Advanced Wireless Communications (Lecture 2: Overview of GSM, IS95 and 3G standards)

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Acknowledgment

- The material in this lecture is based on the book “Fundamentals of Wireless Communications” by David Tse (University of California, Berkeley) and Pramod Viswanath (University of Illinois, Urbana Champaign).
- Other important reference used is:
Introduction to cellular systems

- A cellular system consists of a number of base stations, typically one for each cell.
  - Different from TV or radio broadcast because (i) Users are interested in their own messages. (ii) There is feedback involved between transmitter and receiver. (iii) Usually are point-to-point in nature.
- Two main issues in cellular systems are: (i) Interference management (physical layer) and (ii) Multiple access (medium access control (MAC) layer).
- Any cellular network has two types of links: (i) Uplink (from mobile to base station) and (ii) Downlink (from base station to mobile).
- **Resource allocation between uplink and downlink:**
  - Time division duplex (TDD).
  - Frequency division duplex (FDD) (*widely used*).
- Cellular system designs can be divided into two types:
  - Narrowband systems (GSM, IS-136).
  - Wideband systems (CDMA, OFDM).
Narrowband Systems

- In narrowband systems, user transmissions within a cell are restricted to separate narrowband channels.
- Neighboring cells use different (narrowband) channels for user transmissions.
- For example if the total bandwidth is $W$ Hz. Then
  - We divide $W$ into $N$ narrowband channels, each of width $W/N$ Hz.
  - Each cell is allotted some $n$ of these $N$ channels.
  - The allotted channels to a given cell need not be contiguous.
  - A channel is allotted to a cell only if it is not used by other neighboring cells.
- Thus the whole network is divided into a no. of point-to-point non-interfering links.
Example for channel allocation

- Channel allocation in a network of 7 channels.

- The ratio \( n/N \) is defined as the frequency reuse factor.
- In the above example, the frequency reuse factor is equal to \( 1/7 \).
- Frequency reuse factor determines how effectively the bandwidth is utilized.
- In the above example \( W/7 \) is the effective bandwidth used by any base station.
Example of narrowband system - Global System for Mobile (GSM)

- GSM (used primarily for voice) is a FDD based system that uses two 25-MHz bands.
  - **Uplink:** 890 – 915 MHz band.
  - **Downlink:** 935 – 960 MHz.
- The above bands are divided into 200-KHz channels.
- These channels are allotted to a number of cells, so that they cause minimal interference to each other.
- Further, each channel in a given cell is shared by users in TDMA fashion.
- To facilitate this the time on each channel is divided into a no. of slots each of 577 µsec.
- Convolutional coding is used along with interleaving to obtain time diversity.
  - Interleaver helps randomize the errors.
  - Error randomization improves speech quality.
- The uplink and downlink of a GSM system are coherent.
Advantages and disadvantages of narrowband systems

- **Advantages:**
  - Due to the lack of interference the operating received SINR is fairly large (upto 30 dB).

- **Disadvantages:**
  - Inefficient use of the bandwidth.
  - Complexity of network planning.
  - Not suitable for universal frequency reuse (due to lack of interference averaging).

- To overcome these disadvantages we go for wideband systems.
Wideband - code division multiple access (CDMA) Systems

- In narrowband cellular systems, the network is decomposed into a no. of point-to-point non-interfering links.
- However, in wideband CDMA systems, the signal is spread over the entire bandwidth using “direct sequence (DS)” spread spectrum technique.
- **DS-CDMA System**: The following are some important characteristics of DS-CDMA systems (henceforth referred to as CDMA systems):
  - Each user in the network spreads his data over the entire bandwidth using a unique code.
  - Thus all the users get access to the full bandwidth (i.e., universal frequency reuse).
  - Since all users access the system simultaneously, tight power control is very important.
  - In general, a CDMA system is interference limited.
- To gain insight into how CDMA is implemented in practice, we study the 2G IS-95 (or CDMA One) system.
- **Useful trivia**: CDMA was first conceived in 1985 by Dr. Irwin Jacobs, Klein Gilhousen and Dr. Andrew Viterbi.
Downlink of IS95 System

- IS95 was standardized in 1993 by telecommunications industry association (TIA) and commercialized in 1995.
- It operates in the 869-894 MHz frequency range and uses FDD mode.
- The downlink of an IS95 system is shown below:
Details of the downlink of IS95 Systems

- The figure shows only one rate set for IS95 downlink. However the IS95 downlink supports two rate sets.
  - The rate set 2 values are 1.5 times the corresponding rate set 1 values.
  - Rate set 1 is encoded using a convolutional code of rate $\frac{1}{2}$.
  - Rate set 2 is encoded using a convolutional code of rate $\frac{3}{4}$.
  - **Note:** The same convolutional encoder (with constraint length $K = 9$) is used to encode both the rate sets.
  - The encoding rate of $\frac{3}{4}$ for rate set 2 is obtained by puncturing the generated codewords for $\frac{1}{2}$ case.

- **Interleaver:** The interleaver interleaves the symbols within the 20 msec. frame.
  - The interleaver randomizes the transmission errors.
  - This could improve the performance of the convolutional decoder.

- Each symbol of the interleaved data is then spread using the 64 chip orthogonal Walsh code sequences.
- This spreading results in an output of $19,200 \times 64 = 1.2288$ Mcps.
Details of the downlink of IS95 Systems (ctd...)

- Each channel (i.e., Traffic, Pilot, Synch, Paging) uses a unique Walsh code for spreading.
- After Walsh spreading the data is spread in both quadratures using short pseudorandom noise (PN) sequences.
  - Each sector uses an offset version of the same PN code sequence.
  - These short PN codes help identify one sector from another.
  - The maximum number of offset PN code sequences are equal to $512$.
  - This enables the reuse of the Walsh code in every sector.
- After the PN spreading, an FIR filter is used for pulse shaping to restrict the spread waveform to the specified bandwidth.
Uplink of IS95 System

- The uplink of an IS95 system is shown below:

![Diagram of Uplink of IS95 System]

**Details of IS95 Uplink:**

- The encoding and interleaving is done just like in the downlink.
- Here it uses a lower rate convolutional code than in the downlink.
- The lower rate code ensures better performance in the typical low SNR regime operated by the uplink.
- The resulting output rate after encoding and interleaving is 28.8 Kbps.
Details of IS95 Uplink (ctd...)

- Demodulation in the reverse link of IS95 system is done non-coherently.
- To improve the non-coherent demodulation, the system designers choose **orthogonal modulation**.
- To this end again Walsh codes are used.
  - Here Walsh codes are used for **symbol separation**.

**Details of Orthogonal Modulation:**

- The orthogonal signaling set contains 64 possible symbols.
- The information to be modulated is segregated into groups of 6 symbols.
  - These 6 symbols are then mapped to a value from 0 to 63.
  - The Walsh code corresponding to the mapped value is then selected for transmission.

- At the end of Orthogonal modulation the symbol rate increases to 307.2 KHz.
- After Orthogonal modulation, the data is spread using a **PN sequence**.
- In uplink users are separated using the PN code (instead of Walsh codes).
Details of IS95 Uplink (ctd...)

- The aforementioned PN spreading increases the bandwidth 4 times to about 1.23MHz.
- After the PN spreading, the quadrature spreading happens with the short code.
- After quadrature spreading, the $Q$ branch data is delayed by $1/2$ of a PN chip time to produce Offset (or Staggered) QPSK (OQPSK).
  - In conventional QPSK the phase can change by $180^\circ$ at a time.
  - This leads to higher amplitude fluctuations when passed through a low pass filter (LPF).
  - If the amplitude fluctuations are large, then the linear range of the power amplifier (PA) has to be large.
  - This could lead to having a fat PA, which is not desirable.
  - However in OQPSK, the phase change cannot be more than $90^\circ$.
  - This yields much lower amplitude fluctuations when passed through an LPF.
  - Thus, PA can be relatively small here.
Details of IS95 Uplink (ctd...)

- **Demodulation**: The demodulation happens at the base station using a RAKE receiver.

  - The steps involved in demodulation are summarized as follows:
    - The RAKE receiver in IS95 has four elements called *fingers*.
    - A searching process happens among these fingers.
    - The searching process identifies strong multipath arrivals and a finger is assigned to demodulate at the offset identified.
    - Now for each orthogonal sequence, the non-coherent detector computes the correlation along each finger, and then forms the sum of the squares.
    - The detector decides in favor of the sequence with the largest sum.
    - We are essentially using energy or square law detector for detection.

- After the symbol detection, the signal is de-interleaved and then passed to Viterbi decoder for decoding.
Power Control in IS95 System

- The power control in IS95 is done only in the uplink.
- Power control in downlink is not that required because the traffic channels vary in strength by only $\pm 4 \text{dB}$, due to various reasons.
- The purpose of power control is to maintain a target SINR at the mobile.
- The power control in IS95 uplink has two components:
  - open-loop.
  - closed-loop.
- In open loop, the mobile sets the transmit power based on measurements of the downlink.
  - This is possible via the common pilot signal broadcasted by the base station.
  - Usually inaccurate, because the uplink and downlink differ in carrier frequency by a few MHz.
- Therefore, closed loop power control is needed for precise power adjustment.
Power control in IS95 System (ctd...)

- Block diagram of closed loop power control in IS95 uplink:

  ![Block diagram of closed loop power control in IS95 uplink](image)

- As can be seen from the above figure the closed loop power control has two loops:
  - Inner loop.
  - Outer loop.

**Inner loop:**
- The inner loop estimates the SINR based on the output of RAKE receiver.
- If the measured SINR $\beta$ (the SINR threshold), then a command is sent to decrease power by 1dB.
- If the measured SINR $\beta$, then a command is sent to increase power by 1 dB.
The power control command is sent by **pseudo randomly puncturing** the data bits in the traffic channel.

The measurement and comparison occurs every $1.25\text{msec}$ (or 800 Hz).

**Outer loop:** The outer loop is used to adjust the SINR threshold $\beta$. This is done as follows:

- The receiver determines the frame error rate (FER) and compares it with a preset value (equal to $1\%$).
- If the measured FER is $< \text{than the preset value}$, then $\beta$ is increased.
- If the measured FER is $> \text{than the preset value}$, then $\beta$ is decreased.

**Note:**

- In general, power control tracks only the slower scale fading (that occurs due to shadowing and path loss).
- The faster scale fading (due to multipath) is typically dealt using diversity techniques.
**Soft Handoff in IS95 Systems**

- Handoff mechanism is one in which a mobile is transferred from one base station to another.
- Most cellular networks use **hard handoff**.
  - i.e., they are assigned to only one cell.
- In IS95 systems **soft handoffs** are possible.
  - In soft handoff, a mobile is connected with more than one base station.
  - This is possible because of the **universal frequency reuse** in CDMA systems.
- **Soft handoff procedure:**
  - The mobile while tracking the downlink pilot of the current cell, also keeps track of other cell pilots.
  - Once a pilot of another cell is detected, the mobile informs the same to the current base station.
  - The current base station informs the switching center, which then enables the second base station to send and receive information to the mobile.
Soft Handoff in IS95 Systems (ctd...)

- **Soft handoff procedure (ctd...):**
  - In the uplink, each base station demodulates independently, and it is upto the switching center to decide, which one to send to the mobile.
  - Usually, the better cell’s decision is used.

- From the above discussion, we can conclude that the soft handoff indeed is a form of **receive diversity** (more specifically “selection combining” receive diversity).

- **Power control in IS95 during soft handoff:**
  - The mobile will decrease power if at least one base station instructs it to do so.
Overview of 3G standards

- **Motivation for 3G standards**: Main motivation is to be able to obtain higher data rates.
  - The data rates offered by IS95 and GSM are good enough for only voice.

- Two main 3G standards are:
  - CDMA2000 (used in S. Korea and USA).
  - WCDMA (used in Europe, Japan)

- **DS-CDMA** is the main physical layer technology in both CDMA2000 and WCDMA.

- **Useful Trivia**:
  - CDMA 2000 was standardized by 3GPP2 and is designed to be backward compatible with IS95.
  - WCDMA was standardized by 3GPP.
CDMA2000 and WCDMA - Similarities

- Enhancements in CDMA2000 and WCDMA over IS95:
  - Both use orthogonal variable spreading factor (OVSF) codes to support various data rates.
    - For high data rates a lower spread factor (SF) code is used.
    - For low data rates a higher SF code is used.
    - The spreading factors vary from 4 to 256.
  - Both employ QPSK modulation and complex PN spreading (shown below) in the uplink.
CDMA2000 and WCDMA - Similarities (ctd...)

- **Enhancements in CDMA2000 and WCDMA over IS95:**
  - Coherent uplink.
  - Uplink power control is also done using the pilot.
  - Downlink power control.
  - Both support usage of turbo codes for FEC.
  - Both enable transmit diversity via the Alamouti code.
CDMA2000 and WCDMA - Differences

<table>
<thead>
<tr>
<th>Feature</th>
<th>CDMA2000</th>
<th>WCDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Bandwidth</td>
<td>1.25 MHz for (1X) and 5MHz for (3X)</td>
<td>5MHz</td>
</tr>
<tr>
<td>Chip rate</td>
<td>1.2288Mcps for (1X), 3.6864Mcps for (3X)</td>
<td>3.84Mcps</td>
</tr>
<tr>
<td>Network synchronization</td>
<td>Synchronous</td>
<td>Asynchronous or Synchronous</td>
</tr>
</tbody>
</table>

- In synchronous mode, all the base station(s) (BS) use the same PN code for scrambling but with different offsets.
  - Requires time reference at all the BSs.
  - Synchronization of CDMA2000 is similar to that of IS95.

- In asynchronous mode, the BSs are identified using distinct scrambling codes.
  - Requires no time reference.
**CDMA2000 1xEV-DO and HSDPA**

- Both CDMA2000 1xEV-DO and High Speed Downlink Packet Access (HSDPA) allow high rate data transmission.

- **Enhancements in CDMA2000 1xEV-DO and HSDPA:**
  
  - High speed packet-switched downlink channelization structure:
    - As part of this enhancement, time slots are introduced in the downlink.
    - In each time slot, all of the resources (such as codes and power) are allocated to a given user.
    - This is in contrast to what happened in CDMA2000 and WCDMA, where a single orthogonal code is dedicated for transmission of a given channel.

  - **Opportunistic Scheduling:**
    - In this approach users with good channel conditions are served.
    - This approach increases network capacity compared to round-robin scheduling.
    - In practice, a *proportional fair opportunistic scheduling mechanism* is used that achieves better network capacity as well as individual user rates.
Enhancements in CDMA2000 1xEV-DO and HSDPA:

- Fast Adaptive Modulation and Coding Schemes:
  - These schemes are used to instantaneously adjust transmission parameters (such as modulation, coding, etc.) as shown in the above figure.
  - The coding rate can vary between $1/5$ to $1/3$. While the modulation schemes include QPSK, 8-PSK and 16-QAM.
Enhancements in CDMA2000 1xEV-DO and HSDPA:

- Fast Hybrid Automatic Request (ARQ) mechanism

As can be seen from the above fig., when a packet $P_1$ sent by the transmitter is not received by the receiver, then the receiver sends a negative acknowledgment (NACK) to the transmitter.

The transmitter then re-sends the packet and the new received packet $P'_1$ is then soft (or chase) combined with the previously transmitted version $P_1$.

If the decoding is correct, then a positive acknowledgment (ACK) is sent to the transmitter.