Telecommunication Systems (GSM)

Mobile Communications (Ch 4)
John Schiller, Addison-Wesley
Telecommunication System

• Wireless extension of traditional PSTN
• Telephony architecture (NOT computer net)
• Many systems in use
  – Europe: GSM (Global System for MC)
  – Japan: PDC (Pacific Digital Cellular)
  – US, Canada:
    • AMPS (Advanced Mobile Phone System)
    • GSM, …
Market Share

- GSM: 800 million (~ 70%)
- Japanese PDC: 60 million
- TDMA: 107 million
- CDMA: 135 million
Development of different generations

**TDMA/FDMA**
- IS-136 TDMA
- GSM
- PDC
- EDGE
- IS-136HS
- UTRA FDD/W-CDMA

**CDMA**
- IS-95 cdmaOne
- Cdma2000 1X
- cdma2000 1X EV-DO
  - 1X EV-DV

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<th>2G</th>
<th>2.5G</th>
<th>3G</th>
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**EDGE**: Enhanced Data-rate for GSM Evolution, **EV-DO**: Evolution-Data Optimized (Only)

**GPRS**: General Packet Radio Service
GSM

- 800+ million users in 100+ countries.
- Primary goal (was): phone + roaming in Europe
- GSM 900
  - 890-915 MHz uplink, 935-960 MHz downlink
- GSM 1800 (DCS: Digital Cellular System)
  - 1710-1785 MHz uplink, 1805-1880 MHz downlink
- GSM 1900 (PCS: Personal Comm Service) ← US
  - 1850-1910 MHz uplink, 1930-1990 MHz downlink
Functional Architecture of GSM

Abis

BSS

MSC

BSC

VLR

HLR

EIR

AuC

OMC

PSTN

PDN

SS7 signaling

2.048 Mbps
(30 x 64kbps con.)

16 or 64 kbps connections

BTS

MS

BTS

MS

IWF

OMC

MSC

GMSC

IWF

PSTN

PDN

SS7 signaling
Interfaces

- **A-interface**: circuit switched, 2.048 Mbits/s, carrying up to 30 64 kbits/s connections.
- **O-interface**: SS7 signaling, management data.
- **Abis-interface**: 16 or 64 kbits/s connections
Subsystems

• BSS: GSM net ➔ several BSS, 1 BSC/BSS
• BTS: radio equipments. Forms a radio cell.
• BSC
  • Reserves frequencies (frequency/ch. assignment)
  • Handles handovers
  • Performs paging of MS
  • Multiplexes radio channels onto fixed net con.
Subsystems

• **MS**: User equipment and software for com
  • SIM (Subscriber Identity Module): IMSI, LAI..
  • GSM 900: transmit power up to 2 w
  • GSM 1800: transmit power 1 w
  • Two parts: TE for comm with network + Services
Subsystems

- MSC
  - Manages several BSCs
  - (Gateway)MSC → other fixed network
  - Interworking Function (IWF) → data nets
  - Connection setup, release and handover
  - Supplementary services (forwarding, conf.)
Subsystems

• HLR (Home Location Register)
  • Most important database with all user relevant info.
  • Static Info.:
    – MSISDN number and IMSI number
    – Subscribed services (call forwarding, roaming, GPRS)
  • Dynamic Info.:
    – Current location area (LA) of the MS
    – Current MSC and VLR
    – Accounting information
  • Specialized databases to meet real-time reqs.
  • Handle millions of users.
Subsystems

- **VLR (Visitor Location Register)**
  - One VLR is associated with one MSC
  - Info about all users in the LA associated to the MSC
  - Info per user (copied from HLR): IMSI, MSISDN, HLR address
  - Need: To avoid frequent communication with HLR
  - Large, real-time database
Subsystems

• **Operation and Maintenance Centre (OMC)**
  - Monitor: traffic, status of all network entities
  - Accounting and billing

• **Authentication Center (AuC)**
  - Contains algorithms for authentication and keys for encryption
  - Can be a part of the HLR.

• **Equipment Identity Register (EIR)**
  - Blacklist of stolen/locked MS
Radio Interface

• FDD is used to separate downlink & uplink.
• Media access combines TDMA and FDMA.
• GSM 900: 124 ch., each 200 KHz wide, FDMA
  • 90 channels to support customers
  • 32 reserved
  • 2 not used (1 and 124)
FDMA in GSM 900

- **960 MHz**: 124
- **935.2 MHz**: 1
- **915 MHz**: 124
- **890.2 MHz**: 1

200 KHz
TDMA in GSM 900

Guard space: avoid overlap of bursts due to path delay + allow tx. on/off

Tail + training for better Receiver performance

S = 0/1 → Data is net/user data

One carrier

TDMA frame

4.615 ms

546.5 micro s.

577 micro s.
Simple MS

- TDMA frame on the uplink is **shifted by three slots** from frame on the downlink.
- If BTS sends data at $t_0$ in slot one on the downlink, the MS accesses slot one on the uplink at time $t_0 + 3 \times 577$ micro sec.
  => MS does not need a full-duplex Tx
Logical channel and frame hierarchy

• **Physical channel**: a slot repeated every 4.615 ms. (114 bits in 4.615 ms \( \Rightarrow \text{Rate} = 24.7 \text{ Kbps} \))

• Reality: Out of every 26 consecutive slots
  - 12 data slots + 1 signaling slot + 12 data slots + 1 unused
  - \( \Rightarrow \text{Rate of a physical channel} = (24/26) \times 24.7 = 22.8 \text{ Kbps} \)

• **Logical channel**: A physical channel may be split into several (logical) channels:
  - Logical channel C1: every 4\(^{th}\) slot
  - Logical channel C2: every other slot
  - C1 and C2 could use the same physical channel with the pattern C1C2xC2C1C2xC2C1
Logical channels …

- Two basic groups of logical channels
  - Traffic channels (TCH)
  - Control channels (CCH)
- TCH
  - Carries user data (voice, fax)
  - Full-rate TCH/F: 22.8 kbits/sec
  - Half-rate TCH/H: 11.4 kbits/sec $\rightarrow$ capacity x 2
  - Other (data)rates: TCH/F4.8, TCH/F9.6, TCH/F14.4
  (They differ in their voice coding schemes.)
Logical channels (CCH)

- **CCH**: access control, ch alloc., mobility
  - **Broadcast CCH (BCCH)**
    - Used by BTS to send info to all MS in a cell
      - Cell ID, options available (f. hop), freq available
  - **Common CCH (CCCH):** for conn. setup
    - Paging CH: for paging an MS (BTS → MS)
    - RACH: MS → BTS. MS wants to make a call. Accessed by all MS in a cell. (random access, coll.)
    - AGCH: BTS → MS. BTS tells MS to use a TCH or an SDCCH.
Logical channels

– Dedicated control channel (DCCH): bidirection
  • Stand-alone DCCH is used while an MS has not established a TCH with a BTS.
  • Stand-alone **DCCH** (782 bits/sec): authentication, registration, etc. needed for setting up a TCH
  • Slow associated dedicated control ch (**SACCH**): Associated with each TCH. For small amount of system info: ch quality, signal power level.
  • Fast associated dedicated control ch (**FACCH**): Uses time slots from the TCH. Handover info.
Typical use of TCH and SACCH

- TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
- T = user traffic in TCH/F, S = signalling
- x = unused slot
- Normal burst carries 114 bits of user data and is repeated every 4.615 ms (24.7 kbit/sec data rate)
- TCH uses 24/26 slots ➔ rate = 22.8 kbit/s
- SACCH: 950 bit/sec
Structuring of time using frames

- **Hyper-frame**: 0 1 | 2047 | 3h, 28m, 53.76s (2,715,648 Frames)
- **Super-frame**: 0 1 | 50 | 6.12 s
- **Multi-frame**: 0 | 25 | 120 ms
- **Frame**: 0 | 7 | 4.615 ms

Each frame is divided into slots and bursts, with a burst duration of 577 micro sec. Use: frame number is an input to the encryption algorithm.
Protocols

- **MS**: CM, MM, RR, LAPDm, radio
- **BTS**: CM, MM, RR, BTSM, LAPDm, LAPD, PCM
- **BSC**: CM, MM, RR, BTSM, LAPD, PCM, BSSAP, SS7
- **MSC**: CM, MM, BSSAP, SS7, PCM

- **Um**
- **Abis**: 16/64 kbit/s
- **A**: 64 kbits/sec / 2.048 Mbits/sec
Protocols

• Radio
  • Creation of bursts, multiplexing, sync with BTS, detection of idle channel, measurement of quality of downlink, encryption/decryption
  • Channel coding/error detection using FEC
  • GSM tries to correct errors, but does not deliver erroneous data
Protocols

• LAPDm (link access protocol D-channel)
  • Light weight LAPD (no sync, no checksum)
  • Flow control
  • Segmentation + reassembly
• RR (radio resource management)
  • Setup, maintenance, release of radio channels
• BTSM (BTS Management)
Protocols

• MM (Mobility Management)
  • Registration, authentication, location updating, temporary mobile subscriber identity (TMSI)
  • TMSI replaces IMSI to hide the real identity of MS
  • TMSI is valid only in current location area of a VLR
Protocols

• CM (Call Management)
  – Call Control (CC)
    • Point-to-point connection between terminals
    • Sends in-band tones (PIN for e-banking, etc.)
  – Short Message Service (SMS)
    • Uses SDCCH + SACCH
Localization and calling

• Feature of GSM
  • Automatic, worldwide localization of users
  • Performs periodic location update

• Roaming
  • Changing VLRs with uninterrupted availability
    » Within the network of one provider
    » Between two providers in one country
    » Different providers in different countries
Localization and calling

- To locate/address an MS, several #s needed
  - MS International ISDN number (MSISDN)
    » Country code + national destn code + subscriber num
  - International Mobile Subscriber Identity (IMSI)
    » Mobile country code + mobile net code + MSIN
  - Temporary Mobile Subscriber Identity (TMSI)
    » Hides TMSI. Assigned by VLR.
  - Mobile Station Roaming Number (MSRN)
    » Hides the ID and location of a subscriber
    » Helps HLR to find a subscriber for an incoming call
Mobile Terminated Call

* GMSC identifies HLR from phone #
* HLR gets MSRN from VLR. Determines MSC.
* MSC gets current status of MS. Page all cells
Mobile Originated Call

1. MS
2. MSC
3. VLR
4. GMSC
5. GMSC
6. PSTN
7. PSTN
8. MSC
9. MSC
10. BSS
Message flow for MTC and MOC

MS

Paging request

Channel request

Immediate assignment

Paging response

Authentication req.

Authentication resp

Ciphering command

Ciphering complete

Setup

Call confirmed

Assignment command

Assignment complete

Alerting

Connect

Connect Ack

Data exchange

BTS

MS

BTS

Channel request

Immediate assignment

Service request

Authentication req.

Authentication resp

Ciphering command

Ciphering complete

Setup

Call confirmed

Assignment command

Assignment complete

Alerting

Connect

Connect Ack

Data exchange
Handover

- Diminished quality of radio link
- Load balancing
Types of handover in GSM

1. Intra-cell: change in freq.
2. Inter-cell, Intra-BSC
3. Inter-BSC, Intra-MSC
4. Inter MSC
Handover decision based on received signal

Received level
BTSold

Received level
BTSnew

MS

HO margin

MS
Intra-MSC handover

Mesurement report

Measurement result

HO decision

HO required

HO request

Resource allocation

Ch. activation

HO command

HO req. Ack

Ch. act. Ack

Link establishment

Clear command

HO complete

Clear complete

HO command

Clear command

Clear complete

Clear command

Clear complete
Dynamic Channel (carrier) Assignment in Cellular Systems

Sources: Section 2.8 (Schiller) and A. Baiocchi, F. D. Priscoli, F. Grilli and F. Sestini, The geometric dynamic channel allocation as a practical strategy in mobile networks, IEEE TVT, Vol 44, No 1, Feb. 1995, pp. 14-23
Topics

• Cellular systems
• Carrier Assignment Problem
  – Static
  – Dynamic
• DCA Algorithm
Cellular Systems

• A geographic area is divided into smaller, circular areas called cells.

• A base station (transceiver) is installed at the cell’s center. Cell = radio coverage area.

• Cell radius
  • 10s of meters in buildings
  • 100s of meters in cities
  • 10s of KM in countryside
Cellular Systems

• Cell shape
  • Never circular: depends on env., weather, load (?)
  • Hexagon ⇐ for study purpose

• An MS in a cell communicates with the local base station (BS)
Cellular Systems

• Advantages of smaller cells
  • Higher capacity (SDM: frequency reuse) \(\leftrightarrow\) users
  • Less transmission power for MS (no BS problem)
  • Local interference only (MS \(\leftrightarrow\) BS)
  • Robust against failures of single components

• Disadvantages of smaller cells
  • Larger infrastructure (antennas, switches, …)
  • Frequent handover
  • Better planning: frequency assignment, etc.
Carrier Assignment Problem

• Facts about GSM 900
  • FDM: 124 frequencies (up/down)
  • TDM: 8 slots/frequency
    ➔ Max number of active users = 124*8

• Low capacity ➔ need for reusing carriers
  • Space division multiplexing: reuse carriers far apart
    » To reduce interference
    » To increase capacity (# of users)
Carrier Assignment Problem

• Problem: Given a set of carriers and a cellular system
  • How to assign carriers to cells?
  • Maximum reuse $\Rightarrow$ maximum capacity
  • Lower failure rate
    » Blocking rate
    » Dropping rate
Cellular model

Minimum reuse distance

Interference region
Carrier Assignment Algorithms

• **Fixed assignment** of carriers to cells
  - Use these carriers until further notice.
  - GSM
  - Simple to implement. No signaling load.
  - Good (bad) for low (high) traffic.

• **Dynamic assignment** of carriers to cells
  - All carriers are “available” in all cells.
  - Improved performance.
  - High signaling load
Dynamic Carrier Assignment

- \((m, n)\): cell at row \(m\) and column \(n\)
- \((x, y)\): center of a cell
- \((x,y)\): center of cell \((m, n)\) is computed as
  - \((x,y) = (n, m)\) 
    - \((x,y) = (n, m)\) 
      - \(\sqrt{3} R\) \(0\) 
      - \(\sqrt{3} R/2\) \(3R/2\)
    - \(R =\) cell radius
Dynamic Carrier Assignment

- Reuse condition: Two carriers can be simultaneously used in two cells only if their separation $> D_{\text{min}}$.
- Assume $D_{\text{min}} = 3\sqrt{3}R$
- Interference neighborhood of a cell $c$
  - $\text{IN}(c) = \{c' | \text{dist}(c, c') < D_{\text{min}}, c \neq c'\}$
  - 30 cells
- If cell $c$ uses a frequency, no cell in $\text{IN}(c)$ can reuse it.
Dynamic Carrier Assignment

- **Status** of a carrier $r$ in a cell $c$
  - **Used**: $\text{status}(r,c) = \text{UC}$, if at least one channel of $r$ is currently used by some user in $c$.
  - **Interfered**: $\text{status}(r,c) = \text{IC}$, if $\text{status}(r,c') = \text{UC}$ for some $c'$ in $\text{IN}(c)$.
  - **Available**: $\text{status}(r,c) = \text{AC}$, if $\text{status}(r,c) \not\equiv \text{UC}$ and $\text{status}(r,c) \not\equiv \text{IC}$. 
Dynamic Carrier Assignment

• **Geometric strategy**
  - Divide the **cell array** into **k groups** $S_0, S_1, \ldots, S_{k-1}$ such that distance between any pair of cells in the same group is at least $D_{\text{min}}$.
  - The **carrier set** is **split** into **k groups** $P_0, P_1, \ldots, P_{k-1}$. Carriers in each $P_i$ is considered to be **ordered**.
  - When a cell $c$ in $S_i$ needs a carrier, it **checks the ordered lists** $P_i, P_{i+1}, \ldots, P_0, \ldots, P_{i-1}$ in that order and **acquires** the first **available** carrier encountered.
Dynamic Carrier Assignment

For $D_{\text{min}} = 3\sqrt{3}\cdot R$, $k = 9$. 
Dynamic Carrier Assignment

• Performance measures
  – **Blocking rate** (**Rb**): failure to assign a channel to new calls.
  – **Dropping rate** (**Rd**): failure to assign a channel to a moved-in call.
  – **Failure rate** (**Rf**): $Rf = Rb + (1-Rb) \times Rd$

• How to obtain **Rf**?
  • Analytic
  • Simulation
Dynamic Carrier Assignment

• Simulation parameters
  • Cell grid ← how big, wrapped around
  • Total available carriers (124 for GSM)
  • TDM slots (8/frequency) ← invisible in algorithm
  • Traffic: call arrival rate
  • Mobility: handoff rate (pattern??)
  • Mean service time
  • Uniform/nonuniform traffic (hot/normal states)
Techniques for lowering failure rates of DCAs

- Power control
- Adaptive antenna array (also, tri-sector)
- Carrier compaction
- Prioritized release
- Lower QoS (channel sub-rating)
- Call on hold
- Synchronous BTS