

# PART 4

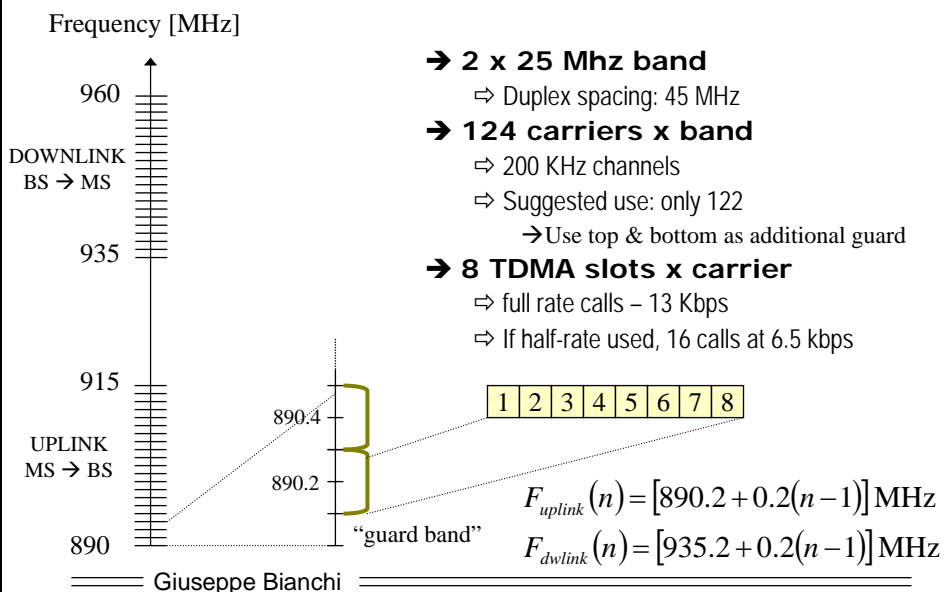
## GSM – Radio Interface

### Lecture 4.1

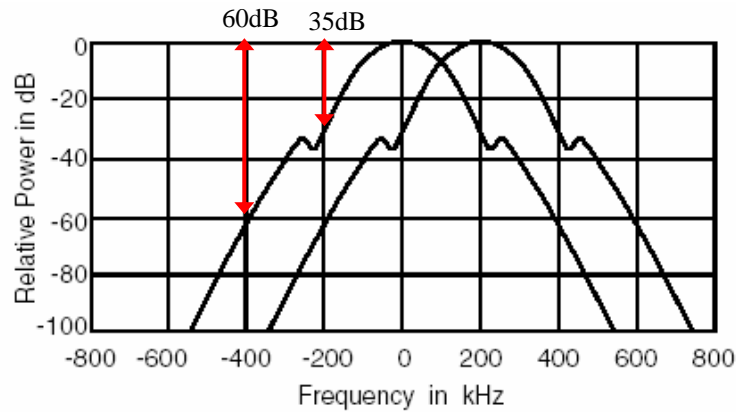
#### Physical channels

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## GSM Radio Spectrum



## Adjacent channels (due to GSM)



Specification: 9dB

In practice, due to power control and shadowing, adjacent channels  
Cannot be used within the same cell...

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## Physical channel

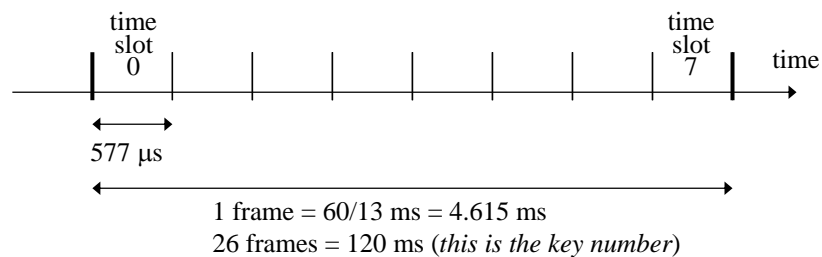
→ 200 KHz bandwidth + GMSK modulation

⇒ 1625/6 kbps gross channel rate (270.8333 kbps)

→ 1 time slot = 625/4 bits

⇒ 156.25 bits

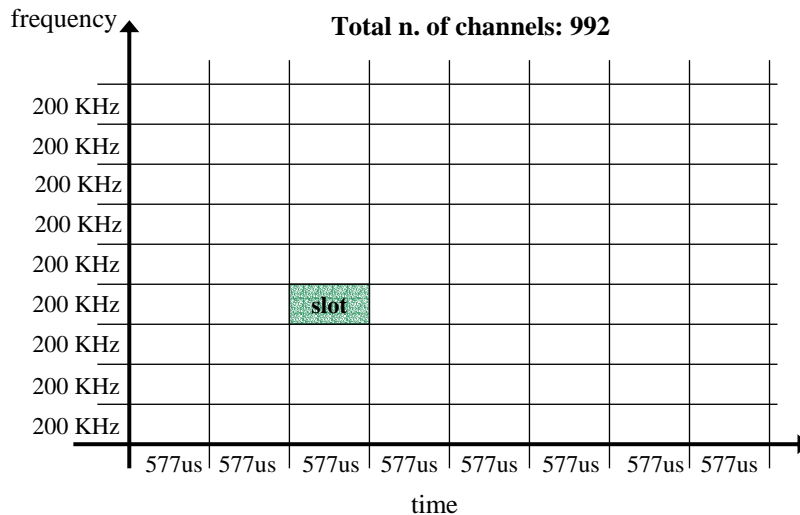
⇒ 15/26 ms = 576.9 μs



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## Hybrid FDMA-TDMA

physical channel = (time slot, frequency)



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## DCS 1800 radio spectrum

### → Greater bandwidth available

⇒ EUROPE: 75 MHz band

→ 1710-1785 MHz uplink; 1805-1880 MHz downlink

⇒ ITALY: 45 MHz band from 2005

→ 1740-1785 MHz uplink; 1835-1880 MHz downlink

### → Same GSM specification

⇒ 200 KHz carriers

→ A total of 374 carriers (versus 124 in GSM)

### → DCS 1800 operators

⇒ Common rule in most of the countries:

→ First and second operators @ 900 MHz; Third etc @ 1800 MHz

→ DCS 1800 deployment (1996+):

» 15 MHz (=75 carriers) to Wind; 7.5 (=37 carriers) to first and second operator (plus existing 27 GSM 900 carriers)

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## Other GSM bands

### → Extended GSM (E-GSM) band

⇒ Uplink: 880-915 MHz

⇒ Downlink: 925-960 MHz

### → Other bands:

⇒ 450 MHz → (450.4-457.6 up; 460.4-467.6 down)

⇒ 480 MHz → (478.8-486 up; 488.8-496 down)

⇒ 1900 MHz → (1850-1910 up; 1930-1990 MHz)

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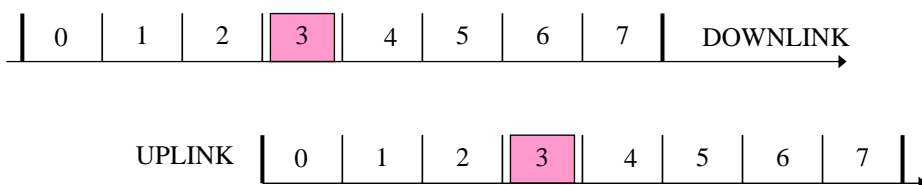
## Duplexing

- MS uses SAME slot number on uplink and downlink

- Uplink and downlink carriers always have a 45 MHz separation

-I.e. if uplink carrier is 894.2 → downlink is 919.2

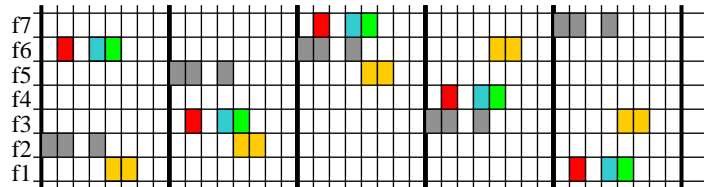
-3 slot delay shift!!



MS: no need to transmit and receive in the same time  
on two different frequencies!

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## Slow Frequency hopping (optional procedure within individual cell)



Hopping sequence (example):

... → f1 → f2 → f5 → f6 → f3 → f7 → f4 → f1...

Slow = on a per-frame basis

- 1 hop per frame (4.615 ms) = 217 hops/second

Physical motivation:

- combat frequency-selective fading

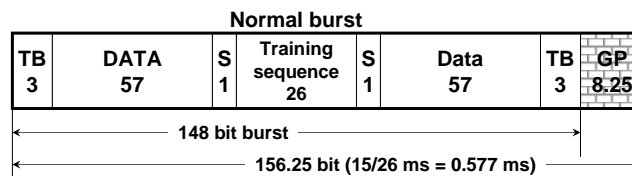
- combat Co-Channel Interference

next slot may not interfere with adjacent cell slot (different hopping sequence)

- improvements: acceptable quality with 9 dB SNR versus 11 dB

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## Structure of a TDMA slot



→ Symmetric structure

→ DATA: 2 x 57 data bits

⇒ 114 data bits per burst

⇒ "gross" bits (error-protected; channel coded)

⇒ "gross" rate: 24 traffic burst every 26 frames (120 ms)

→ 22.8 kbps gross rate

→ 13 kbps net rate!

→ S: 2 x 1 stealing bit

⇒ Also called stealing flags, toggle bits

⇒ Needed to grab slot for FACCH (other signalling possible)

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## Tail & training bits

### → 2 x TB = 3 tail bits set to 000

- ⇒ At start and end of frame
- ⇒ Leave time available for transmission power ramp-up/down
- ⇒ Assures that Viterbi decoding starts and ends at known state

### → 26 bit training sequence

- ⇒ Known bit pattern (8 Training Sequence Code available)
- ⇒ for channel estimation and synchronization
- ⇒ Why in the middle?
  - Because channel estimate reliable ONLY when the radio channel “sounding” is taken!
  - Multipath fading rapidly changes the channel impulse response...

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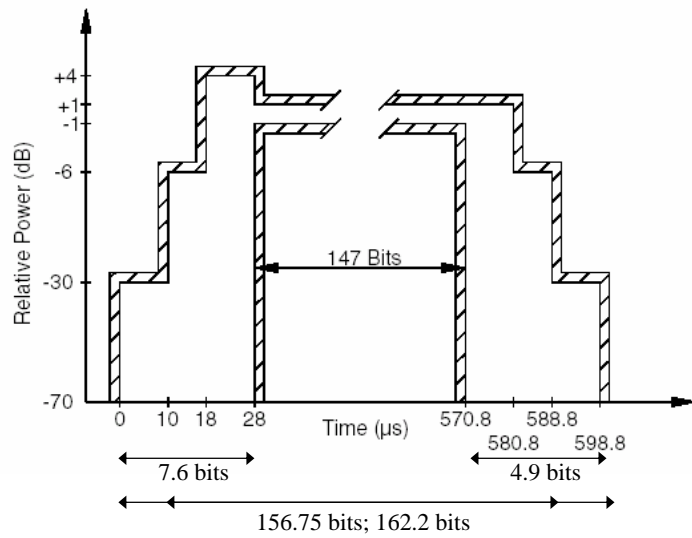
## Training sequences

Training sequence code (TSC)	Training sequence bits (b61, b62, ..., b86)
0	(0,0,1,0,0,1,0,1,1,1,0,0,0,0,1,0,0,0,1,0,0,1,0,0,1,0,1,1,1)
1	(0,0,1,0,1,1,0,1,1,1,0,1,1,1,1,0,0,0,1,0,1,1,0,1,1,1)
2	(0,1,0,0,0,0,1,1,1,0,1,1,0,1,0,0,0,1,0,0,0,1,1,1,1,0)
3	(0,1,0,0,0,1,1,1,1,0,1,1,0,1,0,0,0,1,0,0,0,1,1,1,1,0)
4	(0,0,0,1,1,0,1,0,1,1,1,0,0,1,0,0,0,0,0,1,1,0,1,0,1,1)
5	(0,1,0,0,1,1,1,0,1,0,1,1,0,0,0,0,0,1,0,0,1,1,1,0,1,0)
6	(1,0,1,0,0,1,1,1,1,0,1,1,0,0,0,1,0,1,0,0,1,1,1,1,1,1)
7	(1,1,1,0,1,1,1,1,0,0,0,1,0,0,1,0,1,1,1,0,1,1,1,1,0,0)

*Different codes used in adjacent cells! Avoids training sequence Disruption because of co-channel interference.*

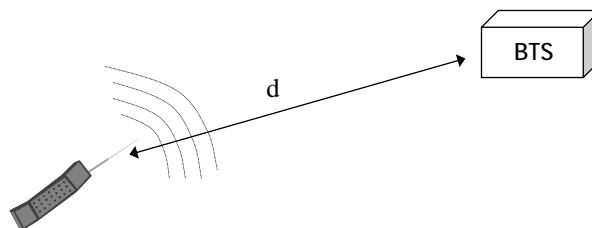
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## Power mask for Normal Burst



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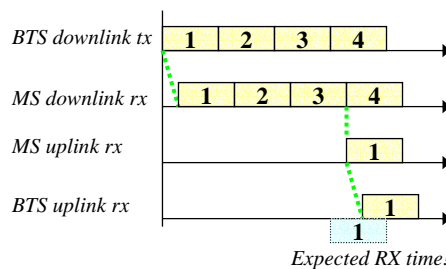
## Guard Period rationale



### → Assume the following synchro mechanism:

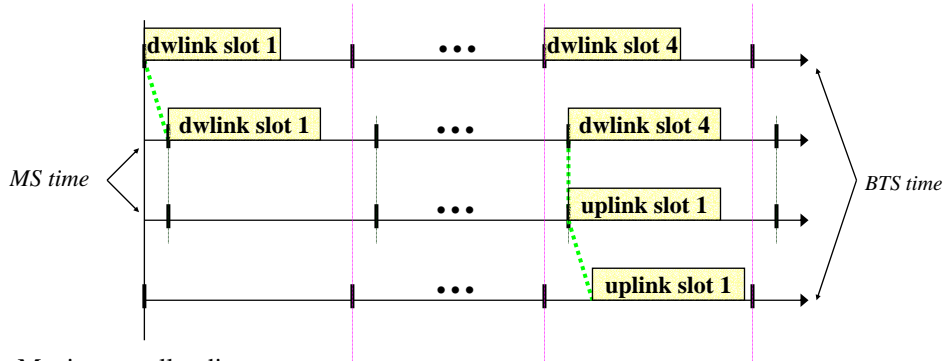
- ⇒ BTS transmits at time 0
- ⇒ MS receives at time  $d/c$
- ⇒ MS transmits at time  $3+d/c$
- ⇒ BTS receives at time  $3+2d/c$

### → Offset depending on d!



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## Guard period sizing



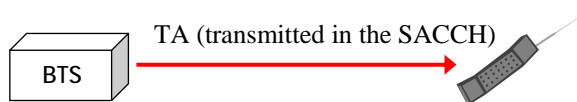
Maximum cell radius:

$$\frac{GT_{bits}}{C_{rate}} = \frac{2d}{c} \rightarrow d = \frac{c \cdot GT_{bits}}{2C_{rate}} \approx \frac{300000 \cdot 8.25}{2 \cdot 270833} \approx 4.5 \text{ Km}$$

**Is there something wrong? (GSM says that cells go up to 35 km)**

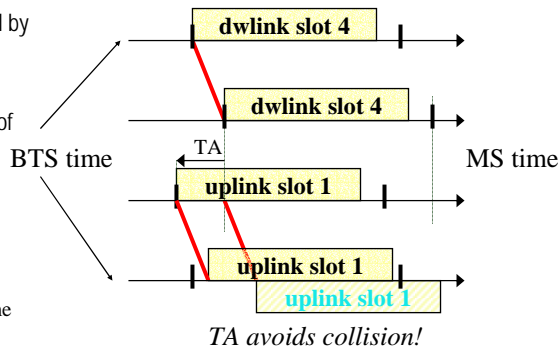
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## Frame synchronization



### → Timing Advance (TA)

- ⇒ Parameter periodically transmitted by BTS during MS activity
- ⇒ 6 bits = 0-63
- ⇒ Meaning: anticipate transmission of TA bits
- ⇒ TA=0: no advance
  - I.e. transmit after 468.75 bits after downlink slot
- ⇒ TA=63:
  - Transmit after 405.75 bits time



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## Timing Advance analysis

→ Downlink propagation delay:

⇒  $d/c$

→ Uplink propagation delay:

⇒  $d/c$

→ Uplink delay with TA:

⇒  $d/c - TA$

→ Perfect resynchronization occurs when

⇒  $TA = 2d/c$

→ Maximum cell size for perfect resync:

$$d = \frac{TA}{2} \cdot c = \frac{31.5 \text{ [bits]}}{270833 \text{ [bits/s]}} \cdot 300000 \text{ [km/s]} = 34.89 \text{ [km]}$$

*8.25 bits Guard time additionally available for imperfect sync (+/- error)*

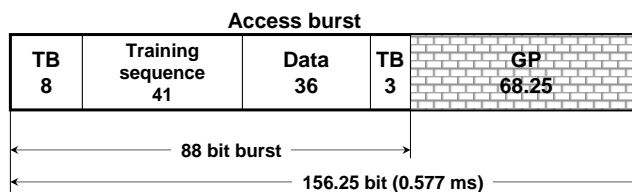
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## And when the user is not connected? But wants to connect...

**Solution: USE A DIFFERENT BURST FORMAT**

**Access Burst: much longer Guard Period available**

**drawback: much less space for useful information**



*No collision with subsequent slot for distances up to 37.8 km*

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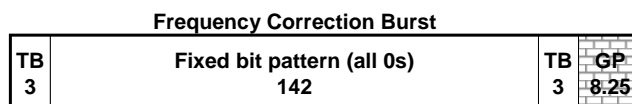
## Other burst formats in GSM

### → 5 different bursts available

- ⇒ Normal Burst
- ⇒ Access Burst
  
- ⇒ Frequency Correction Burst
- ⇒ Synchronization Burst
- ⇒ Dummy Burst

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## Frequency Correction Burst



- All 0s burst (TB=0, too)
- After GMSK modulation:
  - ⇒ Sine wave at  $f_{\text{reference}} + 1625/24$  kHz (67.7083 kHz)
- Acts as a "beacon"
  - ⇒ When an MS is searching to detect the presence of a carrier
- Allows an MS to keep in sync with reference frequency

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## Dummy Burst

Dummy Burst					
TB 3	Fixed bit pattern 58	Training sequence 26	Fixed bit pattern 58	TB 3	GP 8.25

- Used to fill inactive bursts on the BCCH
- Guarantees more power on BCCH than that on other channels
  - ⇒ Important, when MS needs to find BCCH

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## Synchronization Burst

Synchronization Burst					
TB 3	Sync data 39	Training sequence 64	Sync data 39	TB 3	GP 8.25

- **Longer training sequence**
  - ⇒ It is the first burst an MS needs to demodulate!
  - ⇒ 1 single training sequence
- **Data field:**
  - ⇒ Contains all the information to synchronize the frame
    - i.e. synchronize frame counter
  - ⇒ Contains the BSIC (Base Station Identity Code, 6 bits)
    - 3 bits network code (operator)
      - » Important at international boundary, where same frequencies can be shared by different operators
    - 3 bits color code
    - To avoid listening a signal from another cell, thinking it comes from the actual one!

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# **PART 4**

## **GSM – Radio Interface**

### **Lecture 4.2**

#### **logical channels**

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## **Logical vs Physical channels**

<b>Logical channels</b> (traffic channels, signalling (=control) channels)
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<b>Physical channels</b> (FDMA/TDMA)
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#### **→ Physical channels**

- ⇒ Time slots @ given frequencies
- ⇒ Issues: modulation, slot synchronization, multiple access techniques, duplexing, frequency hopping, etc

#### **→ Logical channels**

- ⇒ Built on top of phy channels
- ⇒ Issue: which information is exchanged between MS and BSS

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## Logical – physical mapping

Physical Channel: data rate  $r$ , time slot  $i$



*Logical Channel Mapping:  
Different channels may share a same physical channel*



■ Logical channel A: data rate  $r/3$ , time slot  $i$ , frame  $3k$

■ Logical channel B: data rate  $2r/3$ , time slot  $i$ , frame  $3k+1, 3k+2$

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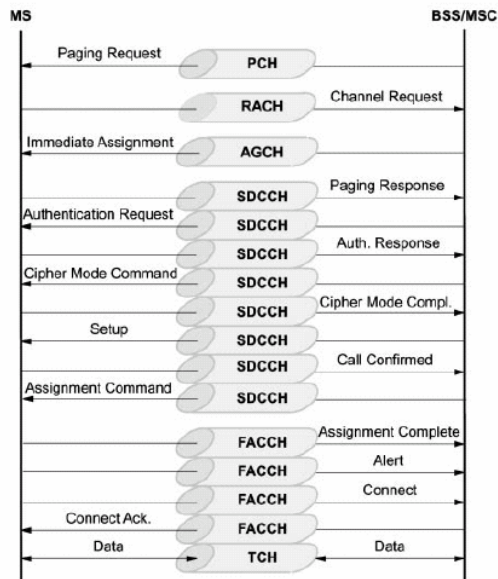
## GSM logical channels

<b>Traffic channel (TCH)</b>	<b>TCH/F</b>	TCH full rate	MS ↔ BSS
	<b>TCH/H</b>	TCH half Rate	MS ↔ BSS
<b>Broadcast channel</b> <i>(same information to all MS in a cell)</i>	<b>BCCH</b>	Broadcast control	BSS → MS
	<b>FCCH</b>	Frequency Correction	BSS → MS
	<b>SCH</b>	Synchronization	BSS → MS
<b>Common Control channel (CCCH)</b> <i>(point to multipoint channels)</i> <i>(used for access management)</i>	<b>RACH</b>	Random Access	MS → BSS
	<b>AGCH</b>	Access Grant	BSS → MS
	<b>PCH</b>	Paging	BSS → MS
<b>Dedicated Control channel (DCCH)</b> <i>(point-to-point signalling channels)</i> <i>(dedicated to a specific MS)</i>	<b>SDCCH</b>	Stand-alone Dedicated control	MS ↔ BSS
	<b>SACCH</b>	Slow associated control	MS ↔ BSS
	<b>FACCH</b>	Fast associated control	MS ↔ BSS

Additional logical channels available for special purposes  
(SMS, group calls, ...)

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## An example procedure involving signalling



Setup for an incoming call (call arriving from fixed network part - MS responds to a call)

Steps:

- paging for MS
- MS responds on RACH
- MS granted an SDCCH
- authentication & ciphering on SDCCH
- MS granted a TS (TCH/FACCH)
- connection completed on FACCH
- Data transmitted on TCH

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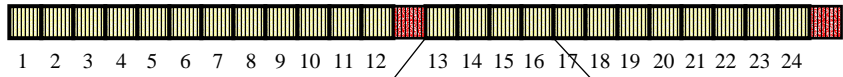
## PART 4 GSM – Radio Interface

### Lecture 4.3 Traffic channels and associated signalling channels

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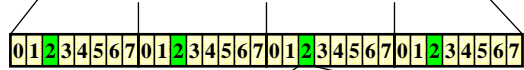
## Traffic channels (TCH/F)

Periodic pattern of 26 frames (120 ms = 15/26 ms/TS \* 8 TS/frame \* 26 frame)



24 TCH frames over 26

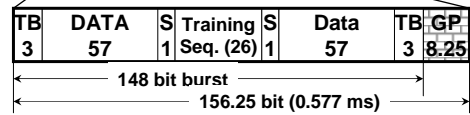
Same TS in every frame



Theoretical rate: 1/8 channel rate:  $r=33.85$  kbps

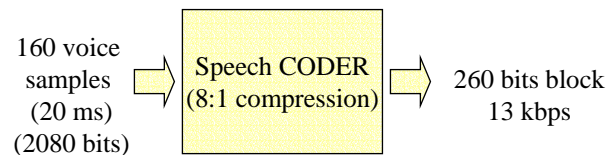
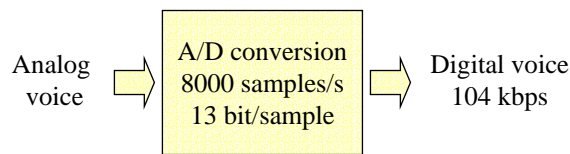
2 signalling frames:  $r \rightarrow 31.25$  kbps

Burst overhead (114 bits over 156.25):  
 $r \rightarrow 22.8$  kbps



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## Speech coding

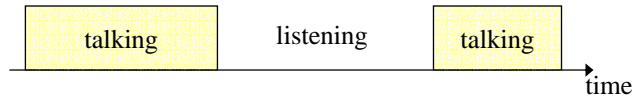


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## Discontinuous transmission

→ **Speech coder implements Voice Activity Detection (VAD)**

- ⇒ Voice activity: idle for about 40% of the time
- ⇒ To avoid clipping: hangover period (80ms)



→ **When IDLE, do not transmit**

- ⇒ Save battery consumption
- ⇒ Reduces interference

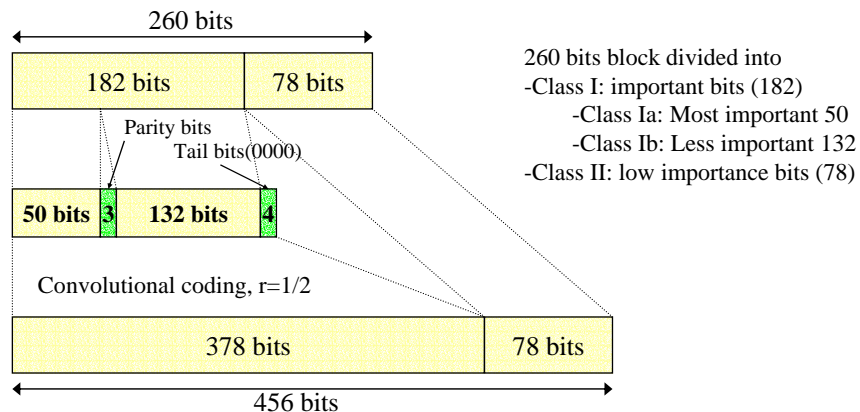
→ **Receiver side: silence is disturbing!**

- ⇒ Missing received frames replaced with "comfort noise"
- ⇒ Comfort noise spectral density evaluated by TX decoder
- ⇒ And periodically (480ms) transmitted in special frame (SID= Silence Descriptor)

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## 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



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

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## Bad Frame Indicator

→ When errors cannot be corrected:

⇒ Frame must be discarded

→ In substitution, transmit speech frame

⇒ predictively calculated

⇒ No more than 16 consecutive BFI

→ If this happens, receiver muted

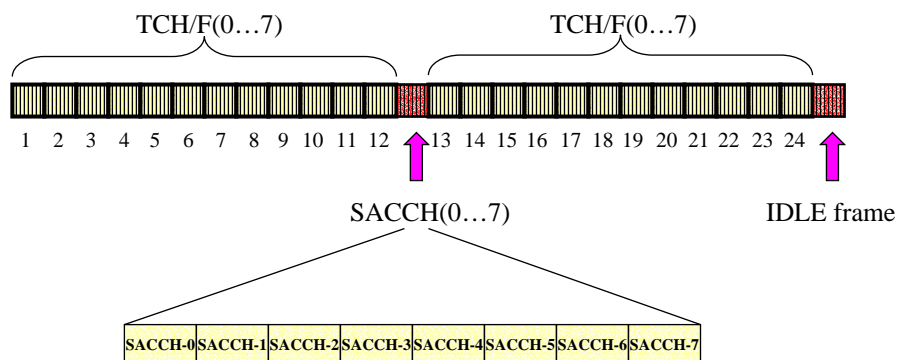
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## Slow Associated Control Channel

→ Always associated to instaurated call on TCH (TCH + SACCH = TACH)

→ On the same Time Slot

→ Periodic (order of ½ second) time-scale information for radio link control



1 SACCH burst (per TCH) every 26 frames (120 ms)

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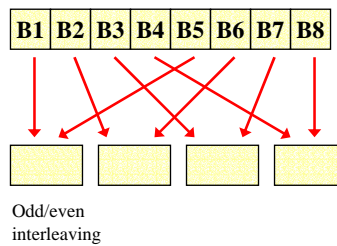
## SACCH block

→ **184 signalling bits**

- Block coding adds 40 bits (=224)
- 4 tail (zero) bits (=228)
- 1/2 Convolutional encoding (=456 bits)

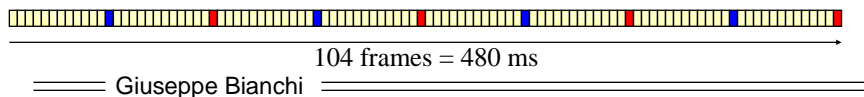
→ **Interleaving:**

- ⇒ 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



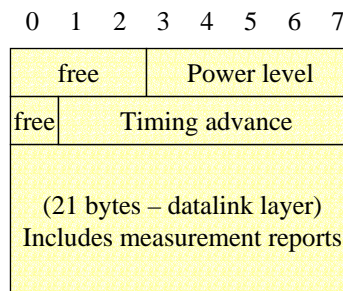
## SACCH contents

→ 184 bits = 23 bytes

- Power level
- Timing advance
- Measurement reports for link quality
- Measurement reports for handover management

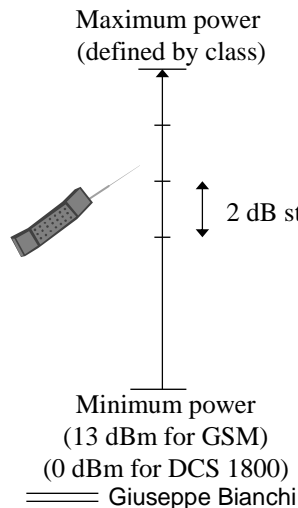
→ **When available space:**  
**SMS**

- ⇒ When call in progress!



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## Power control



- MS has ability to reduce/increase power
  - ⇒ Up to its power class maximum
- Maximum one 2 dB step every 60 ms
- uplink power measures taken by BTS
- notified back to MS via SACCH
  - ⇒ Power level values: 0-15
  - 0 = 43 dBm (20 W)
  - 15 = 13 dBm (20 mW)
- algorithm: manufacturer specific
  - ⇒ runs on BSC
- power control applied also on downlink

## Measurement values

### → RXLEV

- ⇒ Power level
- ⇒ Present channel + neighbor cell)

RX signal level	From (dBm)	To (dBm)
RXLEV_0	-	-110
RXLEV_1	-110	-109
RXLEV_2	-109	-108
RXLEV_3	-108	-107
...	...	...
...	...	...
RXLEV_62	-49	-48
RXLEV_63	-48	-

### → RXQUAL

- ⇒ Bit Error Rate (raw)

Bit error Ratio	From (%)	To (%)
RXQUAL_0	-	0.2
RXQUAL_1	0.2	0.4
RXQUAL_2	0.4	0.8
RXQUAL_3	0.8	1.6
RXQUAL_4	1.6	3.2
RXQUAL_5	3.2	6.4
RXQUAL_6	6.4	12.8
RXQUAL_7	12.8	-

Averaged over 1 SACCH block (480ms = 104 frames)

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## Fast Associated Control Channel

### → FACCH: urgent signalling

⇒ Used when several signalling information needs to be transmitted

→ Call setup

→ Handover

### → FACCH block = 184

⇒ 456 after coding

### → Interleaved as voice block

⇒ Spreaded on 8 bursts

### → Replaces a voice block (20 ms) on the TCH

⇒ Via stealing bits

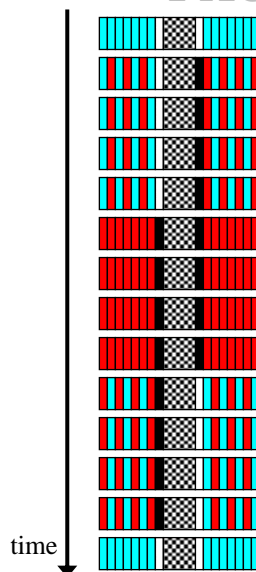
⇒ Voice block(s) discarded

### → Maximum FACCH bit rate

⇒  $184 \cdot 6 / 120$  [bits/ms] = 9.2 kbps (vs 383 bps of SACCH!)

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## FACCH insertion in TCH



Via Stealing bits

- upper bit = odd bits stolen
- lower bit = even bits stolen
- both bits = all burst stolen

*Figure: shows example of 2 FACCH blocks stealing a TCH (note begin and end behavior due to interleaving)*

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## Half-rate traffic channels (TCH/H)

→ Support for 5.6 kbps voice codecs

→ Specification in 1995

→ 228 bits block

⇒ 112 bits of compressed 20ms voice

→ 95 bits class 1

» + 3 parity + 6 tail + convolutional coding 104/211

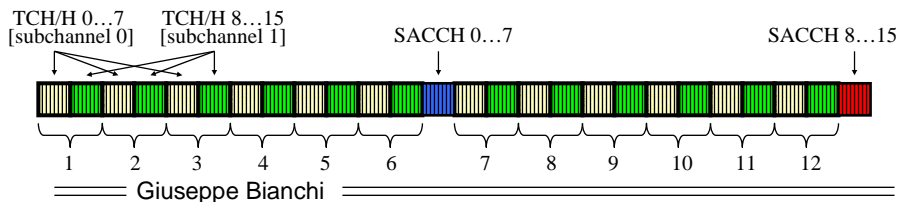
→ 17 bits class 2

→ Interleaving:

⇒ Same as voice (block + diagonal + odd/even)

⇒ But on 4 bursts

→ Framing:



## Other traffic channels

→ TCH data

⇒ Basic speed: 9.6 kbps (data, fax)

⇒ Other speeds: <2.4; 4.8; 9.6; 14.4;

→ Different coding details

⇒ See text(s)

→ Major difference with voice:

⇒ Interleaving with depth = 19 (!!!)

⇒ complete fading of a burst is recoverable (unlike voice)

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# PART 4

## GSM – Radio Interface

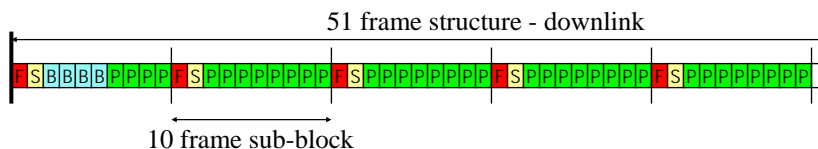
### Lecture 4.4

#### Broadcast Carrier and Channels

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## 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]

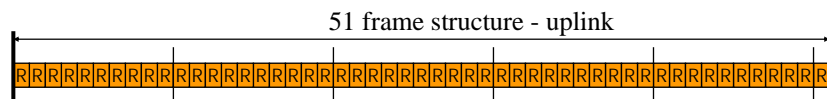


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## BCCH carrier placement

### → On Downlink

⇒ Corresponding uplink dedicated to Random Access Channel



### → On one frequency per cell (beacon)

### → MUST BE on Time Slot #0

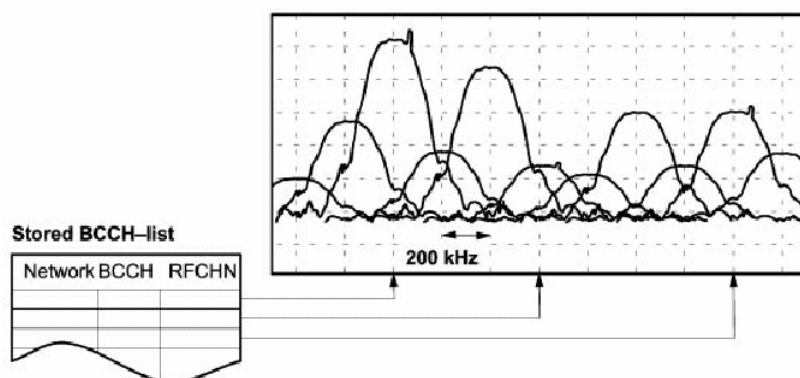
### → Other Time slots may be used by TCH

#### Provided that:

- All empty slots are filled with DUMMY bursts
- Downlink power control must be disabled

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## MS powering up



First operation when MS turned ON: spectrum analysis  
 (either on list of up to 32 Radio Frequency Channel Numbers of current network)  
 (or on whole 124 carriers spectrum)

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## tuning

→ MS listens on strongest beacon for a pure sine wave (FCCH)

⇒ Coarse bit synchronization

⇒ Fine tuning of oscillator

→ Immediately follows SCH burst

⇒ Fine tuning of synchronization (64 bits training sequence)

⇒ Read burst content for synchronization data

→ 25 bits (+ 10 parity + 4 tail + ½ convolutional coding = 78 bits)

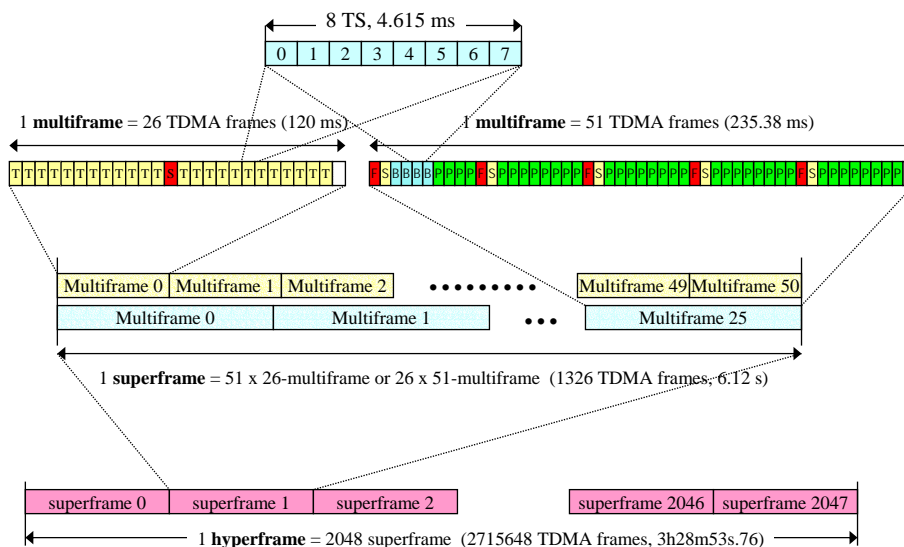
→ 6 bits: BSIC

→ 19 bits: Frame Number (reduced)

→ Finally, MS can read BCCH

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## Multi-framing structure



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## Why frame number?

FN = 

Superframe #	Multiframe #	frame #
--------------	--------------	---------

### → Frame #

⇒ Distinguishes logical channels in the same physical channel

### → Multiframe #

⇒ Determines how BCCH is constructed

→ I.e. which specific information transmitted on BCCH during a given multiframe

### → Superframe #

⇒ Used as input parameter by encyphering algorithm

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## BCCH contents

### → 184 bits

⇒ Coded in 456 bits and interleaved in 4 bursts

⇒ same coding and interleaving as SACCH

⇒ BCCH capacity

→  $184 \text{ bits} / (51 * 8 * 15 / 26 \text{ ms}) \sim 782 \text{ bps}$

### → Information provided

⇒ Details of the control channel configuration

⇒ Parameters to be used in the cell

→ Random access backoff values

→ Maximum power an MS may access (MS\_TXPWR\_MAX\_CCCH)

→ Minimum received power at MS (RXLEV\_ACCESS\_MIN)

→ Is cell allowed? (CELL\_BAR\_ACCESS)

→ Etc.

⇒ List of carriers used in the cell

→ Needed if frequency hopping is applied

⇒ List of BCCH carriers and BSIC of neighboring cells

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# PART 4

## GSM – Radio Interface

### Lecture 4.5

#### Paging, Random Access, dedicated signaling

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### Why paging

⇒ Channel assignment:

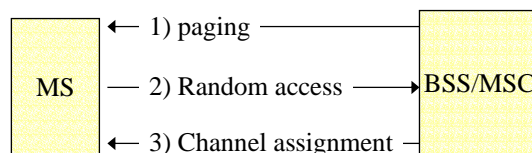
→ only upon explicit request from MS

⇒ Paging

→ needed to “wake-up” MS from IDLE state when incoming call arrives to MS

⇒ MS accesses on RACH to ask for a channel

→ Generally SDCCH (but immediate TCH assignment is possible)



Paging channel:	PCH	} PAGCH	} CCCH	
Access Grant Channel:	AGCH			Common Control
Random Access Channel:	RACH			Channel

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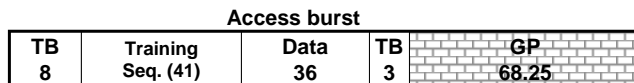
## Access procedure

→ **Always activated by MS**

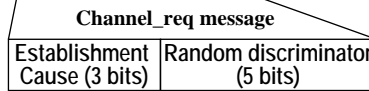
- ⇒ In response to paging (incoming call)
- ⇒ When location update needs to be performed
- ⇒ When new call is generated by MS

→ **Based on access burst sent on RACH**

- ⇒ Access burst coding: 8 payload bits (channel\_req) → 36 coded bits
- +6 parity; + 4 tail; + ½ convolutional coding



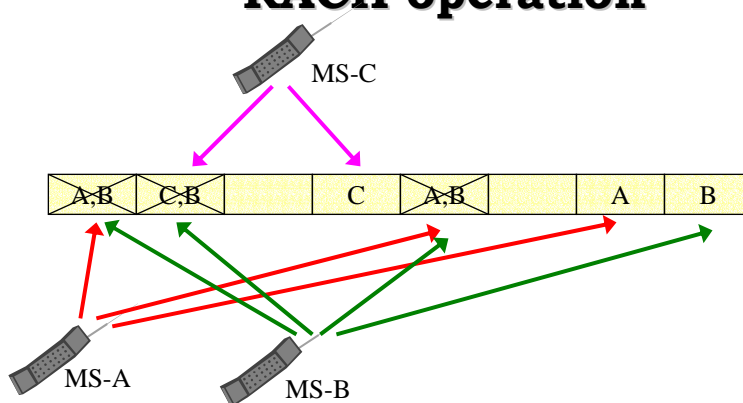
- 100: response to radio call
- 101: emergency call
- 110: new establishment of call
- 111: supplementary service (SMS, etc)
- ...
- 000: other case



Random discriminator: (0...31) value randomly generated by MS

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## RACH operation



Multiple Access Technique for simultaneous access  
 Collision resolution based on

- random retrial period
- "permission" probability

} Same thing..!

(SLOTTED ALOHA protocol)

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## RACH performance

→ N stations

→ Each transmits with probability p

⇒ Retries, in average, every 1/p slots

→ relevant probabilities:

idle:  $(1-p)^N$

success:  $Np(1-p)^{N-1}$

collision:  $\sum_{k=2}^N \binom{N}{k} p^k (1-p)^{N-k}$

*Maximum efficiency: when  $p=1/N$*

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## RACH performance control

→ BCCH broadcasts

⇒ Backoff time

→ uniform distribution; max value: 3 to 50

⇒ Maximum number of retransmission attempts

→ Never greater than 7

→ May also specify:

⇒ time interval for a retry after failure (default=5s)

⇒ RACH group access control

→ MSs divided into 10 groups, depending on SIM-related information

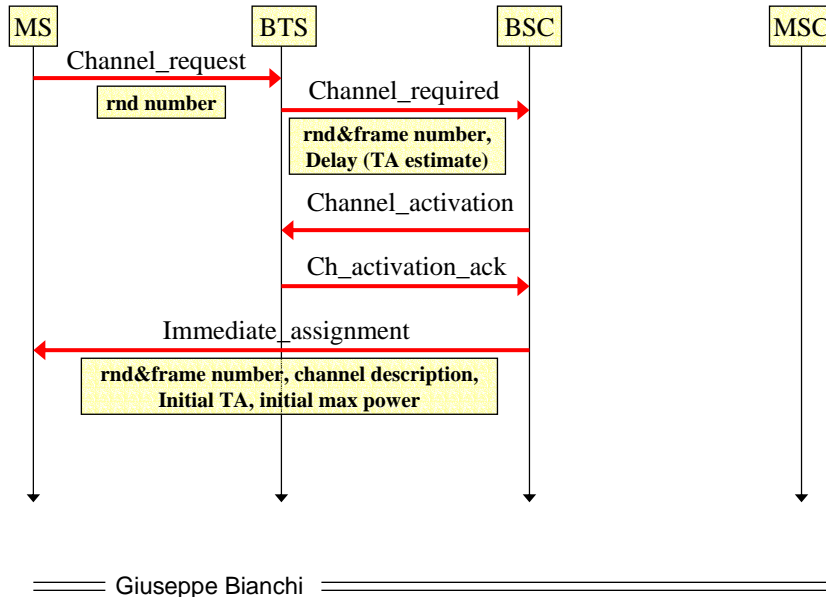
→ BTS may block selected groups

→ Allows to reduce RACH load down to as low as 10%

» Emergency calls bypass this rule...

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## Access signaling - 1



## Immediate Assignment message

### → on paging channel

⇒ I.e. AGCH is a dynamically mapped channel

– name PAGCH is perhaps better...

### → Sent "as soon as possible"

⇒ MS continues accessing the RACH

⇒ Message scheduling is an implementation dependent issue

→ I.e. which message to send in case of many messages, and on which paging slot (4 bursts)

⇒ MS must disable DRX

→ To monitor PAGCH for Immediate Assignment message detection

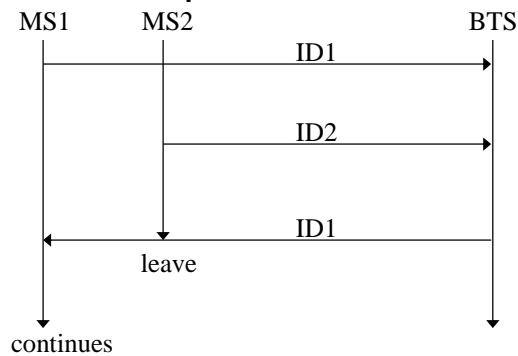
### → Immediate assignment reject possible

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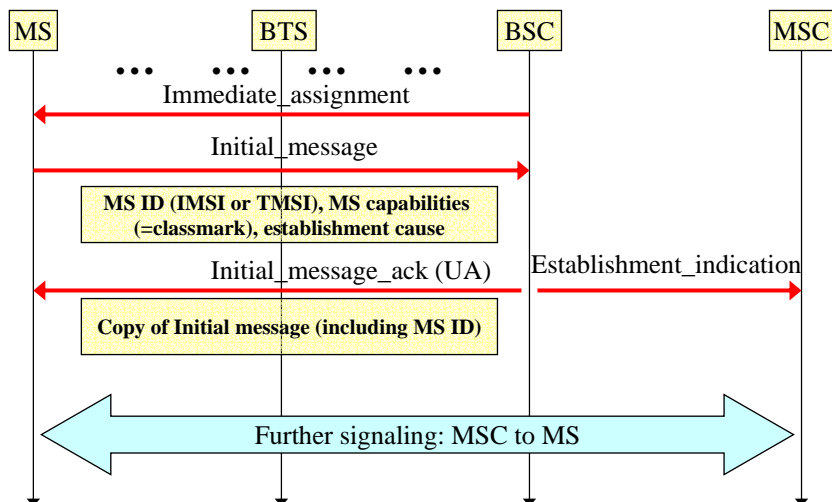
## If same random discriminator?

- two MSs may have same random discriminator
  - ⇒ Likely in heavy load, with only 5 bits
- And transmit in the same frame
- Only one wins (the other is faded)
- contention resolved via explicit MS identification
  - ⇒ On SDCCH



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## Access signaling - 2



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