LECTURE 5

AMPS and GSM

1G Cellular Systems

- Goal: Provide basic voice service to mobile users over a large area
- 1 G Systems developed in late 70's/early 80's – deployed in 80's
  - Advanced Mobile Phone System (AMPS) - USA
  - Total Access Communications Systems (TACS) - UK
  - Nordic Mobile Telephone (NMT) System – Scandinavian PTTs
  - C450 - W. Germany
  - NTT System - Nippon Telephone & Telegraph (NTT) – Japan
- Incompatible systems using different frequencies!
  - Have similar characteristics though

Characteristics of 1G Cellular Systems

- Use Cellular Concept to provide service to a geographic area (i.e. number of small adjacent cells to provide coverage)
  - Frequency Reuse
  - Handoff/Handover
- FDMA/FDD systems
  - Common Air Interface standards only
    - Analog Voice communications using FM
    - Digital Control channels for signaling
  - Adjustable Mobile Power levels
  - Macro Cells : 1-40 km radius
- Focus on AMPS system

Characteristics of 1G Cellular Systems (continued)

- First generation systems targeted to few subscribers with car phones
  - Rapid growth in demand for cellular services
  - Availability of low cost, lightweight, portable handsets
  - → Growing demand for system capacity
- Capacity can be increased by smaller cells but:
  - More difficult to place base stations at locations for necessary radio coverage
- Increased signaling for handoffs, and more frequent handoffs
  - Base stations handle more access requests and registrations
  - Analog technology has limited options to combat interference effects from smaller cells
- Demand for 2G digital cellular
  - Also, incompatible first generation (analog) standards in Europe motivated new pan-European digital standard

Summary of 1G systems

	Japan	North America	England	Scandinavia	Germany
System	NTT	AMPS	TACS	NMT	C450
Dwnlink Freq (MHz) Uplink Freq (MHz)	870-885 925-940	869-894 824-849	917-950 872-905	463-467.5 453-457.5	461.3-465.74 451.3-455.74
Spacing between uplink and downlink bands (MHz)	55	45	45	10	10
Channel Spacing(kHz)	25, 12,5	30	25	25	20
Number of channels	600	832 (control ch.21×2)	1320 (control ch.21×2)	180	222

Summary of 1G Systems (continued)

Audio signal modulated with FM; Control signal modulated with FSK

	Japan	North America	England	Scandinavia	Germany
System	NTT	AMPS	TACS	NMT	C450
Coverage radius (km)	5 -10	2-20	2-20	1.8-40	5-30
Audio signal freq. deviation (kHz)	±5	±12	±9.5	±5	±4
Control signal freq. deviation (kHz)	±4.5	±8	±6.4	±3.5	±2.5
Data Tx. Rate (kb/s)	0.3	10	8	1.2	5.28
Message Protection	Transmitted signal is checked when sent back to the transmitter by the receiver.	Principle of majority decision	Principle of majority decision	Receiving steps pre- determined according to the message content.	Message sent again when an error is detected.

AMPS

- Advanced Mobile Phone System is first generation wireless in US
  - Earlier systems used line of sight radio (e.g., AT&T's Improved Mobile Telephone Service in 1960s)
  - AT&T developed cellular concept in 1940s
  - 1971 proposed High Capacity Mobile Phone Service to FCC
  - 1979 FCC standardized it as AMPS in 800-900 MHz range
  - 1983 launched in Chicago
- Licenses for geographic service areas (similar to radio station model) – areas based on commercial trading zones
  - MSA: metro service area, RSA: rural service area

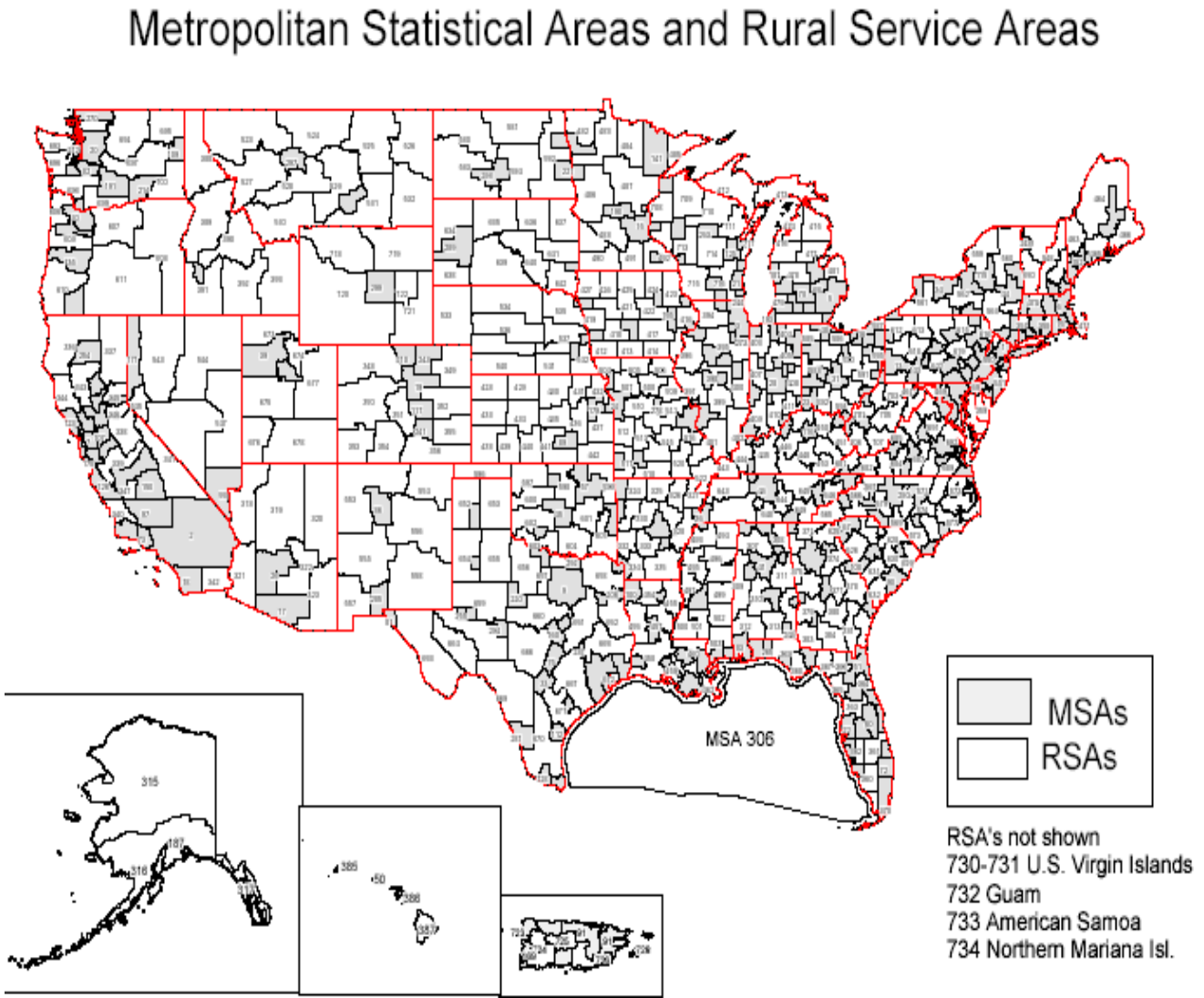
MSAs and RSAs

FCC allocated 2 licenses for each MSA,RSA

One license to local phone company: wireline common carrier (WCC)

Other license given out by lottery: radio common carrier (RCC)

Speculation and fraud in RCC lottery!



Frequency Allocation in AMPS

- Originally 40 MHz of spectrum separated into two bands of 20 MHz each (A and B band). Later expanded to 25 MHz each
  - A band lower spectrum went to RCC, B band to WCC
- FDD used with 45 MHz separation in uplink and downlink – prevents self interference.
- AMPS uses 30 kHz radio channels between mobile station and base stations (EIA/TIA-533 radio interface)
- Two service providers in area are each allocated 25 MHZ => 12.5 MHz for each direction => 416 pairs of channels: split into 395 voice channels + 21 control channels for signaling
- Channels numbered consecutively 1-666 , when expanded kept same numbering assuming 30 KHz channels even in places where no spectrum allowed
- $f(c)_{uplink} = 825{,}000 + 30 \times (c)$ KHz $\quad 1 \leq c \leq 799$
- $f(c)_{uplink} = 825{,}000 + 30 \times (c\text{-}1023)$ KHz $\quad 991 \leq c \leq 1023$
- $f(c)_{downlink} = f(c)_{uplink} + 45{,}000$ KHz

Initial AMPS System Operators

Market No.	Area	System Operator	No. of Cells	Switching Equipment
1	New York	W (B-Side) -Nynex Mobile (6/15/84) NW-Metro One (A-Side) (4/5/86)	56 36	AT&T Motorola
2	LA	W-PacTel Cellular (6/13/84) NW-LA Cellular (3/27/87)	81 38	AT&T Ericsson
3	Chicago	W-Ameritech Mobile (10/13/83) NW-Cellular One (1/3/85)	73 31	AT&T Ericsson
4	Philadelphia	W-Bell Atlantic Mobile (7/12/84) NW-Metrophone (2/12/86)	38 32	AT&T Motorola
5	Detroit	W-Ameritech Mobile (9/21/84) NW-Cellular One (7/30/85)	37 31	AT&T Ericsson
6	Boston	W-Nynex Mobile (1/1/85) NW-Cellular One (1/1/85)	30 10	AT&T Motorola
7	San Francisco	W-GTE Mobilnet (4/2/85) NW-Cellular One (9/26/86)	28 36	Motorola Ericsson
8	Washington	W-Bell Atlantic Mobile (4/2/84) NW-Cellular One (12/16/83)	46 34	AT&T Motorola
9	Dallas	W-SW Bell Mobile (7/31/84) NW-MetroCel (3/1/86)	41 28	AT&T Motorola

Mobility Management in AMPS

- Initially could not roam a whole lot
  - Restricted to limited geographical regions (MSA or RSA)
  - Legal hurdles, billing problems, proprietary systems in the backhaul
  - 1G standards are air interface standard only - basically didn't think it would be needed
    - Implementation of databases/signaling to handle mobility was not available/standardized
- Replaced by ad hoc measures
  - Manual clearing house approach
  - Follow-me roaming (GTE) – automated clearing house
    - User has to register when he goes to a new location

Second Generation Cellular Systems

- Motivation for 2G Digital Cellular:
  - Increase System Capacity
  - Add additional services/features (SMS, caller ID, etc..)
  - Reduce Cost
  - Improve Security
  - Interoperability among components/systems (GSM only)
- 2G Systems
  - Pacific Digital Cellular ← orphan technology
  - North American TDMA (NA-TDMA) ← orphan technology
  - Global System for Mobile (GSM)
  - IS-95 (cellular CDMA)

GSM: Global System of Mobile Communications

- A heterogeneous analog cellular implementation was observed in Europe in the 1980s
  - United Kingdom, Italy, Spain, Austria: TACS (900 MHz)
  - Scandinavia, Germany, The Netherlands, Spain: NMT (450 MHz, 900 MHz)
  - France: Radiocom
- 1987: 12 Member countries sign MOU for a common standard
- ETSI: European Telecommunications Standards Institute in 1989 took over the standardization of all cellular telephony in Europe
  - Strongly influenced by ISDN
  - Signaling System 7
    - Used for delivery of control messages/ establishment and tear down of calls.
    - Can support features like three way calling.

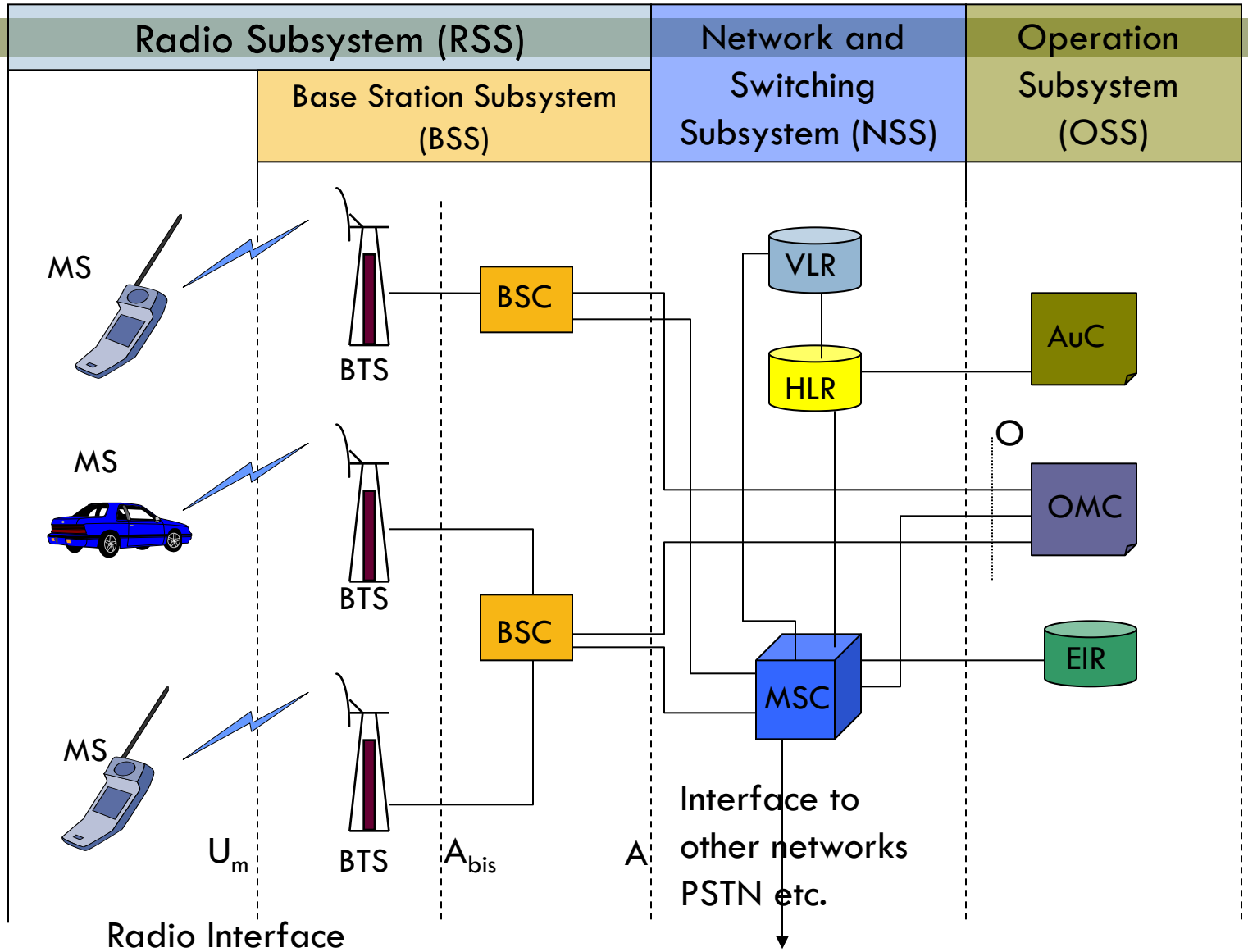
GSM Objectives

- A broad offering of speech and data services
- Compatibility with wire-line networks
- Cross-border system access for all users
- Automatic roaming and handoff
- Efficient use of frequency spectrum
- Support for different types of mobile terminals (car, hand-held, portable)
- Digital transmission of signaling and user data
- Supplier independence
- Low infrastructure costs and terminal equipment costs

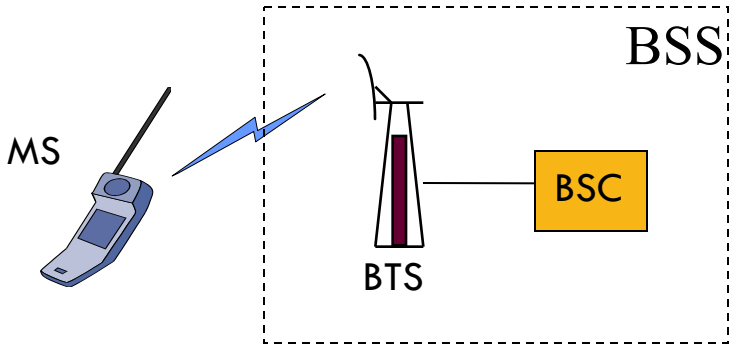
GSM Details

- Based on TDMA/FDMA
- Each frequency carrier is 200 kHz wide and carries eight voice channels
- Example Spectrum in Europe
  - Uplink (Mobile to BS): 890-915 MHz
  - Downlink (BS to Mobile): 935-960 MHz
- Modulation Scheme: GMSK
- Optional Frequency Hopping

Functional Architecture



Radio Subsystem



- It is made of the Mobile Station (MS) and the Base Station Subsystem (BSS)
- It deals with the radio part of the GSM system

Mobile Station (MS)

- It has two parts
  - A part containing the hardware and software components related to the radio interface
  - A subscriber identity module (SIM)
    - A smart card like device that contains the identity of the subscriber
    - It can be used in portable devices (the user does not have to carry his MS)
    - PIN used to lock/unlock the MS
- Transmit power can be 0.8W to 20W
- Non-volatile memory contains authentication key, SIM type, subscriber number, a PIN, etc.
- Dynamically changeable data includes a list of BCCH's (later), the temporary number, ciphering key, list of blocked PLMNs etc.

MS Numbers

- International Mobile Subscriber Identity (IMSI)
  - Includes mobile country code, mobile network code and mobile subscriber identity (~15 digits)
- Temporary Mobile Subscriber Identity (TMSI)
  - Conceals the IMSI
- MS-ISDN Number (MSISDN)
  - ISDN like number used for calling (has a country code, national destination code, subscriber number)
- MS Roaming Number (MSRN)
  - Provides link to current location of the MS

Base Station Subsystem (BSS)

- A BSS has two parts
  - It is controlled by a Base Station Controller (BSC)
  - It transmits using a Base Transceiver System (BTS)
- Interfaces to the MS via the U_m interface
- Contains parameters for the air interface such as GMSK modulation, status of carrier frequencies, the channel grid etc.
- Also contains parameters of the A-interface like PCM signals (64 kbps for a 4 kHz voice) carried over Frame Relay etc.

Base Station Controller (BSC)

- Performs all functions necessary to maintain radio connections to an MS
- Manages several BTSs
- It multiplexes traffic onto radio channels
- Handles intra-BSS handoff
- Reserves radio channels and frequencies for calls
- Tasks also include paging and transmitting signaling data to the MSC

Base Transceiver System (BTS)

- Includes all hardware
  - Transmitting and receiving facilities
  - Antennas
  - Speech coder and decoder
  - Rate adapter
- It can form a radio cell (100m – 35km)
- It can form a cell sector if directional antennas are employed
- Connects to the BSC via the A-bis interface

BSC Vs BTS Functions

- Tasks of a RSS are distributed over BSC and BTS
- BTS comprises radio specific functions
- BSC is the switching center for radio channels

Functions	BTS	BSC
Management of radio channels		X
Frequency hopping (FH)	X	X
Management of logical channels		X
Mapping of logical onto radio channels		X
Channel coding and decoding	X	
Rate adaptation	X	X
Encryption and decryption	X	X
Paging	X	X
Uplink signal measurements	X	
Traffic measurement		X
Handover management		X

The Network and Switching Subsystem (NSS)

- This is the “heart” of the GSM backbone
- Connections to the standard public network
- Performs handoffs
- Functions for worldwide localization of users
- Support for charging, accounting and roaming of users
- Consists of
  - MSC, HLR, VLR

Mobile Services Switching Center (MSC)

- High performance digital ISDN switches
- Manages several BSCs
- A Gateway MSC (GMSC) connects different service providers and networks like the PSTN and ISDN
- SS-7 is used for signaling needed for connection set up, connection release, and handoff of connections
- Also handles call forwarding, multiparty calls, reverse charging, etc.

Home Location Register (HLR)

- Equivalent of the generic “home database”
- Stores all user relevant information
  - Static information like MSISDN, authentication key, subscribed services etc.
  - Dynamic information like current location area (LA)
- For each user, there is exactly one HLR where the information is maintained
- Also supports charging and accounting

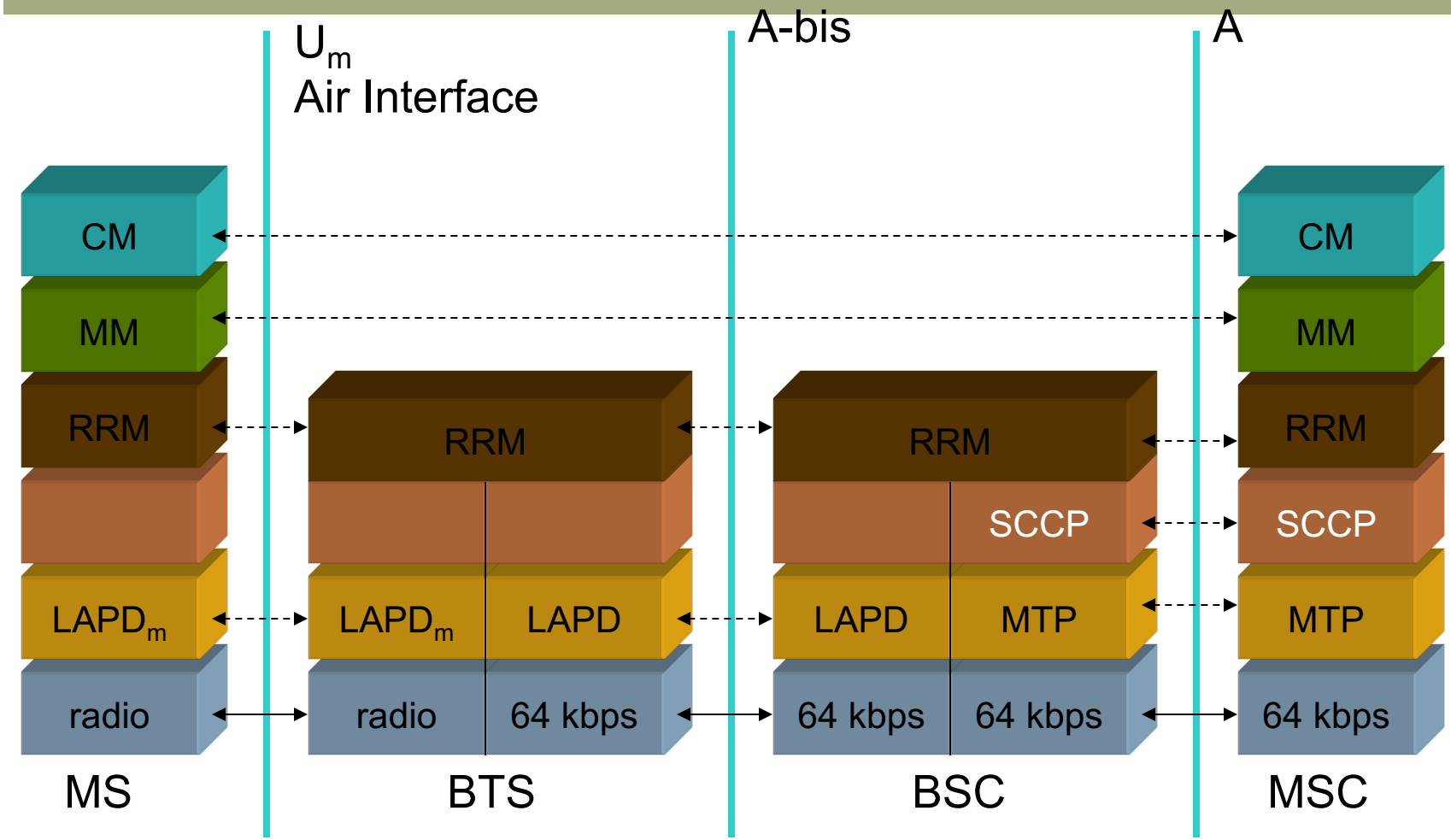
Visitor Location Register

- It is associated with each MSC
- A dynamic database that stores all information about MSs that are in its location area associated with the MSC
- If a new MS comes into the LA, its information is copied from the HLR into the VLR

The Operation Subsystem (OSS)

- Operation and Maintenance Center (OMC)
  - Monitors and controls all network entities using SS-7 and X.25
  - Traffic monitoring, status reports, accounting, billing etc.
- Authentication Center (AuC)
  - Algorithms for authentication and keys for encryption
  - Usually a special part of the HLR
- Equipment Identity Register (EIR)
  - Stores all device identifications
  - Contains blocked and stolen list and a list of valid and malfunctioning IMEI's

GSM protocol architecture



CM: Connection Management; MM: Mobility Management; SCCP: Signal Connection Control Part
RRM: Radio Resource Management; MTP: Message Transfer Part; LAPD: Link Access Protocol-D

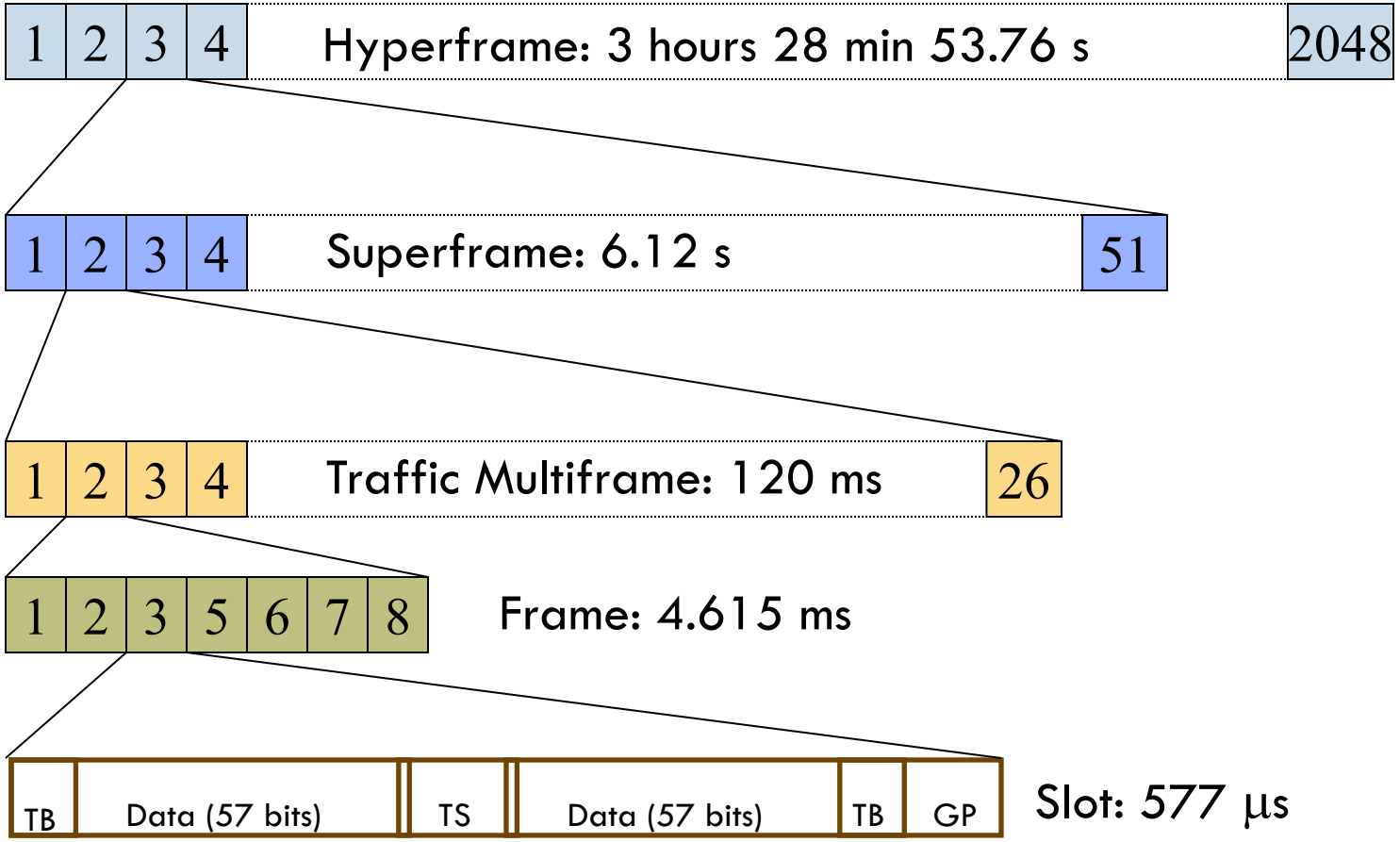
Layers

- Radio layer
  - FEC, Synchronization, channel quality estimation.
- LAPD
  - Variant of HDLC
  - Reliable link layer transfer
- Layer 3
  - Contains RRM which does channel setup, allocation, release etc.
- MM
  - Authentication, Location updating, Assigning a TMSI etc.
- CM
  - Call control – call establishment, release etc.
  - SMS – using control channels
  - Supplementary services – Caller ID, Call forwarding etc.

Air Interface

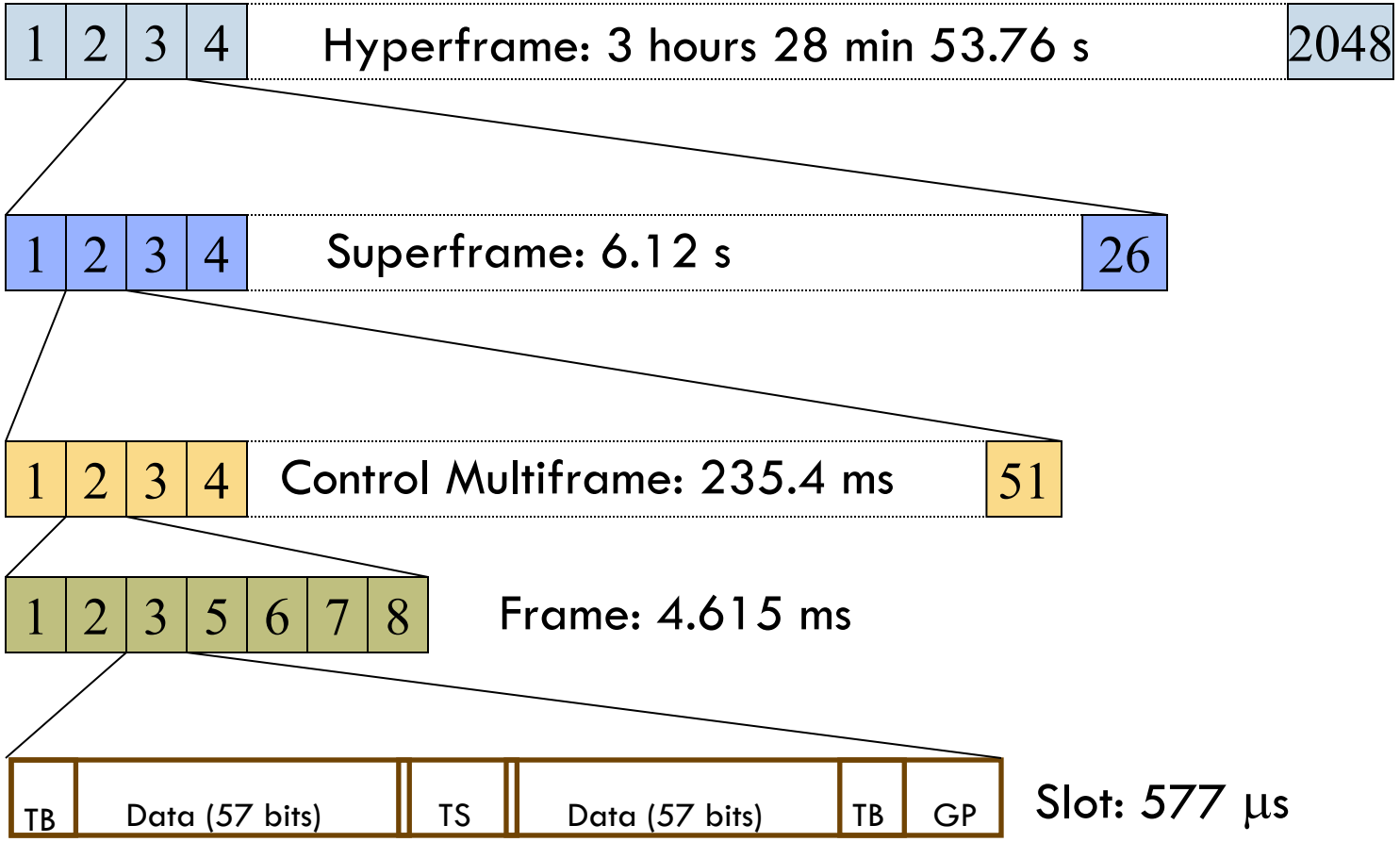
- 25 MHz of bandwidth is divided into 124 frequency bands of 200 kHz each and two 100 kHz pieces on either side
- Carrier frequencies are given by:
  - Fu (n) = 890.2 + 0.2(n-1) MHz n=1,2,3,…,124
  - Fd (n) = 935.2 + 0.2(n-1) MHz n=1,2,3,…,124
- Example:
  - On the uplink, Channel 1 = 890.1-890.3 MHz
  - On the downlink, Channel 1 = 935.1-935.3 MHz
- Usually, Channels 1 and 124 will not be used if possible

Framing Scheme in GSM (Traffic Channels)



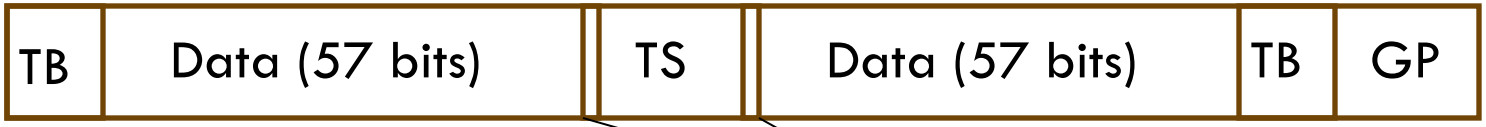
Framing scheme is implemented for encryption and identifying time slots

Framing Scheme in GSM (Control Channels)



Framing scheme is implemented for encryption and identifying time slots

One Time Slot (typical)



TB: Tail Bits (3 bits)
TS: Training Sequence (26 bits)
GP: Guard Period (8.25 bits)

- A time slot lasts 577 μs (546.5 μs of data and 30.5 μs of guard-time)
- Bits per slot = 3+57+1+26+1+57+3+8.25 = 156.25
- Bit rate = 156.25/577 μs = 270.79 kbps

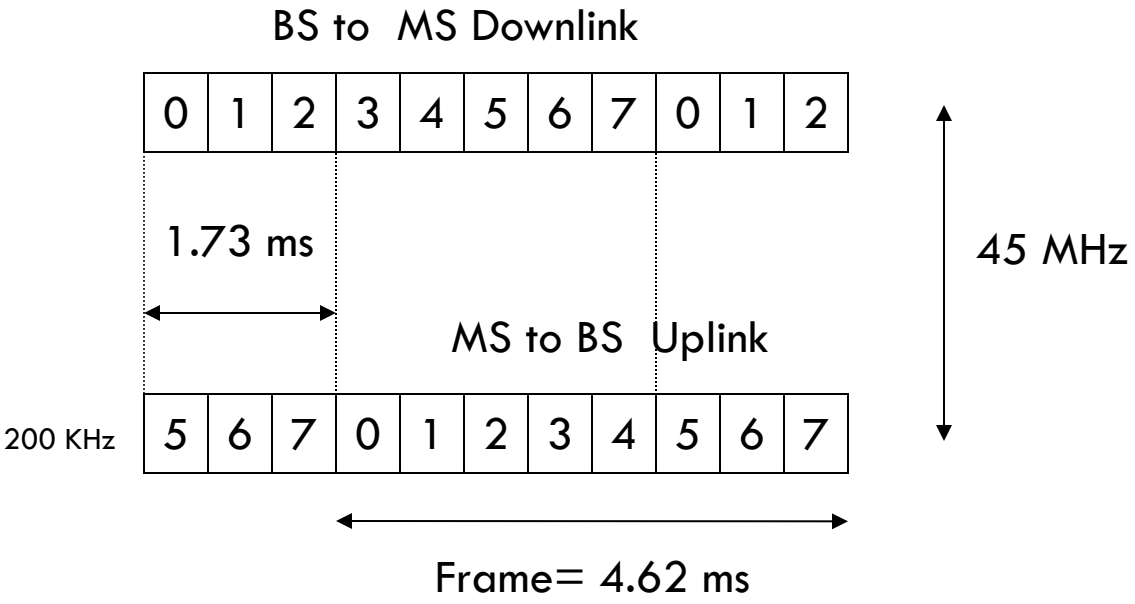
Fields in a slot

- Tail bits – usually set to `0'; can be used to enhance receiver performance.
- Training – used to determine channel characteristics (multipath)
  - Choose the strongest signal if multiple signals are available due to multipath.
- Flags: Indicate whether burst contains user data or network control data.

Types of Time Slots

- Normal Burst
  - 57 data bits are encrypted voice or control traffic
- Synchronization Burst
  - Used for time synchronization of MS
- Frequency Correction Channel Burst
  - All bits are zero, sending an un-modulated carrier
  - Sync up correctly to the carrier frequency
- Access Burst
  - Random access and has larger guard period
  - Used for initial connection set up
- Dummy Burst
  - Sent by BTS sometimes when there is no data

GSM: FDD Channels



Uplink and Downlink channels have a 3 slot offset – so that MS doesn't have to transmit and receive simultaneously

MS can also take measurements during this offset time and delay between next frame

GSM Logical Channels

- No RF carrier or time slot is reserved for a particular task except the BCCH
  - Any time slot on any carrier can be used for almost any task
- Channels are of two types:
  - Traffic Channels (TCH)
    - Voice at 13 kbps (full rate) or 5.6 kbps (half rate)
  - Control Channels (CCH)
    - Broadcast, Common and Dedicated

Traffic Channel

- 20 ms of voice (260 bits @ 13kbps) is converted to 456 bits after CRC and convolutional encoding
- Effective data rate = 22.8 kbps
- 456 bits = 8 × 57 bits
  - (Reminder: a time slot has two 57 bit units separated by a training sequence)
- Voice samples are interleaved and transmitted on the TCH
- Data and Control bits are also encoded to end up with 456 bits over 20 ms

Broadcast Control Channels (Unidirectional)

- BCCH (Broadcast Control Channel)
  - Used to transmit cell identifier, available frequencies within and in neighboring cells, options (like FH) etc.
  - Continuously active
  - Contains two sub-channels
    - FCCH (Frequency Correction Channel)
      - Uses a frequency correction burst
    - SCH (Synchronization Channel)
      - Time synchronization information

Common Control Channels (Unidirectional)

- Used for all connection set up purposes
- The paging channel (PCH) is used for paging a mobile when it receives a call
- The random access channel (RACH) is used by the MS to set up a call
  - Slotted ALOHA on the RACH
- Access grant channel (AGCH) is used by the BTS to allocate a channel to the MS
  - This can be a TCH (start using voice)
  - Or a SDCCH (negotiate further for connection setup)

SDCCH: Stand alone dedicated CCH

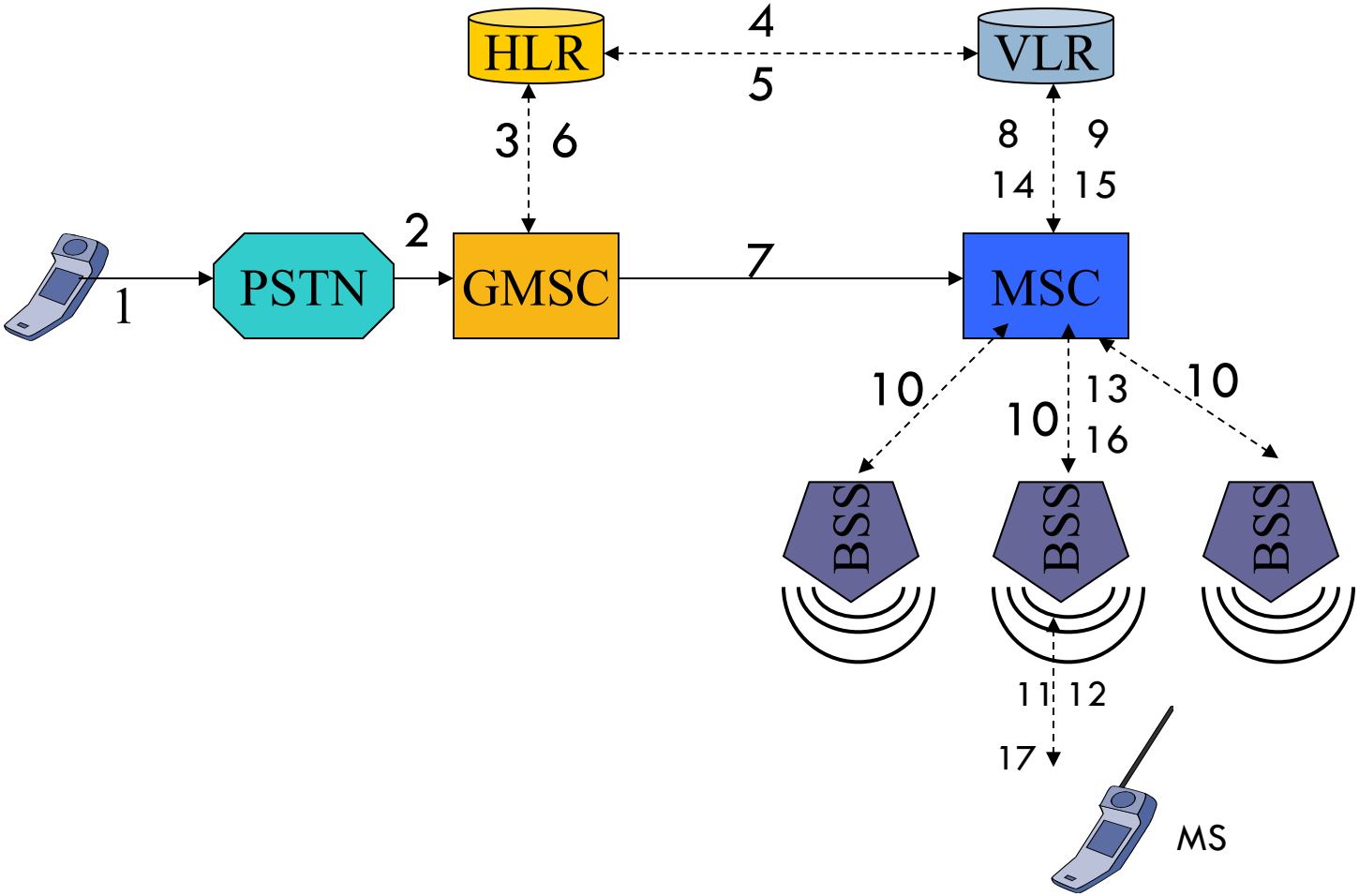
Dedicated Control Channels (Bidirectional)

- As long as a MS has not established a TCH, it will use a stand-alone dedicated control channel (SDCCH) for signaling and call set up
  - Authentication
  - Registration, etc.
- Each TCH has a Slow Associated Control Channel (SACCH)
  - Exchange system information like channel quality, power levels, etc.
- A Fast Associated Control Channel (FACCH) is used to exchange similar information urgently (during handoff for instance)

Pre-registration

- Upon powering up, the following events occur
  - MS scans common control channels and monitors the signal levels
  - It selects the channel with the largest signal strength
  - It will search for the FCCH on this RF carrier
    - If it is not available, it will try the next largest carrier
    - It will synchronize the RF carrier frequency
  - Repeats the same step for the SCH that occurs eight TDMA frames after the FCCH
  - After synchronization, the MS decodes the BCCH
  - BCCH contains information about the current cell, neighbouring cells, etc.
- If the location area has changed, the new location is updated by a registration procedure

Example: Mobile Terminated Call



Mobile Terminated Call

1) User dials a phone number of a GSM subscriber
2) PSTN forwards the call set up to the GMSC
3) GMSC identifies the HLR and signals the call set up to it
4) HLR verifies number, does authentication etc. and requests the MSRN from the VLR
5) VLR sends the information to the HLR
6) HLR determines what MSC is involved and sends this information to the GMSC

Mobile Terminated Call

7) GMSC forwards the call set up to the MSC
8) MSC requests information about the MS from the VLR
9) VLR provides relevant information… is the mobile available, etc.
10) MSC initiates a paging of the mobile through all its BSSs
11) All of the BSSs transmit the page on their PCH
12) The MS answers one of the BSSs

Mobile Terminated Call

13) BSS intimates the MSC
14) MSC requests authentication and security set up (encryption) from the VLR
15) VLR responds with the information
16) MSC sets up connection with the MS
17) Traffic channel is allocated

Handoff in GSM

- Reasons for Handoff
  - Signal quality handoff (user oriented)
  - Traffic Balancing Handoff (network oriented to ease traffic congestion by moving calls in a highly congested cell to a lightly loaded cell)
    - Needs significant overlap of adjacent cells
- Types of Handoff
  - Synchronous: Old and new cells are synchronized (100ms)
  - Asynchronous: MS must re-synchronize to new BTS after handoff (may take up to 200 ms)

Mobile Assisted Handoff (MAHO)

- The BTS provides the MS a list of available channels in neighbouring cells via the BCCH
- MS monitors the RSS from the BCCH's of these neighbouring cells and reports these values to the MSC using the SACCH
- The BTS also monitors the RSS from the MS to make a HO decision
- Proprietary algorithms are used to decide when a handoff should be initiated

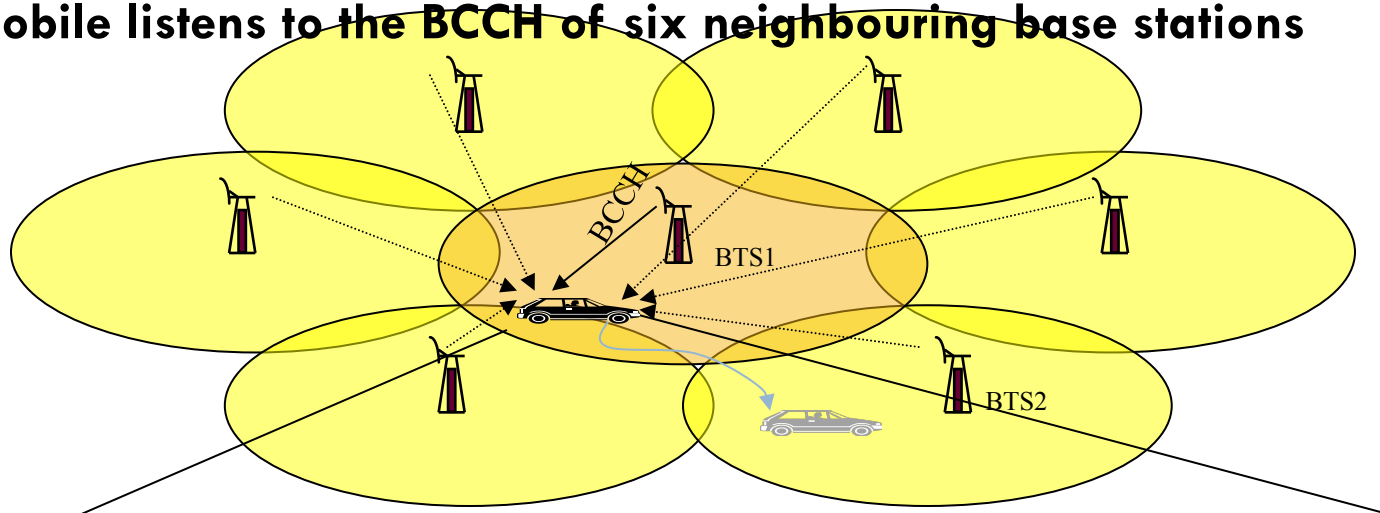
Handoff Criteria

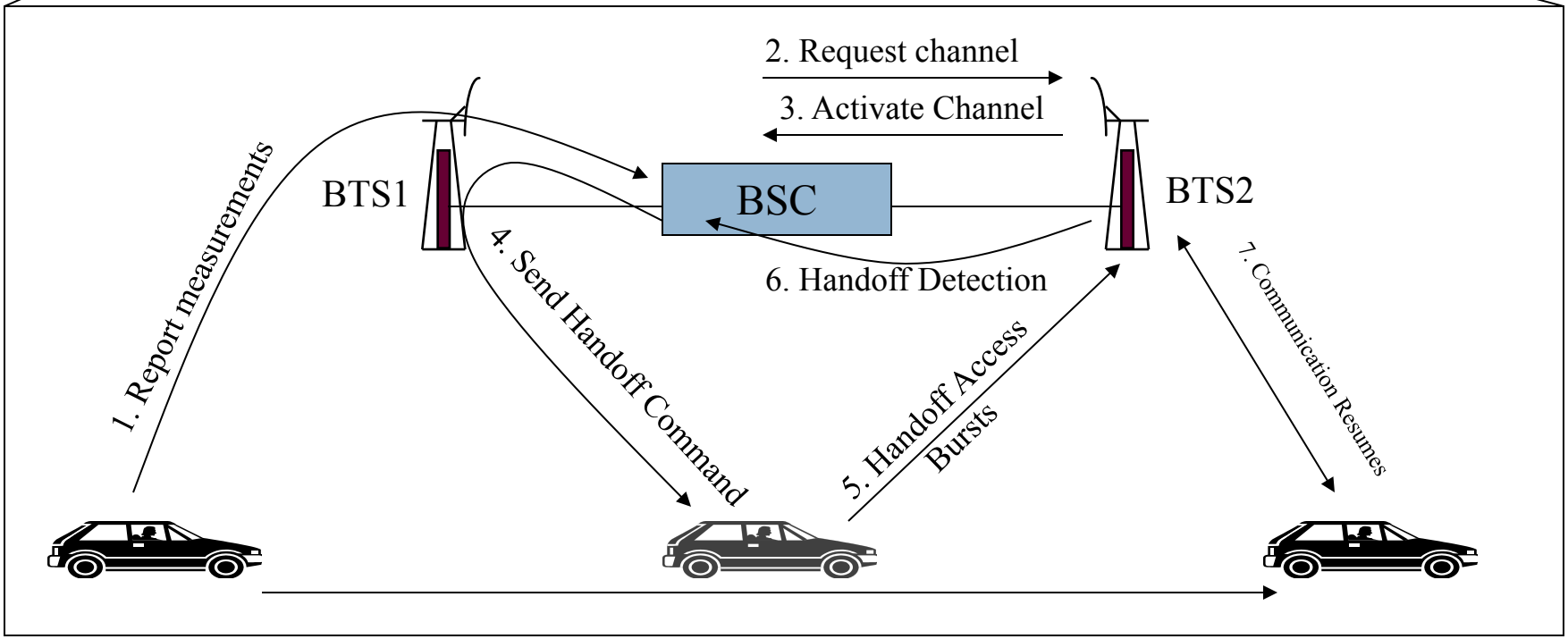
- Roundtrip time can be measured and corrected by the BTS for all MSs
  - This is used in handoff when a MS moves beyond a certain distance from the BTS
- Mobile measurements are sent to the BSC once or twice a second (480 to 960 ms via the SACCH)
- Gross bit error rate
- Cell capacity, number of free channels, number of new connections waiting etc.

Measurement Reporting

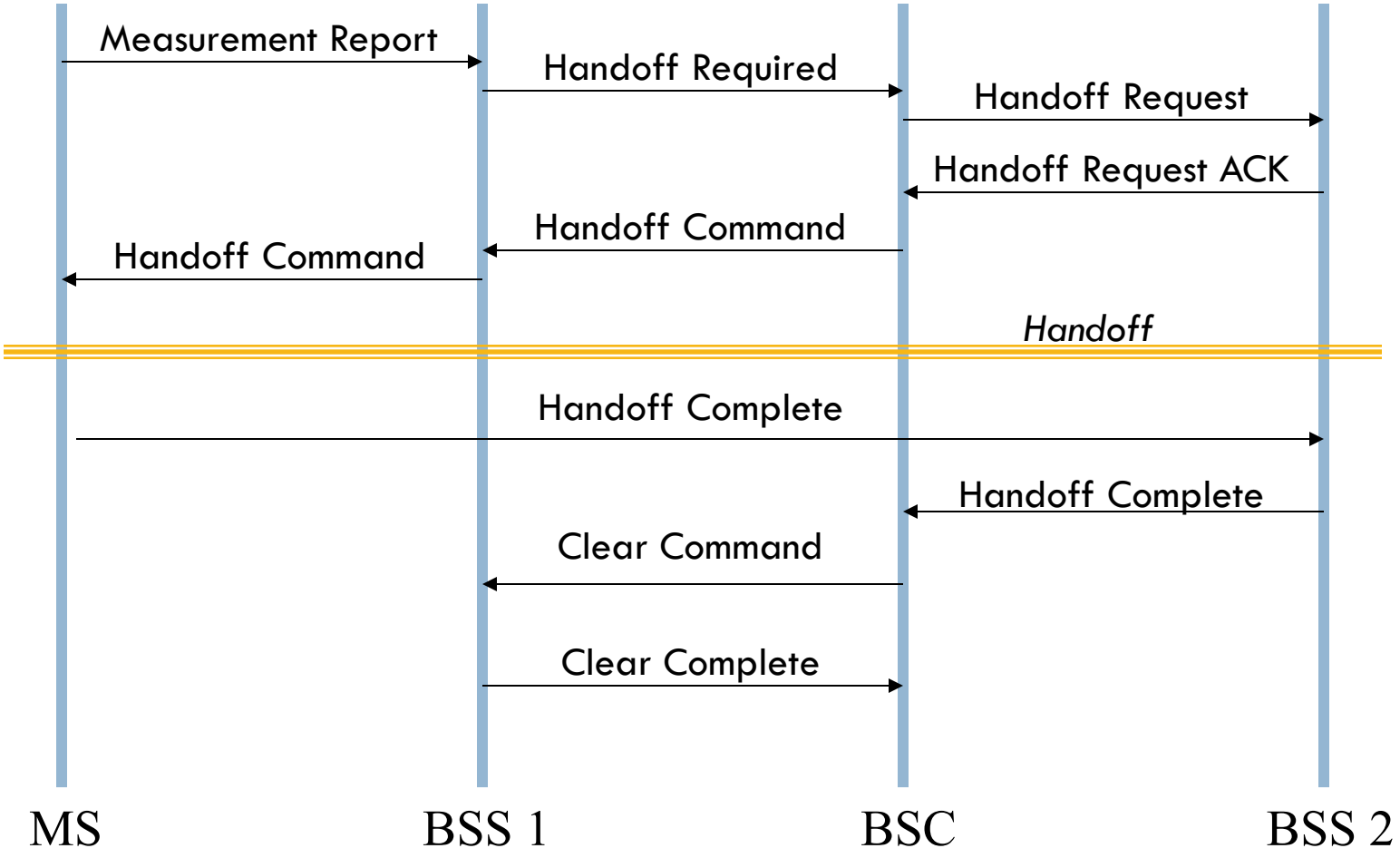
- Mean value of 100 measurements of 24 TCH bursts are sent
- Neighbouring cell RSS is measured based on the continuously keyed BCCH of the neighbouring cells
- The MS sends the following data
  - RSS of the traffic channel
  - BER of the traffic channel
  - RSS of the BCCH of up to six neighbouring cells and the corresponding BSIC (Base station identity code)
    - BSIC distinguishes between co-channel cells
  - Frequency of these BCCH's

0. Mobile listens to the BCCH of six neighbouring base stations





Handoff Executed with an MSC



Data Services in GSM

- Circuit switched data at a maximum data rate of 9.6 kbps
- Short messaging service (SMS)
  - Short alphanumeric messages can be exchanged by the MS and the GSM system
  - Point-to-point and broadcast services are available
  - An SMSMC (SMS Message Center) is responsible for store-and-forward service