g(t) = x(t)g(t)g(t) + n(t)g(t) = x(t) + n(t)g(t)$
  - The signal $x(t)$ is recovered, the noise is spread...
**DSSS: interference filtering (2)**

\[ X(t) = \text{signal} \]
\[ G(t) = \text{code} \]
\[ S(t) = \text{signal} \cdot \text{code} \]
\[ N(t) = \text{noise} \]
\[ B_d \]

\[ Y(t) = S(t) + N(t) \]

\[ Y(t) \cdot \text{Code} \]

**DSSS: multiplexing**

- All terminals send on the same frequency, probably at the same time, and use the whole bandwidth of the channel.
- Each sender has a unique pseudo random sequence, that he multiplies (or XORs) with the signal.
- The receiver can recover this signal if he knows the pseudo random sequence.

**Disadvantages:**
- Higher complexity of a receiver.

**Advantages:**
- All terminals can use the same frequency, no planning needed.
- Huge code space (e.g., \(2^{32}\)) compared to frequency space.
- Interferences (noise) are not coded.
- Forward error correction and encryption can be easily integrated.

**DSSS drawback (not with FH)**
- Near Far problem:
  - If A and B use the same power, the signal received by the BS from B is much stronger than the signal received.
  - B masks A!
- Precise power control is needed.
- The BS tells each node to adjust its transmission power according to its distance.

**FHSS (Frequency Hopping Spread Spectrum)**
- Discrete changes of carrier frequency.
  - The freq. sequence is determined by a pseudo random sequence.
- Two versions:
  - Fast Hopping: several frequencies per user bit.
  - Slow Hopping: several user bits per frequency.

**Advantages:**
- Frequency 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.
**Cellular Systems (1)**

- Most commercial radio and television systems are designed to cover as much area as possible:
  - they operate at the maximum allowed power with the highest possible antennas
- **Cellular systems** take the opposite approach: they make an efficient use of available channels by using low-power transmitters in order to allow frequency reuse at much smaller distances:
  - maximize the number of times each channel may be reused in a given geographical area
- **Difficult tradeoff:**
  - more channels \(\rightarrow\) smaller cells
  - smaller cells \(\rightarrow\) more interferences + more handovers

**Cellular Systems (2)**

- In a cellular system, the space is divided into clusters.
- Each cluster uses the whole frequency spectrum of the system.
- Each cluster is divided into cells.
- Each cell of a cluster uses different frequency band.
- Cells are laid out such as 2 cells of 2 clusters using the same frequency band do not interfere.

**Cellular Systems (3)**

In practice:

- A cell is covered by a base station.
- A cell coverage is not hexagonal but an irregularly shape circle.
- A cell size varies from few hundred meters to 50 kms.
- Any number of cells by cluster can be used. However, geometry shows that regular pattern leads to more efficient use of the spectrum. A Pattern is regular if the number of cells \(K\) verifies the following equation:
  - \(K = i^2 + j^2 + ij\) where \(i\) and \(j\) are positive integer.
  - \(K = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, 25, 27,\ldots\)

**Cellular Systems (4)**

If a regular pattern is used, it can be shown that:

- the number of interfering cells is always equal to 6:
  \[
  D/R = (3K)^{1/2}
  \]
  - where \(R\) is the center-to-vertex distance of a cell and \(D\) is the co-channel separation distance.
Co-channel Interference Ratio

- The co-channel interference ratio at a receiver is:
  \[ S/I = S/\left(\sum_{k=1}^{y} I_k\right) \]
  where:
  \[ I_k = S/(D/R) \]
  \[ 2 + y = 5 \text{ depending on the terrain environment} \]
- therefore:
  \[ S/I = (D/R)/6 = 1/6 \times (3K)^{1/2} \]
- 18 dB = 10 log(63.1) is the agreed value for correct voice quality for current cellular systems
  - with \( y = 4 \), we find:
  - \( (D/R) = (6 \times S/I)/3 = 6.49 \)
  - therefore \( K = (D/R)^2/3 = 6.49 \approx 7 \)
  a seven-cell reuse pattern is needed!

Co-channel Interference Ratio (2)

- Consider a cellular system with 396 total allocated voice channel frequencies.
- We have the following results for different \( K \):
  \[
  \begin{array}{|c|c|c|c|}
  \hline
  K & \text{Voice chan./cell} & S/I (dB) & \text{total channels} \\
  \hline
  4 & 99 & 14.0 & 396 \\
  7 & 56 & 18.7 & 392 \\
  12 & 33 & 23.3 & 396 \\
  \hline
  \end{array}
  \]
- By increasing the reuse factor (\( K \)):
  - the quality (\( S/I \)) is increased (better cell separation)
  - the capacity per cell is reduced (fewer frequencies per cell)
- These results are independent of the cluster size!
- For a given \( K \), the capacity of a system can be increased by reducing the cluster size:
  \[ C \text{ (channels/m}^2) = \text{total nb of channels / cluster size} \]

3.5- Packet Radio Access

- In Packet Radio access techniques, many hosts attempt to access a single channel in an uncoordinated manner
- Transmission is done on a per-packet basis
- Collisions from simultaneous transmissions of multiple transmitters are detected at a receiver that broadcasts:
  - ACK (acknowledgement) if the packet is successfully received
  - NACK (Negative ack) if the packet is not received correctly
  - nothing is the packet is not been received at all
- A wireless host uses the CSMA-CA (Contention Avoidance) technique
  - derived from Ethernet’s CSMA/CD
  - cf. cours réseaux de capteurs...

3.6- Duplexing

- In wireless communication systems, it is often desirable to allow the mobile to send simultaneously information to the BTS while receiving information from the BTS: this is called Duplexing.
- Duplexing may be done using frequency or time domain techniques:
  - Frequency Division Duplexing (FDD): provides 2 distinct frequency bands per user: one for emission, one for reception
    - A duplex channel actually consists of two simplex channels and a duplexer is used to receive and send on 2 different frequency bands
    - The frequency split between the forward and reverse channel is constant for the whole system
  - Time Division Duplexing (TDD): uses time instead of frequency to provide both a forward and reverse link
    - Introduces some delay between emission and reception
    - simpler than FDD.
Duplexing vs Multiple Access

- Any combinations of Duplexing and Multiple Access scheme can be used.

- Example 1: FDMA/FDD - GSM

[Diagram showing frequency band allocation for GSM]

Duplexing vs Multiple Access (2)

- Example 2: TDMA/TDD - DECT

[Diagram showing time slot allocation for DECT]