Lecture overview

- Signal Processing in GSM
- Physical and Logical channels in GSM
- Call set-up
- GSM time hierarchy
- Modifications and derivatives of GSM
- Data transmission in GSM:
  - HSCSD
  - GPRS – part one
Signal processing in GSM

Speech
\[\downarrow\]
Digitizing and source coding
\[\downarrow\]
Channel coding
\[\downarrow\]
Interleaving
\[\downarrow\]
Burst Formatting
\[\downarrow\]
Ciphering
\[\downarrow\]
Modulation

Radio Channel

Speech
\[\uparrow\]
Source decoding
\[\uparrow\]
Channel decoding
\[\uparrow\]
De-interleaving
\[\uparrow\]
Burst Formatting
\[\uparrow\]
De-ciphering
\[\uparrow\]
Demodulation
Analogue to digital conversion

- Sampling at 8 kHz
- Quantization with 192 levels
- Coding using 13 bits
- $8\text{kHz} \times 13\text{b} = 104\text{ kb/s}$
- $104\text{kb/s} \times 8\text{ slots} = 832\text{ kb/s total BR after A/D}$
- Much too high for 200 kHz channel spacing in GSM
- Speech coding used to lower the bit rate
Speech Coding

- Sending information about tone and filter not the signal
  - Speech limited to 4 kHz using anti-aliasing filter
  - Filter parameters constant over 20 ms (equivalent to 50 Hz sampling)
  - Each 20 ms speech frame represented using 260 bits (50*260= 13 kb/s*8 slots=104 kb/s total BR after speech coding)
- Voice Activity Detector (VAD) – user speaks for less then 40% of time
- Discontinuous Transmission Mode - transmitter inactive during silence periods
- Comfort Noise Subsystem (CNS) – introduces background noise
Channel Coding

- Used to detect and correct errors in a received bit stream
- Capable of handling single or short error sequences
- 260 bits input – 456 bits output

- 50 Very important bits
- 132 Important bits
- 4 Tail bits
- 78 Not so important bits

- Last 78 bits are not protected
Block code — adds extra bits to each block of input data
- Parity bits added to block of message bits to create codeword
- Ability of a code to correct errors depends on code distance
- Distance of a code — no. of elements in which 2 codewords differ

Convolution coding — maps a continuous stream of information into a continuous sequence of encoded output bits
- Generated by passing data through a finite state shift register
- Modulo-2 function performed on k no. of bits n times
- Outputs multiplexed together — consists of n bits (k<n), code rate $R_c = k/n$ (for 1/2 code each input bit represented by 2 output bits)
- Can be expressed using generation polynomials e.g.: $g(D) = 1+D^2$ where D is a unit delay (mod-2 data with output of the 2nd flip-flop
- Decoded Maximum Likelihood Sequence Estimator implemented using Viterbi algorithm (finding sequence with min distance to the received signal)
Interleaving

- Reduces impact of sudden fades on received data:
  - First level of interleaving - 456 bits (20 ms of speech) broken to eight 57 bit sub-blocks
  - Blocks don’t carry consecutive bits
• Second level - block spread over 8 consecutive frames
• Each time slot carries two 57 bit groups from two different 20 ms speech segments

![Diagram of normal burst with numbers and segments]

Normal burst
Speech frame

Second level of interleaving
Ciphering

- Modifies content of 8 consecutive interleaved blocks by encryption – does not add bits
- Encryption algorithm changed from call to call
- A3 algorithm for encryption of user authentication and verification of users passcode from the SIM
- A5 scrambling for the 114 coded data bits

Burst formatting – adds binary data to encrypted blocks to help with synchronisation and equalization of received signal
Modulation: 0.3 Gaussian Minimum Shift Keying (GMSK)

- Continuous Phase Frequency SK – constant envelope of signal, reduces degradation due to components nonlinearities
- Binary 0’s and 1’s represented by RF carrier shifted by ±67.708 Hz (1/4 of BR – improves spectral properties of the signal)
- Data signal (square pulses) passed through Gaussian filter prior to modulation – smoothing rapid frequency transitions, that would spread energy to adjacent channels
- Intersymbol interference occurs – pulses last long than bit period
- Bandwidth (filter) – bit duration product determines the spectral efficiency and amount of ISI
Generation of GMSK signal

Power spectra of a GMSK signal for different values of BT
Frequency hopping

- In cells where users have severe multipath problem
- Slow frequency hopping – on frame-by-frame basis
- Max. rate 217.6 hopes per second
- There can be up to 64 frequencies in a hopping sequences

Equalisation

- Performed by receiver using information from the training bits transmitted in midamble in every TS
Physical channels in GSM

- Physical channel corresponds to a time slot on a frequency carrier
- There are 8 physical channels per carrier in GSM
- Physical channel can be used to transmit speech, data or signalling information
- Different messages transmitted on the physical channels are called logical channels
Logical Channel Description and function

- There are 4 main types of logical channels in GSM:
  - Traffic Channel (TCH) – carries speech or data
  - Broadcast Channel (BCH) – downlink direction only
  - Common Control Channel (CCCH)
  - Dedicated Control Channel (DCCH)
Logical Channel Description

- Traffic Channels (TCH) – full-rate or half rate (data sent every second frame), carry either speech or data
  - Full-rate channel [speech or data] (TCH/FS or FD) – raw data at 13 kb/s plus channel coding results in 22.8 kb/s signal
  - Half-rate [speech or data] channel (TCH/HS or HD) – speech sampled at half the speed of full rate channel. 6.5 kb/s + coding results in 11.4 kb/s signal

Channels used for communication between the MS and BSS when a call is in progress
Broadcast Channels – transmitted always on first frequency in the first time slot (TS0) in downlink direction only

- Frequency Correction Channel (FCCH) – Transmitted every 10 frames starting with the first one, allows the MS to synchronize to BS local oscillator

- Synchronization Channel (SCH) – every 10 frame follows FCCH, frame no, BS identity code, timing advance command, training sequence – calculation of impulse response of the channel for signal detection; synchronisation within the time hierarchy of system

- Broadcast Control Channel (BCCH) – frame 2-5, cell and network ID, channel availability etc. (dissemination of general information from the BS to MS)
- Common Control Channels (CCCH) transmitted on BCH frequency in TS0 not occupied by BCH

- Paging Channel (PCH) – downlink direction, for locating the MS, calling a mobile station, broadcasting SMS

- Random Access Channel (RACH) – uplink direction, replay to a page from PCH, resource request by the MS,

- Access Granted Channel (AGCH) – downlink, response to RACH, for subscriber authorization, resource allocation
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<th>14</th>
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<td>S</td>
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<td>F</td>
<td>S</td>
<td>C3</td>
<td>C3</td>
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**B** – BCCH  
**F** – FCCH  
**S** – SCH  
**I** - Dummy  
**Cn**- CCCH (PCH or AGCH)

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*Figure 4-8  Multiplexing of BCHs and CCCHs on TS0*
Dedicated Control Channel (DCCH) bidirectional, any TS except TS0 on BCH:

- Stand-alone Dedicated Control Channel (SDCCH) – ensuring connection during user identification and resources allocation, physical channel or on TS0 of BCH if free, assigned to connection before TCH assignment

- Slow Associated Control Channel (SACCH) e.g. change power of MS, timing advance, send report on measurements done by MS, send within the TCH

- Fast Associated Control Channel (FACCH) – urgent messages, steal frames from TCH, which it is associated with

- Non-associated version of FACCH – transmission of short messages
Figure 4-9  Multiplexing of SDCCHs and SACCHs on TS1
Mapping of control and traffic logical channels to physical channels

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<tr>
<th>Carrier Frequency</th>
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<th>2</th>
<th>3</th>
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<th>5</th>
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</tbody>
</table>

Legend:
- B: BCH
- C: CCCH
- D: DCCH
- T: TCH
<table>
<thead>
<tr>
<th>Logical Channel</th>
<th>Direction</th>
<th>BTS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand alone Dedicated Control CHannel (SDCCH)</td>
<td>Uplink and downlink, point to point</td>
<td>The BTS switches to the assigned SDCCH, used for call set-up signaling. TCH is assigned on SDCCH (SDCCH is also used for SMS messages to MS).</td>
<td>The MS switches to the assigned SDCCH. Call set-up is performed. The MS receives a TCH assignment information (carrier and time slot).</td>
</tr>
<tr>
<td>Cell Broadcast CHannel (CBCH)</td>
<td>DL, point to multi point, mapped on SDCCH</td>
<td>Uses this logical channel to transmit short message service cell broadcast.</td>
<td>MS receives cell broadcast messages.</td>
</tr>
<tr>
<td>Slow Associated Control CHannel (SACCH)</td>
<td>Uplink and downlink, point to point</td>
<td>Instructs the MS on the allowed transmitter power and parameters for time advance. SAACH is used for SMS during a call.</td>
<td>Sends averaged measurements on its own BTS (signal strength and quality) and neighboring BTS's (signal strength). The MS continues to use SACCH for this purpose during a call.</td>
</tr>
<tr>
<td>Fast Associated Control CHannel (FACCH)</td>
<td>Uplink and downlink, point to point</td>
<td>Transmits handover information.</td>
<td>Transmits necessary handover information in access burst</td>
</tr>
</tbody>
</table>
### Common Control Channels (CCCH)

<table>
<thead>
<tr>
<th>Logical Channel</th>
<th>Direction</th>
<th>BTS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paging CHannel (PCH)</td>
<td>Downlink, point to multi-point</td>
<td>Transmits a paging message to indicate an incoming call or short message. The paging message contains the identity number of the mobile subscriber that the network wishes to contact.</td>
<td>At certain time intervals the MS listens to the PCH. If it identifies its own mobile subscriber identity number on the PCH, it will respond.</td>
</tr>
<tr>
<td>Random Access CHannel (RACH)</td>
<td>Uplink, point to point</td>
<td>Receives access-request from MS for call setup/loc. update/SMS</td>
<td>Answers paging message on the RACH by requesting a signaling channel.</td>
</tr>
<tr>
<td>Access Grant CHannel (AGCH)</td>
<td>Downlink, point to point</td>
<td>Assigns a signaling channel (SDCCH) to the MS.</td>
<td>Receives signaling channel assignment (SDCCH).</td>
</tr>
<tr>
<td><strong>Logical Channel</strong></td>
<td><strong>Direction</strong></td>
<td><strong>BTS</strong></td>
<td><strong>MS</strong></td>
</tr>
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<td>-------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Frequency Correction Channel (FCCH)</td>
<td>Downlink, point to multipoint</td>
<td>Transmits a carrier frequency.</td>
<td>Identifies BCCH carrier by the carrier frequency and synchronizes with the frequency.</td>
</tr>
<tr>
<td>Synchronization Channel (SCH)</td>
<td>Downlink, point to multipoint</td>
<td>Transmits information about the TDMA frame structure in a cell (e.g. frame number) and the BTS identity (Base Station Identity Code (BSIC)).</td>
<td>Synchronizes with the frame structure within a particular cell, and ensures that the chosen BTS is a GSM BTS - BSIC can only be decoded by an MS if the BTS belongs to a GSM network.</td>
</tr>
<tr>
<td>Broadcast Control Channel (BCCH)</td>
<td>Downlink, point to multipoint</td>
<td>Broadcasts some general cell information such as Location Area Identity (LAI), maximum output power allowed in the cell and the identity of BCCH carriers for neighboring cells.</td>
<td>Receives LAI and will signal to the network as part of the Location Updating procedure if the LAI is different to the one already stored on its SIM. MS sets its output power level based on the information received on the BCCH. The MS stores the list of BCCH carrier frequencies on which Rx level measurement is done for Handover decision.</td>
</tr>
</tbody>
</table>
Call set-up in GSM

- Mobiles originated call:
  - MS synchronizes to BS by monitoring BCH (FCCH, SCH, BCCH)
  - MS transmits a burst of RACH data using BS BCH (uplink)
  - BS responds with AGCH on CCCH assigning new SDCCH to MS (frequency and TS)
  - MS tunes to SDCCH and waits for SACCH (max 26 frames, 120 ms)
  - Receives timing advance, power level (determined by BS from RACH)
  - SDCCH sends messages between BS and MS taking care of authentication and user validation
Meanwhile PSTN connects the dialled party to MSC and MSC switches the speech path to the serving BS

After few seconds MS is ordered by SDCCH to tune to new frequency and TS - TCH

On TCH speech data is transferred in both directions and SDCCH is vacated

Call originated from PSTN:

- BS broadcasts PCH during TSO of BCH
- The called MS replies using RACH
- BS uses AGCH to assign SDCH and SACCH to the connection
- After MS establishes the timing advance and authentication BS issues new physical channel for TCH
Call to an MS
GSM burst structures

- There are 5 types of bursts:
  - Normal burst (TCH and DCCH)
  - FCCH
  - SCH
  - Dummy (filler information for unused frames)
  - RACH
<table>
<thead>
<tr>
<th>Burst Type</th>
<th>Purpose</th>
<th>Used by</th>
<th>Contents</th>
</tr>
</thead>
</table>
| Normal          | Used to carry information on traffic and control channels | BCCH, PCH, AGCH, SDCCH, CBCH, SACCH, FACCH, TCH | • Two blocks of 57 bits each for traffic  
• Training sequence (26 bits)  
• Steal flags (1 bit each) to indicate that FACCH has temporarily stolen 57 bits  
• Tail bits (always 000)  
• Guard period: 8.25 bit durations |
| Frequency Correction | Used for frequency synchronization of the mobile | FCCH                   | • 142 frequency correction bits  
• Tail bits  
• Guard period: 8.25 bit durations |
| Synchronization | Used for frame synchronization of the mobile | SCH                    | • Two blocks of 39 bits for TDMA frame structure information  
• 64 synchronization bits  
• Tail bits  
• Guard period: 8.25 bit durations |
| Access          | Used for random and handover access               | RACH, FACCH            | • 41 synchronization bits  
• 36 bits of access information  
• Tail bits  
• Guard period: 68.25 bit durations. A longer GP is used because it is the first transmission from the mobile - no timing advance information is available |
| Dummy           | Used when no other channel requires a burst to be sent and carries no information | All free TS on C0. (1-7) | • Pattern consists of Training sequence and a mixed bits pattern. |
Figure 4-3. Logical channels and bursts
GSM Time Hierarchy

- Single bit lasts 3.69µs – corresponds to BR 270.833 kb/s
- There 148 bits in a time slot (exception RACH – 88 bits) – burst
- Time slot length is 0.577 ms (156.25 bits) – guard time added for:
  - Switching the transmitter amplifier on and off
  - Ensuring the time alignment of bursts within a slot – accounting for variation in propagation delay due to distance BS – MS
- Access burst – access request sent by MS – 88 bits – longer guard time to minimize probability of collisions between burst sent by multiple MS without knowledge of the timing
8 time slots constitute a frame:

For traffic and control channels:
- **26 frames create multiframe**
- **51 multiframes constitute a superframe – 6.12 s**

For broadcast channels:
- **51 frames create multiframe**
- **26 multiframes constitute a superframe**

Either way 2048 superframes create the highest level unit of the GSM time hierarchy – **hyperframe**

Hyperframe lasts 3 hours 28 min 53 s 760 ms

After this time the system clock returns to its initial state

Long period of the clock due to the data encryption algorithm, encryption sequence generated using frame no. (increased security and call privacy)
1 hyperframe = 2048 superframes = 2,715,648 TDMA frames (3 hours 28 minutes 53 seconds 760 milliseconds)

1 superframe = 1326 TDMA frames (6.12 seconds)

(= 51 (26-frame) multiframes or 26 (51-frame) multiframes)

1 (26-frame) multiframe = 26 TDMA frames (120 ms)

1 (51-frame) multiframe = 51 TDMA frames (235 ms)

TDMA frame = 8 timeslots (120/26 ~ 4.615 ms)

1 timeslot = 156.25 bit durations (15/26 ~ 0.577 ms)

(1 bit duration 48/13 ~ 3.69 micro sec)

<table>
<thead>
<tr>
<th>Normal burst (NB)</th>
<th>Encrypted bits</th>
<th>flag</th>
<th>Training sequence</th>
<th>Encrypted bits</th>
<th>TB</th>
<th>GP</th>
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<td>Dummy burst (DB)</td>
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TB: Tail bits
GP: Guard period
Summary

- Signal Processing in GSM
  - Coding (speech, data, channel)
  - Interleaving, ciphering, modulation
- Logical channels in GSM – function, direction, physical channel allocation
- Call set-up
  - MS originated
  - PSTN originated
- GSM time hierarchy
  - TS, frames multi-, super-, hyperframes
  - Burst structure – 5 types