GSM Radio – Part 1: Physical Channel Structure

1 Frequency Bands and Channels

GSM (Global Systems for Mobile) **frequency bands** are the radio spectra designated by the ITU (International Telecommunications Union) for the operation of the GSM for mobile systems.

- Original GSM radio band is 900 MHz (GSM 900). Another band later added to it as DCS (Digital Cellular System) at 1800 MHz (DCS 1800). The most of the world (except North America) uses these bands. These bands are, however, are not available in North America as they were allocated to some other wireless services. The North America uses 850 MHz (GSM 850) and 1900 MHz (PCS 1900). (PCS = Personal Cellular System)

  There are many GSM mobile stations (MSs) that support all these frequencies in order to make the MS globally compatible. An MS that supports multiple frequencies is called multiband MS.

- Besides the standard GSM bands as above there are many special bands exist to meet special requirements

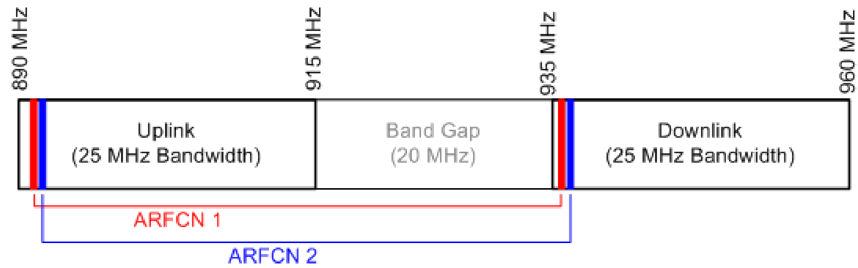
http://en.wikipedia.org/wiki/GSM_frequency_ranges

System	Band	Uplink (MHz)	Downlink (MHz)	Channel Number
T-GSM-380	380	380.2–389.8	390.2–399.8	Dynamic
T-GSM-410	410	410.2–419.8	420.2–429.8	Dynamic
GSM-450	450	450.4–457.6	460.4–467.6	259–293
GSM-480	480	478.8–486.0	488.8–496.0	306–340
GSM-710	710	698.0–716.0	728.0–746.0	Dynamic
GSM-750	750	747.0–762.0	777.0–792.0	438–511
T-GSM-810	810	806.0–821.0	851.0–866.0	Dynamic
GSM-850	850	824.0–849.0	869.0–894.0	128–251
P-GSM-900	900	890.0–915.0	935.0–960.0	1–124
E-GSM-900	900	880.0–915.0	925.0–960.0	975–1023, 0-124
R-GSM-900	900	876.0–915.0	921.0–960.0	955–1023, 0-124
T-GSM-900	900	870.4–876.0	915.4–921.0	Dynamic
DCS-1800	1800	1710.0–1785.0	1805.0–1880.0	512–885
PCS-1900	1900	1850.0–1910.0	1930.0–1990.0	512–810

Note 1: The table shows the extents (ranges) of each band and not its center frequency
Note 2: The channel number indicates ARFCN number (discussed later) and includes only the useable channels. There are a number of channels which are reserved and not used for traffic or control. A number of them are used as guard band from the neighboring bands.

- P-GSM, Standard or Primary GSM-900 Band
- E-GSM, Extended GSM-900 Band (includes Standard GSM-900 band)
- R-GSM, Railway GSM-900 Band (includes Standard and Extended GSM-900 band)
- T-GSM or TETRA-GSM (TETRA = TErrestrial Trunked RAdio, formerly Trans-European Trunked Radio)

- Each GSM bands are divided into uplink (lower frequency sub-band), downlink (upper frequency sub-band) and band gap (middle sub-band). Example: GSM 900



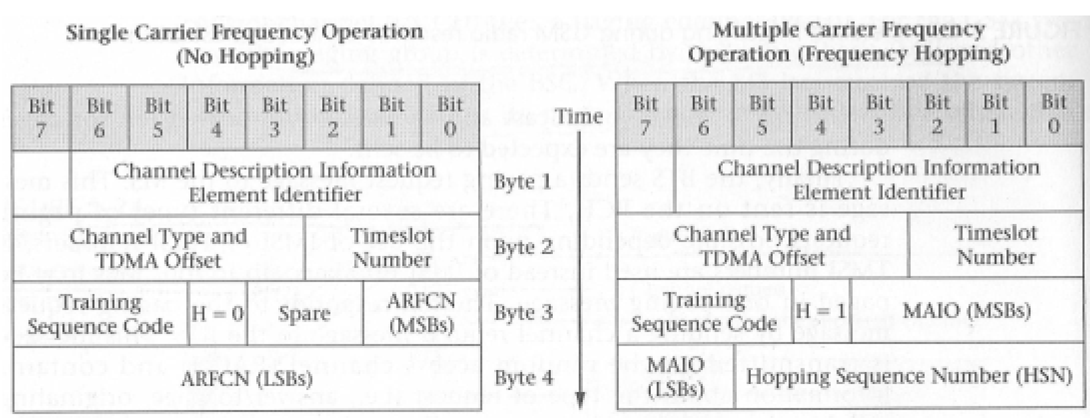
- GSM radio channel is **<u>0.2 MHz</u>** wide. Each channel has a fixed ID number, called Absolute Radio Frequency Channel Number (ARFCN) as given in the second column of the table below.
  Example: GSM 900
  ARFCN 0 represents the 0.2 MHz channel from 890 to 89.2 MHz (usually called 890 MHz channel)
  ARFCN 1 to 124 represent **890 + ARFCN * 0.2 MHz** channels
  Note: ARFCN 0 is reserved as a guard band between GSM band and its neighboring band.

Band	ARFCN Range	Uplink Frequency (MHz)	Downlink Frequency (MHz)
P-GSM 900	1..124	890+ARFCN*0.2	935+ARFCN*0.2
E-GSM 900	0..124	890+ARFCN*0.2	935+ARFCN*0.2
	975..1023	890+(ARFCN-1024)*0.2	935+(ARFCN-1024)*0.2
DCS 1800	512..885	1710.2+0.2*(ARFCN-512)	1805.2+0.2*(ARFCN-512)
PCS 1900	512..810	1850.2+0.2*(ARFCN-512)	1930.2+0.2*(ARFCN-512)
R-GSM 900	0..124	890+ARFCN*0.2	935+ARFCN*0.2
	955..1023	890+(ARFCN-1024)*0.2	935+(ARFCN-1024)*0.2
GSM 450	259..293	450.6+0.2*(ARFCN-259)	460.6+0.2*(ARFCN-259)
GSM 480	306..340	479+0.2*(ARFCN-306)	489+0.2*(ARFCN-306)
GSM 850	128..251	824.2+0.2*(ARFCN-128)	869.2+0.2*(ARFCN-128)
GSM 750	438..511	747.2+0.2*(ARFCN-438)	777.2+0.2*(ARFCN-438)

http://www.analytek.co.uk/files/GSM_Quick_Ref.pdf

GSM Frequency Calculator: http://www.aubraux.com/design/arfcn-calculator.php

- GSM represents an ARFCN with a 10-bit number (0 to 1023). When the network assigns a channel to an MS (mobile station) it identifies this number. Example (GSM Layer 3 Message):



Ref: Wireless Communications Systems and Networks, By Mullett, Thomson Publisher

- Each ARFCN channel is a duplex channel and consists of an up and a down links. When we say ARFCN 1 we mean uplink 890.2 MHz and its downlink 935.2 MHz channels as a duplex. The uplink and downlink of all ARFCNs maintain a frequency distance equal to band gap + unidirectional bandwidth.
  Example: GSM 900 has band gap = 20 + 25 = 45 MHz

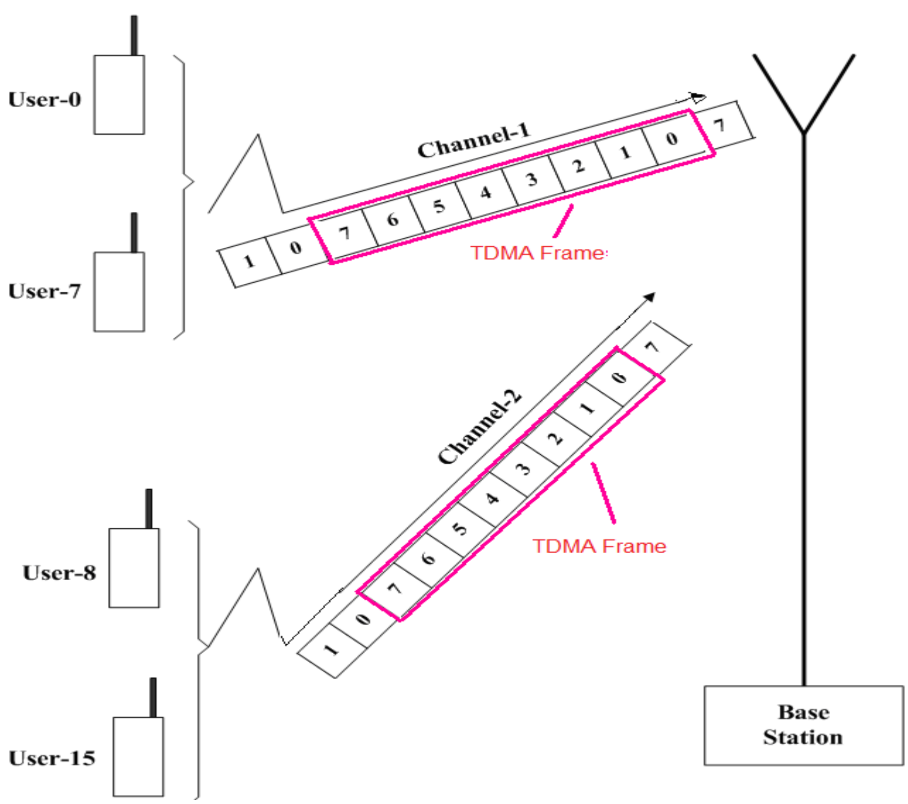
	Uplink Frequency Range (MHz)	Down Link Frequency Range (MHz)	Bandwidth in each direction (MHz)	Gap between up and down link (MHz)	Duplex Distance (MHz	Max. possible Frequency Channels
GSM 850	824–849	869–894	25	20	45	125 (124 useable)
GSM 900	890 – 915	935 – 960	25	20	45	125 (124 useable)
GSM 1800	1710 – 1785	1805 – 1880	75	20	95	375 (373 useable)
GSM 1900	1850 – 1910	1930 – 1990	60	20	80	300 (298 useable)

Note: The signal attenuation increases with frequency rise at a rate of 20 dB/decade. The ulink signal, which is lower in frequency, suffers less attenuation. The MS, therefore, requires less transmission power.

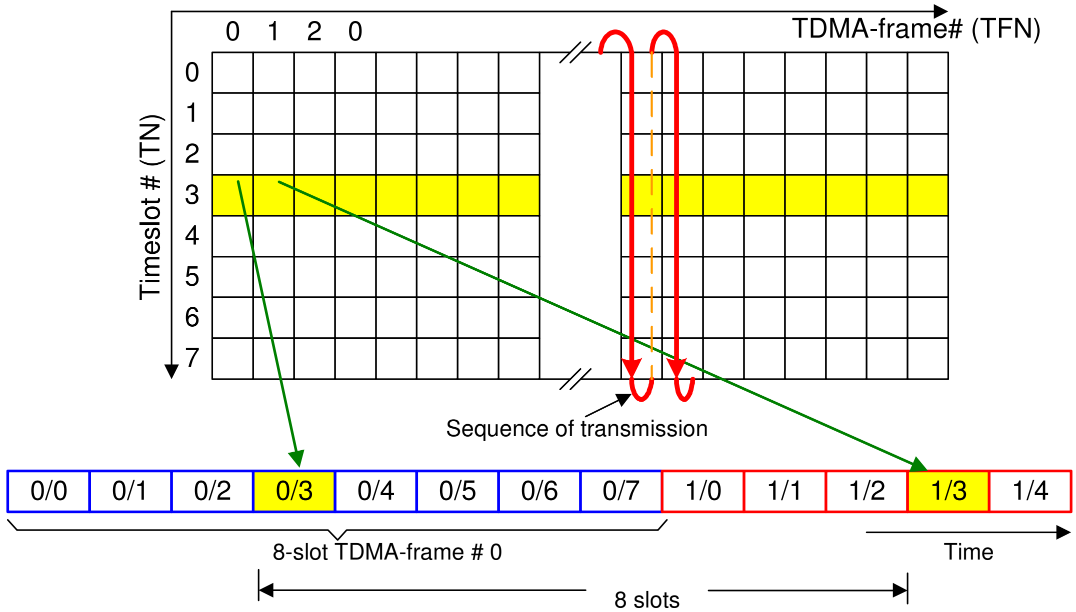
2 GSM TDMA

Each frequency channel or ARFCN (200 kHz bandwidth) is shared by multiple users and/or control signal functions – one at a time. That is, it works in a TDMA (Time Division Multiple Access) fashion. The TDMA scheme divides the channel into **577 μs** long time-slots. For a voice channel every 8th time-slot belongs to the same user. That is, a continuous digitized voice stream is sent periodically as data-burst (roughly 577 μs burst for 577 x 8 = 4.6 ms voice). The following figure illustrates the GSM TDMA concept

Note 1: The voice channels are duplex channels.
Note 2: The above calculation is to provide the concept. The accurate calculation is little bit complicated and will be discussed later.

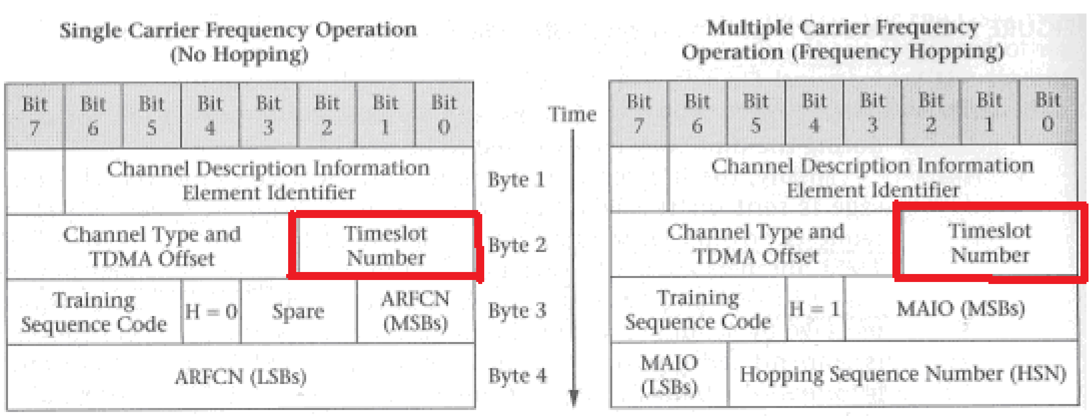


A voice channel needs every 8th slot. That is why GSM calls a set of consecutive 8 time-slots a TDMA frame (Slot 0 to Slot 7) as shown in the above figure. A particular slot (say, Slot 3) of each of the TDMA frame is the fundamental voice/data-stream channel (called TDMA channel). The following figure illustrates that feature.



A frequency-channel carries TDMA frames, which are organized and transmitted as illustrated in the figure above. In the above figure Slot# 3 (with yellow shade) is a TDMA channel. Such a channel can be used for a voice or mix of a variety of control and management signaling (discussed later).

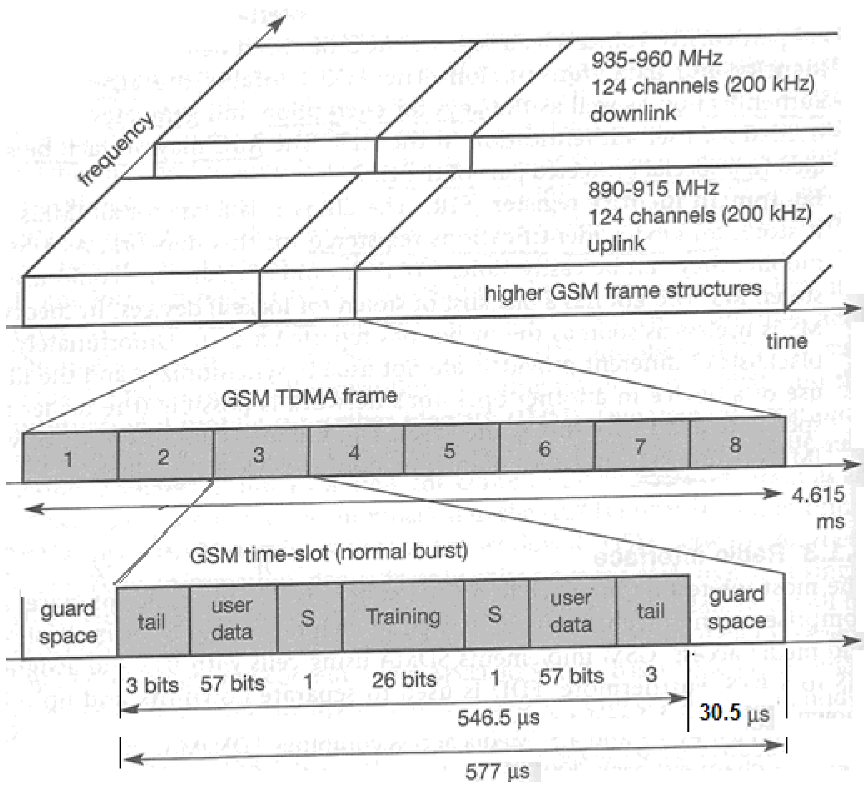
A GSM system identifies a time slot using 3-bit code (0 to 7). When the network assigns a slot to an MS (mobile station) it identifies ARFCN and Time-Slot #. Example (GSM Layer 3 Message):



Ref: Wireless Communications Systems and Networks, By Mullett, Thomson Publisher

Each of the time-slots is the basic unit of a data packet (GSM calls it a data-burst). Thus the multiplexing in GSM takes the following format.

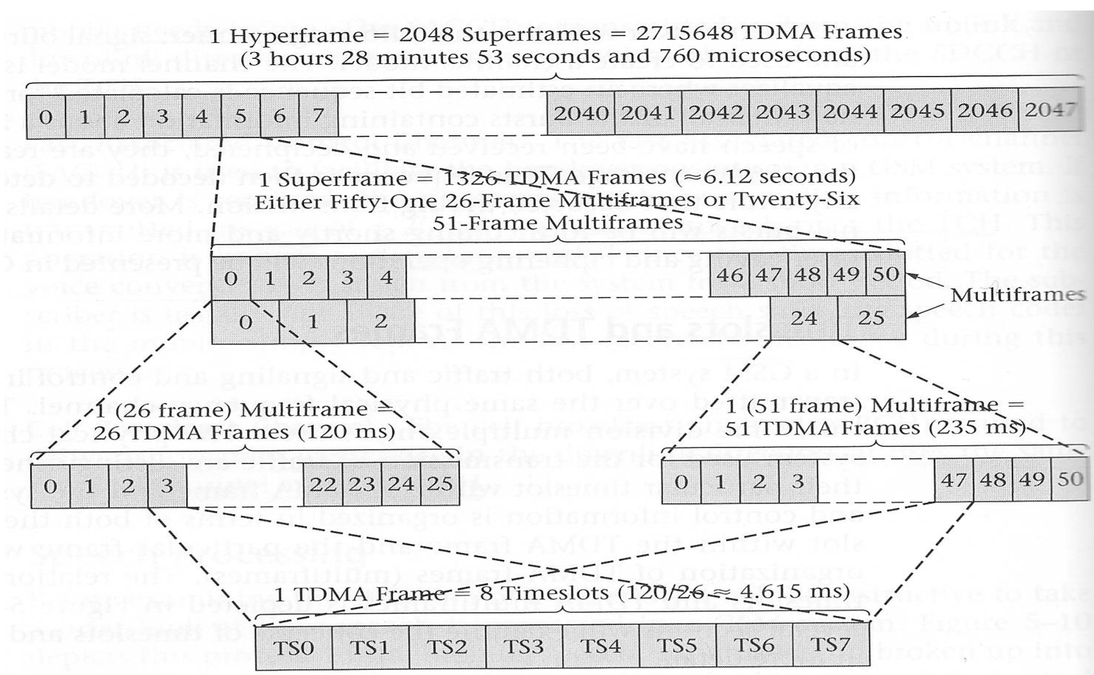
GSM band -----→ GSM Frequency Channel ---------→ GSM time-slot



Ref: Wireless Communications Systems and Networks, By Mullett, Thomson Publisher

3 TDMA Frame Hierarchy

The data-filled time-slots travel over the air interface one after another in sequence. However, the slots are logically arranged as a hierarchy (see below) – TDMA slots ---→ TDAM frame ---> Multi-frame ----> Super-frame ------> Hyper-frame.



Ref: Wireless Communications Systems and Networks, By Mullett, Thomson Publisher

The hierarchy has a strange structure. The multiframe has two different sizes: 26-multiframe for traffic and 51-multiframe for control channels. The reason of such structures is to solve the following problem:

> Suppose a voice call is connected to Slot # 4 of a frequency but Slot # 4 of another frequency is set for its paging. In that case the user can not listen to the paging for another call (think call waiting service) if both the frames have the identical period of repetition.

With the 26- and 51-multiframe structure a mobile station may miss on page due to coincidence of the voice and the page time-slots but will be able to capture the next repetition of the page since there will be no overlap of those time-slots.

There are too many time values to remember. One of the easiest ways to remember all is remembering:

- **120 ms** long 26-multiframe.
  Note that, a 26-multiframe sends/receives 6 blocks of voice (each of them is 20 ms long).

- **270.8 kbps** bit-rate or **3.69 µS** bit-duration

The following table summarizes the numbers.

	Symbol (bit)	Bursts	Frames	Time	Rate
Symbol (bit)	1	1/156.25	1/1250	48/13 µs (3.692 µs)	270833/s
Burst	156.25	1	1/8	15/26 ms (576.9 µs)	1733/s
Frame	1250	8	1	60/13 ms (4.615 ms)	216.6/s
26 Multiframe	32500	208	26	120 ms	8.333/s
51 Multiframe	63750	408	51	235.4 ms	4.248/s
52 Multiframe	65000	416	52	240 ms	4.167/s
Superframe	2071875000	84864	1326	6120 ms	9.803/min
Hyperframe	4.2432E+12	173801472	2715648	3h:28m:53.760s	6.893/day

http://www.analytek.co.uk/files/GSM_Quick_Ref.pdf

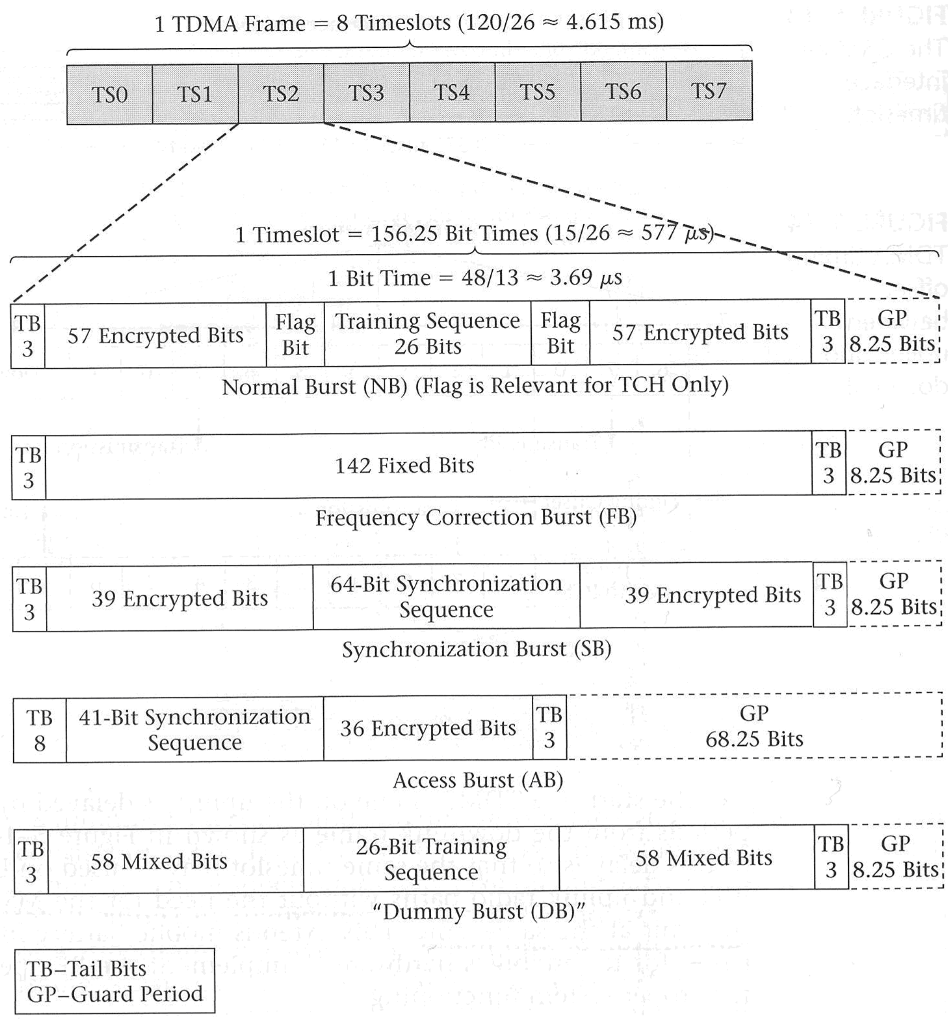
4 Burst Structure

- The burst is the transmission quantum of GSM. An MS sends or receives signal or information in the form of burst (that is, not continuously).

- A burst is put in a TDMA-timeslot. That is, a burst is carried by a time-slot. A burst in a time-slot must not overlap the bursts in the previous and next time-slots. Therefore, the time-slot is set to 156.25 bit-periods - bigger than the biggest burst (148 bits). The spare time (minimum 156.25 – 148 = 8.25 bit-periods) is the guard time. That is, ***Time-slot = burst-period + guard-period.***

- A burst includes:
  - Information (user data/voice or control/signaling messages)
  - Tail-bits to allow the signal level to rise to an amplitude-level from zero-level before sending actual information-bits (and vice versa). This consists of all 0s (un-modulated carrier).
  - Training sequence – some predefined bit-sequence, known to the receiving end, to help extract information bits accurately. It typically consists of alternating 1s and 0s.

The internal structure of a burst may have any one of the following five structures depending on the usage.



Ref: Wireless Communications Systems and Networks, By Mullett, Thomson Publisher

- **Frequency Correction Burst**
  This burst format is used by FCCH channel only. The whole data space (142 bits) is used for unmodulated carrier (pure sinusoid) or carrier modulated with <u>all zero bits</u>. The frequency is **1625/24 kHz** (or approximately 67 **kHz**).This pure carrier is the 'identity' of a beacon frequency (also called BCCH-frequency or base-frequency) and FCCH slot.

- **Synchronization Burst**
  This burst format is used by SCH channel only. This channel makes a mobile station time-synchronized with the base station clock. That is why the synchronization training sequence is very large for this burst. Only one training sequence is defined for this burst.

- **Access Burst**
  This burst format is used by RACH and AGCH channels. When a mobile station sends an RACH message and receives an AGCH reply the MS and the BTS does not have the timing-advance information. For that reason, the actual message is relatively short and have a long guard band (GB) in order to make sure that there will be no overlap with the next burst. The length of the guard band in the access burst (68.25 bits x 3.69 = 251.16 µs) is equivalent to 37.5 km propagation delay. The GSM allows a cell radius up to of 35 km. That is, an RACH message from an MS at a distance of up to 35 km from the base station can reach to the base station antenna without overlapping the next burst. The FACCH channel uses this burst during handover operation (when the timing advance of new cell is not yet known). Only one training sequence is defined for this burst.

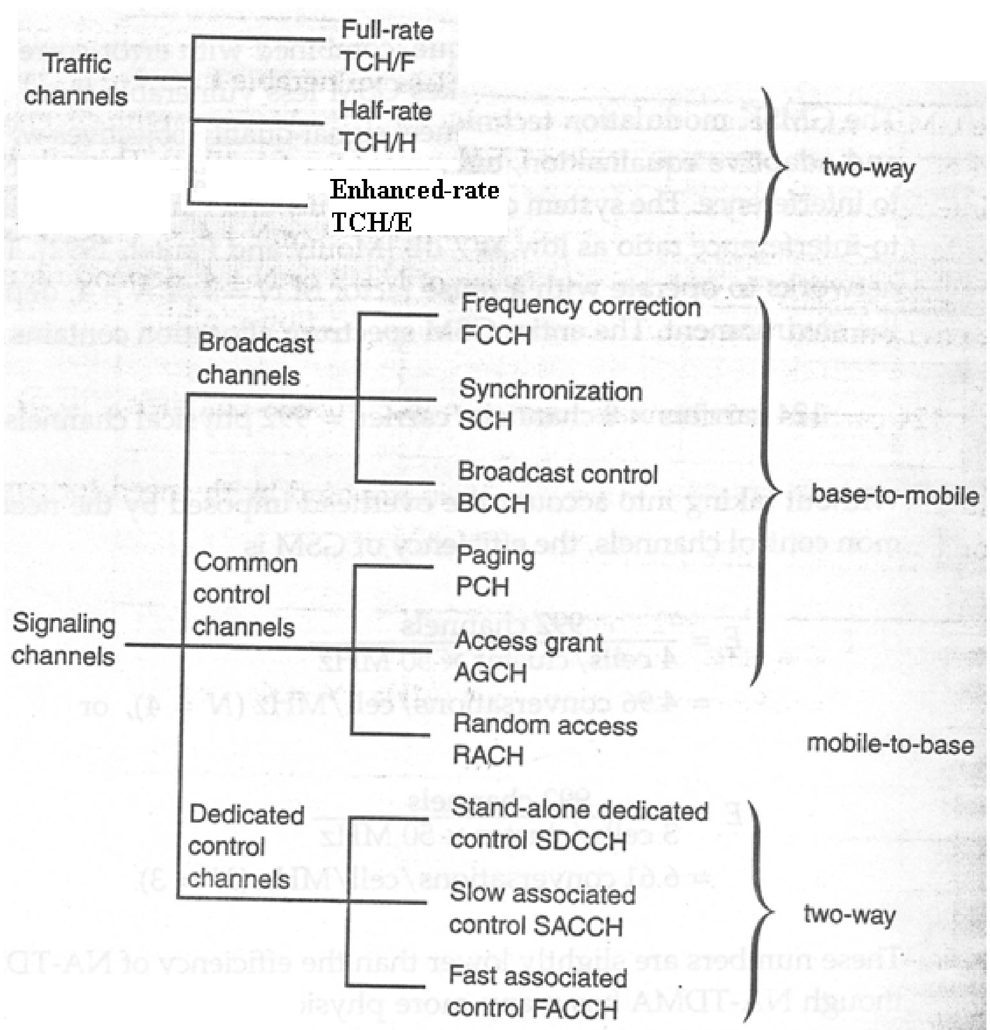
- **Normal Burst**
  This burst format is used by all other channels (except FCCH, SCH, RACH and AGCH). That is, a normal burst is used by TCH, SDCCH, SACCH, FACCH, BCCH and PCH. Few important features of the burst is stated below.

  - Maximum 57 x 2 = 114 bits of voice/data per burst
  - Flag bit is to indicate if the channel is carrying user traffic (Flag = 0) or control message bits (Flag = 1). That is the flag is 0 for TCH and 1 for others.

- **Dummy Burst**
  This is like normal burst but has no meaning of its payload bits.

5 TDMA Multiframe Structure

The multiframe structure defines how the GSM channels (see below) can be structured.

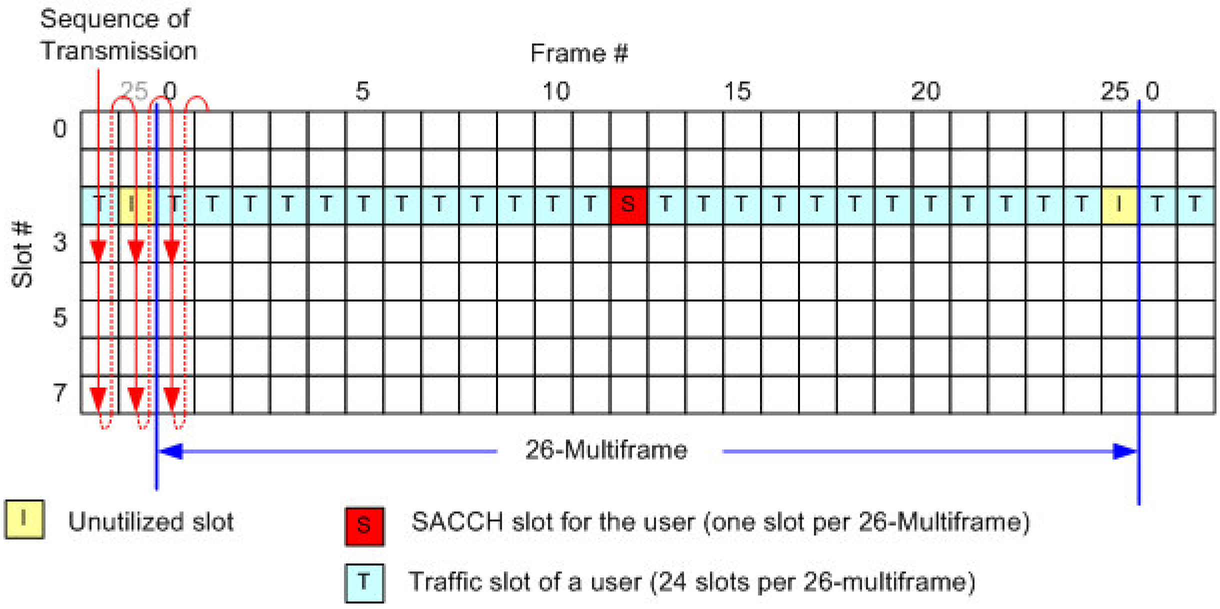


Ref: Wireless Personal Communications Systems, By David Goodman (modified)

Note: Cell Broadcast Channel (CBCH) is another dedicated control channel (not shown in the table above)which is used for downlink SMS broadcast. This is a special SDCCH channel. Only one CBCH can be supported per cell

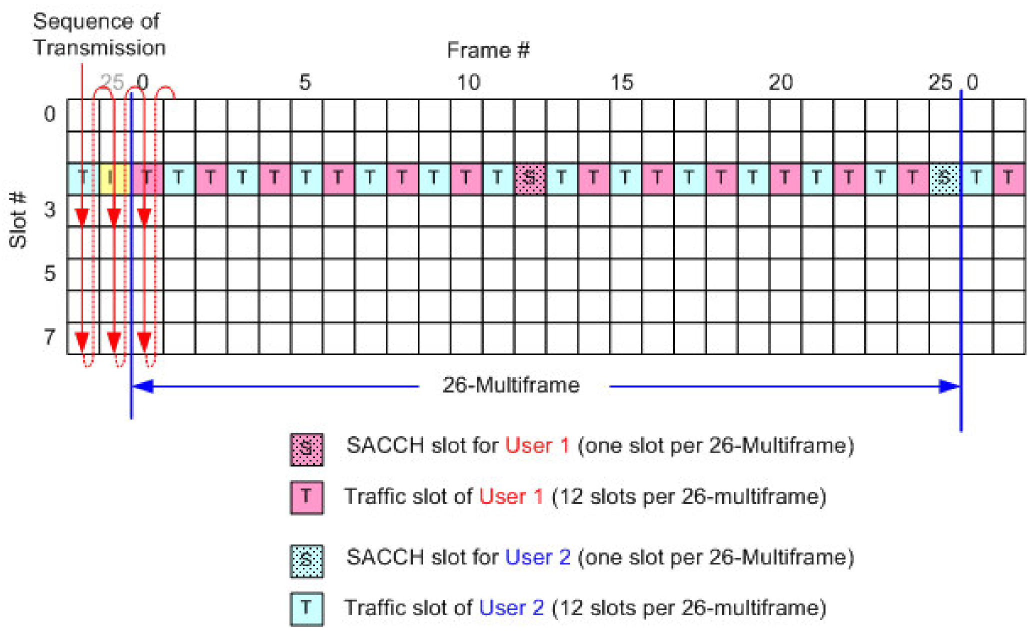
5.1 Traffic Multiframe (26-Multiframe)

The following figure depicts 26-multiframe structure for TCH/FR and TCH/ER.



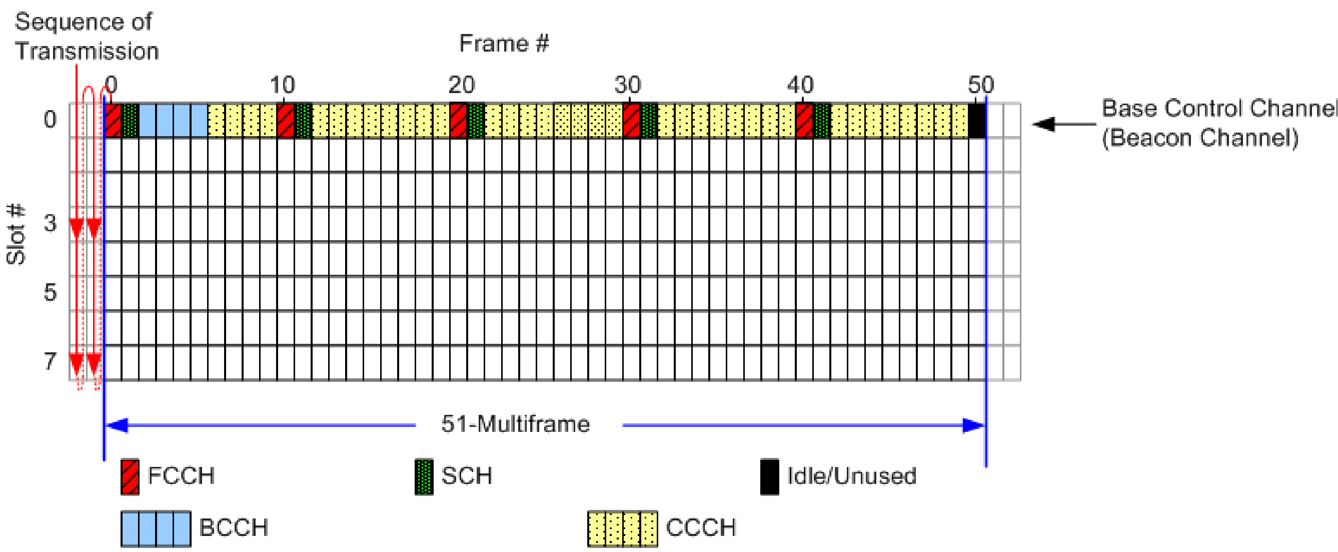
- Every 8th slot belongs to a TDMA channel. A consecutive 26 such (that is, 8th) slots of a TDMA channel forms a 26-multiframe.
- 24 out of 26 time-slots of a TDMA channel (Slot # 1 to 12 and 14 to 24) carry voice
  13th slot (Slot # 12) is for SACCH of that TCH channel
  26th slot (Slot # 25) is unused
  FACCH channel has no time slot since it steals TCH slots whenever required.
- 24 voice slots of a multiframe carry 6 blocks of 20 ms digitized voice (total 120 ms voice). That is why the length of the multiframe is 120 ms.

The following figure depicts 26-multiframe structure for TCH/HR.



5.2 Control Multiframe (51-Multiframe)

Any TDMA channel (that is every 8th time-slot of a frequency channel) is formatted as a 51-multiframe when used for control channels (other than TCH+SACCH/T+FACCH channels). The following diagram depicts the 51-multiframe structure with an example of base (beacon) frequency.

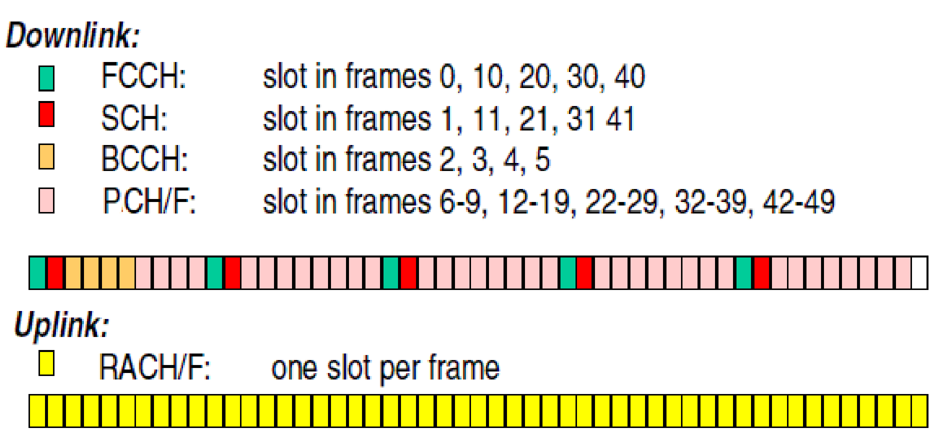


Beacon Frequency Channel

- This channel is a Slot # 0 channel (TDMA Channel 0) of a designated GSM frequency for a cell (see the picture above). It is formatted as 51-multiframe.
- The first slot (Slot # 0 of the multiframe) of the multiframe is FCCH. The next one is SCH. This pair (FCCH and SCH) repeats 5 times in a multiframe at the designated location (see the figure above)
- BCCH channel (4 slots long) appears once per 51-multiframe and it takes Slot # 2 to 4 (3rd, 4th, 5th and 6th slots)
- The remaining slots (dotted yellow in the above figure) care common control channels or CCCH (PCH and AGCH) in this example.
- Some control channels, such as BCCH, CCCH, SDCCH, SACCH and FACCH, form a message of 4 slots long.
- The beacon is a downlink channel. Since GSM always has a pair of frequencies (up and down links) per ARFCN this beacon has its uplink counter part. That uplink contains RACH channel in this example (see the figure below).

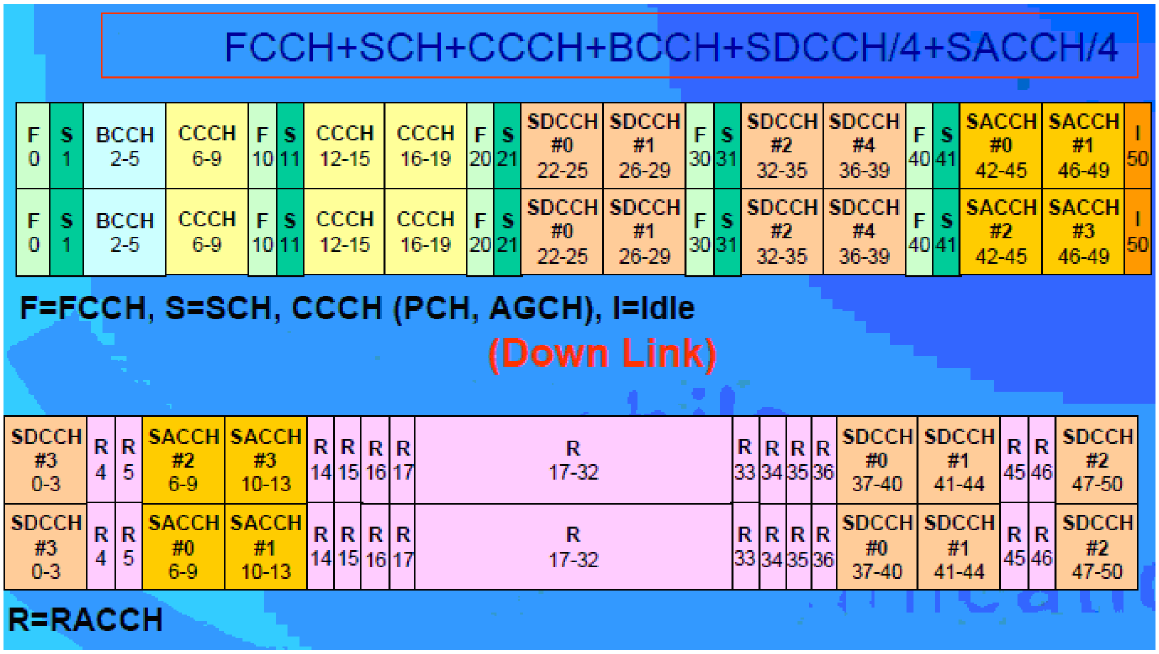
  The following figure depicts a beacon TDMA channel (up and down link) for normal capacity cell. For a low capacity cell the number of PCH (downlink) and RACH (uplink) can be reduced and hence some SDCCH or TCH can be accommodated.

EXAMPLE 1:



http://www.cs.usyd.edu.au/~elec5508/lectures/W05_gsm_architecture_and_channel_structure.pdf

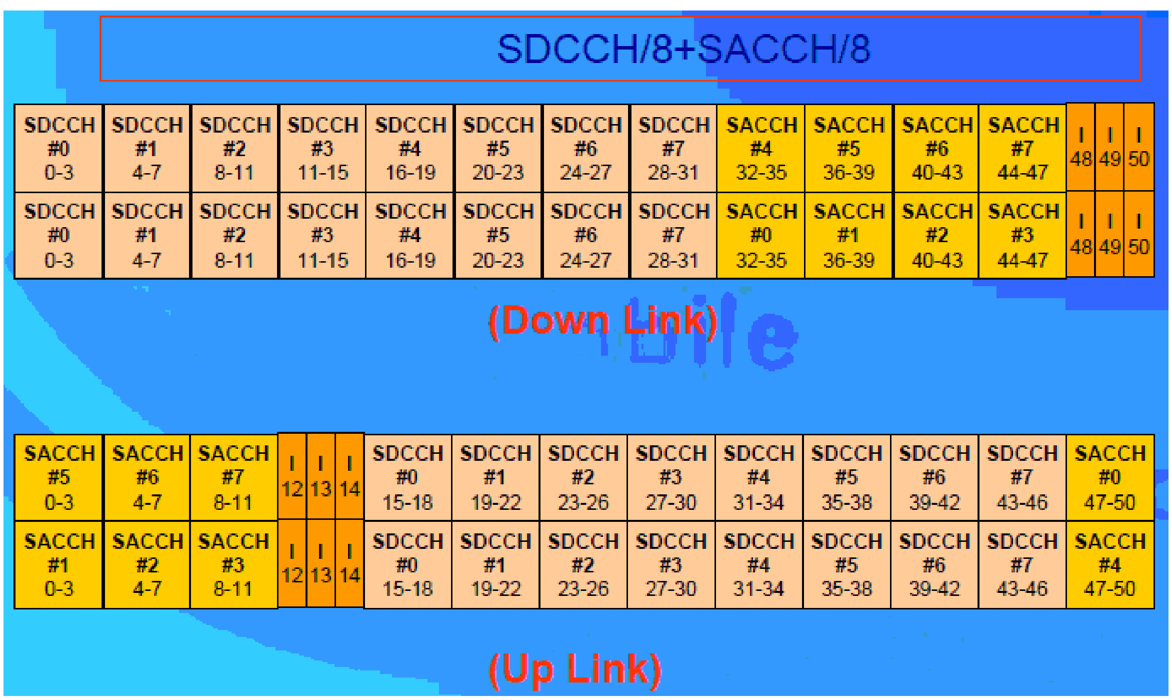
EXAMPLE 2:



http://www.wicomtech.com/conferences/GSM-NET.pdf

Note: SDCCH associates a SACCH channel. The average data rate of SACCH is half of SDCCH and 1/24th of TCH/F, That is why two SDCCH message (4 slots each) pair with one SACCH message.

EXAMPLE 3:



http://www.wicomtech.com/conferences/GSM-NET.pdf

5.3 Cell Frequency Configurations

A GSM base-station (called Base Transceiver Station or BTS) has one or more GSM frequency channels (ARFCN). One of those frequency channels is defined as the base-frequency (beacon frequency or BCCH frequency). The first time-slot (Slot-0) of the base-frequency TDMA is used as the base-control channel (or beacon channel). Remaining part of the frequency channel (Slot-1 to 7) can be used as any mix of traffic and control channels. All other frequencies are mostly for traffic but can also be used for control channels. Mix of traffic and control channels depends on number of frequency channels per BTS (that is the capacity of a cell) and the traffic patterns. Examples:

- Infrequent calls need less RACH channels
- Shorter calls and/or less number of voice calls need less TCH
- High traffic cell has a large number of frequency channels and it is likely that the base-frequency channel will have no traffic channel.

GSM standard provides a number of combinations for traffic and control channels in order to suit different conditions. A list of such combinations is given below.

Physical Channel Combo #	GSM	
	DL (TX)	UL (RX)
I	TCH/FS + SACCH	TCH/FS+ SACCH
II & III	TCH/HS + SACCH	TCH/HS + SACCH
IV	FCCH +SCH+CCCH (PCH/AGCH)+BCCH	RACH
V	FCCH +SCH+ CCCH+BCCH+SDCCH/4 +SACCH/4	RACH+ SDCCH/4 + SACCH/4
VI	CCCH+BCCH	RACH
VII	SDCCH/8+SACCH/8	SDCCH/8+SACCH/8
	GPRS/EDGE	
XI	PBCCH+PCCCH(PCH/AGCH/PNCH) +PDTCH/F+PACCH/F+PTCCH/F	PRACH + PDTCH/F + PACCH/F + PTCCH/F
XII	PCCCH(PCH/AGCH/PNCH)+PDTCH/F +PACCH/F+PTCCH/F	PRACH + PDTCH/F + PACCH/F + PTCCH/F
XIII	PDTCH/F+PACCH/F+PTCCH/F	PDTCH/F + PACCH/F + PTCCH/F

http://www.delcomsys.com/images/DELCOM_GSM_LAYERONE.pdf

Notes:

- TCH/FS = TCH/Full-Slot = TCH/FR;   TCH/HS = TCH/Half-Slot = TCH/F
- SDCCH/4+ SACCH/4 means four SDCCH channels and two SACCH channels per 51-muliframe
  SDCCH/8+ SACCH/8 means eight SDCCH channels and four SACCH channels per 51-muliframe

A Complete Example:

Carrier C_0	Downlink								Uplink							
	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
Frame 0	F	T	D_0	T	T	T	T	T	R	T	A_5	T	T	T	T	T
	S	T	D_0						R	T	A_5					
	B	T	D_0						R	T	A_5					
	B	T	D_0						R	T	A_5					
	B	T	D_1						R	T	A_6					
	B	T	D_1						R	T	A_6					
	C	T	D_1						R	T	A_6					
	C	T	D_1						R	T	A_6					
	C	T	D_2						R	T	A_7					
	C	T	D_2						R	T	A_7					
	F	T	D_2						R	T	A_7					
	S	T	D_2						R	T	A_7					
12	C	I	D_3	I	A	I	A	I	R	I	I	I	A	I	A	I
	C	T	D_3						R	T	I					
	C	T	D_3						R	T	I					
	C	T	D_3						R	T	D_0					
	C	T	D_4						R	T	D_0					
	C	T	D_4						R	T	D_0					
	C	T	D_4						R	T	D_0					
	C	T	D_4						R	T	D_1					
	F	T	D_5						R	T	D_1					
	S	T	D_5						R	T	D_1					
	C	T	D_5						R	T	D_1					
	C	T	D_5						R	T	D_2					
	C	T	D_6						R	T	D_2					
25	C	A	D_6	A	I	A	I	A	R	A	D_2	A	I	A	I	A
	C	T	D_6						R	T	D_2					
	C	T	D_6						R	T	D_3					
	C	T	D_7						R	T	D_3					
	C	T	D_7						R	T	D_3					
	F	T	D_7						R	T	D_3					
	S	T	D_7						R	T	D_4					
	C	T	A_0						R	T	D_4					
	C	T	A_0						R	T	D_4					
	C	T	A_0						R	T	D_4					
	C	T	A_0						R	T	D_5					
	C	T	A_1						R	T	D_5					
	C	T	A_1						R	T	D_5					
38	C	I	A_1	I	A	I	A	I	R	I	D_5	I	A	I	A	I
	C	T	A_1						R	T	D_6					
	F	T	A_2						R	T	D_6					
	S	T	A_2						R	T	D_6					
	C	T	A_2						R	T	D_6					
	C	T	A_2						R	T	D_7					
	C	T	A_3						R	T	D_7					
	C	T	A_3						R	T	D_7					
	C	T	A_3						R	T	D_7					
	C	T	A_3						R	T	A_0					
	C	T	I						R	T	A_0					
	C	T	I						R	T	A_0					
50	I	T	I						R	T	A_0					

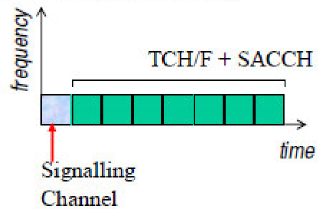
A (SACCH), **B** (BCCH), **C** (CCCH = PCH, RACH and AGCH), **D** (SDCCH), **F** (FCCH), I(unused), **R** (RACH), **S** (SCH), **T** (TCH)

- **<u>Typical small capacity cell with only one frequency channel</u>**

One TRX, consisting of:

TN 0: FCCH, SCH, BCCH, PAGCH/T, RACH/H,
4 (TCH/8 plus associated SACCH)

TN 1 to 7: 1 (TCH/F plus associated SACCH)



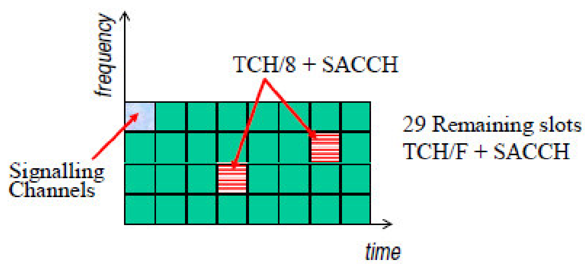
Note 1: TCH/8 + SACCH is, indeed, SDCCH+SACCH

Note 2: PAGCH/F is PCH. Note that, many implementations do not reserve any physical location for AGCH. A slot for PCH is also used as a slot for AGCH when required (AGCH has higher priority). It is better naming such as channel (PCH/AGCH) as CCCH

- **<u>Medium Capacity Cell (example: four frequency channels)</u>**

Four TRXs, consisting of:

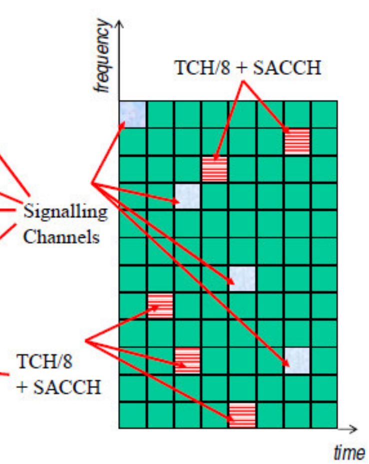
One TN 0 group: FCCH, SCH, BCCH, PAGCH/F, RACH/F
Two sets of 8 (TCH/8 plus associated SACCH)
29 (TCH/F plus associated SACCH)



- **<u>Large Capacity Cell (example: twelve frequency channels)</u>**

Twelve TRXs, consisting of:

One TN 0 group: FCCH, SCH, BCCH, PAGCH/F, RACH/F
One TN 2 group: BCCH, PAGCH/F, RACH/F
One TN 4 group: BCCH, PAGCH/F, RACH/F
One TN 6 group: BCCH, PAGCH/F, RACH/F
Five sets of 8 (TCH/8 plus associated SACCH)
87 (TCH/F plus associated SACCH)



5.4 TDMA Duplex

One uplink slot and a downlink slot of a duplex GSM frequency (an ARFCN) forms a pair to provide one voice connection. These slots carry voice traffic bursts. This is called **Traffic Channel (TCH)** according to GSM terminology. Note that, the slots are like physical carrier, good for any type of data. A duplex pair of them becomes TCH when they are used (or designated) for voice traffic.

The timing of uplink and downlink slots maintains a 3-slot distance in order to ensure that a cell-phone does not require transmission and reception operations simultaneously. This helps avoid a number of complexities including the requirement of high peak power, processor speed and large memory. This also helps simplify transceiver circuit.