	Bit periods	*Durata*	*Velocità*
TDMA frame (8 time slots)	1250	4.615 *ms*	270.83 *kbit/s*
Time slot = burst	156.25	576.87 μs	33.85 *kbit/s*
Normal burst	Dati = 114 Altro = 42.25	576.87 μs	Dati = 24.7 *kbit/s* Altro = 9.2 *kbit/s*
Hyperframe (2^{11} = 2048 Superframes)	3394560000	12533.760 *sec* (3^h28'53.760")	270.83 *kbit/s*
Superframe (26*51 = 1326 Frames)	1657500	6.12 *sec*	
Multiframe 26 (26 Frames)	32500 Dati netti = 23712	120 *ms*	Dati lordi = 22.8 *kbit/s* Dati netti = 13 *kbit/s* Altro = 1.9 *kbit/s*
Multiframe 51 (51 Frames)	63750 Dati netti = 46512	235.4 *ms*	

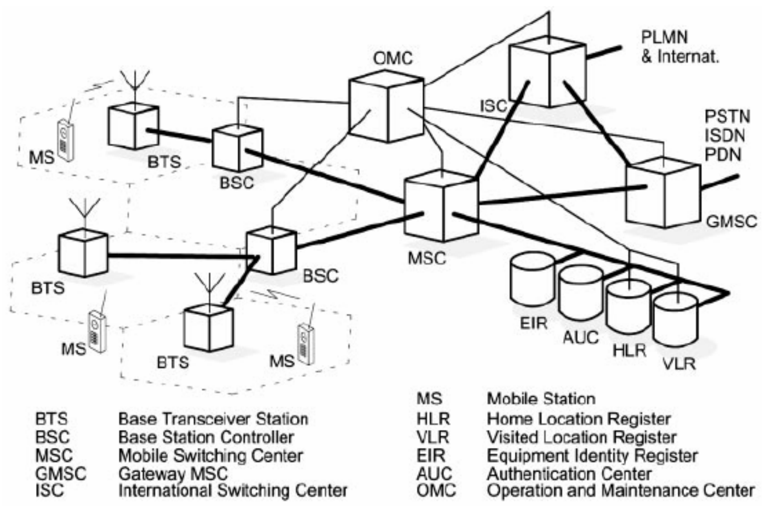


Figure 3.2: GSM system architecture with essential components

Table 3.1: Mobile subscriber data in the HLR

Subscriber and subscription data	Tracking and routing information
International Mobile Subscriber Identity (IMSI)	Mobile Station Roaming Number (MSRN)
International Mobile Subscriber ISDN Number (MSISDN)	Current VLR address (if available)
Bearer and teleservice subscriptions	Current MSC address (if available)
Service restrictions, e.g. roaming restrictions	Local Mobile Subscriber Identity (LMSI) (if available)
Parameters for additional services	
Information on the subscriber's equipment (if available)	
Authentication data (subject to implementation)	

Table 3.2: Mobile subscriber data in the VLR

Subscriber and subscription data	Tracking and routing information
International Mobile Subscriber Identity (IMSI)	*Mobile Station Roaming Number (MSRN)*
International Mobile Subscriber ISDN Number (MSISDN)	*Temporary Mobile Station Identity (TMSI)*
Parameters for supplementary services	*Local Mobile Subscriber Identity (LMSI) (if available)*
Information on subscriber-used equipment (if available)	Local Area Identity (LAI) of LA, where MS was registered (used for paging and call setup)
Authentication data (subject to implementation)	

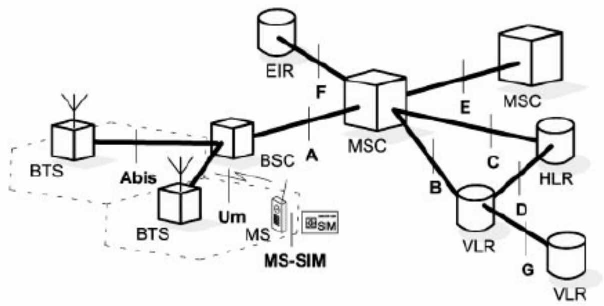


Figure 3.9: Interfaces in a GSM PLMN

Table 5.1: Classification of logical channels in GSM

Group		Channel	Function	Direction
Traffic channel	Traffic channel (TCH)	TCH/F, Bm	Full rate TCH	MS ↔ BSS
		TCH/H, Lm	Half rate TCH	MS ↔ BSS
Signaling channels (Dm)	Broadcast channel	BCCH	Broadcast control	MS ← BSS
		FCCH	Frequency correction	MS ← BSS
		SCH	Synchronization	MS ← BSS
	Common control channel (CCCH)	RACH	Random access	MS → BSS
		AGCH	Access grant	MS ← BSS
		PCH	Paging	MS ← BSS
		NCH	Notification	MS ← BSS
	Dedicated control channel (DCCH)	SDCCH	Stand-alone dedicated control	MS ↔ BSS
		SACCH	Slow associated control	MS ↔ BSS
		FACCH	Fast associated control	MS ↔ BSS

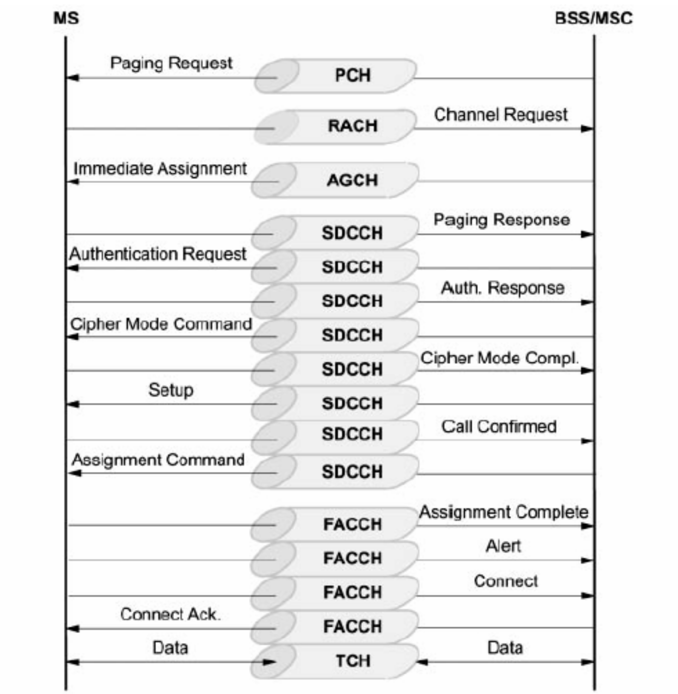


Figure 5.1: Logical channels and signaling (connection setup for an incoming call)

Channel type	Net data throughput (in kbit/s)	Block length (in bit)	Block distance (in ms)
TCH (full-rate speech)	13.0	182 + 78	20
TCH (half-rate speech)	5.6	95 + 17	20
TCH (data, 14.4 kbit/s)	14.5	290	20
TCH (data, 9.6 kbit/s)	12.0	60	5
TCH (data, 4.8 kbit/s)	6.0	60	10
TCH (data, ≤ 2.4 kbit/s)	3.6	72	10
FACCH full rate	9.2	184	20
FACCH half rate	4.6	184	40
SDCCH	598/765	184	3060/13
SACCH (with TCH)	115/300	168 + 16	480
SACCH (with SDCCH)	299/765	168 + 16	6120/13
BCCH	598/765	184	3060/13
AGCH	n × 598/765	184	3060/13
NCH	m × 598/765	184	3060/13
PCH	p × 598/765	184	3060/13
RACH	r × 27/765	8	3060/13
CBCH	598/765	184	3060/13

Table 5.3: Channel combinations offered by the base station

	B1	B2	B3	B4	B5	B6	B7	B8	B9
TCH/F	■							■	■
TCH/H		■	■						
TCH/H			■						
BCCH				■	■	■			
FCCH				■	■				
SCH				■	■				
CCCH				■	■	■			
SDCCH					■		■		
SACCH	■	■	■		■		■	■	■
FACCH	■	■	■					■	

CC1:	TCH/F + FACCH/F + SACCH/TF
CC2:	TCH/H(0,1) + FACCH/H(0,1) + SACCH/TH(0,1)
CC3:	TCH/H(0) + FACCH/H(0) + SACCH/TH(0) +TCH/H(1)
CC4:	FCCH + SCH + BCCH + CCCH
CC5:	FCCH + SCH + BCCH + CCCH + SDCCH/4(0,1,2,3) + SACCH/C4(0,1,2,3)
CC6:	BCCH + CCCH
CC7:	SDCCH/8 + SACCH/8

Table 2.16: Logical channel configurations that can be mapped onto a single physical channel in GSM.

Possible time slots	Channels	
	Down-link	Up-link
0–7	1 TCH/F (+SACCH)	1 TCH/F (+SACCH)
0–7	2 TCH/H (+SACCH)	2 TCH/H (+SACCH)
0–7	8 SDCCH (+SACCH)	8 SDCCH (+SACCH)
0	1 SCH + 1 FCCH + 1 BCCH + 1 AGCH + 1 PCH	1 RACH
0	1 SCH + 1 FCCH + 1 BCCH + 1 AGCH* + 1 PCH* + 4 SDCCH (+SACCH)	1 RACH* + 4 SDCCH (+SACCH)
2,4,6	1 BCCH + 1 AGCH + 1 PCH	1 RACH

*Reduced rate channels.

Table 5.4: Channel combinations used by the base station

	M1	M2	M3	M4	M5	M6	M7	M8
TCH/F					■			n+m
TCH/H						■	■	
TCH/H							■	
BCCH	■		■					
CCCH		■	■					
SDCCH				■				
SACCH				■	■	■	■	n+m
FACCH					■	■	■	■

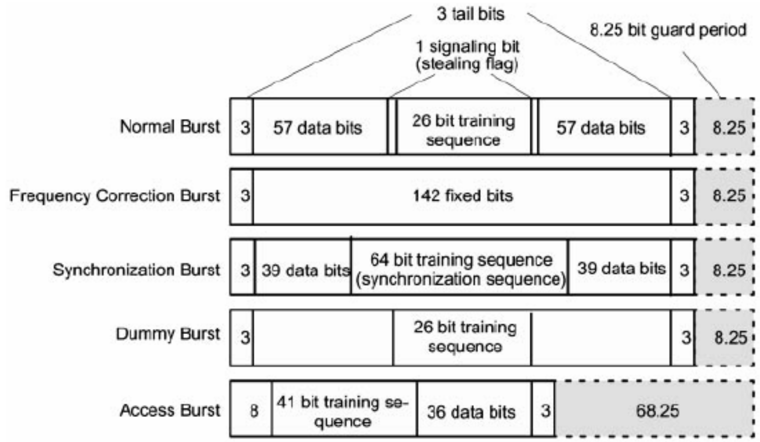


Figure 5.6: Bursts of the GSM TDMA procedure

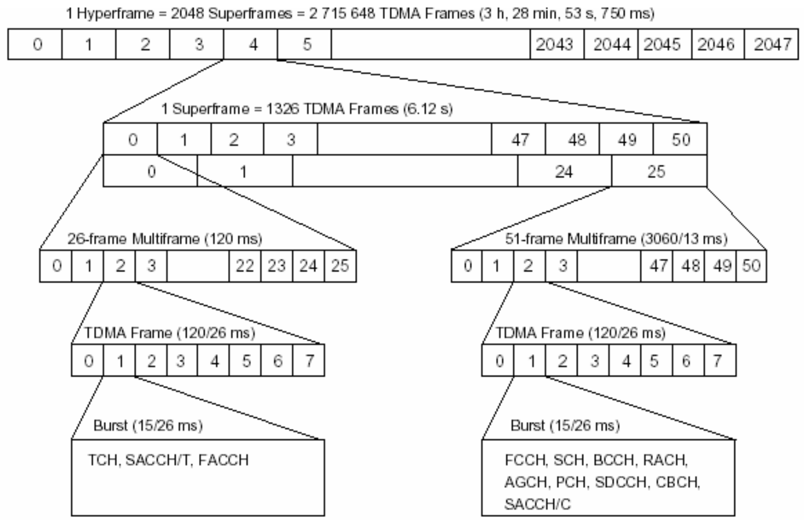


Figure 3.12: The structure of a transmission medium with TDMA frames, multiframes, superframes and hyperframes

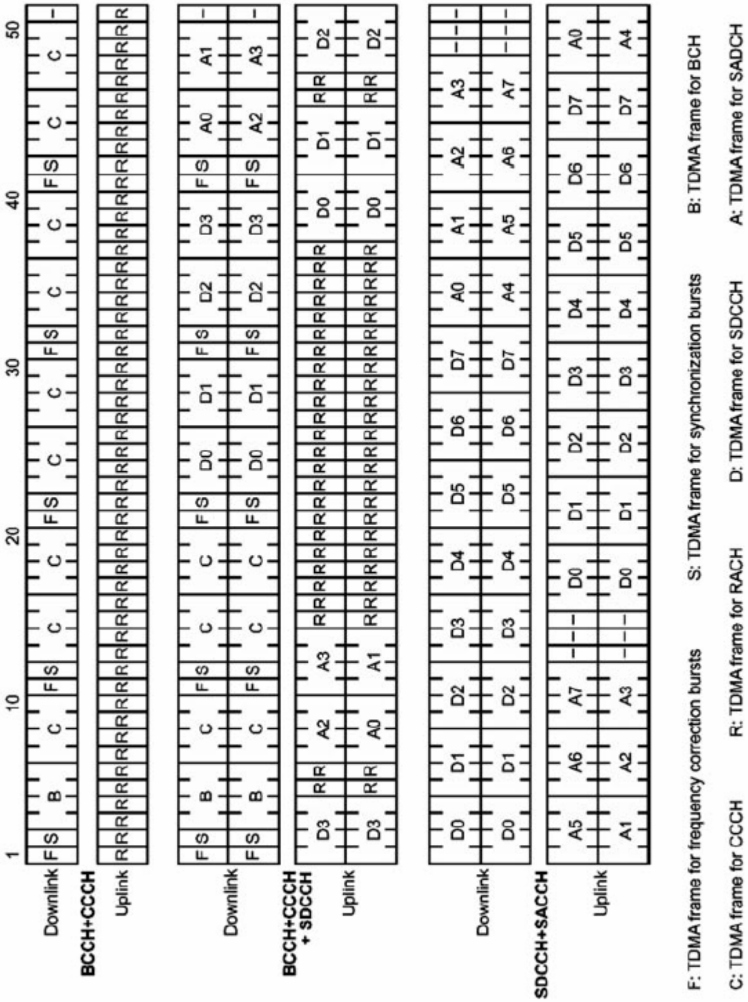


Figure 5.17: Channel organization in a 51-frame multiframe

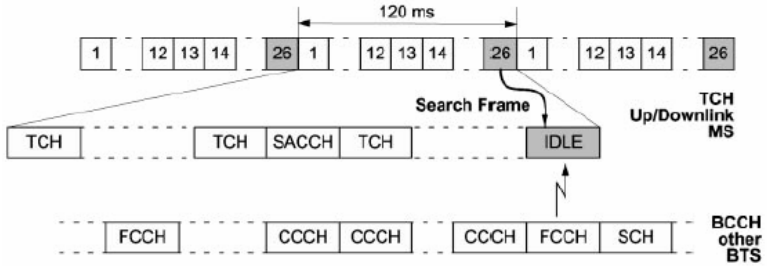


Figure 5.20: Synchronization with adjacent cells during a call

Table 6.2: Error protection coding and interleaving of logical channels

Channel type	Abbr.	Block distance (ms)	Bits per block			Convol. code rate	Encoded bits per block	Inter-leaver depth
			Data	Parity	Tail			
TCH, full rate, speech	TCH/FS	20	260				456	8
Class I			182	3	4	1/2	378	
Class II			78	0	0	–	78	
TCH, half rate, speech	TCH/HS	20	112				228	4
Class I			95	3	6	104/211	211	
Class II			17	0	0	–	17	
TCH, full rate, 14.4 kbit/s	TCH/F14.4	20	290	0	4	294/456	456	19
TCH, full rate, 9.6 kbit/s	TCH/F9.6	5	4 × 60	0	4	244/456	456	19
TCH, full rate, 4.8 kbit/s	TCH/F4.8	10	60	0	16	1/3	228	19
TCH, half rate, 4.8 kbit/s	TCH/H4.8	10	4 × 60	0	4	244/456	456	19
TCH, full rate, 2.4 kbit/s	TCH/F2.4	10	2 × 36	0	4	1/6	456	8
TCH, half rate, 2.4 kbit/s	TCH/H2.4	10	2 × 36	0	4	1/3	228	19
FACCH, full rate	FACCH/F	20	184	40	4	1/2	456	8
FACCH, half rate	FACCH/H	40	184	40	4	1/2	456	6
SDCCH, SACCH			184	40	4	1/2	456	4
BCCH, NCH, AGCH, PCH		235	184	40	4	1/2	456	4
RACH		235	8	6	4	1/2	36	1
SCH			25	10	4	1/2	78	1
CBCH		235	184	40	4	1/2	456	4

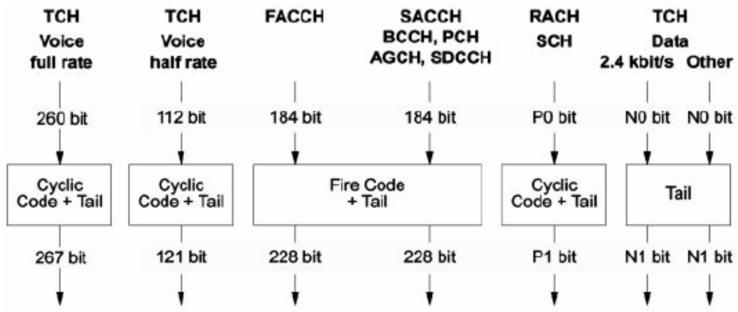


Figure 6.7: Overview of block coding for logical channels (also see Table 6.2)

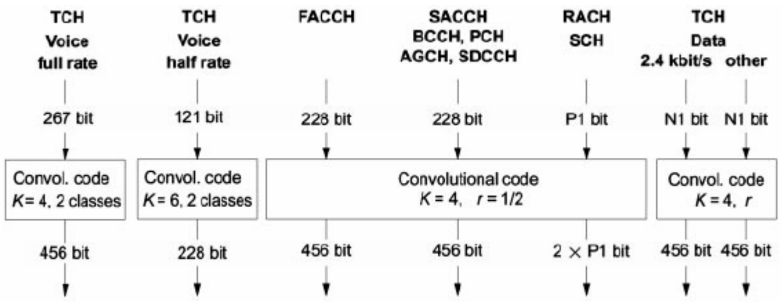


Figure 6.10: Overview of convolutional coding of logical channels (continued from Figure 6.7; also see Table 6.2)

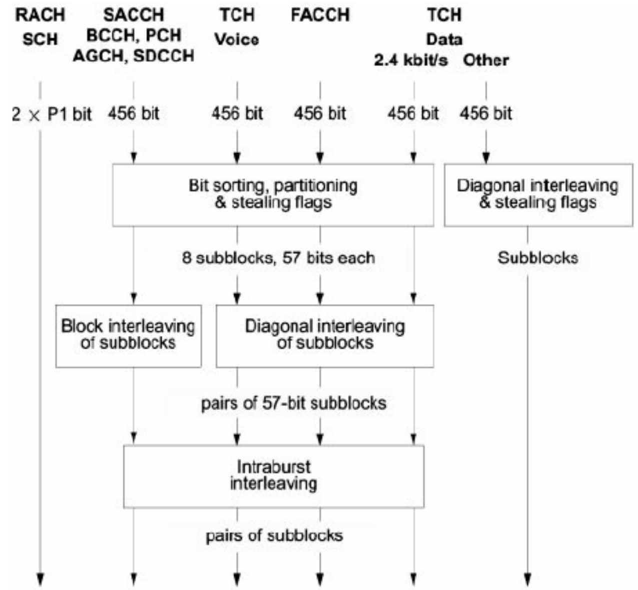


Figure 6.14: Overview: interleaving of (full-rate) logical channels

Table 6.8: Transmission delay caused by interleaving

Channel type	Interleaving depth	Transmission delay (ms)
TCH, full-rate, voice	8	38
TCH, half-rate, voice	4	
TCH, full-rate, 14.4 kbit/s	19	93
TCH, full-rate, 9.6 kbit/s	19	93
TCH, full-rate, 4.8 kbit/s	19	93
TCH, half-rate, 4.8 kbit/s	19	185
TCH, full-rate, 2.4 kbit/s	8	38
TCH, half-rate, 2.4 kbit/s	19	185
FACCH, full-rate	8	38
FACCH, half-rate	8	74
SDCCH	4	14
SACCH/TCH	4	360
SACCH/SDCCH	4	14
BCCH, AGCH, PCH	4	14

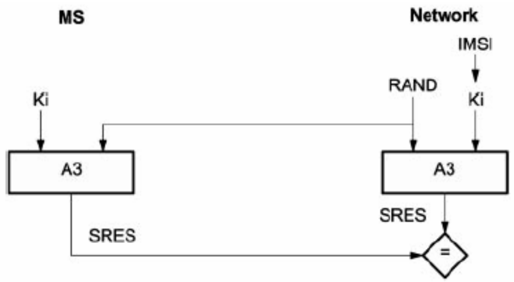


Figure 6.21: Principle of subscriber authentication

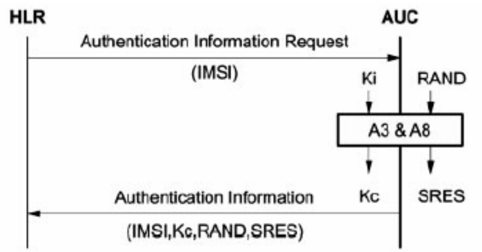


Figure 6.22: Generation of a set of security data for the HLR

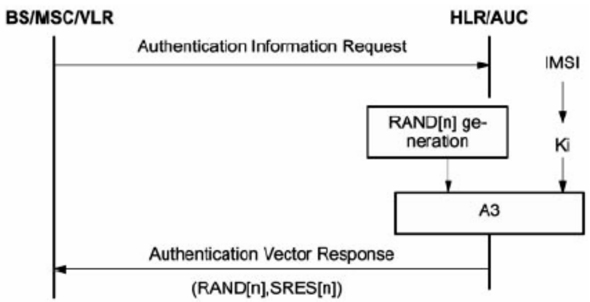


Figure 6.23: Highly secure authentication (no transmission of Ki)

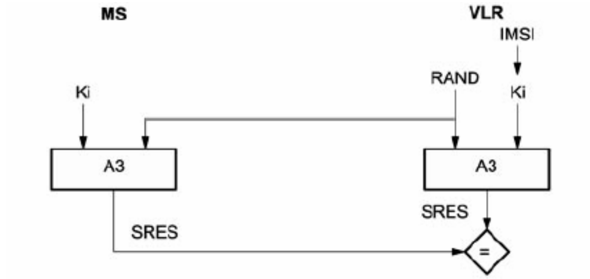


Figure 6.24: Weakly secure authentication (transmission of Ki to VLR)

Figure 6.26: Generation of the cipher key Kc

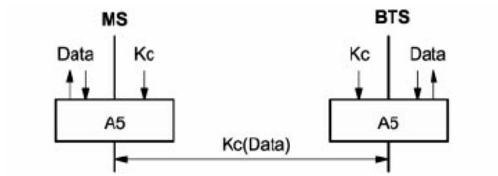


Figure 6.27: Principle of symmetric encryption of user data

Table 7.4: RR messages

Category	Message	Logical channel	Direction	MT-code
Channel establishment	Additional assignment	DCCH	N → MS	00111011
	Immediate assignment	CCCH	N → MS	00111111
	Immediate assignment extended	CCCH	N → MS	00111001
	Immediate assignment rejected	CCCH	N → MS	00111010
Ciphering	Ciphering mode command	DCCH	N → MS	00110101
	Ciphering mode complete	DCCH	MS → N	00110010
Handover	Assignment command	DCCH	N → MS	00101110
	Assignment complete	DCCH	MS → N	00101001
	Assignment failure	DCCH	MS → N	00101111
	Handover access	DCCH	MS → N	–
	Handover command	DCCH	N → MS	00101011
	Handover complete	DCCH	MS → N	00101100
	Handover failure	DCCH	MS → N	00101000
	Physical information	DCCH	N → MS	00101101
Channel release	Channel release	DCCH	N → MS	00001101
	Partial release	DCCH	N → MS	00001010
	Partial release complete	DCCH	MS → N	00001111
Paging	Paging request, Type 1/2/3	PCH	N → MS	00100xxx
	Paging response	DCCH	MS → N	00100111
System information	System information Type 1/2/3/4	BCCH	N → MS	00011xxx
	System information Type 5/6	SACCH	N → MS	00011xxx
Miscellaneous	Channel mode modify	DCCH	N → MS	00010000
	Channel mode modify acknowledge	DCCH	MS → N	00010111
	Channel request	RACH	MS → N	–
	Classmark change	DCCH	MS → N	00010110
	Frequency redefinition	DCCH	N → MS	00010100
	Measurement report	SACCH	MS → N	00010101
	Synchronization channel information	SCH	N → MS	–
	RR-status	DCCH	MS ↔ N	00010010

Table 7.5: MM messages

Category	Message	Direction	MT
Registration	IMSI detach indication	MS → N	0x000001
	Location updating accept	N → MS	0x000010
	Location updating reject	N → MS	0x000100
	Location updating request	MS → N	0x001000
Security	Authentication reject	N → MS	0x010001
	Authentication request	N → MS	0x010010
	Authentication response	MS → N	0x010100
	Identity request	N → MS	0x001000
	Identity response	MS → N	0x001001
	TMSI reallocation command	N → MS	0x001010
	TMSI reallocation complete	MS → N	0x001011
Connection management	CM service accept	MS ↔ N	0x100001
	CM service reject	N → MS	0x100010
	CM service request	MS → N	0x100100
	CM reestablishment request	MS → N	0x101000
Miscellaneous	MM-status	MS ↔ N	0x110001

Table 7.6: CC messages for circuit-switched connections

Category	Message	Direction	MT
Call establishment	Alerting	N → MS	0x000001
	Call confirmed	MS → N	0x001000
	Call proceeding	N → MS	0x000010
	Connect	N ↔ MS	0x000111
	Connect acknowledge	N ↔ MS	0x001111
	Emergency setup	MS → N	0x001110
	Progress	N → MS	0x000011
	Setup	N ↔ MS	0x000101
Call Information Phase	Modify	N ↔ MS	0x010111
	Modify complete	N ↔ MS	0x011111
	Modify reject	N ↔ MS	0x010011
	User information	N ↔ MS	0x010000
Call Clearing	Disconnect	N ↔ MS	0x100101
	Release	N ↔ MS	0x101101
	Release complete	N ↔ MS	0x101010
Miscellaneous	Congestion control	N ↔ MS	0x111001
	Notify	N ↔ MS	0x111110
	Start DTMF	MS → N	0x110101
	Start DTMF acknowledge	N → MS	0x110010
	Start DTMF Reject	N → MS	0x110111
	Status	N ↔ MS	0x111101
	Status enquiry	N ↔ MS	0x110100
	Stop DTMF	MS → N	0x110001
	Stop DTMF acknowledge	N → MS	0x110010

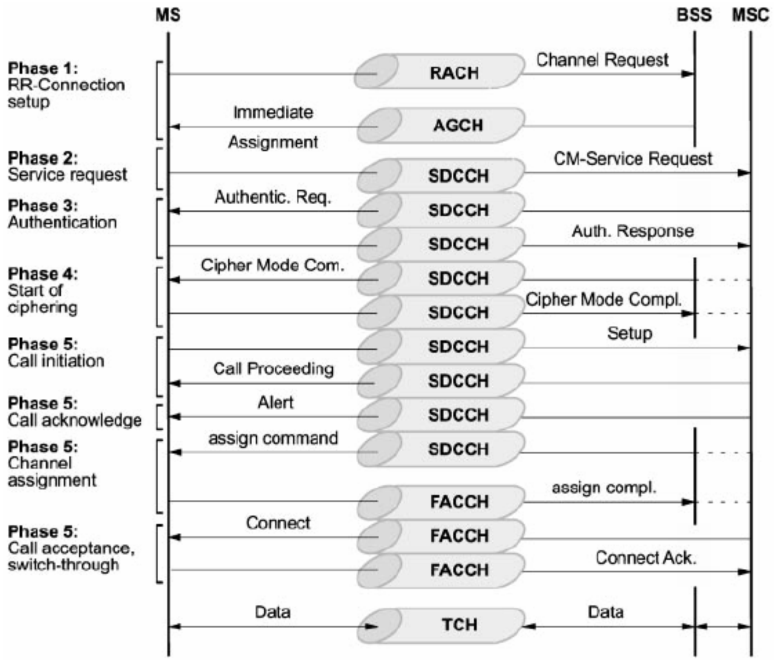


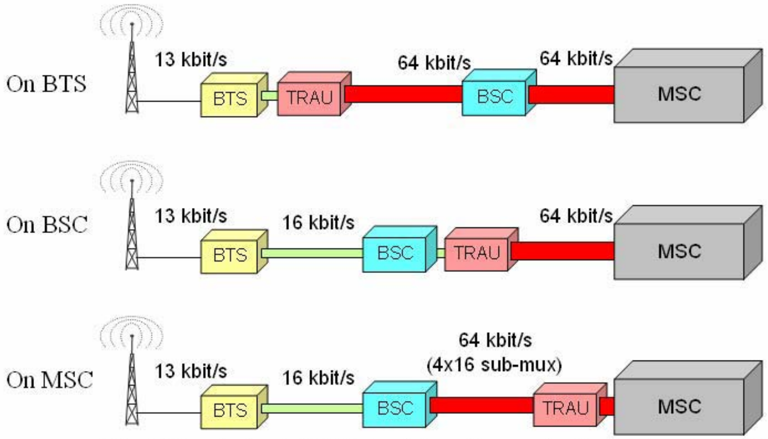
Figure 7.31: Mobile-initiated call setup with OACSU (*late assignment*)

$$d_{[m]} = \frac{1}{2}\cdot GP_{[bit]}\cdot\frac{1}{CR_{[bit/ms]}}\cdot c_{[m/ms]} = \frac{1}{2}\cdot GP_{[bit]}\cdot\frac{1}{270.833}\cdot 3000000$$

$$d_{[Km]} = \frac{1}{2}\cdot GP_{[bit]}\cdot\frac{1}{CR_{[bit/s]}}\cdot c_{[Km/s]} = \frac{1}{2}\cdot GP_{[bit]}\cdot\frac{1}{270833}\cdot 3000000$$

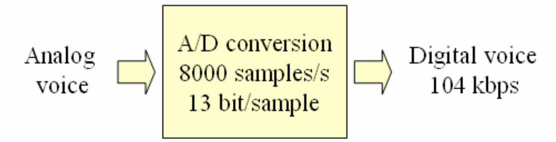
con $\begin{cases} GP = \text{guard period} \\ CR = \text{channel rate} \end{cases}$

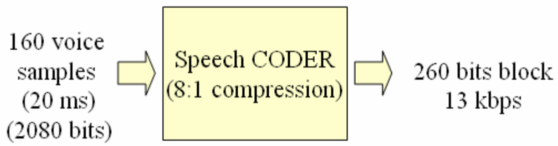
TRAU possible placements



Why 16 kbps instead of 13? Inband signalling needed for BTS control of TRAU (TRAU needs to receive synchro & decoding information from BTS)

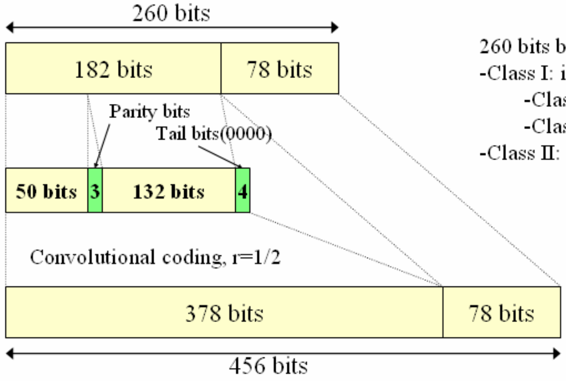
Speech coding





Channel Coding

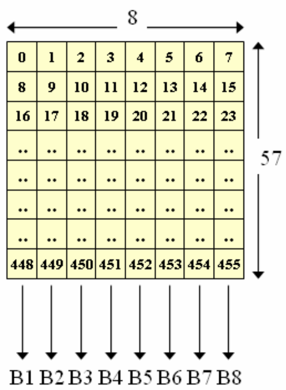
Coding: needed to move from 10^{-1} to 10^{-3} radio channel native BER down to acceptable range (10^{-5} to 10^{-6}) BER



260 bits block divided into
- Class I: important bits (182)
  - Class Ia: Most important 50
  - Class Ib: Less important 132
- Class II: low importance bits (78)

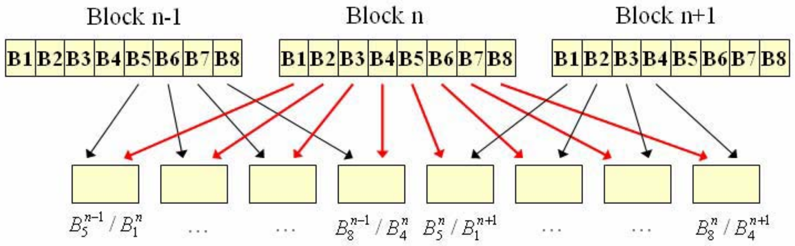
First step: block coding for error detection in class Ia (error→discard frame)
Second step: convolutional coding for error correction

Block interleaving



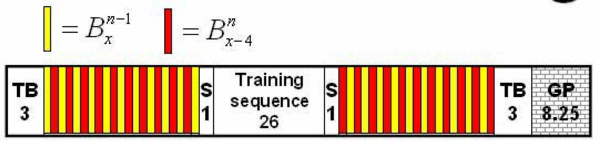
8 blocks, each with 57 bits

Diagonal Interleaving



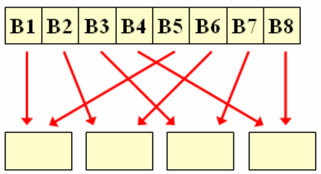
PRICE TO PAY: delay!! (block spreaded over 8 bursts → 37 ms)

Inter-burst Interleaving

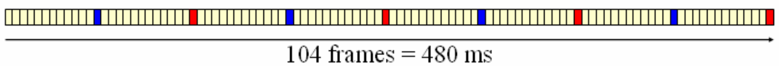


SACCH block

- **→184 signalling bits**
  - →Block coding adds 40 bits (=224)
  - →4 tail (zero) bits (=228)
  - →1/2 Convolutional encoding (=456 bits)
- **→Interleaving:**
  - ⇨ 8 blocks of 57 bits;
  - ⇨ spreaded into four consecutive bursts
  - ⇨ 4 bursts = 1 and only 1 SACCH block!
- **→SACCH rate:**
  - ⇨ 184 bits/480 ms = 383.3 bit/s

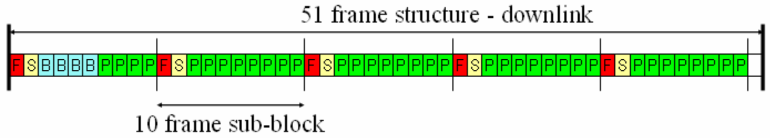


Odd/even interleaving

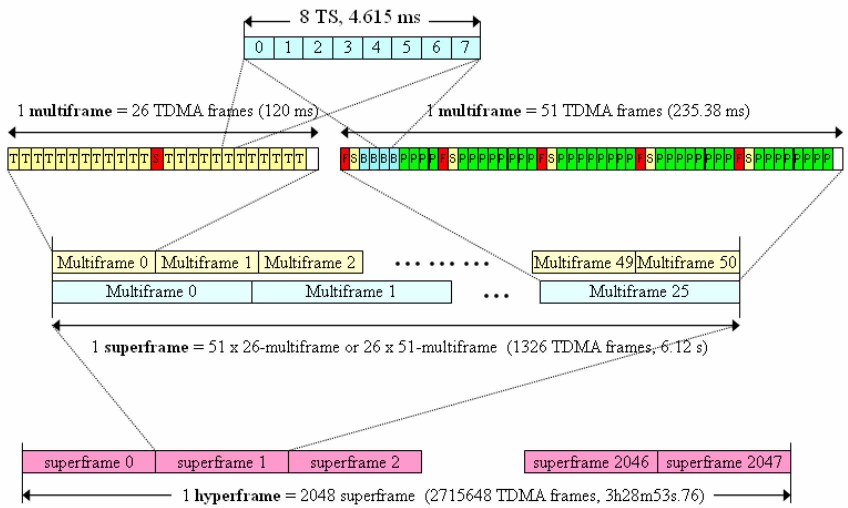


Broadcast Channel (usual) organization

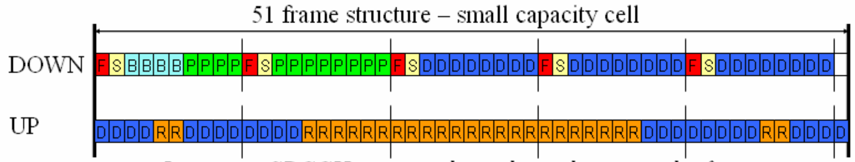
- **→ 51 frame structure vs 26**
  - ⇨ 235.38 ms period (vs 120 ms)
- **→ Sub-blocks with 10 frames**
  - ⇨ Starting with Frequency Correction Channel (FCCH)
  - ⇨ Immediately followed by Synchronization Channel (SCH)
- **→ Other frames** (numbered from #0 to #50):
  - ⇨ #50 idle
  - ⇨ #2,3,4,5 BCCH
  - ⇨ Remaining: Paging (PCH) / Access Grant (AGCH) [=PAGCH]



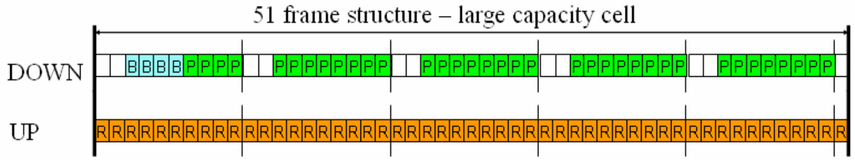
Multi-framing structure



control channel alternative organization

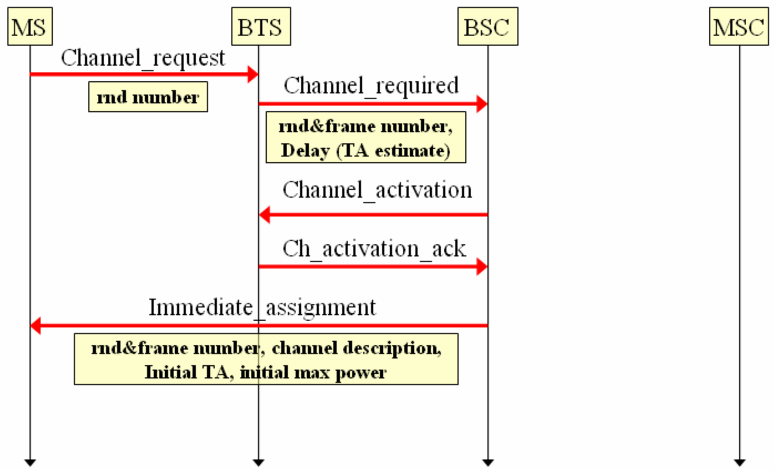


Integrates SDCCH in same channel as other control information
Leaves additional TS all available for TCH

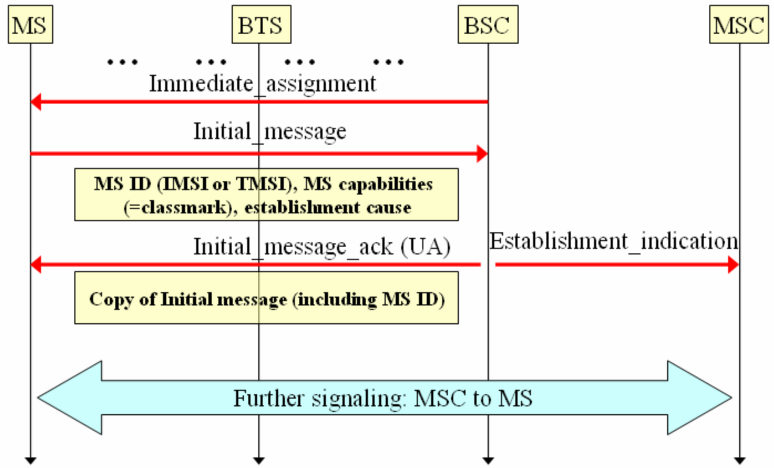


Used in TS 2 (and, eventually, 4 and 6) of beacon carrier
Provides additional paging and RACH channels

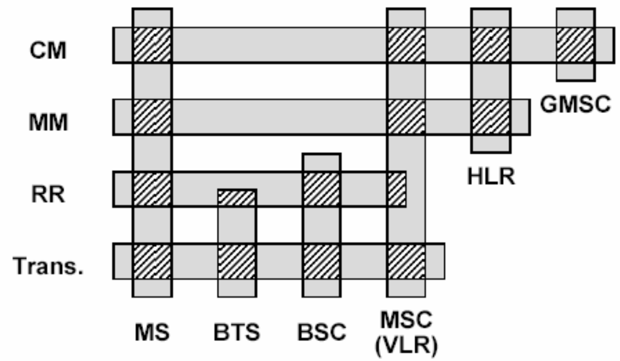
Access signaling - 1



Access signaling - 2



Protocol placement



Camping cell selection
path loss criterion C1

Select cell with greatest c1(n)>0:

$$C1(n) = RXLEV(n) - RXLEV\_ACCESS\_MIN - \max[0, (MS\_TXPWR\_MAX\_CCH - P)]$$

- **RXLEV(n): received power from BTS(n)**
- **RXLEV_ACCESS_MIN: minimum received power level required for registration in the cell**
  - (parameter transmitted on BCCH; typically –98 to –106 dB)
- **MS_TXPWR_MAX_CCH: maximum allowed transmitted power on RACH**
  - (parameter transmitted on BCCH; typically 31-39 dBm)
- **P: maximum MS power (from MT class)**

When cell parameters are the same, simply select cell with higher RXLEV!

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Cell reselection criterion (C2)

→Reselect cell with greatest C2>0:

$$C2(n) = C1(n) + CELL\_RESELECT\_OFFSET - TEMPORARY\_OFFSET \times H(PENALTY\_TIME - T)$$

$$\text{where } H(x) = \begin{cases} 0 & x < 0 \\ 1 & x \geq 0 \end{cases}$$

- **T: amount of consecutive time since considered cell became with C1>0**
- **PENALTY_TIME, CELL_RESELECT_OFFSET, TEMPORARY_OFFSET: BCCH parameters**
- **If all parameters = 0, reselect cell with better path loss performance (no time hysteresis included)**

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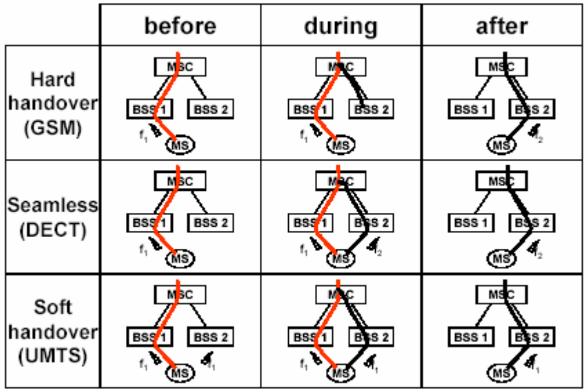
Hard, Seamless, Soft handover



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Handover classification

Classification by motivation

- **Rescue handover (mandatory handover)**
  - Driven by radio channel quality degradation
- **Confinement handover (network-directed handover)**
  - Target: minimize radio interference
  - Assign new channel when old channel results critical for total interference
- **Traffic handover (network-directed handover)**
  - Driven by traffic congestion conditions
  - Also called load-balancing

Classification by typology

- **Internal handover**
  - Intra-BTS
    - →New radio channel in the same cell
    - →Not termed as "handover" but as "subsequent assignment"
  - Inter-BTS (Intra-BSC)
    - →Under control of same BSC
- **External handover**
  - Inter-BSC (Intra-MSC)
    - →Change reference BSC; may imply a location area update
  - Inter-MSC
    - →Most complex: need to change MSC

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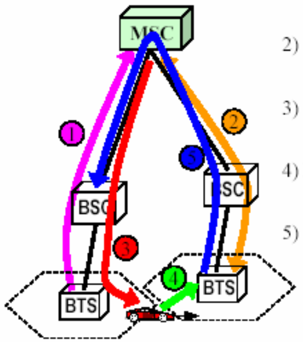
handover procedure skeleton



1) Handover request goes up to switching point

2) Switching point prepares new path on fixed net

3) Switching point sends HO command to MS

4) MS accesses new channel

5) Old channel/path torn down

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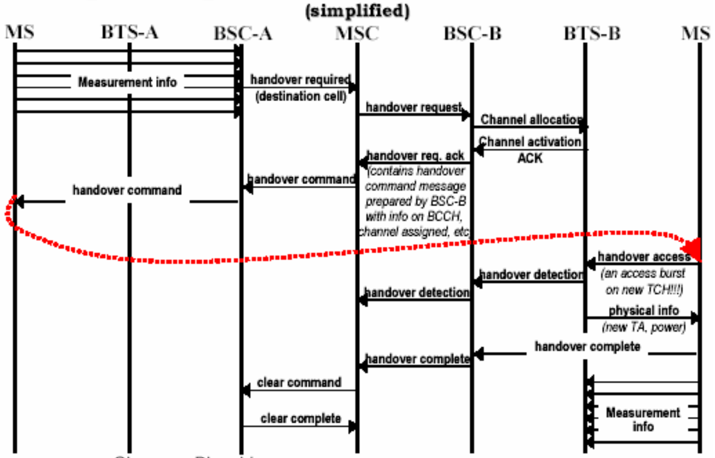
Signaling for intra-MSC handover

(simplified)



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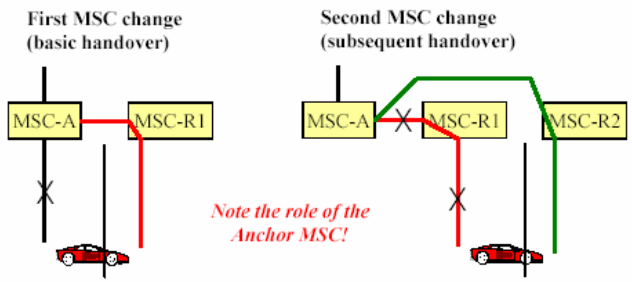
Inter-MSC handover

- ➔ **More complex, as an ISDN circuit must be set between MSCs**
  - ⇨ We'll not enter into details (just the basic ideas)
- ➔ **Two cases**



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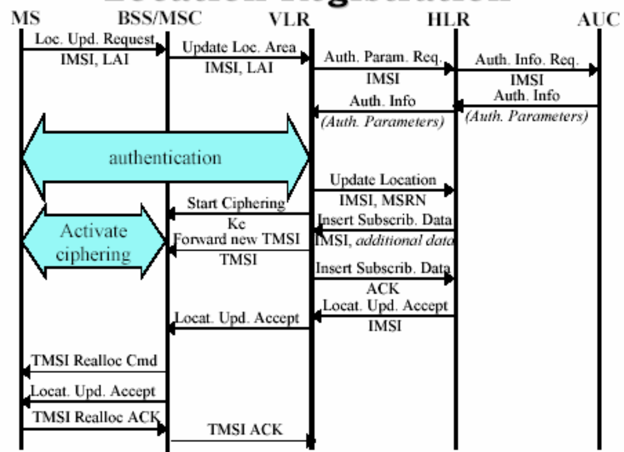
Location Registration



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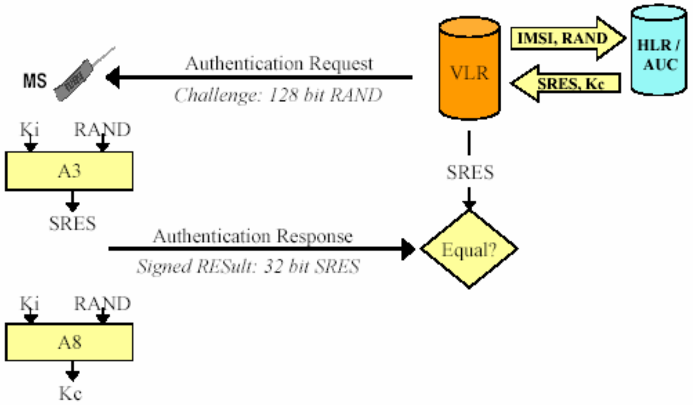
Authentication
(managed by VLR)



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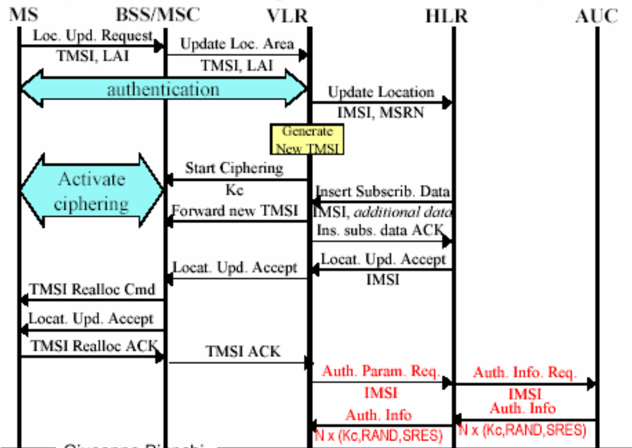
Location Update in same VLR
(same as location registration, but with TMSI)



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TMSI

- **TMSI = Temporary Mobile Subscriber Identity**
  - 4 octets (32 bits)
  - Renewed periodically; at every LU / IMSI_attach
    - Via TMSI_Reallocation_Command/TMSI_Reallocation_Complete
    - RATIONALE: renew TMSI when transmitted in clear! (TMSI reallocation occurs in ciphering mode)
- **Meaningful only in a given VLR**
  - Specifically, only for a given Location Area!!
    - Some author (Mouly-Pautet) uses the term
      - » TIC (Temporary Identity Code) = 4 bytes
      - » TMSI = TIC+LAI = unambiguous user identification
- **While entering a new Location Area:**
  - user must identify itself with TMSI+LAI pair.

> Operator may set a 6min up to 24hrs periodicity for LU (value transmitted on BCCH)
>
> IMSI_attach = a special LU in a same Location Area;
>
> IMSI_attach follows an IMSI_detach (power-down of MS)

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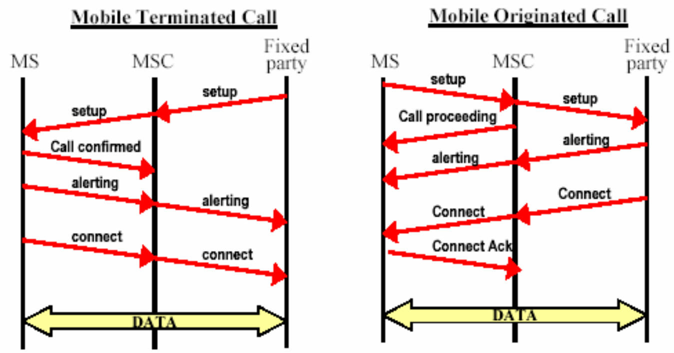
Call establishment basics



In ISDN ISUP:
- setup = IAM (Initial Address Message);
- Alerting = ACM (Address Complete Message);
- Connect = ANS (Answer)

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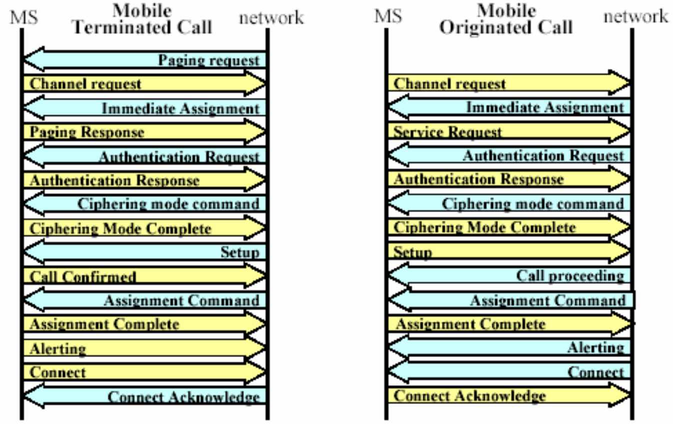
Call establishment steps



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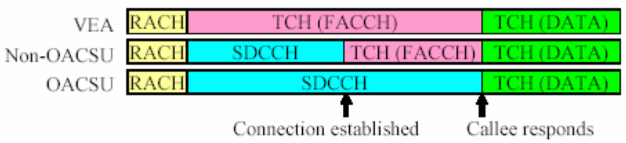
Radio Resource allocation

three standardized solutions

- **Non-Off Air Call Set-Up (Non-OACSU)**
  - Normally used (previous description)
- **Off Air Call Set-Up (OACSU)**
  - TCH assigned only when the called party actually responds!
    - →Best utilization of radio resource (avoids allocation if callee not available)
    - →Call drop if no TCH is available at this point
- **Very Early Assignment (VEA)**
  - Immediate assignment of TCH
    - →Fastest signalling process
    - →Waste of resources



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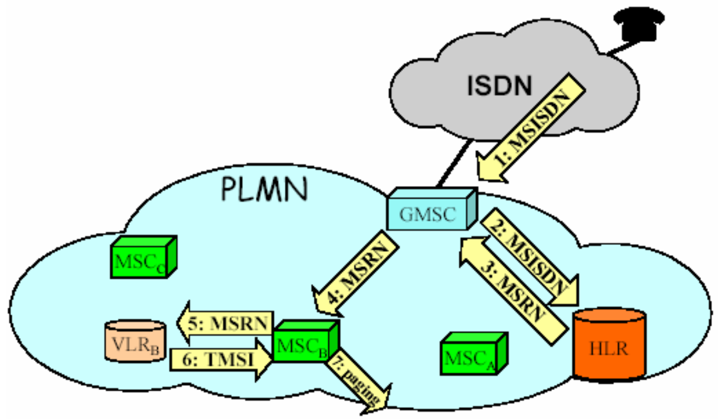
Routing an MTC



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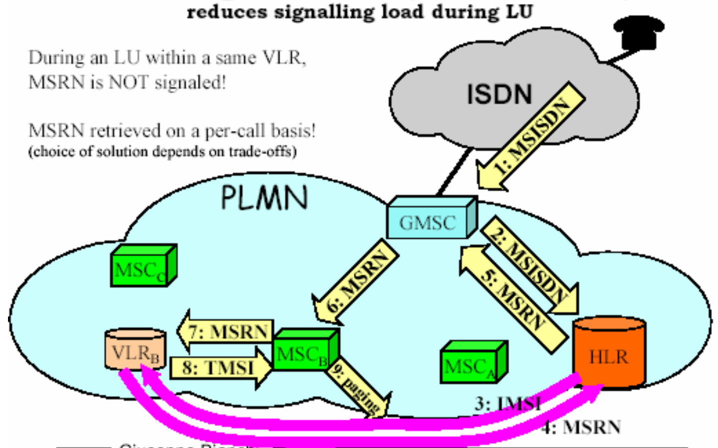
Routing an MTC (alternative)

reduces signalling load during LU

During an LU within a same VLR, MSRN is NOT signaled!

MSRN retrieved on a per-call basis!
(choice of solution depends on trade-offs)



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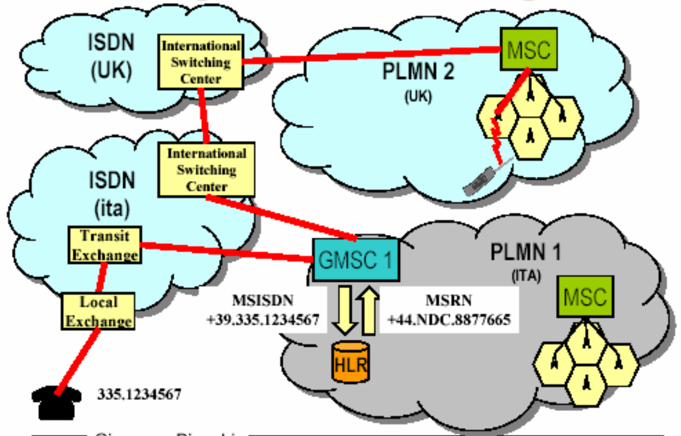
Routing calls to Roaming MS



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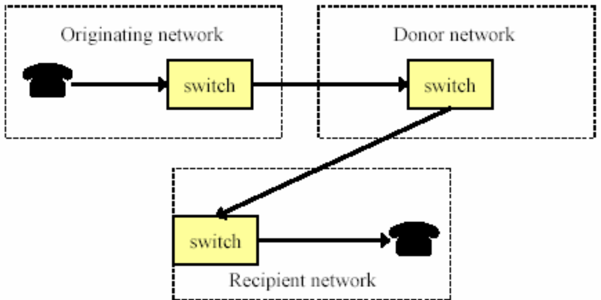
Technical solutions
a) call forwarding



Originating switch sets-up trunk to donor switch
Donor switch sets-up trunk to recipient switch
Simplest solution, as call forwarding is a feature available in virtually all switches

But extremely inefficient routing and trunking resource consumption!

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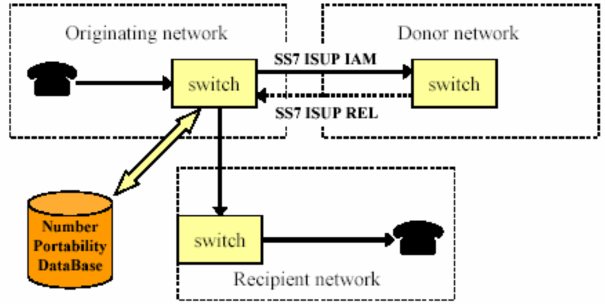
Technical solutions
b) query on release



Donor switch "blocks" incoming call with a release message (REL)
REL carries a QoR cause value, stating that called party number is ported
Originating switch then queries Number Portability database

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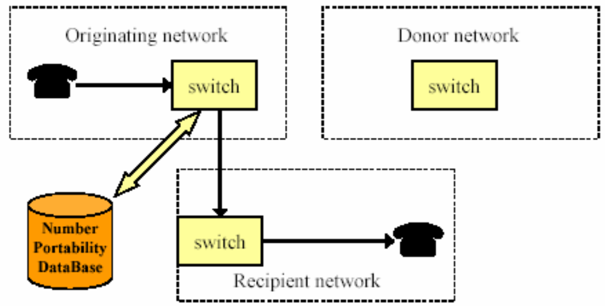
Technical solutions
c) all-call query



Originating switch queries Number Portability database for every call!!
- best solution if majority of numbers are ported (no interaction with donor)
- but very high DB load, as EVERY number must be looked-up!

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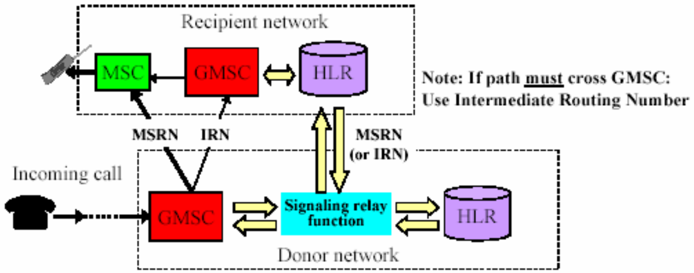
Mobile Number Portability

- ➔ **Same ideas as fixed number portability**
  - ⇨ The donor switch is the GMSC of the donor network
- ➔ **Donor GMSC Call forwarding (if more efficient fixed number portability not supported)**
  - ⇨ While porting number, may also get MSRN!



Clearly, still suffers of tromboning!

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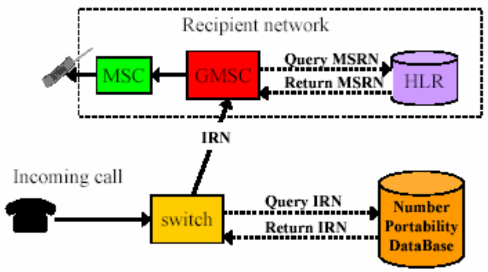
Mobile Number Portability
(with all call query approach)



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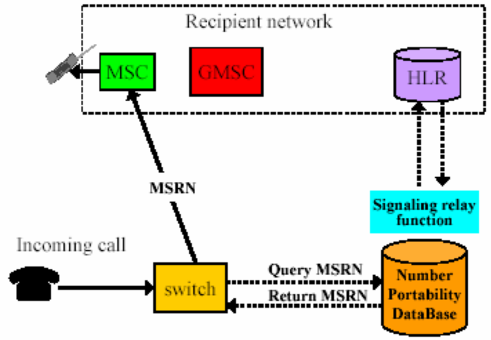
Mobile Number Portability
improved – (with all call query approach)



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