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GSM factsheet

Introduction

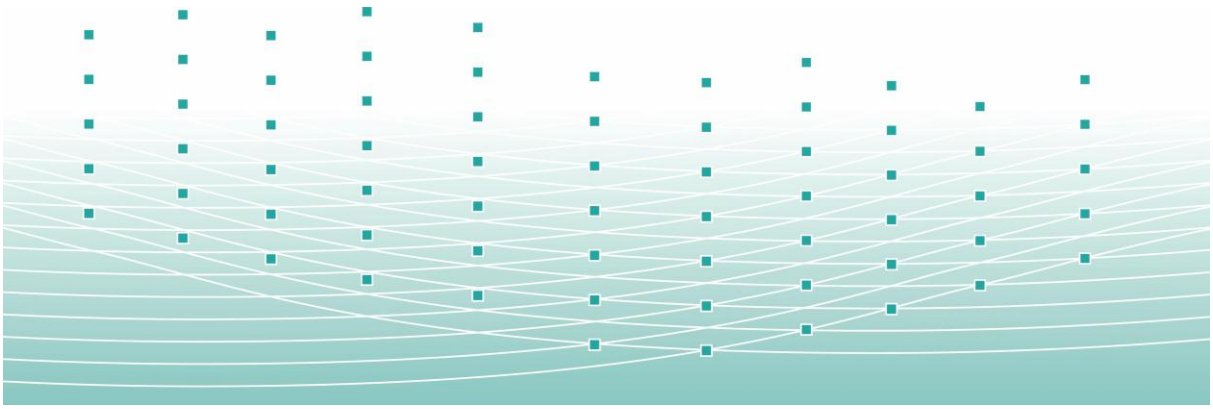
GSM (Global System for Mobile Communications) is an extremely powerful and complex digital mobile radio system of the second generation (2G), which offers very many services, good operating characteristics and high security.

In the mid-eighties a multiplicity of mutually incompatible *analogue* first-generation (1G) mobile radio systems was introduced into Europe, the USA and Japan. The best-known standards were: AMPS (in the USA and Canada), TACS (in England, Italy and Austria), Radiocom 2000 (in France), C 450 (in Germany and Portugal) and NMT (in all the Nordic countries, in the Benelux states and in Switzerland).

With the growth rates of these conventional analogue mobile radio systems, it soon became clear that planning for a future digital system with distinctly higher capacity was essential. Another goal of such a new system was to achieve international compatibility, in order to replace the patchwork of different analogue networks.

From 1982 to 1990, the ETSI (European Telecommunications Standards Institute), in co-operation with the European industry and the network operators, developed the GSM standard. With GSM, as a world first, a *digital* mobile radio standard was developed with modern performance characteristics and above all for transnational use (roaming).

The GSM system was originally designed for the mobile voice telephone service. The rising demand for new, faster data services was soon acknowledged and the GSM standard was extended with new functionalities such as HSCSD (High Speed Circuit Switched Data), GPRS (General Packet Radio Service) and EDGE (Enhanced Data rates for GSM Evolution). These services allow higher data rates and formed the basis for innovative new data services.



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1 Abbreviations

3GPP	3rd Generation Partnership Project
AIPN	All-IP Network
AMC	Adaptive Modulation and Coding
APN	Access Point Name
bps	Bits per second
CDMA	Code Division Multiple Access
DECT	Digital Enhanced Cordless Telecommunications
DSL	Digital Subscriber Line
DVB-T	Terrestrial Digital Video Broadcast
eMBMS	Evolved Multimedia Broadcast/Multicast Service
EDGE	Enhanced Data Rates for GSM Evolution
EPC	Evolved Packet Core
EPS	Evolved Packet System (EPS = E-UTRAN + EPC)
E-UTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
EV-DO	Evolution-Data Optimized
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FTTx	Fibre To The x (Home, Building, Curb …)
GBR	Guaranteed Bitrate
GHz	Giga-Hertz (10^9 Hertz)
GSM	Global System for Mobile Communications
HetNet	Heterogeneous Network
HSPA	High Speed Packet Access
ICIC	Inter Cell Interference Coordination
IEEE	Institute of Electrical and Electronics Engineers
IMS	IP Multimedia System
IMT	International Mobile Telecommunications
IP	Internet Protocol
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
LIPTO	Local Internet Protocol Traffic Offload
LTE	Long Term Evolution
LTE-A	LTE-Advanced
MBMS	Multimedia Broadcast/Multicast Service
MHz	Mega-Hertz (10^6 Hertz)
MIMO	Multiple Input Multiple Output (multiple antenna technique)
OFCOM	Federal Office of Communications
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PER	Packet error rate
PRB	Physical Resource Block
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying

RAT	Radio Access Technology
RB	Resource Block
RRM	Radio Resource Management
SAE	Services Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SDMA	Space Division Multiple Access
SFN	Single-Frequency Network
SIPTO	Selected Internet Protocol Traffic Offload
SIR	Signal to Interference Ratio
SMS	Short Message Service
SON	Self Organising Network
TDD	Time Division Duplex
TTI	Transmission Time Interval
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
VoIP	Voice over IP
VoLTE	Voice over LTE
WiMAX	Worldwide Interoperability for Microwave Access
WRC	World Radio Conference (ITU)

2 Development in Europe

In 1987, in a Memorandum OF Understanding (MoU), the network operators of 13 European countries agreed on the following minimum expansion plan:

1991: Start-up of a GSM pilot network in each country

1993: Coverage of the main cities including international airports

1995: Coverage of all main traffic axes and large cities.

However, the rapid success of GSM meant that this plan was very rapidly surpassed in most countries. By the end of 1993 the threshold of one million mobile radio customers had already been reached. By mid-1994, more than 50% of the inhabited area in Europe was covered by GSM.

In mid-2007 the number of mobile radio customers (GSM and UMTS) in the 27 European Union states including Switzerland amounted to approximately 443 million (approximately 3.5 billion worldwide). Mobile penetration in Switzerland was approximately 111%.

The high point of the worldwide spread of GSM-only user devices was exceeded in about 2012. This was due to the then strongly growing market share of 3G and later 4G smartphones, in developing countries too. Under the pressure of the volume of data on mobile radio networks, which was doubling about every year, the spectrum was increasingly being exploited with spectrally more efficient technology (bits per second and Hertz bandwidth). Consequently the significance of GSM (2G) is reducing. For cost reasons, network carriers are keen to reduce the number of technologies they operate.

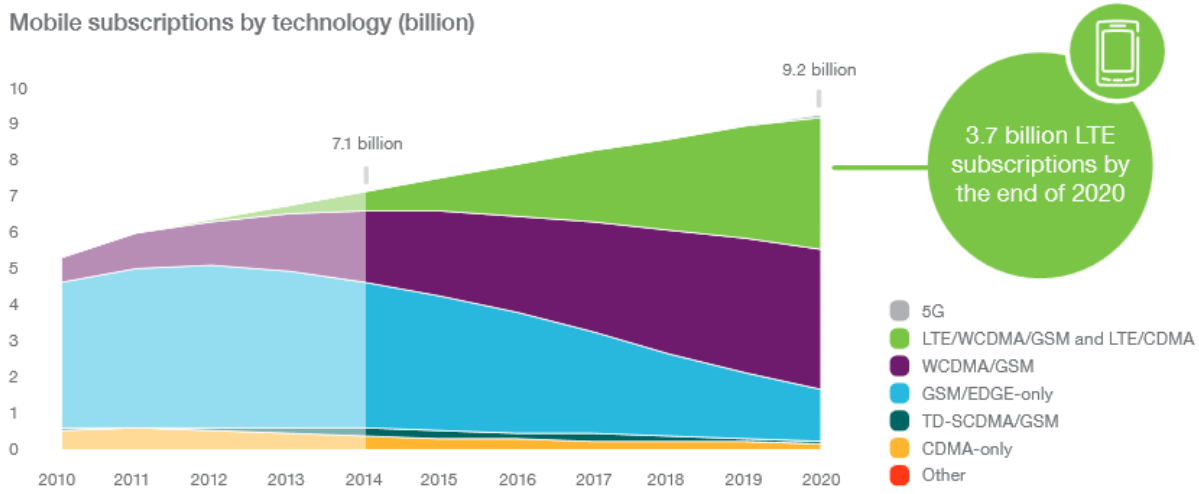


Figure 1: Development of user connections according to technology (source: Ericsson Mobility Report, June 2015)

3 Frequencies and licences

The first GSM network in Switzerland was launched commercially under the brand name Natel D in the spring of 1993 at the Geneva Motor Show by the then PTT (now Swisscom). At that time Telecom PTT was the only mobile radio operator in Switzerland, because it was the only organisation authorised to provide mobile communications as a monopoly service.

With the liberalisation of the telecommunications market and the entry into force of the revised Telecommunications Act in 1998, the foundations were created for competition in mobile networks in Switzerland. As early as autumn 1997, ComCom (the Federal Communications Commission) had decided to invite tenders for two additional mobile radio licences, using the GSM standard. Subsequently, nine applications for licences were submitted by five candidates. The ensuing competition, based on criteria, finally led, in April 1998, to the licensing of two additional mobile radio operators in Switzerland: Diax (now Sunrise Communications) and Orange (now Salt). The two new networks

were rapidly constructed. Diax was able to start operating its network commercially by the end of 1998, and Orange by mid-1999.

By the end of 2000, it was possible to allocate additional frequencies in the so-called E-GSM band (the 900 MHz band) to the three mobile radio operators in Switzerland.

At the beginning of 2004 two more GSM licences were awarded to the two companies Tele2 and In&Phone.

In mid-2007 the number of GSM mobile customers in Switzerland numbered 6.83 million in total. Of these Swisscom Mobile AG had a 62% market share, Sunrise Communications AG 18%, Orange Communications SA 20% and Tele2 0.3%. The number of active mobile connections in Switzerland, including all mobile radio technologies (GSM, UMTS and LTE), amounted to 11.9 million[1] at the end of March 2015 for a constant resident population in the year 2013 of 8.2 million[2]. This corresponds to a mobile radio penetration of approximately 147%.

In February 2012 the Federal Communications Commission ComCom auctioned all the mobile radio frequencies available at that time[3]. All 5 MHz frequency blocks from the frequency bands specified in Table 1 were acquired by auction by the three existing Swiss mobile radio operators. GSM supports E-UTRA bands 8 and 3. The proceeds for the Confederation from the auction amounted to approximately CHF 996 million.

Frequency band	E-UTRA operating bands	Bandwidth	Duplex technique	Mobile radio technologies used
800 MHz	20	2x30 MHz	FDD	LTE-A
900 MHz	8	2x35 MHz	FDD	GSM/EDGE, UMTS/HSPA+
1800 MHz	3	2x75 MHz	FDD	GSM/EDGE, LTE-A
2100 MHz	1	2x60 MHz	FDD	UMTS/HSPA+
2600 MHz	7 38	2x70 MHz 1x45 MHz	FDD TDD	LTE-A
	Total	**585 MHz**		

Table 1: Frequency bands for mobile radio in Europe, status mid-2015

The switch from the GSM frequency assignments valid until the end of 2013 to the new frequency assignments auctioned in 2012 was concluded in August 2014[4].

4 Technology of the GSM air interface

4.1 Traditional GSM

GSM is a fully digital system, i.e. all signals are transmitted digitally, even on the radio section. This allows combined use of GSM for voice and/or data. In addition, highly developed security measures against fraud and interception are integrated into the system.

The connection between the mobile station (MS) and the base station (BTS) is termed the radio interface. Data is sent on the radio channel as short packets (bursts), with these being inserted into frames of 8 time slots. During a call, an individual handset or base station occupies precisely one such slot on a specific carrier frequency, i.e. one logical channel. During the call, the transmitter is switched off approximately 217 times per second (see Figure 2). This channel access procedure is

[1] http://www.comcom.admin.ch/dokumentation/00439/00467/index.html?lang=de

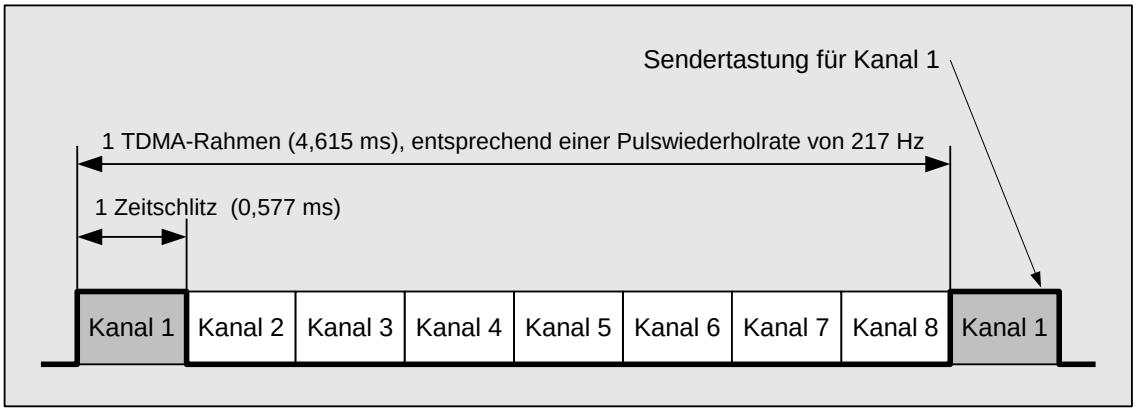
[2] http://www.bfs.admin.ch/bfs/portal/de/index/themen/01/01/key.html

[3] http://www.comcom.admin.ch/themen/00783/index.html?lang=de

[4] http://www.comcom.admin.ch/themen/00783/index.html?lang=de

termed TDMA (Time Division Multiple Access). Normally, in one cell, multiple carrier frequencies with the TDMA structure shown in figure 2 are emitted from the base station.

In each cell, the control channel is transmitted on a specific carrier frequency in the first time slot from the base station to the handsets. The other seven time slots on this carrier frequency can be used for calls. The control channel is used to transfer the network's system data to the handsets and to establish synchronisation between the base station and the handsets. This carrier is constantly transmitted by the base stations at full power, so that the handsets can find the cell when they are switched on, when they are roaming or during the handover. This carrier is transmitted at full power on all eight slots even when no calls are being made in the cell.



Transmit keying for channel 1

1 TDMA frame (4.615 ms), corresponds to a pulse repetition rate of 217 Hz

1 time slot (0.577 ms)

Channel 1 ……..8

Figure 2: GSM's TDMA channel access method

The modulation procedure used is GMSK (Gaussian Minimum Shift Keying). This modulation technique has the major advantage that it allows relatively cheap transmitters to be used.

The most important radio parameters of GSM are shown in Table 2 below.

Table 2: Important radio parameters of GSM.

Parameter	*Value*
Channel pattern for carrier frequencies	200 kHz
Frequencies for public GSM systems	P-GSM900 (2 x 125 carrier frequencies): Handset sends (uplink): 890 - 915 MHz Base station sends (downlink): 935 - 960 MHz E-GSM900 (additional 2 x 50 carrier frequencies to P-GSM900): Handset sends (uplink): 880 - 915 MHz Base station sends (downlink): 925 - 960 MHz GSM1800 (2 x 374 carrier frequencies): Handset sends (uplink): 1,710 - 1,785 MHz Base station sends (downlink): 1,805 - 1,880 MHz
Duplex spacing	GSM900: 45 MHz GSM1800: 95 MHz
Base station transmitting power	The radiated transmitting power is of the order of 1 W up to several hundred W ERP per high-frequency carrier. As a rule, several high-frequency carriers are operated on one base station.
Maximum handset transmitting power (typical)	GSM900: 2 W GSM1800: 1 W

Maximum average transmitting power (handset), averaged over one frame (typical, in a telephone call)	GSM900: 250 mW GSM1800: 125 mW
Reception sensitivity, dynamic	Handset: Base station: -102 dBm -104 dBm
Mode	Duplex
Channel access method	TDMA
Modulation	GMSK (BT = 0.3)
Channel bit rate	270,833 kbit/s
Maximum data rate, non-protected (gross bit rate) This data rate corresponds to the net data rate (see below) plus the error protection (channel coding) on the air interface	22.8 kbit/s
Net data rates (with different channel codings) This data rate is available to the subscriber or for the application	TCH/F2.4: 2.4 kbit/s TCH/F4.8: 4.8 kbit/s TCH/F9.6: 9.6 kbit/s TCH/F14.4: 14.4 kbit/s
Range	approx. 30 km

One important element for digital speech transmission on the GSM air interface is the speech encoder/decoder in the handset. The analogue speech signal from the microphone is sampled 800 times per second and converted into a digital signal. This signal is fed to the speech encoder which codes this signal at the basic rate of 13 kbit/s. This signal is then transmitted across the air interface by adding the channel coding (error protection on the air interface) at the gross bit rate of 22.8 kbit/s.

5 Services

An extensive range of services has been developed for GSM. Within the framework of this brief overview of GSM it is possible to list only the most important services.

5.1 Teleservices:

- **TELEPHONY SERVICES:** normal voice telephony service with the possibility of making and receiving calls to mobile or fixed users worldwide.
- **EMERGENCY CALL SERVICE:** dialling 112 in any country connects the user to a national emergency service.
- **SHORT MESSAGING SERVICE (SMS):** offers the possibility of sending short alphanumeric messages up to 160 characters long.
- **FAX:** allows transmission and reception of faxes at 2.4 – 9.6 kbit/s.

5.2 Carrier services

Carrier services are services for data transmission:

- **CIRCUIT-SWITCHED[5] DATA TRANSMISSION:** transparent and non-transparent synchronous or asynchronous circuit-switched data transmission from 1.2 – 9.6 kbit/s.
- **HSCSD:** circuit-switched data service at bitrates up to 57.6 kbit/s (see section 5.2.2).
- **GPRS:** packet-switching[6] data service at bitrates up to 171.2 kbit/s (see section 5.5.3).
- **EDGE (E-GPRS):** further development of HSCSD and GPRS by 8-PSK type modulation, enables higher data rates of 8.8 kbit/s up to 59.2 kbit/s/slot or if 8 slots are used max. 473.6

[5] With circuit switching the transmission channel is used exclusively by one application. The entire bandwidth of the channel is available exclusively to this application.

[6] With packet switching an existing transmission channel is used concurrently by multiple users. A virtual transmission channel is established for each user. The available channel bandwidth is allocated among users statistically, i.e. demand-orientated

kbit/s

- **E-EDGE: (EVOLVED EDGE):** further development of EDGE by 16QAM and 32QAM type modulation

5.2.1 Data services HSCSD, GPRS, EDGE and E-EDGE

In order to meet the demand at that time for significantly higher data rates than the 9.6 kbit/s originally offered by GSM, the GSM system was extended.

The principle of HSCSD (High Speed Circuit Switched DATA) and GPRS (General Packet Radio Service) is so-called channel bundling: Several time slots are assigned to one specific connection (see

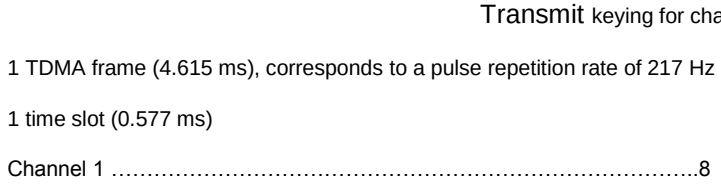


Figure 2). As a result, the data rates of individual users can be greatly increased. The number of time slots which a user device can process depends on the device category.

In addition to channel bundling new channel codings (transmission protection on the air interface), and in the case of EDGE (Enhanced Data Rates for GSM evolution) even a new modulation procedure, were introduced at the same time. This means that the maximum possible data rate on the air interface can be optimally adapted to the prevailing transmission conditions (interference, distance between base station and mobile phone, etc.).

By means of channel bundling on the uplink, i.e. by the simultaneous occupancy of several time slots by the user, the average performance of the mobile telephone is increased during a call.

5.2.2 HSCSD (High Speed Circuit Switched Data)

As the name indicates, HSCSD is a circuit-switched data service. With HSCSD, up to four slots of a carrier can be occupied by a single user. Since the net data rate per slot is 9.6 kbit/s or 14.4 kbit/s – depending on the channel coding – up to 57.6 kbit/s are available for the individual users (see Table 3). This data service was relatively simple to incorporate into existing GSM networks, because the GSM core network was already prepared for 64 kbit/s circuit-switched data services.

HSCSD was largely displaced by the successful introduction of packet-switched technologies such as GPRS (see below).

5.2.3 GPRS (General Packet Radio Service)

With the packet-switched GPRS service, data signalling rates up to 171.2 kbit/s are theoretically possible. However, optimal propagation conditions must exist to achieve these rates. The signalling rates in real networks – at least in the initial phase – were far below this theoretical upper limit. Today, data rates of approximately 40 kbit/s are offered in practice, i.e. 'only' three channels or rather slots are trunked with channel coding CS-2 (see Table 3) for a specific connection. The limiting factor in this context is the handsets.

With GPRS, instead of making a channel exclusively available to a subscriber for the entire duration of a connection, the capacity of the radio channel is utilised only when data actually exists for transmission. This increases the spectrum efficiency of the system. Network capacity is therefore a resource which is available to all users simultaneously and at any time. New models can also be introduced for charging. For example, a user can always be logically connected to a server (always-on), but only pays for the data which is actually physically transmitted (charging by volume). The time-consuming call set-up and disconnection procedures are therefore eliminated. This always-on principle with GPRS extended GSM to the mobile internet.

As with HSCSD, for GPRS new handsets or plug-in computer must also be introduced. Unlike HSCSD, new elements are also required for GPRS in the fixed network in order to support packet-switched services.

Today, GPRS is implemented in the vast majority of GSM mobile radio systems.

5.2.4 EDGE (Enhanced Data rates for GSM Evolution)

EDGE allows a further increase in data rates by a factor of three, thanks to an improved modulation technique (8-PSK). EDGE is used predominantly in conjunction with GPRS (see above). These services are designated EGPRS (Enhanced GPRS).

The advantages of the types of modulation and channel coding used by EDGE can also be exploited together with HSCSD (see above). In this context the term ECSD (Enhanced Circuit Switched Data) is used. It offers the possibility of achieving the maximum data rate of 57.6 kbit/s with less than four slots. In the case of the circuit-switched services, this is the maximum data rate, which is limited by the capabilities of the fixed network.

EDGE is currently implemented in many GSM mobile radio systems and has made a crucial contribution to the considerable success of GSM for mobile package-switched data services with moderate data rates (mobile internet).

5.2.5 E-EDGE (Evolved EDGE)

EDGE was further developed and E-EDGE offered

- theoretical data rates of 1.3 Mbit/s on the downlink,
- 653 kbit/s on the uplink.
- Latencies around 100 milliseconds

E-EDGE was therefore called christened a 2.75G system by industry observers and gave a foretaste of 3G, which was introduced shortly thereafter. The fact that some network carriers invested very large sums in the 3G licences meant that there was no major proliferation of E-EDGE. Also, GSM does not support the 3G frequency bands and the money was invested in the 3G network construction, not in the expansion of GSM/EDGE networks.

Table 3: Examples of data rates of HSCSD, GPRS and EDGE (ECSD and EGPRS).

Service	*Channel coding*	*Modulation*	*Net data rate per slot*	*Maximum data rate*
HSCSD	TCH/F9.6	GMSK	9.6 kbit/s	4 x 9.6 kbit/s = 38.4 kbit/s
(circuit-switched)	TCH/F14.4		14.4 kbit/s	4 x 14.4 kbit/s = 57.6 kbit/s
GPRS	CS-1 (Code rate 0.5)	GMSK	9.05 kbit/s	8 x 9.05 kbit/s = 72.4 kbit/s
(packet-switched)	CS-2 (Code rate 0.67)		13.4 kbit/s	8 x 13.4 kbit/s = 107.2 kbit/s
	CS-3 (Code rate 0.75)		15.6 kbit/s	8 x 15.6 kbit/s = 124.8 kbit/s
	CS-4 (Code rate 1)		21.4 kbit/s	8 x 21.4 kbit/s = 171.2 kbit/s
ECSD (EDGE)	TCH/F28.8	8-PSK	28.8 kbit/s	2 x 28.8 kbit/s = 57.6 kbit/s [a)]
(circuit-switched)	TCH/F43.2		43.2 kbit/s	1 x 43.2 kbit/s = 43.2 kbit/s [a)]
EGPRS (EDGE)	MSC-5 (Code rate 0.37)	8-PSK	22.5 kbit/s	8 x 22.5 kbit/s = 180 kbit/s
(packet-switched)	MSC-9 (Code rate 1)		59.2 kbit/s	8 x 59.2 kbit/s = 473.6 kbit/s

Comments:

a) In the case of the circuit-switched services, the maximum data rate on the air interface is 57.6 kbit/s.

5.3 Additional services

5.3.1 CALL OFFERING: Diversion or forwarding services for incoming calls.

- Call Forwarding Unconditional (Service 21): if this form of call forwarding is activated, an incoming call is forwarded to a national or international number programmed by the subscriber.
- Call Forwarding on Mobile Subscriber Busy (Service 67): if the called subscriber is

engaged, the next call is diverted to a pre-programmed number.

- Call Forwarding on No Reply (Service 61): forwarding of calls to a programmed national or international number, if the called subscriber does not answer. The mobile subscriber can program delayed forwarding within a range of 5 to 30 seconds.
- Call Forwarding on Mobile Subscriber Not Reachable (Service 62): forwarding of calls to a programmed national or international number, if the called subscriber is not reachable, i.e. when the device is not switched on or is in an area which is not covered.

5.3.2 Call Restriction

These services are restrictions or bars on incoming or outgoing calls. Pre-programming of the service concerned by the network operator and activation/deactivation by the mobile customer are necessary.

- Barring of All Outgoing Calls: all outgoing calls, national and international (apart from the emergency service) are barred.
- Barring of Outgoing International Calls: all outgoing international calls are barred.
- Barring of Outgoing International Calls except to the Home PLMN Country: barring as above, but if the mobile customer is abroad, he can make calls back to his home country.
- Barring of all Incoming Calls: all incoming calls are routed to a spoken text (e.g. "No calls can be received on this number at present").
- Barring of all Incoming Calls when Roaming outside the Home PLMN: if the subscriber is abroad, incoming calls are not forwarded but routed to a spoken text (e.g. "No calls can be received on this number at present").

5.3.3 CALL COMPLETION

These services provide enhanced facilities for call handling.

- Call Waiting: if a user is on a call and another call arrives, the called user is made aware of this other call.
- Call Hold: if a call is in progress, it can be put on hold in order to answer another call or set up another call. Often used together with "Call Waiting".

5.3.4 Number Identification

These services make it possible for the network operator or the customer to identify the calling or called subscriber.

- Calling Line Identification Presentation (CLIP): the caller's number can be displayed to the called subscriber when an incoming call is received.
- Calling Line Identification Restriction (CLIR): allows a specific subscriber to prevent identification at the called user.
- Connected Line Identification Presentation (COLP): the number of the called subscriber is indicated to the calling subscriber. In the case of call forwarding or diversion, this may be different from the dialled number.
- Connected Line Identification Restriction (COLR): allows a specific subscriber to prevent indication of the called number to the calling subscriber.

♦ **LOCATION SERVICES:** location services are used to determine the position of the handset within the mobile radio network. At present it is only possible to establish the cell in which a subscriber is located. Location services can be used for various applications:

- Determining of position for emergency calls: in the case of an emergency call from a mobile phone, the emergency services can determine the position of the caller. This

location service became a legal requirement in the USA on 1 October 2001.

- Location-dependent charge calculation: operators have the possibility of making call charges dependent on the caller's geographical location (Location Based Charging). For example, lower charges can be imposed for calls from home or the office than elsewhere in the network (home and office zone calls).
- Commercial services: supervision of children; fleet management (e.g. optimisation of taxi journeys); finding the nearest hotel; finding the nearest pizzeria or filling station; determining locations; navigation; identifying the location of stolen handsets , etc.